SOIL CONSERVATION HANDBOOK

Chinese Edition compiled by the

Council of Agriculture, ROC
Taiwan Provincial Soil and Water Conservation Bureau
and the
Chinese Soil and Water Conservation Society, ROC

English Edition prepared by the

Food and Fertilizer Technology Center
for the Asian and Pacific Region
5TH FL. 14 WENCHOW STREET, TAIPEI, TAIWAN
REUPBLIC OF CHINA

June 1995

FOREWORD

Taiwan is a subtropical island characterized by high precipitation and heavy rainfall. Its topography is dominated by steep mountains and large areas of hilly land. Furthermore, it has a dense population which has pushed farming towards very intensive land use and the exploitation of marginal arable land. The combination of these factors makes Taiwan highly susceptible to accelerated soil erosion. Forty years ago, the Government of the Republic of China became aware of this threat, and began to take preventive and corrective measures. One of the major steps in this program was to train soil and water conservation workers who would educate and assist farmers to practice soil conservation.

For this training of soil conservation field workers, a Soil Conservation Handbook was compiled in 1964 and revised in 1975 by the Mountain Agricultural Resources Development Bureau (MARDB), under the guidance of the Sino-American Joint Commission on Rural Reconstruction (JCRR). With a view to sharing Taiwan's experience with other countries in a similar situation, the Food and Fertilizer Technology Center (FFTC) for the Asian and Pacific Region translated this handbook into English in 1977, and distributed it to more than 75 countries.

Later the Council of Agriculture, ROC, which succeeded the JCRR, and the Taiwan provincial Soil and Water Conservation Bureau, with assistance from the Chinese Soil and Water Conservation Society, revised the Handbook in 1981, and again in 1992. This latest edition has been greatly enriched by the experience and research results which have accumulated over the past 28 years. In comparison with the original edition, which consisted of 87 pages, this new expanded edition has 410 pages. In addition to Farmland Erosion Control, the new edition includes two further sections, namely, Engineering Works and Vegetative Measures.

In view of the world-wide interest in sustainable agriculture, for which soil and water conservation is one of the fundamental requirements, the FFTC is glad to offer the English version of this revised Handbook to all those concerned with the long-term productivity of agricultural soils.

Chin-chao Koh
Director, FFTC

PREFACE

Heavy rainfall, erodible soils, steep slopes and other factors contribute to serious erosion and slope stability problems in Taiwan. Consequently, Taiwan has instituted and implemented a national program in soil and water conservation since early1950s. This program has accumulated many years of knowledge and experience.

Soil and water conservation practices with proven effectiveness in Taiwan are included in the Soil Conservation Handbook first published in 1963 for use as a guide of standard technology for field application. This handbook was revised in 1973, 1981 and more recently in 1992. This latest edition has been greatly expanded and divided into three volumes, namely, Farmland Erosion Control, Engineering work, and Vegetative Measures.

The knowledge and experience of Taiwan in soil and water conservation can be very valuable to other countries confronted with similar circumstances in selecting methods and techniques for sustainable slopeland development. With support from the Council of Agriculture, Republic of China, the Chinese Soil and Water Conservation Society has co-operated with the Food and Fertilizer Technology Center (FFTC) in publishing an English version of the latest edition of the Soil Conservation Handbook for distribution as references for agencies and individuals abroad in carrying out their tasks of conserving soil and water resources in their respective countries. It is our great pleasure to see the completion of this very worthwhile project.

F. C. Yu,
President,
Chinese Soil and Water
Conservation Society

INTRODUCTION

1. This handbook has been complied in line with the "Regulations and Rules Governing Slopeland Use and Conservation", for the benefit of soil and water conservation workers.

2. This handbook is divided into three parts, including 'Farmland erosion control', 'Engineering Works' and 'Vegetative measures'. The primary purpose of this first part is to provide technical criteria for farmland erosion control, which should be followed in all soil and water conservation field operations. Any alteration of these criteria in response to unusual situations needs the approval of the responsible authorities.

3. In the first part, various erosion control methods and facilities are described. Where technical problems involve engineering works or vegetative measures, the other two parts of this manual should be consulted.

4. This handbook was first published in 1964. Revisions were made in 1975 and 1981. It has now been revised for a third time, on the basis of new research findings and new requirements in slopeland farming.

5. For any questions or suggestions, the Taiwan Provincial Soil and Water Conservation Bureau, Chung Hsing Village, Nantou, Taiwan, ROC, should be contacted.

Technical Supervisory and Editing Committee

Part III. Vegetative Measures

林信輝 Hsin-Hui Lin, Cheif Editor

呂理燊 Li-Shen Lu	邱創益 Chuang-I Chiu
李　鏐 Liu Li	李耀旭 Yao-Hsu Li
胡蘇澄 Su-Cherng Hu	陳振盛 Chen-Sheng Chen
張賢明 Hsien-Ming Chang	蘇錦松 Chin-Sung Su
鍾弘遠 Hung-Yuan Chung	

Secretary: 孫明德 Ming-Teh Sun　沈福成 Fu-Cheng Shen

English Edition

Editor: 馮紀洪 John C. Feng

Translation:

Part I: 馮紀洪 John C. Feng
Part II: 溫理仁 Li-Jen Wen
Part III: 胡蘇澄 Su-cherng Hu

CONTENT

SOIL CONSERVATION HANDBOOK

Part I

Farmland Erosion Control

1995

λ

CONTENT

(5

TABLES

八

SOIL CONSERVATION HANDBOOK

Part I. Farmland Erosion Control

Chapter 1. Introduction

1.1 Concept of farmland soil conservation

The primary purpose of soil and water conservation is to ensure sustained productivity of land, through conservation of water resources and prevention or reduction of soil erosion, land slides and debris flows. This objective is to be achieved with the help of agronomic, vegetative and engineering methods. The term 'farm land' may cover all land that is used for agricultural activities. However, in this handbook, farm land includes only land used directly for growing crops and pasture. All soft top soils, when exposed to rains or storms, are subject to erosion. Washed off soil, when carried away by runoff water, will bring upon downstream area pollution and damage. Therefore, in addition to the maintenance of land fertility, soil conservation should also anticipate these problems. The overall objectives of soil conservation should aim at the following:

(1) promotion of proper land use
(2) Prevention of soil erosion and restoration of the fertility of eroded land
(3) Maintenance of soil fertility
(4) Reduction of water runoff and regulation of water resource
(5) Prevention of water and land pollution caused by carried off soil and debris
(6) Enforcement of safe drainage and irrigation on slope land
(7) Prevention of wind erosion

As the title of this Part has indicated, only those soil conservation measures which can be applied directly to farm land are included in this Part. In each subsequent chapter description of a specific measure will be given, covering the definition, purpose, application, design, work procedure, etc.

1.2 Soil Erosion

Soil erosion is a phenomenon that happens when soil is washed by rain, runoff water or waves; blown by wind, or affected by gravity or drastic temperature variation. Under these influences, soil structure disintegrates and soil particles become detached. Eventually the particles will be carried away and deposited at another location. Soil erosion is mostly caused by water and wind. Water and wind often work simultaneously or consecutively at the same locality. When that happens, their destructive power will be multiplied. Water erodes soil with the force of impact, e.g. rain drops, or shearing force, e.g. runoff. Wind tears off soil particles from their seat. Over development or excessive utilization of land for farming is likely to strip the ground of its protective cover and destabilize the top soil. Rain will then detach soil particles which will be carried away by runoff. Consequently, the fertile top soil, whose formation takes a great many years, is lost.

1.2.1 Normal Erosion

Also known as natural erosion or geological erosion. This is part of the process of geological evolution. This type of erosion takes place when the environmental elements in an area remain undisturbed, and the natural vegetative cover unbroken. It goes on unceasingly all the time. However, the progress of erosion is so slow that the movement of soil particles is hardly perceptible. Under this condition, the speed of the formation of new soil through transformation of the parent rock will be able to catch up with the loss of top soil. A state of equilibrium will be attained, so that no appreciable damage to the existing soil as well as its fertility takes place.

1.2.2 Accelerated Erosion

Accelerated or abnormal erosion will take place when vegetative cover or the stability of top soil is broken. In this type of erosion, movement of soil particles becomes extensive. Furthermore, in movement soil particles are stripped of their structural chemical elements. Since the speed of soil formation can no longer match the movement of soil particles, the natural equilibrium in soil evolution is disrupted. This will result in loss of top soil together with plant nutrients, thus reduing the fertility of the land. In the long run, top soil will completely wash away, so that the subsoil or even the parent rock will be exposed. In this stage, gullies will be etched into the land, and if not stopped, will continue to expand. The washed off soil and debris will be carried downstream to be deposited onto plains or deltas, and will pollute the water and farm land there.

1.2.3 The Process of Erosion

Rains induce soil erosion in three steps:

(1) Detachment

When a rain drop hits exposed soil, two-thirds of its kinetic energy will be spent in loosening soil particles and creating a crater. With the remaining one-third energy, the rain drop will spatter the loosened particles around. These loose particles tend to slip into the pores in soil, and gradually seal them. Finally the surface of top soil becomes a hard crust of poor permeability. Since low permeability handicaps the draining of precipitation through soil, water on the ground forms a film. Into this film loosened soil particles and soil colloids will be absorbed and suspended. The loosening of soil particles and suspending them in a water film is called 'detachment' of soil.

(2) Transporation

When the water film thickens with increased precipitation, it will slide toward a lower position. As it moves, it carries with it the soil particles. When the water film further thickens, it will become rivulets, which having stronger tractive force can move not only soil but also gravels. The movement of soil from one place to

10

another is called the process of transportation. Nearly all severe erosion is brought about by this process.

(3) Deposition

When runoff reaches flat lowland, the current slows down so that dirt carried with it settles to the bottom. This is 'deposition', the last stage of accelerated erosion. Although deposition itself is not erosive, it often has a considerable influence on the area where it takes place. Typically it affects the pattern of land use, through changing of land characteristics. For instance, it may strew gravels and debris on fertile farm land and fill up water sources and reservoirs.

1.2.4 Type of Erosion

Accelerated erosion begins with the impact of rain drops on the ground, and the tractive force of runoff on soil. The action of these forces may have several different types of erosion.

(1) Splash Erosion

Also known as rain drop erosion, this takes place when a rain drop hits the ground. At the point of impact, the soil structure will be torn apart by the kinetic energy released by the rain drop. The detached soil particles will then be splashed [illegible]e surrounding area. If these particles are not transported away by runoff they will pile up, sometimes attaining a thickness of several centimeters.

(2) Sheet Erosion

When precipitation slightly exceeds soil permeability, excessive water will form a thin sheet or film no more than 0.1 - 3.0 mm thick. Water in this state moves over the ground surface and between soil particles, sometimes with very small ripples. This the moving water film is called a film current. As its speed of flow increases, especially when the film slides over a slope without resistance, it peels the surface soil off layer by layer. Sheet erosion removes fine particles and organic matter from the soil without leaving any clear traces, although the soil will be deprived of its fertility. It is extremely difficult to rehabilitate soil which has deteriorated in this way.

(3) Rill Erosion

When more water has accumulated on the ground, the film of water becomes runoff. At first, runoff will etch on the ground numerous wrinkles. The wrinkles will deepen into grooves and then gutters. When runoff moves down into lower areas, especially when it follows planting furrows which are cut down a slope instead of along the contours, rills that spread out like fingers of a hand will form. A rill is always no more than 30 cm in depth and 100 cm in width. A cut beyond this dimension should be called a gully.

(4) Gully Erosion

Gully erosion is the result of further progress of rill erosion. At this stage, rills merge into gullies. In gullies, runoff converges into powerful torrents with enhanced capability of erosion. Depending on the texture of soil and bedrock, as well as the gradient of the slope, gullies are generally cut into one of the following four forms:

a. Shallow trough form: Usually found in places where the soil is heavy and firm. The gully is wide but shallow, with obtuse edges.

b. V Form: Found where thick top soil exists.

c. U Form: Gullies of this type are cut where there is hard bed rock under soft top soil.

d. Complex Form: This is a combination of U and V forms, with a U at the top of the gully and a V at the bottom. Formation of this type of gully is mainly due to the existence of a hard substatum sandwiched between the top soil and another layer of soil beneath. A U-shaped gully is cut by the current first, and when the hard substratum has eroded through, a V shaped bottom appears beneath it.

1.3 Factors Affect Soil Erosion

There are many elements that influence the process of soil erosion, including climate, topography, vegetation, soil texture, and human behavior. The correlation between these elements is illustrated as follows:

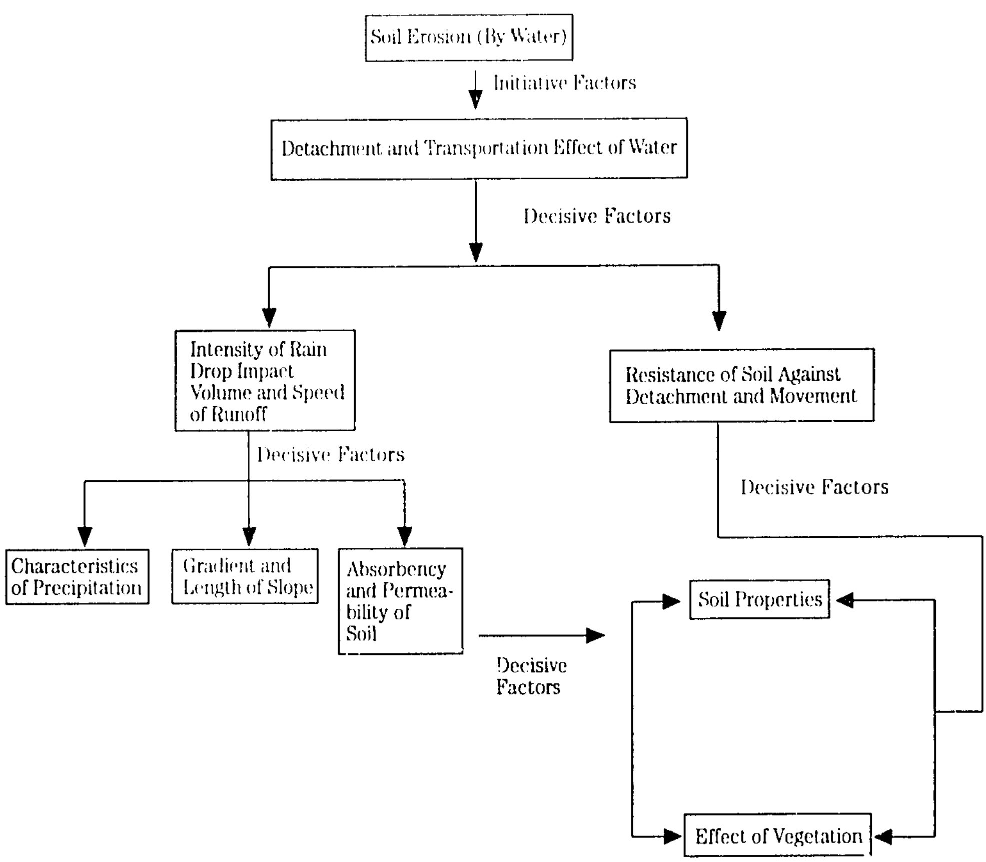


Fig. 1-1. Correlation of Various Factors Involved in Soil Erosion

1.4 Assessment of the Extent of Soil Erosion

Table 1-1. Extent of Soil Erosion

1st Grade	Light Erosion	Ground surface lacks any marked evidence of erosion. Soil permeability high, vegetative cover in good condition. No sign of any long-distance movement of soil. Top soil loss less than 25%.
2nd Grade	Moderate Erosion	Gullies 30 - 100 cm wide, 15 - 30 cm deep, are formed. Gravel content in top soil is less than 20%. Top soil loss 25 - 75%.
3rd Grade	Severe Erosion	Width of gullies exceeds 100 cm, depth more than 30 cm. Cross section of the gullies may have an U, V or combined U and V form. Gravel content of soil is 20 - 40%. Sub-soil loss less than 50%. At this stage it is still possible to control the erosion by vegetative measures.
4th Grade	Very Severe Erosion	All top soil is loose. Erosion has reached the sub-soil or even parent rock. Gravel content exceeds 40%. Loss of sub-soil over 50%. Parent rock may be exposed. Landslides occur in places. Control by vegetative measures is very difficult.

1.5 Farm Land Soil Conservation

(1) Concept

The primary objective of farm land soil conservation is to prevent soil erosion. Development of slope land for farming inevitably will bring on soil erosion, which will not only reduce soil fertility, but also cause considerable trouble for people and industries downstream. Therefore, for slopeland farming, soil conservation is essential. There are quite a number of elements involved in farmland soil conservation. These are shown in Fig. 1-2.

(2) Measures

In Part I of this handbook, there are a total of 35 measures for farmland soil conservation.

a. Engineering Measures
Hillside ditches
Bench terraces
Stone walls
Broad-based terraces

b. Agronomic and vegetative measures
Contour planting
Grass planting on hillside ditches
Planting grass on risers of terraces
Cover crops

Green manure
Grass barriers
Mulching
Windbreaks

c. Road design for soil conservation
Access roads
Link roads
Farm paths
Grassed farm roads
Vegetative side slope stabilization

d. Drainage
Diversion ditches
Drainage ditches
Grassed waterways
L-shaped road-side ditch
Dip
Drop structure
Culvert (small size)

e. Erosion damage control measures
Gully control
Check dams
Farmland shaping
Sediment basins

f. Irrigation system for slopeland
Slopeland irrigation
Water source facilities
Water conveyance facilities
Water storage tank
Pumping facilities
Farm ponds

g. Soil conservation oriented planning
This is essential in the development of any slopeland.

Soil conservation measures for farmland should be planned in accordance with the following steps and guiding principles:

a. Planning of land use according to land capability, on the basis of conservation farm planning.

b. Reducing splash erosion with vegetation which shields the ground surface against the impact of rain.

c. Strengthening soil resistance against erosion with vegetative, agronomic and engineering measures.

d. Reducing runoff, through increase of the absorption capacity of ground, with agronomic, vegetative and engineering measures.

e. Increasing the roughness of ground surface so as to reduce the speed of runoff by engineering, agronomic and vegetative measures.

f. Draining runoff with a specially designed drainage system aimed at preventing of erosion. Vegetative measures may be incorporated to strengthen the preventive effect.

g. Reinforcing protection of points, such as farm paths and drainage channels, where erosion and slides are likely to take place, with adequate drainage systems.

It should never be expected that any one of the above-mentioned 35 measures used in isolation can achieve erosion control. There is always a need for a combination of selected measures to do the job. Careful evaluation of the situation and proper use of a combination of these measures will assure success.

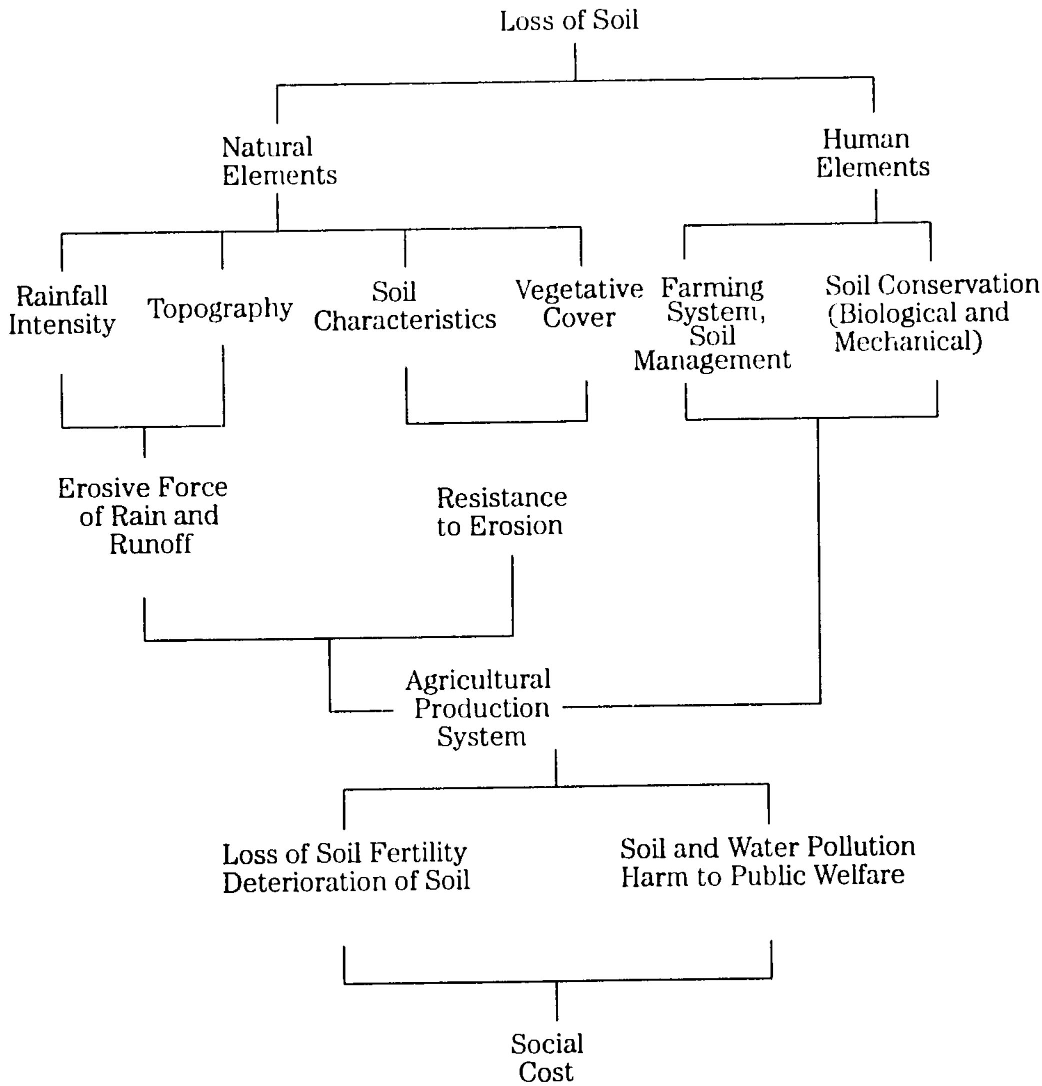


Fig 1-2. Correlation between Elements Involved in Farm Land Soil Conservation

Chapter 2. Hillside Ditches

2.1 Definition

A series of shallow ditches built along the contour lines of a hillside slope at proper intervals.

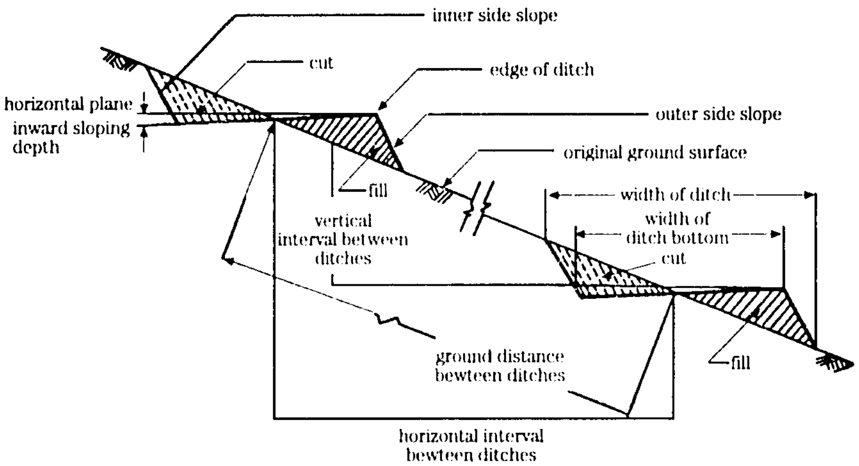
2.2 Objectives

(1) To break up a long slope into several short slopes, in order to intercept runoff water.

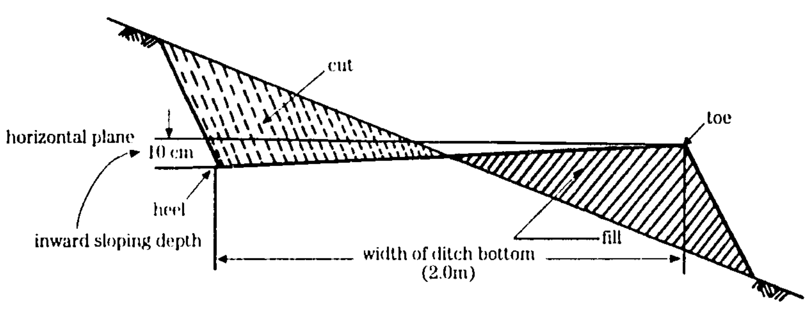
(2) The ditches may also serve as farm paths to facilitate transporation that the operating cost may be reduced.

2.3 Diagram:

Cross-section

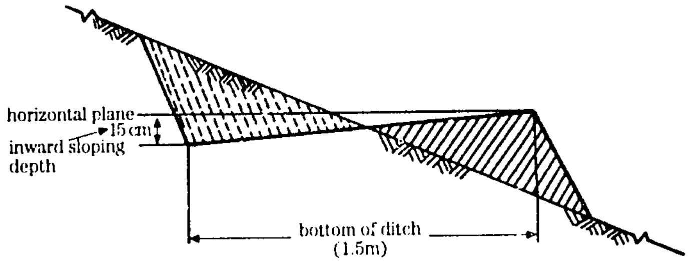


(1) Broad type



14

(2) Narrow type



2.4 Application

(1) Suitable for slopes of less than 40% gradient

(2) In cases where there are outward type bench terraces or grass barriers, hillside ditches may be used on slopes greater than 40%.

(3) Suitable for slopes of up to 55%, on tree farm, orchard and pasture land, provided the slopes are fully covered by vegetation.

2.5 Design

(1) Spacing: The space in meters between ditches is determined by the following formula:

$$VI = \frac{S+6}{10} \qquad HI = \frac{VI}{S} \times 100 = \frac{S+6}{S} \times 10$$

VI=Vertical interval between ditches (m)

S =Gradient (%)

HI=Horizontal interval between ditches (m)

Table 2-1. Quick Conversion of Gradient and Spacing

Gradient	Slope	Space between ditches (m)	
%	Degree	Horizontal interval (HI)	Ground surface distance
3	1.7	30	30
4	2.3	25	25
5	2.9	22	22
6	3.4	20	20
7	4.0	19	19
8	4.6	18	18
9-10	5.1-5.7	16.5	16.6
11-15	6.3-8.5	15	15.1
16-20	9.1-11.3	13.3	13.5
21-25	11.9-14.0	12.6	12.9
26-30	14.5-16.7	12.1	12.5
31-40	17.1-21.8	11.7	12.4
41-55	22.3-28.8	11.0	12.0

The spacing given in this table may be adjusted within a range of ±25%, depending on the permeability of the soil and the degree of erosion, the types of crops being grown and the types of farming practices being employed. When slopes are covered by grass to be used for hay or silage, the spacing may be increased by 100%. However, it is tentatively ruled that the spacing may be increaseed by no more than 50%, if it is grazed by stock. When the ditches are being designed, the spacing of crop rows and the requirement for farm mechanization should be taken into consideration. For the benefit of mechanization, the design should be so arranged that short crop rows can be avoided.

In an orchard, within the permitted range of interval between ditches, interval spacing is determined by the number of rows of trees to be planted. Up to 3 rows may be accommodate in one interval.

(2) Selection of a type: The broad type (2m wide at bottom) is used on gentle slopes while the narrow type (1.5 m wide at bottom) is suitable for steeper slopes.

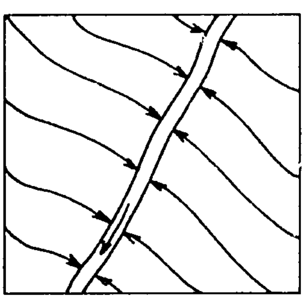
(3) Gradient: The gradient of the ditch should be 1 - 1.5% in principle. When necessary, it may be extended to 5%.

(4) Length: The length of a ditch should be no more than 100 m if the ditch drains in one direction. When a ditch is longer than 100 m, the drainage water should be directed to both ends or to the center of the ditch.

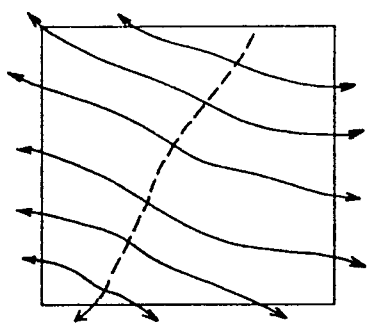
(5) Drainge: Normally, water in hillside ditches is drained by waterways built along the slope. Where the waterway and the hillside ditches meet, the bottom ofthe water way should be built into a shallow curve, and paved with bricks or stones, or planted with grasses, to facilitate passing of farm machinery on wheels. A small culvert can be installed instead when necessary.

(6) Outlet: At the outlet, the width and the gradient of the ditch should be increased. The junction between the hillside ditch and the waterway should be even and smooth.

(7) Grass planting: Grasses should be planted on the bottom and side slopes of the ditches.



Natural water channel
or grass waterway



Grass or forest land

Illustration of the Drainage of Hillside Ditches

2.6 Operational procedures and points to be observed

(1) Survey and planning: Investigation and survey should be made first on the whole area which is to be developed. Location and type of main drains should be decided according to topography, soil type, degree of erosion, natural waterways, etc.

(2) Determination of VI: Check over the average slope of the area in which the ditches are to be constructed, and, from the above Quick Conversion table, find out the most desirable vertical interval between ditches.

(3) Staking the ditch lines: a. Commence at the outlet of the ditch, and place a stake every 5 - 10 m following the contour line. In case of sharp curves, increase the number of stakes. b. After the ditch line has been staked out, check its accuracy and make necessary adjustment to avoid sharp turns or to reduce curvature.

(4) Order of construction: Construct the first ditch at the top of the slope and proceed to the others one by one downward.

(5) Soil settlement: Around 10% additional earth should be put in the fill, depending on the soil conditions, to allow soil settlement.

(6) Finishing: Once the ditches have been constructed, recheck the work to see whether it follows the designed cross-section and gradient, and make necessary corrections accordingly.

(7) The depressions and gullies where a hillside ditch crosses, should be filled, and the fill should be firmly compacted. At these points, the sides and bottom of the ditch should be reinforced.

2.7 Complementary treatments

(1) Diversion or interception ditches

(2) Contour planting, cover cropping or mulching

(3) Planting grass cover on ditches

(4) Appropriate drainage

2.8 Maintenance

(1) Inspect ditches before and after rainy season and repair any damage immediately.

(2) Remove debris and sediment from ditches.

Chapter 3. Grass Planting in Hillside Ditches

3.1 Definition

The establishment of specific grasses on hillside ditches, including both the bottom and side slopes of each ditch.

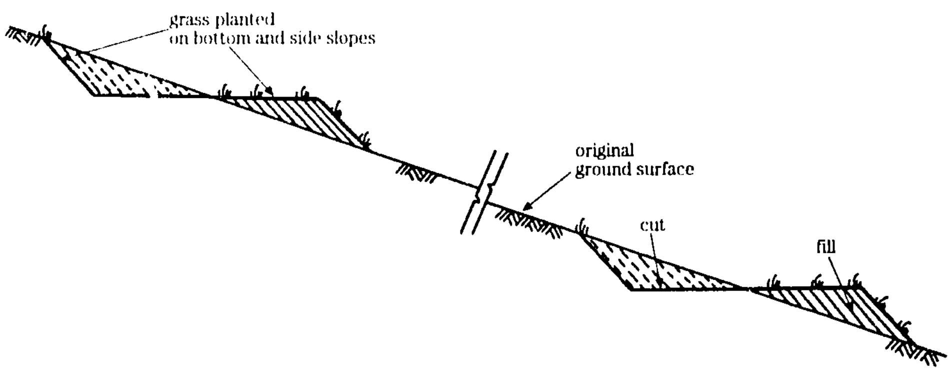
3.2 Objectives

(1) To stabilize the hillside ditch and thus reduce maintenance costs.

(2) To save the labor costs of weeding.

(3) To prevent soil erosion on the upper side-slope of the ditch and to gradually reduce the slope as sliding soil is trapped by the grass.

3.3 Diagram



3.4 Application

(1) As cover for the ditch bottom, carpet grass (Axonopus compressus and A. affinis) bermuda grass (Cynodon dactylon), bahia grass (Paspalum rotatum), centipede grass (Eremchloa opiuroides) and sour grass (Paspalum conjugatum) are generally suitable, while indigenous creeping grasses are also useful.

(2) For protection of the side-slopes and the edge of the ditch, bahia grass is recommended; spacing: 30 cm × 30 cm.

(3) Planting of bermuda grass may be done by spreading grass cuttings on the ground and covering them with soil, and then compacting the soil.

3.5 Operational procedures

(1) Planting should be done as soon as ditch construction is completed.

(2) If grass sprigs are used, the sprigs should be planted individually in dense triangle patterns. If seeds are used, hydroseeding and vegetation belt are the recommended planting methods.

3.6 Management

(1) Inhabitation of rodents should be prevented.

(2) Thorough vegetative cover should be maintained. Replanting should be done without delay when wilting or damage of any part of the grass takes place. Fertilizer should be applied when necessary.

Chapter 4. Bench Terraces

4.1 Definition

A series of level or nearly level platforms built along contours at suitable intervals.

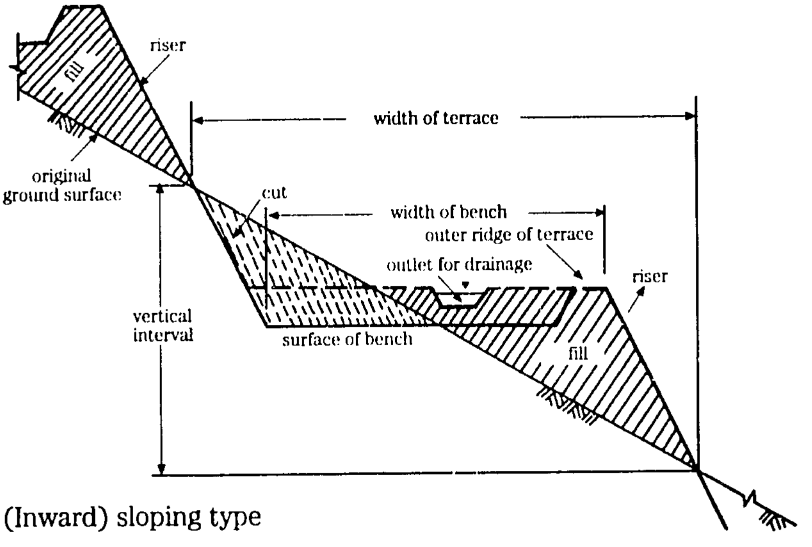
4.2 Objectives

(1) To intercept runoff and control soil erosion.

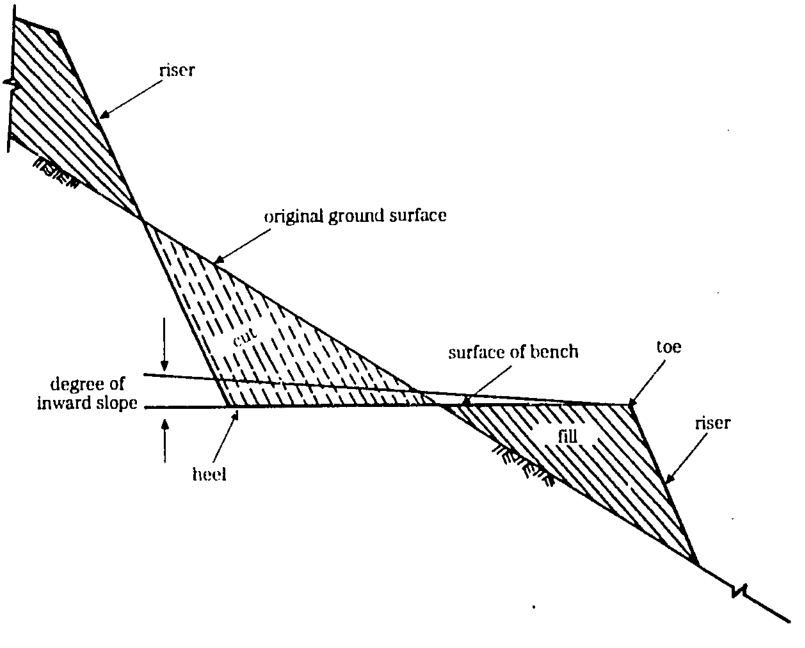
(2) To make cropping operations possible and safe on slopeland.

4.3 Diagrams

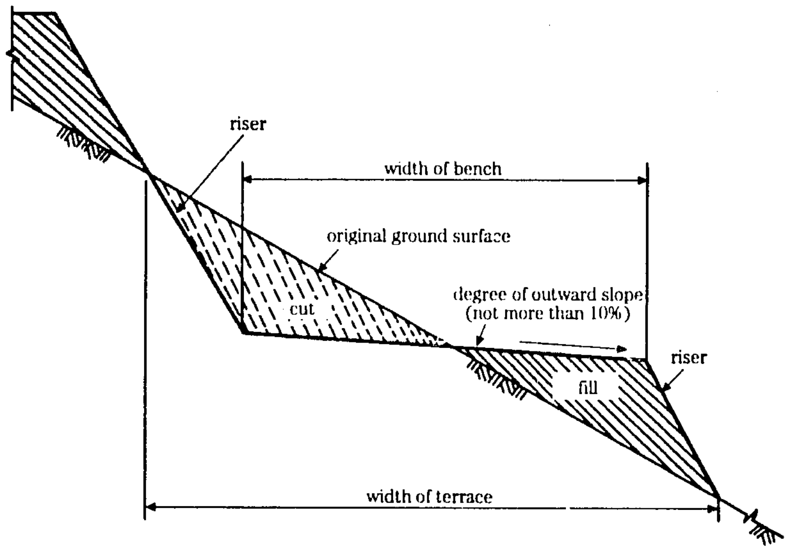
(1) Level and retention type



(2) Reverse (Inward) sloping type



(3) Outward-sloping type



4.4 Application

(1) Suitable for steep sloping farmland with considerable depth of soil. This erosion control practice is adopted to facilitate specific crop management systems and the operation of farm machinery.

(2) Suitable for steeper slopes where intensive cultivation is practiced.

(3) Usually, outward-sloping type bench terraces should be used with hillside ditches.

(4) When erosion can be controlled by less costly measures, construction of bench terraces should be avoided.

4.5 Design

(1) Bench Width: Depending on the gradient of slope, depth of soil, crops and types of farm machinery used. The width of an outward-sloping bench terrace normally should not exceed half of the distance between hillside ditches.

(2) Riser: The upper riser-slope ratio is 1 : 0.5 and the lower riser slope ratio is 1 : 1-0.5. However, adjustments may be made depending on soil type and whether the risers will be covered with grass or faced with stone. The outward sloping bench should be provided with dense grass cover.

(3) Vertical interval: The vertical interval between benches may be calculated by the following formulas:

a. Level type: $$VI = \frac{W \cdot S}{100 - S \cdot \mu} = \frac{W \cdot S / \mu}{100/\mu - S} = \frac{d \cdot S}{100}$$

b. Inward sloping type: $VI = \dfrac{W \cdot S + k \cdot S \cdot \mu}{100 - S \cdot \mu} = \dfrac{W{\cdot}S / \mu + k{\cdot}S}{100 / \mu - S} = \dfrac{d{\cdot}S}{100}$

c. Outward-sloping type: $VI = \dfrac{W \cdot S - k \cdot S \cdot \mu}{100 - S \cdot \mu} = \dfrac{W \cdot S/\mu + WzS}{100/\mu - S} = \dfrac{d \cdot S}{100}$

VI = vertical interval (m)

W = width of bench (m)

S = slope of original surface (%)

d = width of terrace (m)

k = difference in height between front and back of bench (in the case of inward-sloping and outward-sloping benches) (m)

z = slope of the outward-sloping bench (vertical: horizontal ratio)

μ = slope ratio of riser (vertical: horizontal = 1:u)

(4) Width: The width of the bench terrace must fit in with crop spacing and mechanized operations.

a. Level type: $d = \dfrac{100VI}{S} = W + VI \cdot S$

b. Outward-sloping and inward-sloping types:

$$d = \frac{100VI}{S} = W + (VI \pm k)\mu = W + (VI \pm W \cdot z)\mu$$

Note: k and z are positive figures for reverse-slope type benches and negative for the outward-slope type

(5) Gradient: The gradient should be 0.5% to 1% for the inward type of bench, while that of the outward type is the same as for hillside ditches.

(6) Length: The length of a bench terrace should not exceed 100 m when water running along the bench is drained in only one direction.

(7) Height of the reverse slope: On reverse-sloping benches, the height of the toe above the heel should be more than 10 cm once the soil is well settled. When the width of the bench exceeds 3 m, the difference in height may be reduced to 5 cm.

(8) Outward slope: On outward-sloping benches, the outward slope should be less than 10%.

(9) Bench ridge: A bench ridge is built along the outer edge of level type terraces. This ridge should be 20 cm in height and 20 cm in width at the top.

(10) Outlet: For level type terraces, a water outlet about 10 cm deep and 20 cm wide should be constructed at the ridge to drain water into the waterway.

4.6 Operational procedures and points to be observed

(1) Survey and planning: An overall survey should be made of the area, to include topography, slope, depth of soil, soil texture, whether the soil is stony, erosion status, drainage

sites, etc. The type of terraces selected should fit in with cropping pattern, farm machinery to be used and the road system.

(2) Staking terrace lines: Terrace lines are set by selecting a site with a relatively uniform slope, and placing the first guide stake at the top of this slope. Then, working down the slope, other guide stakes are set to mark lower terraces according to the designed spacing. Each terrace line is staked out from its guide stake, along the contour of the slope. The stakes in a terrace line are set 5 to 10 m apart. The width of the terraces should be as uniform as possible, to permit easy cultivation and management. In places where topographical changes are found, localized adjustments of slope gradient and short interrupted contour lines can be made. Terrace lines should be rechecked and any sharp curves smoothed out as much as possible. Attention should also be paid to the connection of the terrace and the waterway.

(3) Land clearing: Before construction begins, all grasses, tree stumps, stones, etc. should be cleared from the surface of the ground.

(4) Cut and fill: Cuts are made by excavating the soil from the uphill side of the center line. The excavated soil is then removed to fill the downhill side of the center line. The filled soil must be in close contact with the original ground surface and should be well compacted at every 30 cm layer to ensure the solidity of the fill.

(5) Riser reinforcement: If stones are available, they may be used to face the risers. A foundation must first be made along the base of each riser. Stones are then laid to form the riser face. Riser facing should start from the bottom of the terrace and proceed uphill.

(6) Finishing: During and after construction, the work should be regularly checked and modified if necessary, to make sure that design specifications of bench width and slope gradient are being met.

(7) Construction sequence: Generally, the construction of terraces should start at the top of the slope and work down the slope so as to facilitate the work and to avoid possible damage by heavy rainfall while the work is in progress. However, in cases where the topsoil has to be replaced, or if the risers are to be faced with stones, construction should start at the bottom and move uphill. During heavy rains, a temporary water diversion ditch should be built if necessary.

(8) Topsoil replacement:

a. Topsoil is removed from the upper terrace site to cover the terrace bench just finished below. This procedure is followed for one terrace after another.

b. Topsoil is collected in one or more sections of the terrace or along the central line of the terrace. After the section of terrace form which topsoil has been removed, is completed, the topsoil is returned. The same procedure is repeated in the other sections of the same tenace.

(9) When a bulldozer is used in construction, the risers should be finished off manually from time to time during and after construction.

(10) As soon as construction is completed, grass should be planted on the risers.

(11) In places where the terrace contour, owing to handicaps, is out of line, special attention should be paid to drainage and erosion control.

4.7 Maintenance and management

(1) Upon completion of the terraces, it is advisable to deep plow the part of ground which has been cut, and apply soil amendments if necessary.

(2) The cross-section of the terraces must be maintained in good order when crops are being grown. If any damage occurs it must be repaired immediately.

(3) The grass on the risers must be properly managed to maintain a good cover.

4.8 Calculation of earthwork

(1) The volume of soil per hectare (v/ha) to be cut and filled is calculated as follows:

$$V/ha = A \times \frac{100^2}{d} = A \times \frac{100^2}{W + (VI \pm k)\mu} (m^3)$$

A is the area of the cross section to be excavated or filled, and

$$A = \frac{W \cdot VI \pm d \cdot k}{8} = \frac{W \cdot VI \pm (W \cdot k + k \cdot VI \cdot \mu \pm k^2 \cdot \mu)}{8}$$

$$= \frac{d \cdot VI - VI^2\mu \pm (d \cdot k - VI \cdot k \cdot \mu)}{8} (m^2)$$

Note: Other symbols such as W, VI, k, μ and d are the same as defined in the formula under 4.5.3.

(2) The total man-days required for the job may be calculated on the basis of the volume of soil to be excavated per hectare and the working efficiency of excavation, filling, levelling and compaction.

(3) The total volume of earth to be excavated and filled for various types of terraces is shown in Appendix 4.

Chapter 5. Planting Grass on Risers

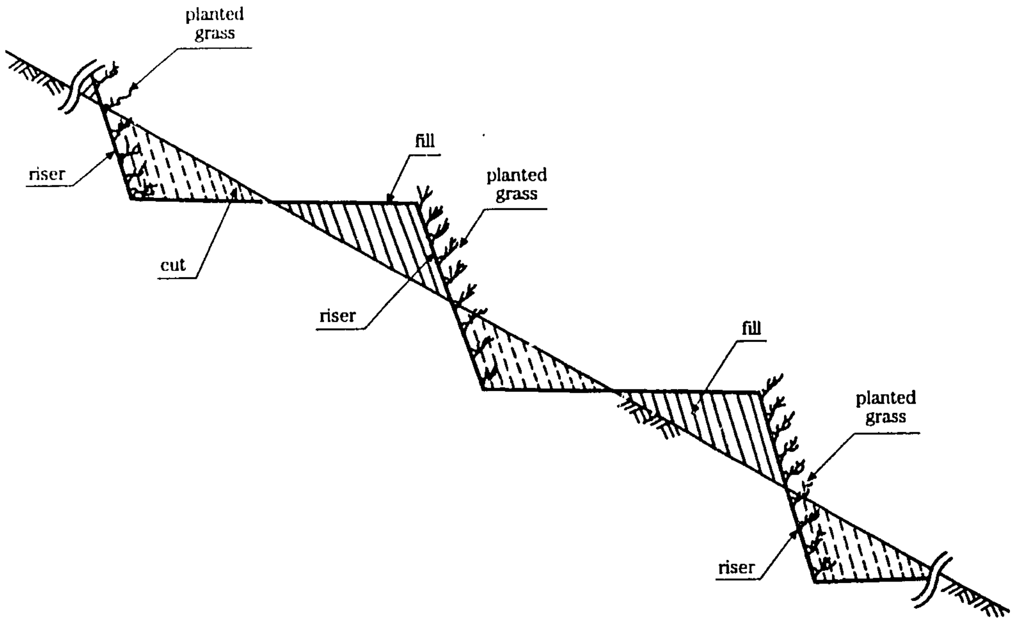
5.1 Definition

The planting of suitable grasses on the risers of bench terraces.

5.2 Objective

To prevent soil erosion from the risers and to maintain the stability of the terraces.

5.3 Diagram



5.4 Application

(1) It is essential to plant grasses on the risers of bench terraces unless they are faced with stone.

(2) Bahia grass, broadleaf Carpet grass, Centipede grass and Bermuda grass are the best choices. Other native creeping grasses are also acceptable.

5.5 Work procedures

(1) Grass should be planted as soon as the terraces have been constructed.

(2) For Bahia grass, planting material may be obtained by splitting clumps of the grass into tillers, which should be planted in rows in a triangular pattern at a spacing of 30 cm × 20 cm. Alternatively, grass seed mixed with asphalt emulsion may be sprayed over the area.

(3) When seeds of other species are used, the seeds may be mixed with emulsion and spread on the surface of the riser. Seed belts may also be used.

5.6 Management

(1) Cut the grass before the commencement of the dry season to minimize the loss of soil moisture.

(2) Make sure that rats do not nest in the grass.

(3) Maintain a thorough grass cover on the soil, and replace any dead or missing plants. Fertilizer may be applied sparingly.

Chapter 6. Broad-based Terraces

6.1 Definition

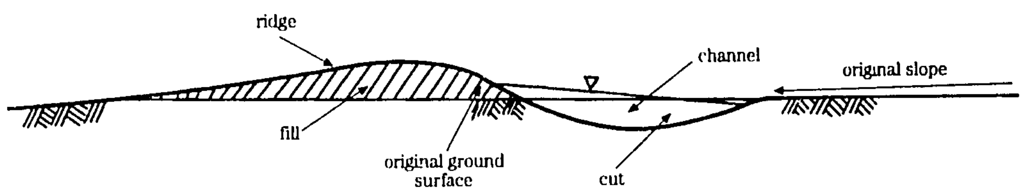
A series of shallow, broad based terraces constructed on gently sloping land at a suitable spacing along the contour lines.

6.2 Objectives

(1) To break the length of a slope to control soil erosion.

(2) To conserve soil moisture so as to help crop growth.

6.3 Diagram



6.4 Application

Slope of less than 12% gradient, with thick topsoil.

6.5 Design

(1) Drainage type - for slopeland with slopes ranging form 2% to 12% on soils of low permeability.

(2) Retention type - for slopes of 0.5% to 5% gradient on soils of high permeability.

(3) Spacing: same as that is specified for hillside ditches.

(4) Gradient: 0.1% to 0.6% for the drainage type of terraces. When the permeability of soils is very low or the terraces are very long, this range may be extended to 0.3% or 0.5%. No gradient is necessary for retention type broad based terraces.

(5) Length: Terraces should not be longer than 300 m in cases where drainage water runs only in one direction. If there is need for the terraces to be longer than this, a two-way drainage system must be used (drainage to both ends of the terrace or to the center).

(6) Cross-section: The area of cross-section of the channel (bottom of terrace) should be from 0.23 m^2 to 0.28 m^2, in order to hold the runoff. The gradient ratios (height to base) on the side slopes of the terrace should be from 1:4 to 1:6, in order to facilitate cropping practices.

(7) Outlets: The drainage outlets from the terraces should be the same as those recommended for hillside ditches.

6.6 Construction procedures

(1) Staking out the terrace lines:

a. Survey the slope from the highest point at the top of the hill and decide the contour and spacing of the terraces.

b. Stake out the guide line. This should be the bottom line of the channel for the drainage type terrace, or the top line of the ridge for the retention type terrace.

c. Assess the staked guide lines, and make any re-alignments necessary to avoid sharp curves, in order to facilitate the operation of machinery for construction and cultivation.

d. During realignment of terrace lines, the gradient of a terrace may be adjusted in order to avoid short crop rows and to make guide lines as nearly parallel as possible.

e. When the slope is quite uniform, the easier parallel terracing procedures may be adopted. The first terrace line is staked out as described above and guide stakes for the following terraces are then fixed at predetermined interval's. The other terrace lines can be staked out by two persons, using a rope or tape. The first person holds one end of the tape at the guide stakes, while the second person holds the other end of the tape, keeping the tape paralled to the first terrace line. The two persons work downward, when the first person meets a stake at the guide stake line, the other person drives in a stake at his end.

(2) Construction of the terrace

a. Levelling the land surface: Fill up guiles and rills and remove debris and weeds before construction begins.

b. Machinery and tools to be used to construct the terraces: disc plow, moldboard plow, bulldozer, grader and scraper.

c. Methods of construction:

With moldboard or disc plows, see fig. 1.
With bulldozer or scraper, see fig. 2.

d. Construction speed: depending on soil moisture content, slope gradient, length of terrace, skill and experience of machinery operator.

Relative speed ratio of moldboard is 1.0, disc and plow 1.1. Actual working speed of bulldozer, scraper, and moldboard: 50-100 meters per hour.

e. Finishing: After the construction is completed the site should be carefully inspected and defects marked. Correction should be made to ensure all parts of the construction will meet the specifications. For drainage type terraces, neither insufficient or excessive depth of the channels should be allowed, and the slopes should not be interrupted by irregular depressions or upheavals. For retention type terraces, the ridges must maintain an even height as specified. Since tractors and bulldozers can not maneuver at the ends of a terrace, those ends have to be worked by manual labor.

6.7 Maintenance

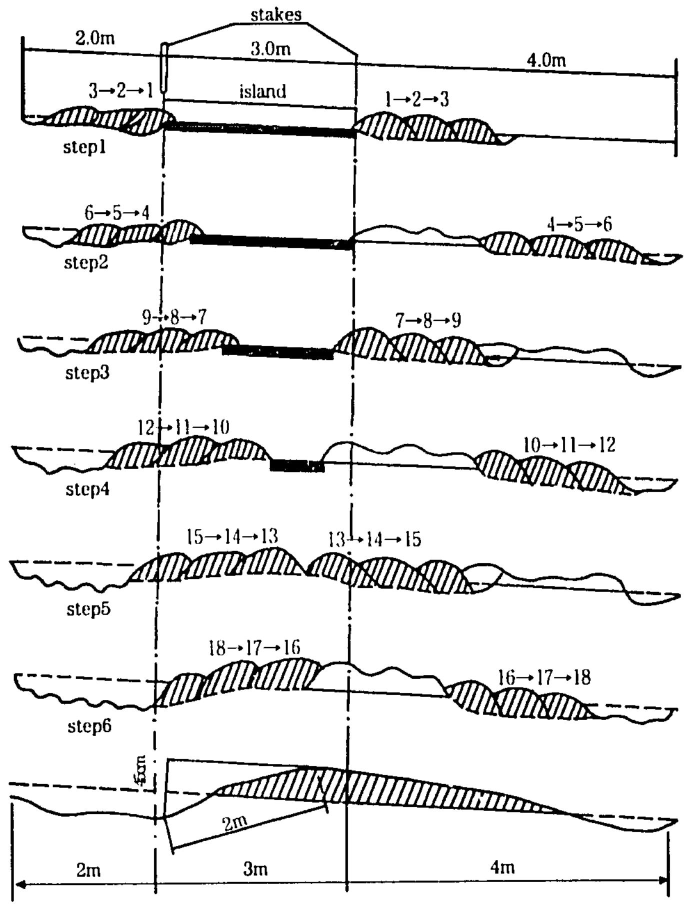


Fig. 6-1. Disc plowing procedures in construction of broad-based terrace and the final cross-section

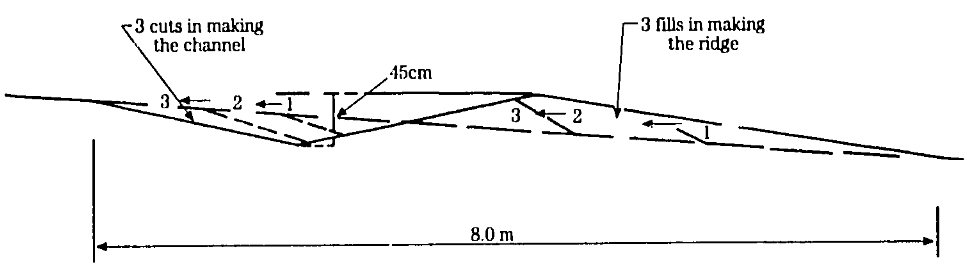


Fig. 6-2. Cuts and fills made by a dozer blade in construction of broad-based terrace.

(1) After the terraces have been completed, they should be periodically inspected and repaired if cracks, depressions, holes or eroded areas appear. The gradient of the terrace must be maintained according to the original design.

(2) Contour farming must be practised.

(3) Proper plowing is essential to the maintenance of the prescribed cross section of the terrace. See Figure 3.

(4) Arrangement of crop rows: At first, make 4-6 long rows parallel to the downward chan-

nel. Then starting from the side of the upward channel, make rows parallel to the upward channel, until the two groups of rows meet. Short rows maybe inserted where there is space in between.

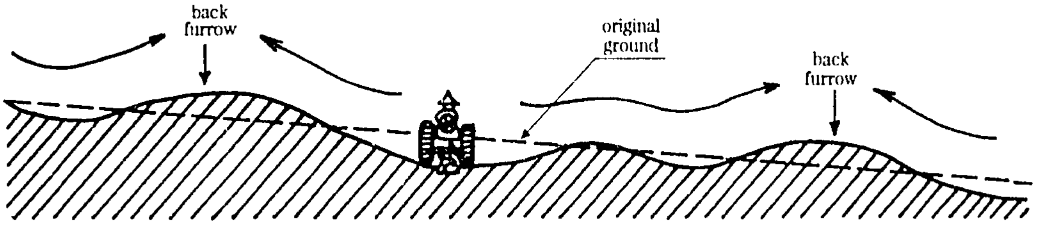


Fig. 6-3. Proper plowing on broad-based terrace - Arrows indicate movement of soil at plowing

If a terrace is plowed always in one direction, after a few years its cross-section will be distorted to such an extent that it will appear to resemble a bench terrace rather than a broad-based terrace. In order to avoid this, a terrace should be plowed to and fro in both directions.

Chapter 7. Stone Walls

7.1 Definition

Using stones to construct walls at a suitable spacing on slopeland along contour lines.

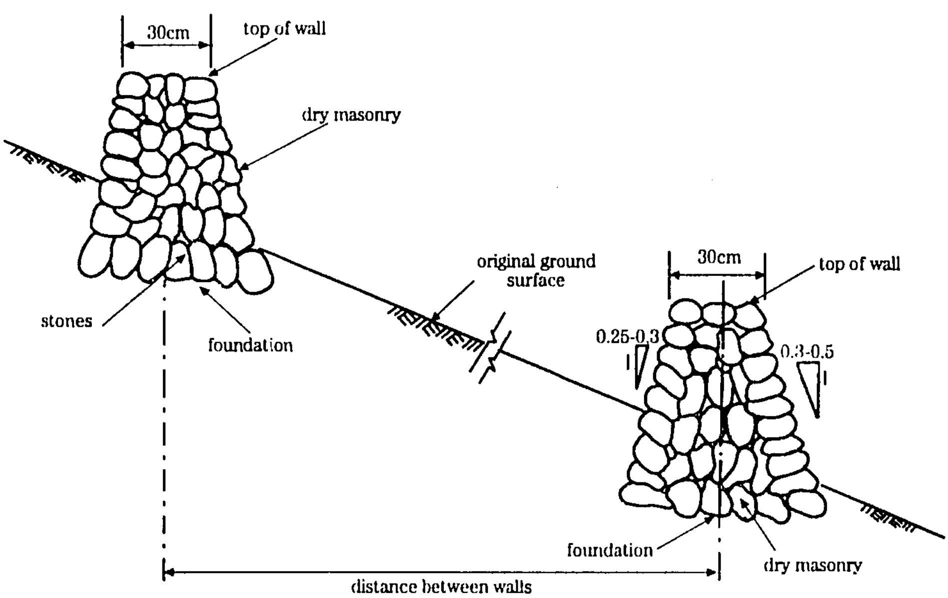
7.2 Objectives

(1) To make good use of rocks and stones existing on slopes, thereby clearing the land for cultivation.

(2) To reduce soil and water losses and to trap the soil washed down from above, thus gradually building up bench terraces and hillside ditches in later years.

(3) To minimize the gradient of a slope to facilitate cultivation, mechanized operations, and soil conservation.

7.3 Diagram



7.4 Application

(1) On slopes where there are many rocks and stones.

(2) Can be used as a preliminary treatment for constructing bench terraces or hillside ditches.

7.5 Design

(1) Cross-section: The size of the cross-section depends on the availability of stones. The gradient ratio (height to base) for the outside face of the walls is usually 1:0.3 to 1:0.5, and that of the inside face 1:0.25 to 1:0.3. The top of the wall should be as level as possible, with a width of at least 30 cm.

(2) Spacing:

a. In cases where bench terraces will ultimately be built, the stone walls should be built where the risers will be situated.

b. In cases where hillside ditches will ultimately be built, the stone wall should be built along the lines of the ditches.

c. To reduce the gradient of slope, stone walls may be constructed at a spacing according to the row width of crops and the requirements of mechanized operations.

(3) Stone walls should be as nearly parallel as possible. For ease of cultivation, interception of crop rows should be avoided.

7.6 Operational procedures

(1) First stake out the basic wall line and then excavate the earth along it to a depth of 30 cm or more.

(2) Select the largest rocks to form the foundation of the wall. The bottom row of stones should be selected for the stability.

(3) Walls should not be too high, if they are to be developed into bench terraces in the future.

(4) In building bench terraces, the walls may be built in several stages, depending on the availability of stones.

7.7 Complementary treatments

(1) Contour planting should be carried out on the land between the stone walls.

(2) When the walls are expected to become bench terraces or hillside ditches, earth accumulating on the upper side of the wall should be leveled to fit the specifications of bench terrace or hillside ditches.

Chapter 8. Grass Barriers

8.1 Definition

Contour planting of suitably spaced strips of grass on slopeland.

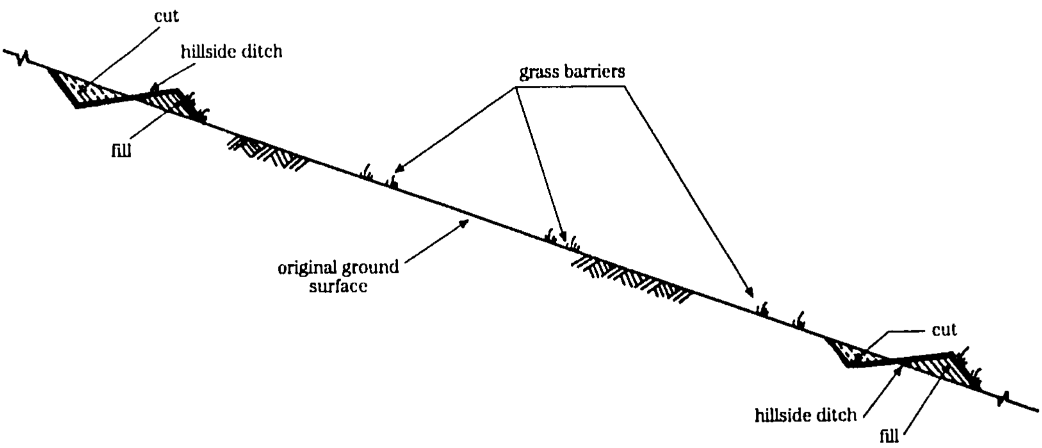
8.2 Objectives

(1) To arrest runoff so as to reduce soil and water losses and to hold soil and prevent it from being washed downhill.

(2) To reduce the slope of a hillside to facilitate cultural practices and mechanical operations.

(3) To gradually convert the barriers into bench terraces.

8.3 Diagram



8.4 Application

(1) On hillsides where orchards or field crops are to be established.

(2) Not suitable for slopes which are not uniform, which are stony, or where there are many gullies.

(3) Gradient of the slope should not exceed 45%.

8.5 Design

(1) Grass species: Bahia grass and weeping love grass, or other species which will not affect the crops and are easy to manage.

(2) Spacing: The spacing of the barriers is governed by the spacing of the crop rows, and normally should be 4-8 meters.

8.6 Operational procedures

(1) Use the hillside ditches as guide lines and stake out the barrier lines between these ditches. Place stakes every 5 to 10 m along the contour line. When necessary, the space between hillside ditches may be adjusted to coordinate with the barrier.

(2) Clear all trees, shrubs, stones, grasses and other obstacles off the slope and level the rough, uneven places as requred.

(3) When fresh root cuttings are used as planting material, set out 2 to 3 cuttings per hill. Plant 2 to 3 rows closely to form one grass barrier. In cases where weeping love grass is used, the row spacing and distance between plants should be 20 cm and 10 cm, respectively; for Bahia grass, these distances should be 50 cm and 20 cm. Planting should be done in a triangular pattern. If seeds are sown, the width of the barrier should be no less than 50 cm. After sowing, straw mats or cloth should be laid on top.

8.7 Maintenance

(1) Keep the grass barriers in good order and replant any dead or missing plants.

(2) Cut grass above ground level and leave the growth points alone to facilitate regrowth.

Chapter 9. Contour Planting

9.1 Definition

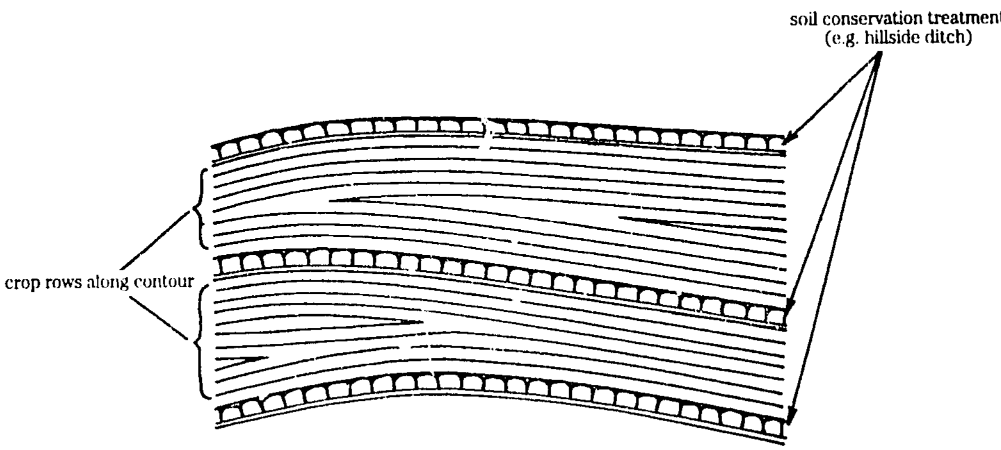
Plowing, furrowing and planting along the contour lines of a slope.

9.2 Objectives

(1) To increase water penetration into the soil and conserve soil moisure.

(2) To control runoff and soil erosion.

9.3 Diagram



9.4 Application

This practice should be adopted wherever cultivated crops are grown on slopeland.

9.5 Operational procedures

(1) When hillside ditches, broad-based terraces or stone walls exist, they should be used as guide lines for plowing, furrowing and other cultivation operations.

(2) The most adequate number of long rows along the guidelines is 4-6.

(3) Short rows should be positioned in the middle between two guide lines.

9.6 Maintenance

Repair any damage which may occur during heavy rain as soon as possible.

Chapter 10. Cover Crops

10.1 Definition

Plants which are grown to cover the surface of the ground with dense foliage, to control soil erosion and improve the soil.

10.2 Objectives

(1) To protect the surface of the soil from the splashing of rain drops.

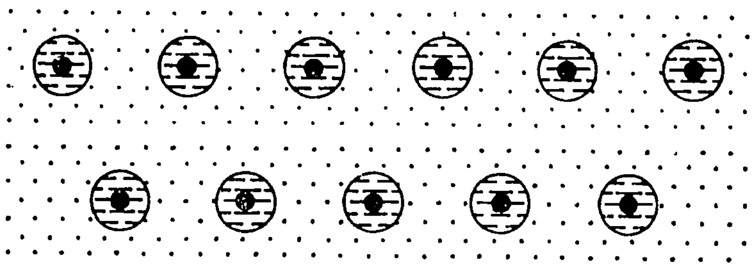
(2) To build up soil organic matter and improve its physical and chemical properties.

(3) To suppress weed growth and reduce management costs.

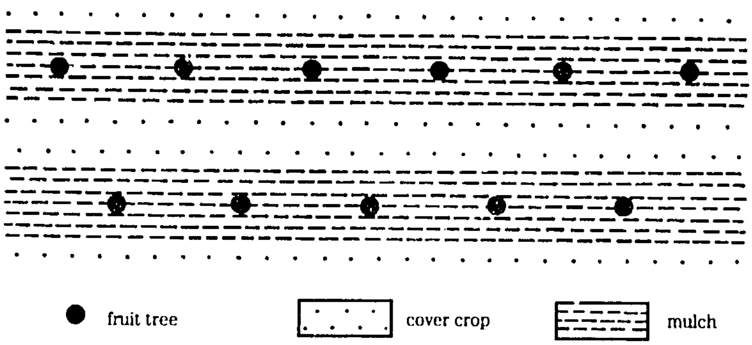
(4) To minimize changes in the micro-climate and in soil temperature, thereby providing a better environment for crop growth.

10.3 Diagram

Overall covering



Strip covering



10.4 Application

(1) Mainly for orchards in combination with other soil conservation treatment.

(2) When grass is to be planted as a cover crop, those species which are proven to be of soil conservation value should be first choice.

(3) Ordinarily, overall covering is recommended for orchards. Mowed grass should be

placed directly under the canopy of the fruit trees as a mulch.

(4) For young orchards, strip covering and mulching are recommended. (see Diagram 10.3)

10.5 Operational procedures

(1) When Bahia grass is used, for example, prepare planting material by splitting healthy mother plants. Plant in a triangular pattern with a spacing of 30 cm × 20 cm, planting 2 to 3 tillers per hill. It is best to do the planting on a rainy day.

(2) If the cover crop is to be direct seeded, mix the seed with soil and broadcast the mixture in rows. The seeds may also be mixed with asphalt emulsion and then sprayed.

10.6 Management

(1) Apply urea at a rate of 100 to 200 kg/ha for the first year.

(2) Cut the grass before the commencement of the dry season, to reduce losses of soil moisture.

(3) Take care to prevent rodents nesting, or allowing grass to dry and become a fire hazard.

(4) Put the cut grass around the tress. If strip covering is adopted, the cut grass should be placed between the covering strips.

39

Chapter 11. Green Manure

11.1 Definition

A green manure crop is grown specifically to improve soil and act as a fertilizer. It is plowed into soil while still green, or shortly after it matures.

11.2 Objectives

To increase organic matter and nutrients in soil, and to improve the physical and chemical characteristics of soil to increase the resistance of soil to erosion.

11.3 Application

(1) Green manure crops may be grown to improve sandy soils, heavy clay, and every type of unproductive soil.

(2) They may be grown between the rows of an existing crop, or on land lying fallow before a commercial crop is planted.

11.4 Design

(1) Selection of green manure crops: These should be adapted to local conditions, easy to raise, fast growing, high yielding, rich in nutrient content, and should have no adverse effects on the main crop. It is desirable that green manure crops be free seeding, so that a farmer may readily collect his own seed supplies. Crops suitable for slopeland are sesbania, desmodium, alfalfa, intortum, lupin, white clover, velvet bean, etc.

(2) Spacing of green manure crops: See the appendix. Adjustments may be made depending on the spacing and growth habit of the main crop.

11.5 Operational procedures

(1) Inoculation: Legume seed should be inoculated with the proper strain of rhizobial bacteria.

(2) Planting time: In spring or fall, when there is adequate soil moisture.

(3) The nitrogen content of a green manure crop is usually at its highest level during the early stages of flowering, when it is succulent and easily decomposed. It should be plowed in at this stage of growth.

11.6 Fertilization:

For legumes, 10 kg of nitrogen, 60 kg of P_2O_5, and 30 kg of K_2O should be applied to each hectare of land.

Chapter 12. Mulching

12.1 Definition

A protective covering of grass, crop residues or other material spread over the ground between crop rows or around the trunks of fruit trees.

12.2 Objectives

(1) To reduce runoff and soil loss, and to increase soil moisture.

(2) To suppress weeds and save labor costs of weeding.

(3) To adjust soil temperature.

(4) To increase soil organic matter.

(5) To reduce evaporation of soil moisture.

12.3 Application

(1) Where runoff and soil losses are high.

(2) When an increase in soil organic matter, reduction of evaporation, suppression of weeds, or adjustment of soil temperature is needed.

(3) When polyethylene is used as a mulch, it will be able to achieve only some of these objectives (12.2(2),12.2(3) and 12.2(5)).

12.4 Operational procedures

(1) Cover crops or grasses planted in orchards are a readily available source of mulching material. The residues of crops may be left in the field after harvest.

(2) Polyethylene sheets and other artificial materials may be used for mulching. However, these materials are suitable mainly for mulching on ridges of planting rows.

12.5 Essential points to be observed

(1) Attention should be paid to pest and disease control and to the elimination of fire hazards.

(2) When polyethylene sheet is used as mulch, runoff will increase, and thus an adequate drainage system will be required.

(3) Large pieces of crop residue should be cut or broken up before application.

(4) When organic materials are used as a mulch in orchards, the mulch should not be too thick. If the entire planted area is to be mulched, the mulch should be laid in strips.

Chapter 13. Windbreaks

13.1 Definition

Strips of trees or tall grasses planted at appropriate intervals to prevent or reduce wind erosion and crop losses caused by wind.

13.2 Objectives

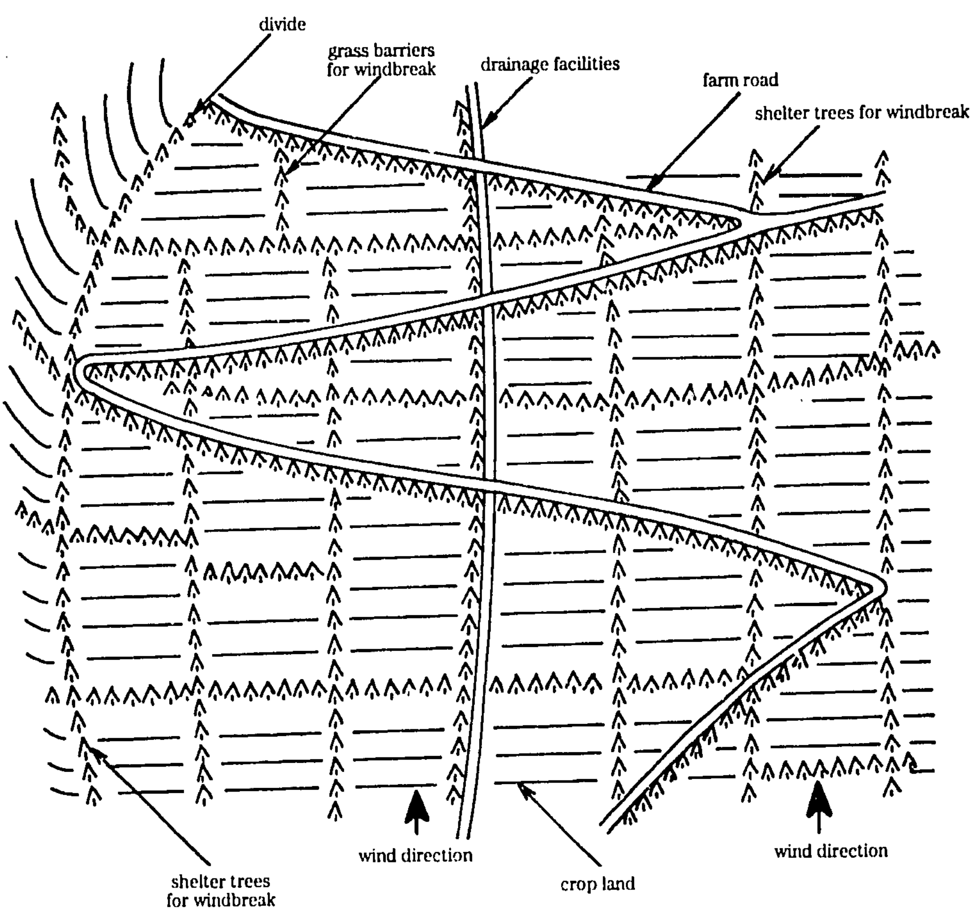
(1) To control wind erosion.

(2) To reduce physiological or mechanical injuries to crops caused by strong winds.

(3) To reduce evapotranspiration.

(4) To reduce salt damage if the locality is near the sea.

13.3 Diagram



13.4 Application

(1) On slopes affected by wind erosion or where strong wind prevails.

(2) For farms on which crops susceptible to wind damage are being grown.

13.5 Design

(1) Tree species: Select erect tree species with a deep root system, exuberant off shoots, and with a trunk and branches capable of withstanding strong winds. In Taiwan, suitable species are Acacia confusa, Casuarina quistifolia, Ryukyu pine, Alnus formosana, Nephalium longana, Tamarix, bamboo, etc.

(2) Grass species: In Taiwan, recommended grass species are Napier grass, and Miscanthus spp.

(3) Spacing: Windbreaks are usually spaced at a distance equal to 7 times the height of the shelter trees or grass, although adjustments may be made on steep slopes to fit in with the topography of the land. The tops of dividing ridges, edges of fields and sides of roads should be utilized as much as possible for the planting of shelter trees,as long as the effectiveness of the windbreak is not affected.

(4) Location and direction:

a. The windbreak should be set at right angles to the prevailing wind.

b. When windbreaks are planted across a hillside, they should follow the contour lines.

c. When grass strips are planted as windbreaks, they should be so arranged so as not to interfere with field work. Where hillside ditches exist, the strips should run along the side of the ditch in double rows.

d. At the time of setting up a tree windbreak, grass strips may be planted on the windward side of the trees in order to protect the tree seedlings and also to serve as temporary windbreaks before the trees are fully grown. The grass will remain as ground cover when the trees are grown.

13.6 Operational procedures

(1) Select the sites of the windbreaks and suitable tree or grass species.

(2) Planting pattern:

a. Acacia spp. may be established from either seeds or seedlings. Seeds may be sown in strips or hills. The spacing should be 0.5 to 1 m within the row, and rows should be 1 m apart.

b. Bamboos are usually planted in a single row. For thorny bamboo (Bambusa senostachya) and long branch bamboo (B. dolichoclada), a plant spacing of 1 to 1.5 m should be appropriate. Kwanying (B. multiplex) and Patzelan (B. pachinensis) varieties should be planted 1 m apart, with 1 to 3 plants in each hill.

c. Napier grass may be planted by cuttings, with hills spaced 20 to 30 cm apart, and 30 to 50 cm between rows.

d. Miscanthus spp. may be planted by cuttings in hills 20 to 30 cm apart, with 30 to 50 cm between rows.

e. Windbreaks consisting of tall trees, e.g. Acacias and Casuarinas, should be incorporated with suitable grass barriers or undergrowth shrubs.

(3) Planting season: Planting is usually done in the early spring or during the rainy season.

(4) Before planting, the land should be plowed and weeded. After planting, fertilizers should be applied. Good management should be maintained.

(5) Care should be taken to control pests and diseases which would cause damage to the main crops.

13.7 Maintenance

(1) Fresh seedlings should be planted to replace any dead plants. Any necessary pruning should be done. For bamboo windbreaks, unnecessary branches or stalks should be removed in order to encourage the growth of small, dense twigs which will give better protection against the wind.

(2) For grass windbreaks, brushwood screens should be erected in the windy season to provide additional resistance to wind.

(3) The roots of shelter trees must not be allowed to interfere with the growth of crops. A ditch should be dug between the shelter and the crop, to prevent the roots of the barrier trees from spreading. The branches of the shelter trees should be pruned if they adversely affect the growth of crop.

Chapter 14. Diversion Ditches

14.1 Definition

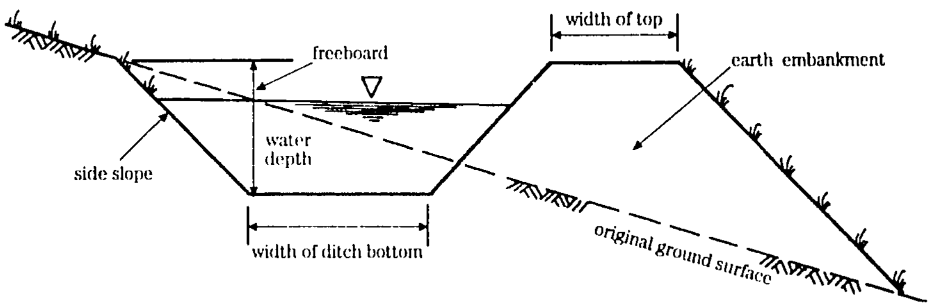
A ditch constructed approximately along the contour of a slope for the purpose of intercepting surface runoff and diverting it to a suitable outlet.

14.2 Objectives

(1) To protect farmland and buildings by diverting runoff from hill slopes.

(2) To control gully erosion.

14.3 Diagram (earth ditch)



14.4 Application

(1) Diversion ditches should be built where runoff is likely to cause damage or erosion.

(2) Grass should be planted along the ditch for protection. The inside wall and bottom may be lined with cement.

(3) Intercepted runoff should be drained off to a safe place.

14.5 Design

(1) Find out the volume of runoff, with reference to the gradient of slope and the area of watershed, from Table 14-1 or Appendix 5, "Runoff Estimation".

Example: For a farm located in the Taipei area with an average gradient of 30% and a watershed of 1 ha, the runoff volume should be 0.434 m^3/sec, according to Table 14-1.

(2) Design the cross-section of the ditch with the assistance of the following tables, on the basis of the lining of the ditch, soil characteristics, gradient of ditch sides and bottom, or by the following procedures:

a. On the basis of the volume of runoff and gradient of the ditch, decide the type, depth and area of cross-section.

(i) The area of cross-section should be in proportion to the volume of runoff.

(ii) Steeper gradients permit a smaller cross-section. However, attention should be paid to the maximum velocity of flow to be tolerated.

(iii) The more the soil is prone to erosion, the less steep the gradient of the ditch should be. The slope of the sides of the ditch also should be gentler.

(iv) A freeboard of 0.1-0.3 m should be included in the design.

b. Estimate roughness coefficient: On the basis of the texture (smoothness) of the lining of the ditch. (See Table 14-3)

c. Calculate hydaulic radius with the following formula:

$R = \frac{A}{P}$ = Hydraulic radius (m)

The area of a trapezoidal cross-section may be found by Fig.14-1 or calculated as follows:

$A = bd + zd^2$=Cross-section area (m^2) of flow

b =Width of ditch bottom (m)

d =Depth of water (m)

z =Slope of ditch side (1: z=Vertical : Horizontal)

P =Wetted perimeter (m)

=Length of cross-section in contact with water

$= b + 2d\sqrt{1+z^2}$

P value can also be obtained directly from Figure 14-2.

If cross-section is rectangular, and the width of ditch bottom and water bottom are known, hydraulic radius can be obtained from Figure 14-3.

d. Compute average velocity V from Fig. 14-4 or from the following formula. The average velocity computed should not be greater than the maximum permissible velocity. The maximum permissible velocities for different types of ditch conduits are given in Table 14-4.

$$V = \frac{1}{n} R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

V =average velocity (m/sec)

R =hydraulic radius equal to $\frac{A}{P}$ (m)

S =hydraulic gradient or ditch bottom gradient

n =Manning roughness coefficient

e. Calculate channel capacity to accommodate the discharge Q from Fig. 14-5 or the following formula:

Q = AV

Q = discharge (m^3/sec)

A = cross-section area (m^2)

V = average velocity (m/sec)

f. If channel capacity is equal to or a little greater than the designed runoff, the design of the cross-section is suitable. If it is too small, the cross-section area has to be increased and re-calculated to accommodate the estimated runoff that may occur. If it is too large, the design will be uneconomical.

(3) Calculation of amount of materials needed

See Appendix 7

14.6 Points to be observed during construction

(1) All trees and stumps should be removed from the ditch site and from the fill materials.

(2) The fill must be properly compacted. Water lying in depressions in the top of the fill should be drained away to keep the fill properly dried. Any wet or water-clogged places should not be filled.

(3) An allowance of 10% of the height of the fill should be made, to allow for the fill settling. Grass should be planted to protect the fill.

(4) Any gravel dug out of the ditch should be utilized to increase the stability of the channel.

(5) The sites for the deposition of fill material should be carefully planned so that further movement of the material can be avoided after it is deposited.

(6) The cross-section and gradient of a diversion ditch should be trimmed to meet the design. This will permit a smooth flow of water.

Table 14-1. Estimate of Runoff on Farmland in Various Areas of Taiwan

Keelung Area

Unit: m^3/sec

Gradient % / Catchment Area (Ha.)	10	15	20	25	30	35	40	45	50	55
0.3	0.140	0.141	0.142	0.142	0.142	0.142	0.142	0.143	0.143	0.143
0.4	0.186	0.187	0.187	0.188	0.188	0.189	0.189	0.189	0.189	1.890
0.5	0.232	0.232	0.235	0.233	0.234	0.234	0.235	0.235	0.235	0.235
0.6	0.274	0.276	0.278	0.279	0.279	0.280	0.280	0.280	0.280	0.281
0.7	0.317	0.320	0.322	0.323	0.324	0.325	0.325	0.325	0.325	0.326
0.8	0.360	0.364	0.366	0.367	0.368	0.369	0.370	0.370	0.371	0.371
0.9	0.402	0.407	0.409	0.411	0.412	0.413	0.414	0.415	0.415	0.415
1.0	0.444	0.449	0.452	0.454	0.456	0.457	0.458	0.459	0.459	0.459
2.0	0.839	0.854	0.864	0.871	0.875	0.879	0.881	0.883	0.885	0.886
3.0	1.230	1.230	1.248	1.260	1.269	1.275	1.280	1.284	1.287	1.289
4.0	1.542	1.584	1.610	1.629	1.642	1.652	1.660	1.665	1.670	1.672
5.0	1.862	1.919	1.955	1.981	1.999	2.013	2.023	2.031	2.037	2.040

Taipei Area

Unit: m^3/sec

Gradient % / Catchment Area (Ha.)	10	15	20	25	30	35	40	45	50	55
0.3	0.132	0.132	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133
0.4	0.176	0.176	0.176	0.176	0.177	0.177	0.177	0.177	0.177	0.177
0.5	0.218	0.219	0.219	0.220	0.220	0.220	0.220	0.220	0.220	0.220
0.6	0.261	0.262	0.262	0.263	0.263	0.264	0.264	0.264	0.264	0.264
0.7	0.303	0.304	0.305	0.305	0.306	0.306	0.307	0.307	0.307	0.307
0.8	0.345	0.347	0.348	0.348	0.349	0.349	0.350	0.350	0.304	0.350
0.9	0.386	0.389	0.390	0.391	0.392	0.392	0.392	0.393	0.393	0.393
1.0	0.428	0.431	0.432	0.433	0.434	0.435	0.435	0.435	0.436	0.437
2.0	0.820	0.837	0.843	0.846	0.849	0.851	0.852	0.853	0.854	0.854
3.0	1.210	1.227	1.237	1.244	1.249	1.253	1.255	1.257	1.259	1.260
4.0	1.575	1.601	1.618	1.629	1.637	1.643	1.647	1.650	1.653	1.654
5.0	1.926	1.963	1.987	2.002	2.014	2.022	2.024	2.033	2.036	2.039

Hsinchu Area Unit: m^3/sec

Catchment Area (Ha.) \ Gradient %	10	15	20	25	30	35	40	45	50	55
0.3	0.100	0.100	0.100	0.100	0.100	0.100	0.101	0.101	0.101	0.101
0.4	0.133	0.133	0.133	0.134	0.134	0.134	0.134	0.134	0.134	0.134
0.5	0.166	0.166	0.166	0.167	0.167	0.167	0.167	0.167	0.167	0.167
0.6	0.198	0.199	0.199	0.199	0.200	0.200	0.200	0.200	0.200	0.200
0.7	0.231	0.231	0.232	0.232	0.232	0.233	0.233	0.233	0.233	0.233
0.8	0.263	0.263	0.264	0.265	0.265	0.265	0.265	0.266	0.266	0.266
0.9	0.295	0.296	0.297	0.297	0.298	0.298	0.298	0.298	0.298	0.298
1.0	0.327	0.328	0.329	0.330	0.330	0.331	0.331	0.331	0.331	0.331
2.0	0.640	0.644	0.647	0.649	0.649	0.651	0.652	0.653	0.658	0.658
3.0	0.942	0.951	0.957	0.960	0.963	0.965	0.966	0.967	0.968	0.969
4.0	1.235	1.252	1.258	1.264	1.269	1.272	1.274	1.276	1.277	1.278
5.0	1.520	1.541	1.554	1.562	1.568	1.573	1.576	1.579	1.581	1.582

Taichung Area Unit: m^3/sec

Catchment Area (Ha.) \ Gradient %	10	15	20	25	30	35	40	45	50	55
0.3	0.124	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.4	0.165	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.167
0.5	0.206	0.206	0.207	0.207	0.207	0.207	0.207	0.207	0.208	0.208
0.6	0.245	0.246	0.247	0.248	0.248	0.248	0.248	0.248	0.248	0.248
0.7	0.286	0.287	0.287	0.288	0.288	0.289	0.289	0.290	0.289	0.289
0.8	0.325	0.326	0.328	0.328	0.329	0.329	0.329	0.328	0.330	0.330
0.9	0.365	0.366	0.367	0.368	0.369	0.369	0.370	0.370	0.370	0.370
1.0	0.403	0.406	0.407	0.408	0.409	0.409	0.410	0.410	0.410	0.410
2.0	0.781	0.790	0.794	0.799	0.800	0.802	0.803	0.804	0.804	0.805
3.0	0.142	1.157	1.167	1.173	1.178	1.181	1.183	1.185	0.187	1.189
4.0	1.488	1.512	1.527	1.537	1.544	1.550	1.554	1.556	1.559	1.560
5.0	1.822	1.856	1.876	1.891	1.901	1.909	1.914	1.918	1.922	1.924

45

Tainan Area

Unit: m³/sec

Catchment Area (Ha.) \ Gradient %	10	15	20	25	30	35	40	45	50	55
0.3	0.143	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144
0.4	0.191	0.191	0.191	0.191	0.191	0.192	0.192	0.192	0.192	0.192
0.5	0.238	0.238	0.239	0.239	0.239	0.239	0.239	0.239	0.239	0.239
0.6	0.285	0.285	0.286	0.286	0.286	0.286	0.286	0.287	0.287	0.287
0.7	0.331	0.332	0.333	0.333	0.333	0.334	0.334	0.334	0.334	0.334
0.8	0.373	0.378	0.379	0.380	0.380	0.380	0.381	0.381	0.381	0.381
0.9	0.423	0.425	0.426	0.427	0.427	0.427	0.428	0.428	0.428	0.428
1.0	0.469	0.471	0.472	0.473	0.473	0.474	0.474	0.475	0.475	0.475
2.0	0.918	0.925	0.929	0.932	0.934	0.935	0.936	0.937	0.937	0.938
3.0	1.354	1.366	1.374	1.379	1.383	1.385	1.387	1.389	1.389	1.391
4.0	1.776	1.796	1.803	1.817	1.822	1.827	1.830	1.832	1.834	1.835
5.0	2.186	2.215	2.233	2.245	2.254	2.260	2.654	2.263	2.271	2.273

Kaohsiung Area

Unit: m³/sec

Catchment Area (Ha.) \ Gradient %	10	15	20	25	30	35	40	45	50	55
0.3	0.116	0.116	0.117	0.117	0.117	0.117	0.117	0.117	0.177	0.117
0.4	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.156	0.156
0.5	0.193	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194
0.6	0.231	0.232	0.232	0.232	0.232	0.233	0.233	0.233	0.233	0.233
0.7	0.269	0.270	0.270	0.270	0.271	0.271	0.271	0.271	0.271	0.271
0.8	0.307	0.303	0.309	0.309	0.309	0.309	0.309	0.309	0.310	0.310
0.9	0.345	0.346	0.347	0.347	0.347	0.347	0.348	0.348	0.349	0.348
1.0	0.383	0.384	0.385	0.385	0.385	0.386	0.386	0.386	0.386	0.386
2.0	0.754	0.758	0.760	0.762	0.763	0.764	0.764	0.765	0.765	0.765
3.0	1.117	1.124	1.129	1.132	1.134	1.136	1.137	1.137	1.139	1.139
4.0	1.472	1.484	1.491	1.495	1.499	1.502	1.504	1.505	1.506	1.507
5.0	1.820	1.837	1.848	1.855	1.860	1.864	1.866	1.869	1.870	1.871

55

Hengchun Area

Unit: m³/sec

Catchment Area (Ha.) \ Gradient %	10	15	20	25	30	35	40	45	50	55
0.3	0.158	0.159	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
0.4	0.209	0.210	0.211	0.212	0.212	0.212	0.212	0.212	0.213	0.213
0.5	0.260	0.261	0.262	0.263	0.264	0.264	0.264	0.264	0.264	0.265
0.6	0.309	0.311	0.313	0.314	0.315	0.315	0.316	0.316	0.316	0.316
0.7	0.359	0.362	0.363	0.365	0.365	0.366	0.366	0.367	0.367	0.367
0.8	0.407	0.411	0.413	0.415	0.416	0.417	0.417	0.418	0.418	0.418
0.9	0.455	0.460	0.462	0.464	0.466	0.467	0.467	0.468	0.468	0.468
1.0	0.503	0.503	0.511	0.514	0.515	0.516	0.517	0.518	0.518	0.519
2.0	0.957	0.972	0.982	0.989	0.993	0.997	1.000	1.002	1.003	1.004
3.0	1.377	1.406	1.424	1.437	1.446	1.452	1.457	1.461	1.464	1.466
4.0	1.773	1.816	1.844	1.863	1.877	1.887	1.895	1.900	1.905	1.908
5.0	2.148	2.207	2.245	2.271	2.291	2.035	2.315	2.323	2.329	2.333

Taitung Area

Unit: m³/sec

Catchment Area (Ha.) \ Gradient %	10	15	20	25	30	35	40	45	50	55
0.3	0.192	0.194	0.196	0.197	0.198	0.198	0.198	0.199	0.199	0.199
0.4	0.250	0.254	0.257	0.258	0.259	0.260	0.261	0.261	0.262	0.262
0.5	0.307	0.312	0.316	0.318	0.319	0.321	0.322	0.322	0.323	0.323
0.6	0.362	0.369	0.3[illegible]	0.376	0.378	0.380	0.381	0.382	0.383	0.383
0.7	0.415	0.424	0.429	0.433	0.436	0.438	0.439	0.440	0.441	0.442
0.8	0.467	0.477	0.484	0.489	0.492	0.494	0.496	0.498	0.499	0.499
0.9	0.517	0.530	0.538	0.543	0.547	0.550	0.552	0.554	0.555	0.556
1.0	0.567	0.582	0.590	0.597	0.601	0.605	0.607	0.609	0.611	0.612
2.0	1.012	1.048	1.072	1.088	1.100	1.110	1.116	1.122	1.125	1.128
3.0	1.397	1.455	1.494	1.520	1.542	1.558	1.569	1.578	1.585	1.589
4.0	1.742	1.823	1.877	1.916	1.945	1.968	1.984	1.996	2.005	2.011
5.0	2.059	2.162	2.231	2.281	2.318	2.346	2.368	2.384	2.396	2.404

Hualien Area

Unit: m³/sec

Gradient % / Catchment Area (Ha.)	10	15	20	25	30	35	40	45	50	55
0.3	0.116	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
0.4	0.154	0.155	0.155	0.155	0.156	0.156	0.156	0.156	0.156	0.156
0.5	0.192	0.193	0.193	0.194	0.194	0.194	0.194	0.194	0.194	0.194
0.6	0.230	0.231	0.231	0.232	0.232	0.232	0.232	0.232	0.233	0.233
0.7	0.267	0.268	0.269	0.270	0.270	0.270	0.270	0.271	0.271	0.271
0.8	0.304	0.306	0.307	0.307	0.308	0.308	0.308	0.309	0.309	0.309
0.9	0.341	0.343	0.344	0.345	0.345	0.346	0.346	0.346	0.347	0.347
1.0	0.378	0.380	0.381	0.382	0.383	0.383	0.384	0.284	0.384	0.384
2.0	0.734	0.741	0.746	0.749	0.751	0.752	0.753	0.754	0.755	0.755
3.0	1.075	1.089	1.097	1.102	1.106	1.109	1.112	1.113	1.114	1.115
4.0	1.403	1.424	1.437	1.446	1.452	1.457	1.461	1.463	1.465	1.466
5.0	1.720	1.750	1.768	1.781	1.790	1.796	1.801	1.805	1.808	1.810

I-lan Area

Unit: m³/sec

Gradient % / Catchment Area (Ha.)	10	15	20	25	30	35	40	45	50	55
0.3	0.171	0.174	0.175	0.176	0.176	0.177	0.177	0.178	0.178	0.178
0.4	0.224	0.227	0.230	0.231	0.232	0.232	0.233	0.233	0.234	0.234
0.5	0.274	0.279	0.232	0.284	0.285	0.286	0.287	0.288	0.288	0.288
0.6	0.324	0.330	0.333	0.336	0.338	0.339	0.340	0.341	0.342	0.342
0.7	0.372	0.379	0.384	0.387	0.389	0.391	0.392	0.393	0.394	0.395
0.8	0.418	0.427	0.433	0.437	0.440	0.442	0.444	0.445	0.446	0.446
0.9	0.464	0.475	0.481	0.486	0.490	0.492	0.494	0.495	0.496	0.497
1.0	0.509	0.522	0.529	0.534	0.538	0.541	0.543	0.545	0.546	0.547
2.0	0.921	0.949	0.968	0.982	0.992	0.999	1.005	1.009	1.012	1.014
3.0	1.286	1.332	1.362	1.384	1.400	1.413	1.422	1.429	1.434	1.438
4.0	1.621	1.684	1.726	1.756	1.779	1.796	1.809	1.819	1.826	1.831
5.0	1.935	2.014	2.068	2.106	2.135	2.157	2.174	2.187	2.196	2.203

Table 14-2. Safety Range of Flow Velocity for Earth Diversion Ditches with Trapezoid Cross Section

Figures on the left of the dark line are within the safety range Unit: m³/sec

Side slope		1 : 0.3					1 : 0.5				
Ditch width / Water depth	Ditch gradient	0.1	0.5	1	2	3	0.1	0.5	1	2	3
b(m)	d(m)										
0.40	0.20	0.034	0.075	0.107	0.149	0.181	0.038	0.085	0.120	0.167	0.203
0.60	0.30	0.101	0.224	0.315			0.113	0.260	0.353		
0.80	0.40	0.217	0.482	0.681			0.244	0.540	0.764		
1.00	0.50	0.391	0.874				0.444	0.991			
1.20	0.60	0.638	1.424				0.720	1.593			
1.40	0.70	0.969	2.153				1.090	2.413			

Side slope		1 : 0.7					1 : 1				
Ditch width / Water depth	Ditch gradient	0.1	0.5	1	2	3	0.1	0.5	1	2	3
b(m)	d(m)										
0.40	0.20	0.043	0.095	0.134	0.187		0.048	0.107	0.150	0.210	
0.60	0.30	0.126	0.279	0.394			0.140	0.313	0.443		
0.80	0.40	0.272	0.600	0.847			0.291	0.649	0.917		
1.00	0.50	0.493	1.094				0.555	1.223			
1.20	0.60	0.797	1.769				0.891	1.998			
1.40	0.70	1.134	2.510				1.352	3.014			

Side slope		1 : 1.5					1 : 2				
Ditch width / Water depth	Ditch gradient	0.1	0.5	1	2	3	0.1	0.5	1	2	3
b(m)	d(m)										
0.40	0.20	0.056	0.125	0.175	0.245		0.064	0.141	0.198	0.277	
0.60	0.30	0.161	0.357	0.502			0.187	0.418	0.587		
0.80	0.40	0.358	0.790	1.114			0.403	0.896	1.261		
1.00	0.50	0.651	1.443				0.730	1.630			
1.20	0.60	1.046	2.331				1.181	2.635			
1.40	0.70	1.578					1.784				

Table 14-3. Roughness Coefficient n for Manning Formula

Ditch surface materials	n values	
	Range	Mean
Without limning		
Claysoil, smooth	0.016-0.022	0.020
Sandy loam or clay loam, smooth	—	0.020
Loosely grassed	0.035-0.045	0.040
Densely grassed	0.040-0.060	0.050
Mixed with gravels from 1 to 3 cm in diameter	—	0.022
Mixed with gravels from 2 to 6 cm in diameter	—	0.025
Smooth, homogeneous rock	0.030-0.035	0.0325
Rough surface rock	0.035-0.045	0.040
With lining		
Brick mortar pitching	0.012-0.017	0.014
Cobble mortar pitching	0.017-0.030	0.025
Cobble dry pitching	0.025-0.035	0.033
Smooth earth bottom, cobble pitching on sides	—	0.025
Rough earth bottom, cobble pitching on sides	0.023-0.035	0.030
Smooth mortar lining	0.010-0.014	0.012

54

Table 14-4. Maximum safe velocites for different types of ditches (m/sec)

Type of ditch soil	Maximum safe velocity
Pure silt	0.23-0.30
Soft silt	0.30-0.46
Coarse stone and fine gravel	0.46-0.61
Ordinary sand	0.61-0.76
Sandy loam	0.76-0.84
Hard loam and clay loam	0.91-1.14
Ordinary gravel	1.23-1.52
Dense grass	1.50-2.50
Coarse gravel & sand	1.52-1.83
Gravelly rock, hard earth layer, soft aqueous rock	1.83-2.44
Hard rock	3.05-4.57
Concrete	4.57-6.10

153

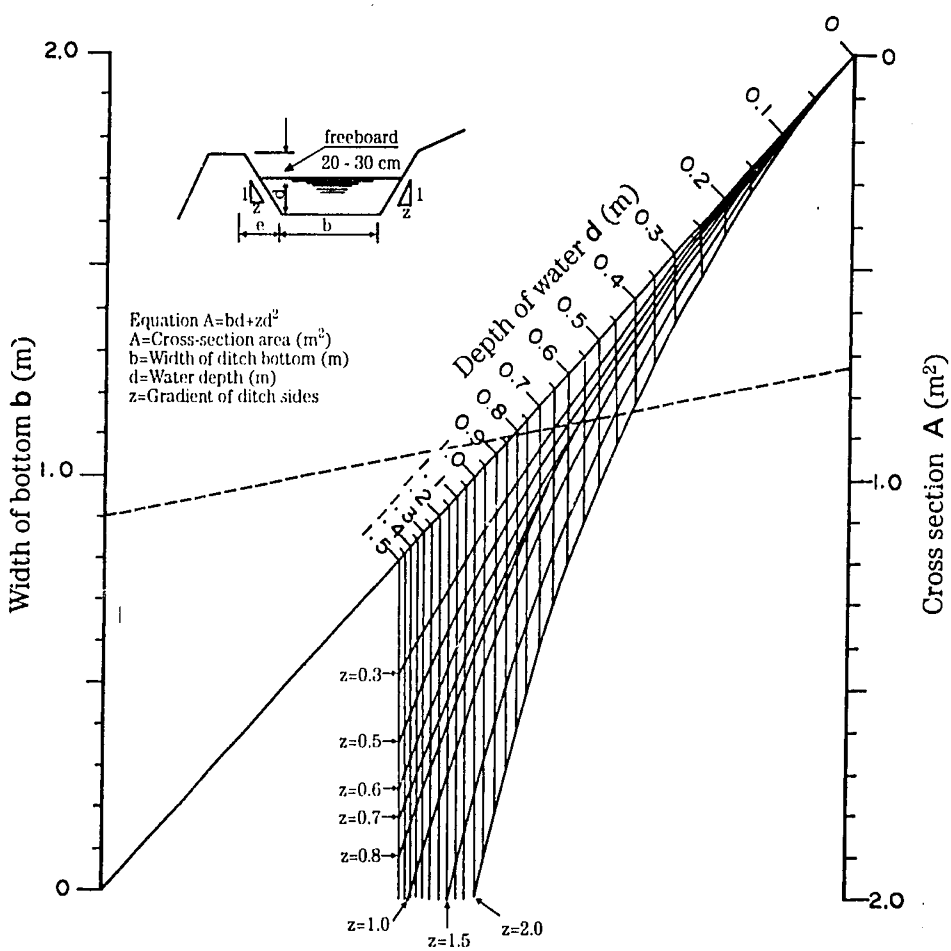


Fig. 14-1. Cross section area for trapezoidal diversion ditch

Example: If b=0.9m d=0.6m z=0.5:1

Find A

Solution: Draw a straight line from b axis (0.9) to a point where d axis (0.6) axis (0.5) intercept. Extend this line to the A axis (0.72)

The answer is thus $A=0.72m^2$

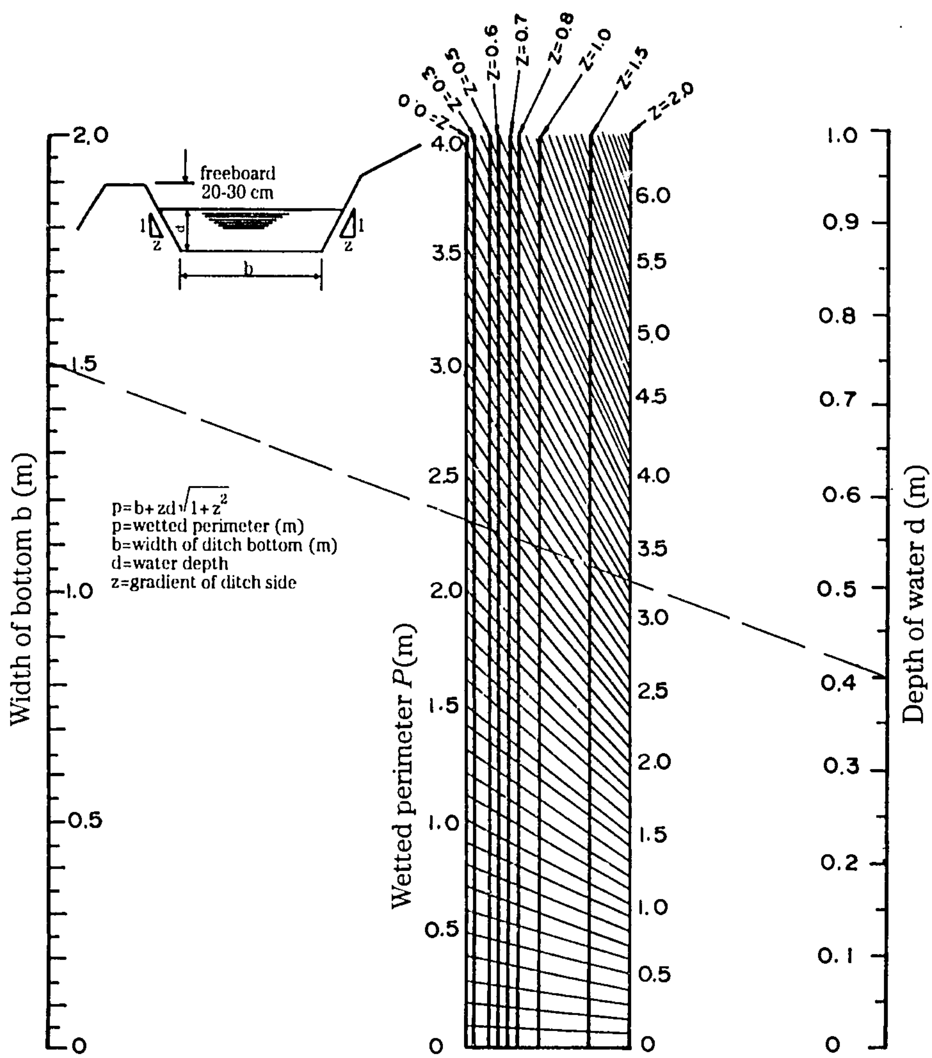


Fig. 14-2. Calculation of the wetted perimeter of a trapezoidal diversion ditch

Example: If b=1.5m d=0.4m z=1:1

Find P

Solution: Draw a straight line from the b axis (1.5) to connect with d axis 0.4). This line will intercept the z axis lines in the center of the figure. As in this example z=1.0, take the point where the line crosses the z=1.0 axis and follow the thin radial line either to right or left, where the P figure may be obtained. In this example P=2.62m

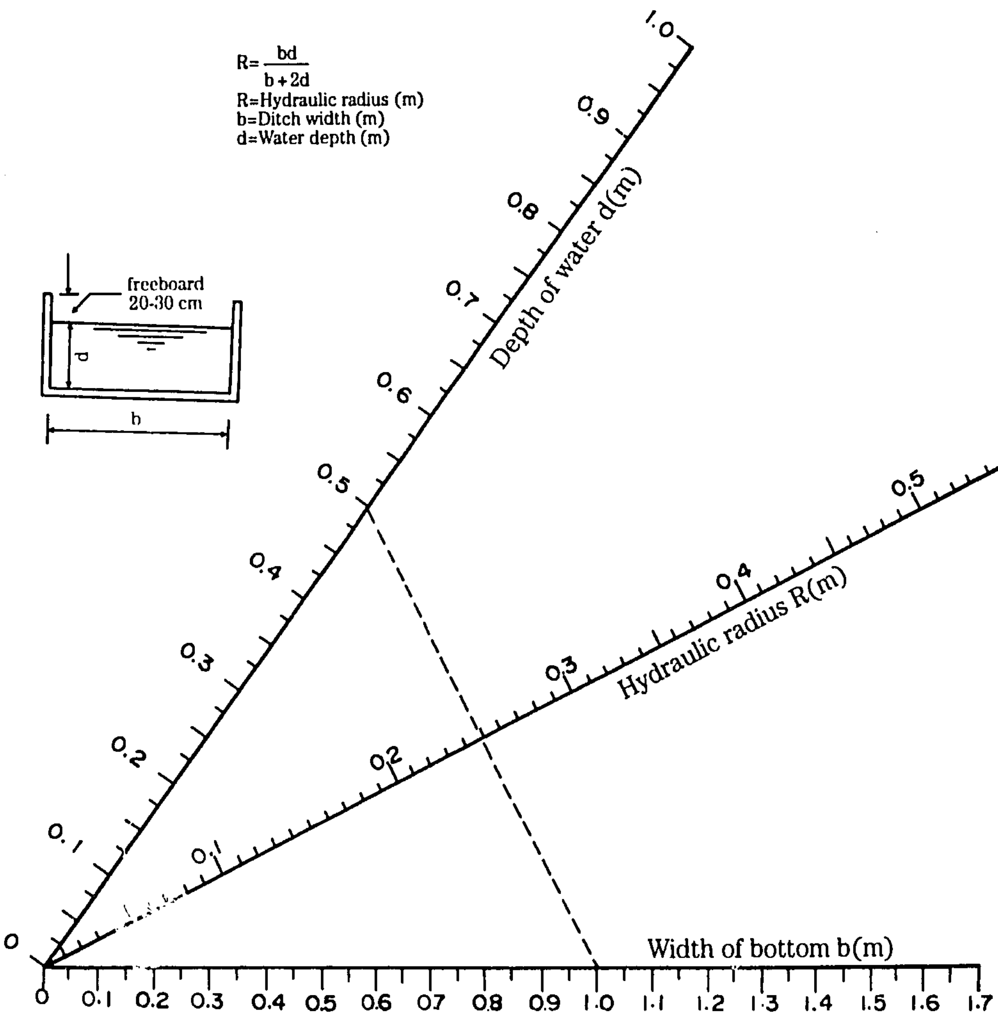


Fig. 14-3. Hydraulic radius of a diversion ditch with rectangular cross section

Example: If d=0.5m b=1.0m

Find R

Solution: Draw a line connecting d axis (0.5) with b axis (1.0), R is obtained when this line crosses the R axis. Answer: R=0.25m

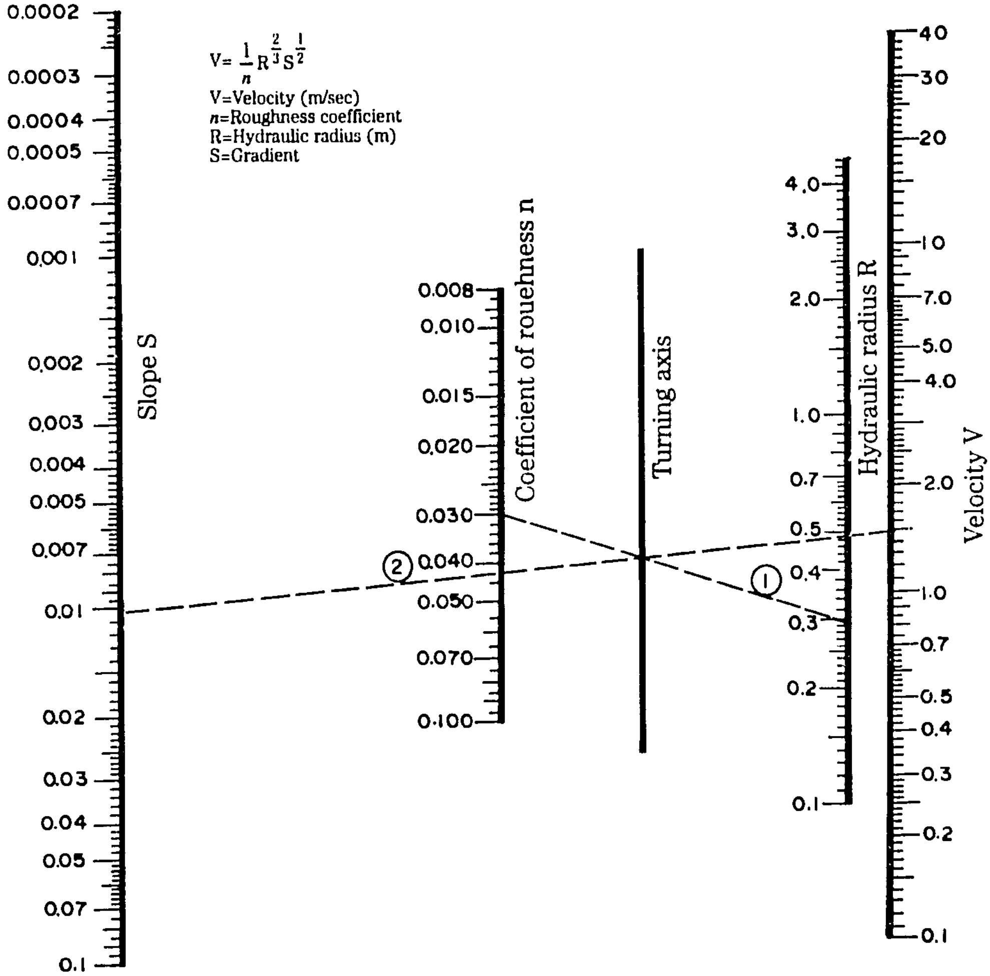


Fig. 14-4. Calculation of average velocity of flow

Example: if n=0.08 R=0.3 s=$\frac{1}{100}$=0.01

Find V

Solution: Draw a straight line ① connecting n axis (0.03) with R axis (0.3). This line intercepts the turning axis at c. Then connect c with s axis (0.01) and project this line to V axis. Answer: V=1.5 m/sec.

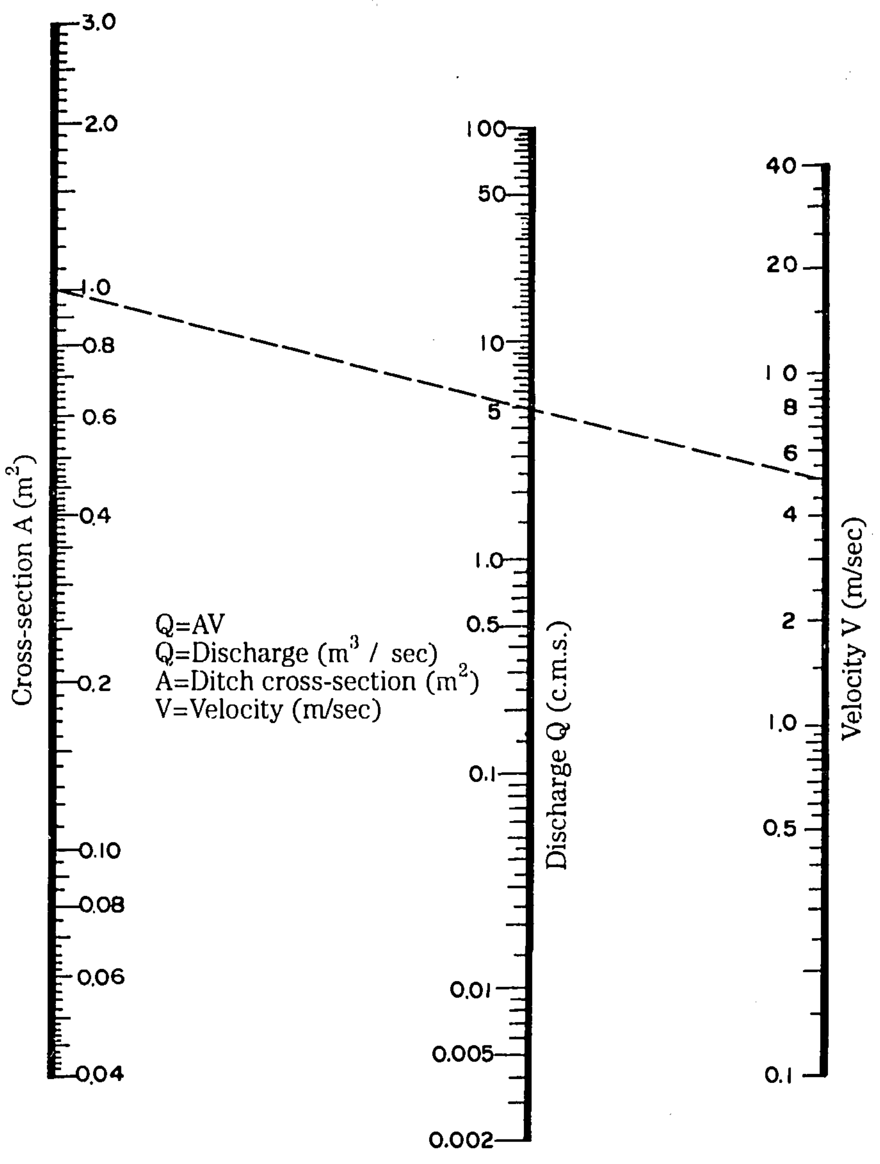


Fig. 14-5. Estimation of discharge

Example: If A=1m^2 V=5m/sec

Find Q

Solution: Draw a line from A axis (1.0) to V axis (5). The point where this line intercepts Q axis gives Q.

Answer: Q=5 c.m. s.

Chapter 15. Drainage Ditches

15.1 Definition

Drainage channels running along a slope, which are lined with stone, brick, or concrete etc.

15.2 Objectives

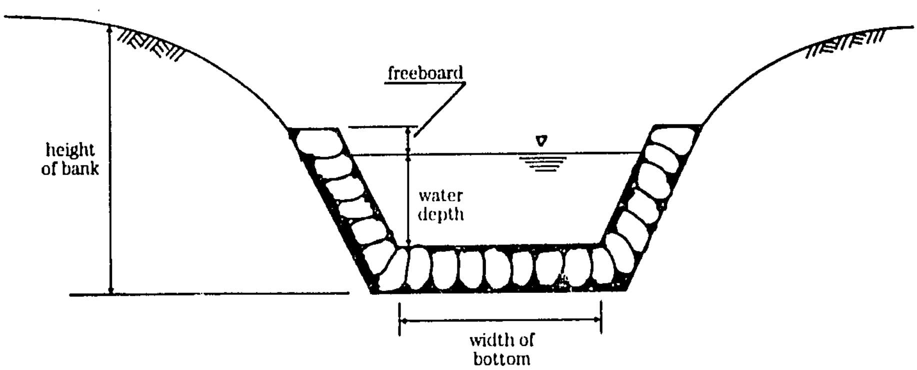
(1) To ease the flow of runoff water and to protect the ditch from erosion.

(2) To gather water flow in hillside ditches and contour drainage channels, and carry the flow to a safe place to be discharged.

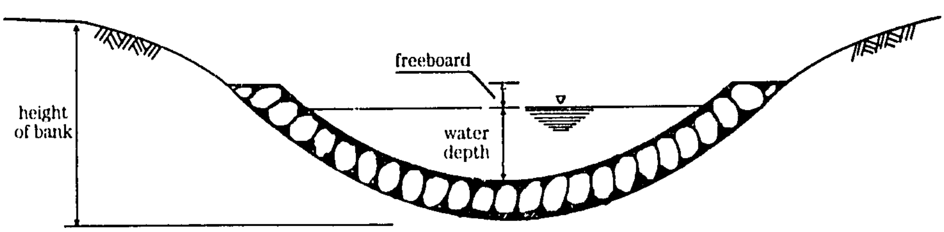
15.3 Diagram

(1) Cobble lined ditch

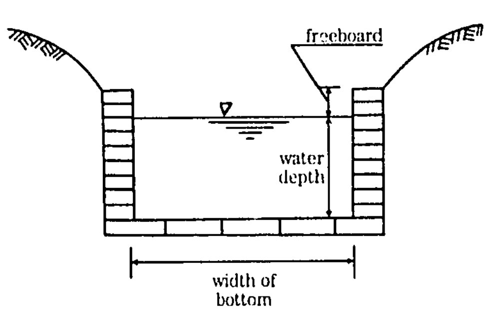
a. Trapezoid type ditch



b. Parabolic type ditch

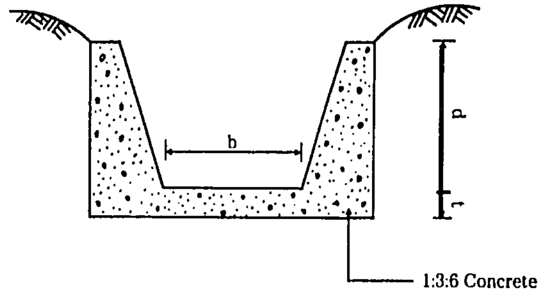


(2) Brick lined ditch

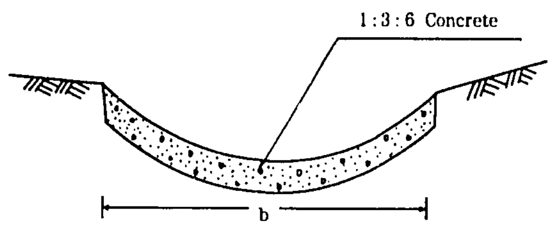


(3) Concrete ditch

a. Trapezoid type

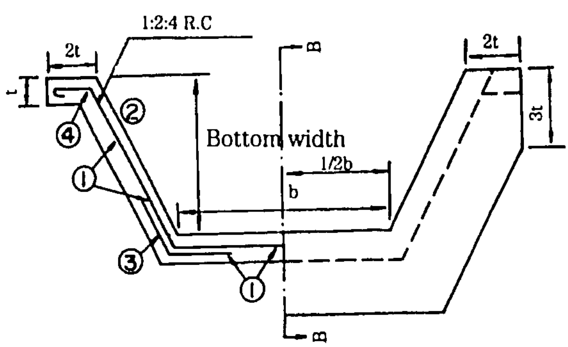


b. Parabolic type

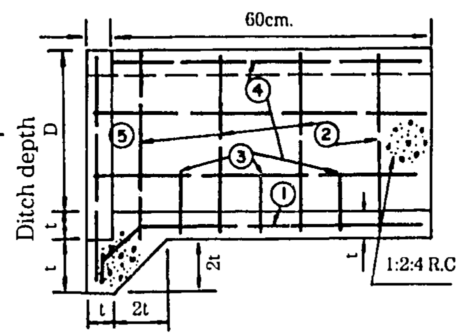


(4) Prefabricated ditch

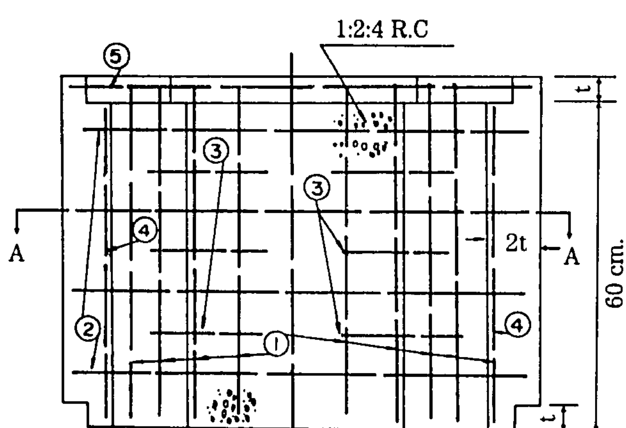
a. Trapezoid type



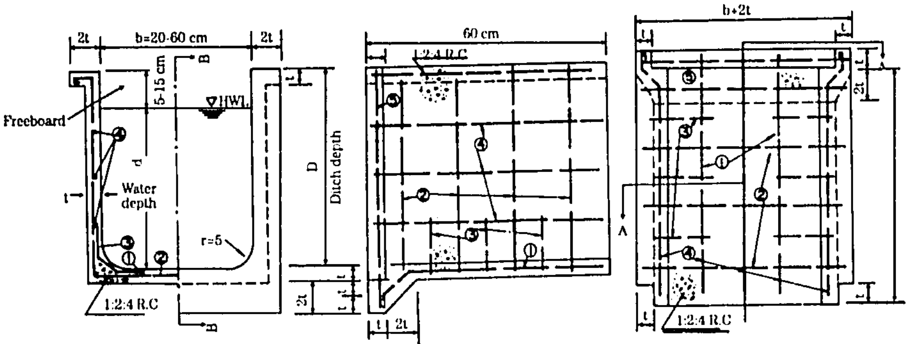
A-A Cross-section



B-B Cross-section

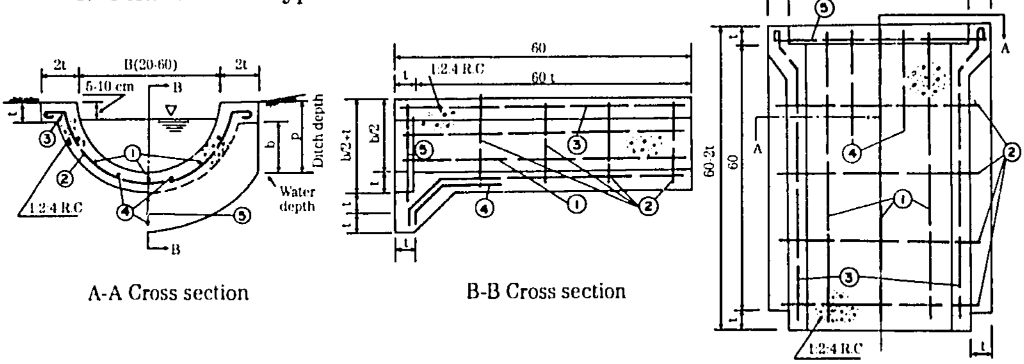


b. U type



A-A Cross section B-B Cross section

c. Semi-circular type



A-A Cross section B-B Cross section

15.4 Application

(1) Suitable for farm drainage systems

(2) Concrete ditches should be used where slopes are steep and volume of flow is large.

(3) Where machinery is used in farming, a parabolic cross-section is desirable.

(4) Concrete should be used where strong stresses exist at the sides of the ditch so that they are likely to collapse.

(5) Stone lining is desirable where stones are plentiful and inexpensive.

(6) Over difficult terrain or in order to save time, prefabricated ditches are preferrable.

(7) Brick-lined ditches with a wide and shallow cross-section may also serve as foot-paths. At steep locations, steps may be built into the ditch.

(8) Where a drainage ditch crosses a farm road or hillside ditch , it should have a broad, shallow cross-section to permit the easy passage of farm machinery. Otherwise, a culvert should be built.

(9) For protection and energy dissipation, drop spillways or revetments should be constructed at proper intervals at the downstream end, when necessary.

(10) Damping barriers should be set up where the slope is very steep and dangerous.

15.5 Design

(1) To estimate the amount of runoff water see 14.5 (1).

(2) Lining material and shape of cross-section: To be decided on the basis of the condition of the site, the requirements of farm management, the volume of water flow, etc.

(3) The size of the ditch: Determined by referring to the Tables 15-1-7, on the basis of slope gradient and runoff volume. This can also be done by following the steps indicated in 14.5(2).

(4) Requirement of materials: See Appendix 7.

15.6 Precautions

(1) During excavation, the specifications of the cross-section and the gradient should be closely observed. The inside of the ditch should be kept flat and smooth to minimize resistance to water flow.

(2) Excavate earth to a sufficient depth so that the top of the ditch is 10cm below the surface of the ground. The banks over the top of the ditch should cant sideways. Soil excavated should be removed or levelled once construction is completed.

(3) Any gap between the concrete and earth at the sides of the ditch should be filled and compacted. Along the top edge of the ditch, grass may be planted for protection. Bahia grass is the most suitable.

(4) Good, hard, uniform-sized cobbles are preferred for lining. If cobbles are set in concrete, before being laid they should be washed and kept moist during and after construction until the concrete is set.

(5) For brick ditches, the bricks should be moistened before they are laid. The layers of bricks should be kept parallel. The joints should alternate from layer to layer, and remain vertical. Deformed bricks should be reserved for laying on the bottom.

(6) Prefabricated ditches must be built in a straight line. If a turn is necessary, a drop structure should be installed at the turning point to serve as a joint. Construction of prefabricated ditches should proceed from the bottom towards the top of the slope. The end of the prefabricated section with a recess for coupling should face upward. All couplings should be tightly connected.

Table 15-1. Flow in trapezoidal ditch with cobble mortar pitching
(slope of ditch wall 1:0.3)

(unit: c.m.s.)

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		0.1	0.5	1	5	10	15	20	25
0.30	0.15	0.013	0.029	0.040	0.088	0.128	0.156	0.180	0.201
0.50	0.25	0.050	0.111	0.156	0.343	0.498	0.606	0.700	0.778
0.70	0.35	0.120	0.266	0.375	0.829	1.204	1.467	1.691	1.882
0.90	0.45	0.238	0.529	0.746	1.656	2.386	2.908	3.350	3.728
1.10	0.55	0.404	0.905	1.274	2.791	4.072	4.956	5.728	6.361
1.30	0.65	0.632	1.409	1.983	4.355	6.357	7.737	8.932	9.924
1.50	0.75	0.930	2.070	2.910	6.410	9.300	11.350	13.100	14.550

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		30	35	40	45	50	55	60	65
0.30	0.15	0.221	0.237	0.253	0.269	0.285	0.297	0.309	0.325
0.50	0.25	0.855	0.917	0.979	1.043	1.106	1.151	1.199	1.260
0.70	0.35	2.069	2.220	2.369	2.520	2.671	2.676	2.788	2.939
0.90	0.45	4.101	4.399	4.697	4.995	5.294	5.517	5.741	6.939
1.10	0.55	6.995	7.510	8.011	8.526	9.034	9.417	9.786	10.169
1.30	0.65	10.915	10.712	11.509	12.279	13.074	13.696	14.280	14.829
1.50	0.75	15.990	17.173	18.335	19.490	20.650	21.530	22.387	23.560

Table 15-2. Flow in trapezoidal ditch with cobble dry pitching (I)
(slope of ditch wall 1:0.3)

(unit: c.m.s.)

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		0.1	0.5	1	5	10	15	20	25
0.30	0.15	0.100	0.022	0.030	0.067	0.097	0.119	0.137	0.152
0.50	0.25	0.038	0.084	0.118	0.259	0.377	0.459	0.530	0.589
0.70	0.35	0.091	0.202	0.285	0.627	0.912	1.112	1.283	1.425
0.90	0.45	0.181	0.401	0.565	1.242	1.807	2.203	2.542	2.824
1.10	0.55	0.308	0.684	0.960	2.121	3.085	3.760	4.338	4.820
1.30	0.65	0.481	1.068	1.505	3.311	4.815	5.869	6.771	7.523
1.50	0.75	0.710	1.570	2.200	4.850	7.050	8.590	9.910	11.030

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		30	35	40	45	50	55	60	65
0.30	0.15	0.167	0.179	0.192	0.204	0.216	0.225	0.234	0.246
0.50	0.25	0.648	0.695	0.742	0.789	0.836	0.872	0.907	0.954
0.70	0.35	1.568	1.682	1.769	1.910	2.024	2.109	2.195	2.309
0.90	0.45	3.106	3.332	3.558	3.784	4.010	4.180	4.349	4.574
1.10	0.55	5.302	5.688	6.073	6.459	6.845	7.133	7.423	7.808
1.30	0.65	8.276	8.877	9.478	10.082	10.683	11.134	11.586	12.188
1.50	0.75	12.130	13.010	13.890	14.770	15.640	16.300	16.960	17.840

62

Table 15-3. Flow in trapezoidal ditch with cobble dry pitching (II)
(slope of ditch wall 1:0.5)

(unit: c.m.s.)

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		0.1	0.5	1	5	10	15	20	25
0.30	0.15	0.011	0.024	0.034	0.074	0.107	0.131	0.151	0.168
0.50	0.25	0.042	0.094	0.132	0.290	0.422	0.514	0.539	0.659
0.70	0.35	0.103	0.230	0.323	0.712	1.035	1.261	1.456	1.617
0.90	0.45	0.202	0.449	0.633	1.393	2.026	2.469	2.849	3.165
1.10	0.55	0.346	0.767	1.081	2.378	3.460	4.216	4.865	5.405
1.30	0.65	0.540	1.198	1.686	3.710	5.396	6.577	7.590	8.432
1.50	0.75	0.790	1.760	2.480	5.440	7.900	9.530	11.12	12.360

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		30	35	40	45	50	55	60	65
0.30	0.15	0.185	0.198	0.211	0.225	0.238	0.248	0.258	0.272
0.50	0.25	0.725	0.778	0.831	0.883	0.936	0.976	1.015	1.068
0.70	0.35	1.780	1.908	2.038	2.167	2.297	2.394	2.491	2.620
0.90	0.45	3.482	3.735	3.988	4.241	4.494	4.684	4.874	5.127
1.10	0.55	5.946	6.378	6.811	7.243	7.676	8.000	8.324	8.757
1.30	0.65	9.276	9.950	10.623	11.299	11.974	12.479	12.989	13.660
1.50	0.75	13.580	14.580	15.560	16.550	17.530	18.280	19.020	20.010

Table 15-4. Flow in ditch with brick mortar pitching

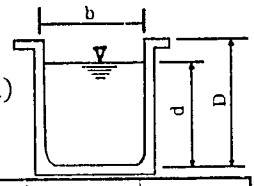
(unit: c.m.s.)

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		0.1	0.5	1	5	10	15	20	25
0.25	0.13	0.011	0.025	0.035	0.076	0.111	0.136	0.156	0.174
0.40	0.20	0.039	0.087	0.123	0.270	0.393	0.479	0.553	0.614
0.50	0.25	0.071	0.158	0.223	0.463	0.714	0.870	1.004	1.116
0.65	0.33	0.144	0.318	0.448	0.984	1.432	1.745	2.014	2.237
0.85	0.43	0.292	0.652	0.918	2.019	2.575	3.578	3.728	4.584
1.00	0.50	0.455	1.007	1.418	3.118	4.035	5.527	5.823	7.082
1.20	0.60	0.734	1.635	2.308	5.059	6.649	8.902	9.564	11.509
1.35	0.68	1.008	2.236	3.148	6.926	10.075	12.279	14.167	15.741

Width of ditch bottom b(m)	Depth of flow d(m)	Slope of bottom of ditch (%)							
		30	35	40	45	50	55	60	65
0.25	0.13	0.191	0.205	0.219	0.233	0.247	0.257	0.268	0.282
0.40	0.20	0.675	0.725	0.774	0.823	0.872	0.909	0.946	0.995
0.50	0.25	1.227	1.317	1.406	1.495	1.584	1.651	1.718	1.807
0.65	0.33	2.461	2.640	2.819	2.998	3.177	3.311	3.445	3.624
0.85	0.43	5.047	5.414	5.581	5.747	6.515	6.790	7.066	7.433
1.00	0.50	7.795	8.362	8.929	9.496	10.063	10.488	10.913	11.480
1.20	0.60	12.667	13.588	14.509	15.430	16.352	17.042	17.734	18.655
1.35	0.68	17.315	18.574	19.834	21.093	22.352	23.297	24.242	25.501

b: Ditch width (m) D:Ditch depth (m)
d: Water depth(m) S:Bottom gradient (%)
V: Flow velocity (m/s) Q:Flow (m^3/sec)

Table 15-5. Flow in U-shaped precast ditches



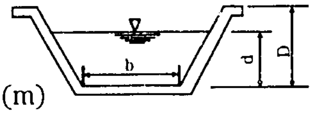
b: width of ditch bottom (m) D: depth of ditch (m) d: depth of flow (m)
s: gradient of ditch (%) V: velocity (m/sec) Q: volume of flow (c.m.s.)

S	b	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
	D	0.25	0.30	0.40	0.45	0.50	0.55	0.60	0.65	0.70
	VQ \ d	0.15	0.20	0.30	0.35	0.35	0.40	0.45	0.50	0.55
2	V	1.60	1.94	2.79	2.92	3.04	3.19	3.35	3.51	3.68
	Q	0.0464	0.1636	0.3464	0.4582	0.5291	0.6839	0.8687	1.0868	1.3404
4	V	2.27	2.75	3.94	4.13	4.29	4.51	4.74	4.97	5.20
	Q	0.0656	0.2313	0.4899	0.6480	0.7483	0.9672	1.2285	1.5370	1.8957
6	V	2.78	3.36	4.83	5.06	5.26	5.53	5.80	6.09	6.37
	Q	0.0804	0.2833	0.6000	0.7937	0.9165	1.1846	1.5046	1.8824	2.3217
8	V	3.21	3.88	5.58	5.85	6.07	6.38	6.70	7.03	7.36
	Q	0.0928	0.3271	0.6928	0.9165	1.0582	1.1368	1.7373	2.1736	2.6808
10	V	3.59	4.34	6.23	6.54	6.79	7.14	7.49	7.86	8.23
	Q	0.1038	0.3657	0.7746	1.0247	1.1831	1.5293	1.9424	2.4302	2.9973
12	V	3.93	4.76	6.83	7.16	7.43	7.82	8.21	8.61	9.01
	Q	0.1137	0.4006	0.8485	1.1225	1.2961	1.6752	2.1278	2.6621	3.2834
14	V	4.12	5.14	7.38	7.73	8.03	8.45	8.87	9.30	9.74
	Q	0.1191	0.4327	0.9165	1.2124	1.3999	1.8095	2.2983	2.8754	3.5465
16	V	4.41	5.49	7.89	8.27	8.59	9.03	9.48	9.94	10.41
	Q	0.1273	0.4626	0.9798	1.2961	1.4966	1.9344	2.4569	3.0739	3.7913
18	V	4.51	5.62	8.08	8.47	8.79	9.25	9.71	10.18	10.66
	Q	0.1304	0.4737	1.0034	1.3273	1.5326	1.9809	2.5161	3.1479	3.8826
20	V	4.92	6.14	8.82	9.24	9.60	10.09	10.60	11.11	11.64
	Q	0.1424	0.5172	1.0954	1.4491	1.6732	2.1627	2.7469	3.4367	4.2388
22	V	5.16	6.44	9.25	9.70	10.07	10.59	11.11	11.66	12.21
	Q	0.1493	0.5425	1.1489	1.5198	1.7549	2.2682	2.8810	3.6045	4.4457
24	V	5.39	6.72	9.66	10.13	10.52	11.06	11.61	12.17	12.75
	Q	0.1559	0.5666	1.2000	1.5874	1.8329	2.3691	3.0091	3.7648	4.6434
26	V	5.61	7.00	10.05	14.54	10.95	11.51	12.08	12.67	13.27
	Q	0.1623	0.5897	1.2490	1.6522	1.9077	2.4658	3.1320	3.9185	4.8330
28	V	5.82	7.26	10.43	10.94	11.36	11.94	12.54	13.15	13.77
	Q	0.1684	0.6120	1.2962	1.7146	1.9798	2.5589	3.2502	4.0664	5.0154
30	V	6.03	7.52	10.80	11.32	11.76	12.36	12.98	13.61	14.25
	Q	0.1743	0.6334	1.3416	1.7747	2.0492	2.6487	3.3643	4.2092	5.1915
32	V	6.23	7.77	11.15	11.69	12.1465	12.77	13.40	14.06	14.72
	Q	0.1801	0.6542	1.3857	1.8830	2.1165	2.7356	3.4747	4.3172	5.3618

69

b		0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
D		0.25	0.30	0.40	0.45	0.50	0.55	0.60	0.65	0.70
S	VQ \ d	0.15	0.20	0.30	0.35	0.35	0.40	0.45	0.50	0.55
34	V	6.42	8.00	11.49	12.05	12.52	13.16	13.82	14.49	15.17
	Q	0.1856	0.6744	1.4283	1.89	2.1816	2.8198	3.5816	4.4810	5.5268
36	V	6.60	8.24	11.83	12.40	12.88	13.54	14.22	14.91	15.61
	Q	0.1910	0.6939	1.4697	1.9441	2.2448	2.9016	3.6854	4.6109	5.6870
38	V	6.78	8.46	12.15	14.74	13.24	13.91	14.61	15.32	16.04
	Q	0.1962	0.7129	1.5099	1.9974	2.3063	2.9811	3.7864	4.7372	5.8428
40	V	6.96	8.68	12.47	13.12	13.58	14.27	14.98	15.72	16.46
	Q	0.2013	0.7314	1.5492	2.0563	2.3663	3.0585	3.8848	4.8600	5.9946
42	V	7.13	8.90	12.78	13.40	13.92	14.93	15.35	16.10	16.86
	Q	0.2063	0.7495	1.5874	2.0999	2.4247	3.1340	3.9807	4.9803	6.1426
44	V	0.73	9.11	13.03	13.71	14.24	14.97	15.72	16.48	17.26
	Q	0.2111	0.7671	1.6248	2.1493	2.4817	3.2078	4.0743	5.0975	6.2871
46	V	7.46	9.31	13.37	14.02	14.56	15.31	16.07	16.85	17.65
	Q	0.2159	0.7844	1.6613	2.1976	2.5375	3.2799	4.1659	5.2121	5.4285
48	V	7.62	9.51	13.66	14.32	14.88	15.64	16.42	17.22	18.03
	Q	0.2205	0.8013	1.6970	2.2449	2.5921	3.3504	4.2556	5.3242	6.5688
50	V	7.78	9.71	13.94	14.62	15.18	15.96	16.75	17.58	18.40
	Q	0.2251	0.8178	1.7321	2.2912	2.6456	3.4195	4.3433	5.4340	6.7022
52	V	7.94	9.90	14.22	14.91	15.48	16.28	17.09	17.92	18.76
	Q	0.2295	0.8340	1.7664	2.3366	2.6980	3.4872	4.4293	5.5416	6.8349
54	V	8.09	10.09	14.49	15.19	15.78	16.59	17.41	18.26	19.12
	Q	0.2339	0.8499	1.8000	2.3311	2.7494	3.5537	4.52	5.6472	6.9651
56	V	8.24	10.27	14.75	15.47	16.07	16.89	17.73	18.60	19.47
	Q	0.2382	0.8655	1.8330	2.4248	2.7998	3.6189	4.60	5.7508	7.0929
58	V	8.38	10.45	15.01	15.74	16.35	17.19	18.04	18.93	19.82
	Q	0.2424	0.8808	1.8655	2.4677	2.8494	3.6829	4.6779	5.8526	7.2185
60	V	8.52	10.63	15.27	16.01	16.63	17.48	18.35	19.25	20.16
	Q	0.2466	0.8958	1.8974	2.5099	2.8981	3.7459	4.7579	5.9527	7.3419
62	V	8.67	10.81	15.52	16.27	16.91	17.77	18.66	19.57	20.49
	Q	0.2506	0.9106	1.9287	2.5514	2.9460	3.8078	4.8365	6.0511	7.4632
64	V	8.80	10.98	18.77	16.54	17.18	18.06	18.95	19.88	20.82
	Q	0.2546	0.9252	1.9596	2.5922	2.9931	3.8687	4.9139	6.1479	7.5826

Table 15-6. Flow in Trapezoidal precast ditches

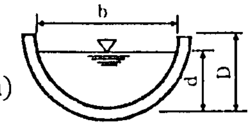


b: width of ditch bottom (m) D: depth of ditch (m) d: depth of flow (m)
s: gradient of ditch (%) V: velocity (m/sec) Q: volume of flow (c.m.s.)

S	VQ \ b / D / d									
	b	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
	D	0.15	0.175	0.20	0.25	0.30	0.325	0.35	0.375	0.40
	d	0.12	0.14	0.16	0.20	0.25	0.275	0.30	0.325	0.35
2	V	1.66	1.87	2.07	2.36	2.68	2.87	3.06	3.24	3.41
	Q	0.0518	0.0837	0.1256	0.2124	0.3521	0.4643	0.5963	0.7497	0.9253
4	V	2.35	2.64	2.92	3.34	3.79	4.06	4.32	4.58	4.82
	Q	0.0732	0.1184	0.1776	0.3003	0.4980	0.6566	0.8432	1.0602	1.3086
6	V	2.87	3.24	3.58	4.09	4.65	4.98	5.30	5.61	5.91
	Q	0.0897	0.1450	0.2175	0.3678	0.6099	0.8042	1.0327	1.2985	1.6027
8	V	3.32	3.74	4.15	4.72	5.37	5.75	6.12	6.48	6.82
	Q	0.1036	0.1674	0.2512	0.4247	0.7043	0.9286	1.1925	1.4994	1.85
10	V	3.71	4.18	4.62	5.28	6.00	6.43	6.84	7.24	7.63
	Q	0.1158	0.1872	0.2808	0.4749	0.7874	1.0382	1.3333	1.6764	2.07
12	V	4.07	4.58	5.06	5.78	6.57	7.04	7.49	7.93	8.36
	Q	0.1268	0.2051	0.3077	0.52	0.8626	1.1373	1.4605	1.8364	2.2665
14	V	4.39	4.94	5.47	6.24	7.10	7.60	8.09	8.57	9.03
	Q	0.1370	0.2215	0.33	0.5609	0.9317	1.2285	1.5775	1.9835	2.4481
16	V	4.69	5.29	5.84	6.67	7.59	8.13	8.65	9.16	9.65
	Q	0.1465	0.2368	0.3552	0.6007	0.9960	1.3133	1.6865	2.1205	2.6172
18	V	4.93	5.61	6.20	7.08	8.05	8.62	9.17	9.71	10.23
	Q	0.1553	0.2512	0.3768	0.6371	1.0564	1.3929	1.7888	2.2491	2.7759
20	V	5.25	5.91	6.53	7.46	8.43	9.09	9.67	10.24	10.79
	Q	0.1637	0.2648	0.3972	0.6716	1.1136	1.4683	1.8855	2.3707	2.9261
22	V	5.50	6.20	6.85	7.83	8.90	9.53	10.14	10.74	11.31
	Q	0.1717	0.2777	0.4166	0.7044	1.1679	1.5399	1.9776	2.4864	3.0689
24	V	5.75	6.47	7.16	8.17	9.2941	9.96	10.59	11.22	11.82
	Q	0.1794	0.2900	0.4351	0.7357	1.2198	1.6084	2.0655	2.5970	3.2054
26	V	5.98	6.74	7.45	8.51	9.67	10.36	11.02	11.67	12.2996
	Q	0.1867	0.3019	0.4529	0.7657	1.2697	1.6741	2.1498	2.7031	3.3363
28	V	6.21	6.99	7.73	8.83	10.04	10.75	11.44	12.11	12.76
	Q	0.1938	0.3133	0.4699	0.7946	1.3176	1.7373	2.2310	2.8051	3.4622
30	V	6.43	7.24	8.00	9.14	10.39	11.13	11.84	12.54	13.21
	Q	0.2010	0.3243	0.4864	0.8225	1.3638	1.7983	2.3039	2.9035	3.5837
32	V	6.64	7.46	8.26	9.44	10.73	11.50	12.23	12.95	13.65
	Q	0.2071	0.3349	0.5024	0.8495	1.4086	1.8573	2.3850	2.9983	3.7012

S	VQ \ b	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
	D	0.15	0.175	0.20	0.25	0.30	0.325	0.35	0.375	0.40
	d	0.12	0.14	0.16	0.20	0.25	0.275	0.30	0.321	0.35
34	V	6.84	7.71	8.52	9.73	11.06	11.85	12.61	13.35	14.07
	Q	0.2135	0.3452	0.5179	0.8756	1.4519	1.9144	2.4534	3.0911	3.8152
36	V	7.04	7.93	8.76	10.01	11.38	12.19	12.97	13.74	14.47
	Q	0.2197	0.3552	0.5329	0.9010	1.4940	1.9699	2.5297	3.1807	3.9285
38	V	7.23	8.15	9.00	10.29	11.68	12.53	13.33	14.11	14.87
	Q	0.2257	0.3649	0.5475	0.9257	1.5349	2.0239	2.5990	3.2678	4.0333
40	v	7.42	8.36	9.24	10.55	12.00	12.85	13.67	14.48	15.2557
	Q	0.2316	0.3744	0.5617	0.9498	1.5748	2.0765	2.6665	3.3527	4.1381
42	V	7.61	8.56	9.47	10.81	12.29	13.17	14.01	14.84	15.63
	Q	0.2373	0.3837	0.5756	0.9732	1.6137	2.1277	2.7324	3.4355	4.2403
44	V	7.78	8.77	9.69	11.07	12.58	13.48	14.34	15.19	16.00
	Q	0.2429	0.3927	0.5891	0.9961	1.6517	2.1778	2.7967	3.5164	4.3401
46	V	7.96	8.96	9.91	11.32	12.87	13.78	14.66	15.53	16.36
	Q	0.2483	0.40	0.6023	1.0185	1.8888	2.2268	2.8596	3.5954	4.4376
48	V	8.13	9.16	10.12	11.56	13.14	14.03	14.98	15.86	16.71
	Q	0.2537	0.4101	0.6153	1.0404	1.7251	2.2747	2.9211	3.6727	4.5331
50	V	8.30	9.34	10.33	11.80	13.41	14.37	15.29	16.19	17.06
	Q	0.2539	0.4186	0.6280	1.0619	1.7607	2.3216	2.9813	3.7485	4.6266
52	V	8.46	9.53	10.53	12.03	13.68	14.65	15.59	16.51	17.39
	Q	0.2640	0.4269	0.6404	1.0829	1.7956	2.3675	3.0403	3.8227	4.7182
54	V	8.62	9.71	10.73	12.26	13.94	14.93	15.89	16.82	17.73
	Q	0.2691	0.44	0.6526	1.1035	1.8298	2.4126	3.0982	3.8955	4.8031
56	V	8.73	9.89	10.93	12.49	14.20	15.21	16.18	17.13	18.05
	Q	0.2740	0.44	0.6646	1.1238	1.8633	2.4569	3.1551	3.9670	4.8963
58	V	8.94	10.06	11.12	12.71	14.45	15.48	16.47	17.43	18.37
	Q	0.2789	0.45	0.6764	1.1437	1.8963	2.50	3.2109	4.0372	4.9830
60	V	9.09	10.24	11.31	12.92	14.07	15.74	16.75	17.73	18.63
	Q	0.2336	0.46	0.6379	1.16	1.9287	2.54	3.2658	4.1062	5.0681
62	V	9.24	10.40	11.50	13.14	14.94	16.00	17.02	18.03	18.99
	Q	0.2333	0.4661	0.6993	1.1825	1.9606	2.59	3.3198	4.1741	5.1519
64	V	9.39	10.57	11.69	13.35	15.18	16.26	17.30	18.31	19.30
	Q	0.2929	0.4736	0.7105	1.2014	1.9920	2.6265	3.3729	4.2409	5.2343

Table 15-7. Flow in Semi-circular precast ditches



b: width of ditch bottom (m) D: depth of ditch (m) d: depth of flow (m)
s: gradient of ditch (%) V: velocity (m/sec) Q: volume of flow (c.m.s.)

S	VQ									
	b	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
	D	0.10	0125	0.15	0.175	0.20	0.225	0.25	0.275	0.30
	d	0.05	0.075	0.10	0.125	0.125	0.125	0.150	0.175	0.20
2	V	0.96	1.23	1.50	1.70	1.73	1.75	1.96	2.16	2.38
	Q	0.0059	0.0153	0.0305	0.0524	0.0580	0.063	0.0972	0.1402	0.1936
4	V	1.36	1.74	2.12	2.40	2.44	2.47	2.77	3.05	3.36
	Q	0.0084	0.0216	0.043	0.0741	0.0820	0.0891	0.1374	0.1982	0.2737
6	V	1.67	2.14	2.60	2.94	2.99	3.02	3.40	3.74	4.12
	Q	0.0102	0.0265	0.0529	0.0907	0.1004	0.1092	0.1693	0.2423	0.3352
8	V	1.92	2.47	3.00	3.39	3.45	3.49	3.92	4.31	4.76
	Q	0.1182	0.0305	0.0611	0.1048	0.1159	0.1261	0.19	0.2804	0.3871
10	V	2.15	2.76	3.36	3.80	3.86	3.91	4.39	4.82	5.32
	Q	0.0132	0.0342	0.0683	0.1171	0.1296	0.1409	0.2173	0.3135	0.4328
12	V	2.36	3.02	3.68	4.16	4.23	4.23	4.80	5.28	5.83
	Q	0.0144	0.0374	0.0748	0.1283	0.1420	0.1544	0.2380	0.3434	0.4741
14	V	2.55	3.26	3.97	4.50	4.57	4.62	5.19	5.08	6.29
	Q	0.0156	0.0404	0.0303	0.1386	0.1533	0.1668	0.2571	0.3709	0.5121
16	V	2.72	3.49	4.25	4.80	0.89	4.94	5.55	6.10	6.73
	Q	0.0167	0.0432	0.0864	0.1481	0.1639	0.1783	0.2748	0.3965	0.5475
18	V	2.79	3.57	4.35	4.92	5.00	5.06	5.68	6.25	6.89
	Q	0.0171	0.0443	0.0884	0.15	0.1679	0.1826	0.2315	0.4060	0.5606
20	V	3.043	3.90	4.75	5.37	5.46	5.52	6.20	6.82	7.52
	Q	0.0187	0.048	0.0966	0.1656	0.1833	0.1993	0.3073	0.4433	0.6121
22	V	3.19	4.09	4.98	5.63	5.73	5.79	6.50	7.16	7.89
	Q	0.0196	0.0507	0.1013	0.1737	0.1922	0.2090	0.3223	0.4649	0.6419
24	V	3.35	4.27	5.20	5.88	5.98	6.05	6.79	7.47	8.24
	Q	0.0205	0.0529	0.1058	0.1814	0.2003	0.2183	0.3366	0.4856	0.6705
26	V	3.47	4.45	5.41	6.12	6.23	6.30	7.07	7.78	8.58
	Q	0.0213	0.0551	0.1101	0.1888	0.2090	0.2272	0.3504	0.5054	0.6979
28	V	3.60	4.62	5.62	6.36	6.46	6.53	7.34	8.07	8.90
	Q	0.0221	0.0572	0.1142	0.1960	0.2169	0.2358	0.3636	0.5245	0.7242
30	V	3.73	4.78	5.81	6.58	6.69	6.76	7.60	8.35	9.21
	Q	0.0229	0.0592	0.1183	0.2029	0.2245	0.2441	0.3764	0.5429	0.7496
32	V	3.85	4.93	6.00	6.79	6.91	6.99	7.84	8.63	9.52
	Q	0.0236	0.0611	0.1221	0.2095	0.2318	0.2521	0.3887	0.5607	0.7742

S	VQ \ b / D / d	0.20 / 0.10 / 0.05	0.25 / 0.125 / 0.75	0.30 / 0.15 / 0.10	0.35 / 0.175 / 0.125	0.40 / 0.20 / 0.125	0.45 / 0.225 / 0.125	0.50 / 0.25 / 0.15	0.55 / 0.275 / 0.175	0.60 / 0.30 / 0.20
34	V	3.97	5.09	6.19	7.00	7.12	7.20	8.09	8.89	9.81
	Q	0.0244	0.0630	0.1259	0.2160	0.2390	0.2599	0.4007	0.5780	0.7980
36	V	4.08	5.23	6.37	7.20	7.33	7.41	8.32	9.15	10.09
	Q	0.0251	0.0648	0.1295	0.2222	0.2459	0.2674	0.4122	0.5947	0.8212
38	V	4.20	5.38	6.54	7.40	7.53	7.61	8.55	9.40	10.37
	Q	0.0258	0.0666	0.1331	0.2283	0.2526	0.2743	0.4236	0.6110	0.8437
40	V	4.30	5.52	6.71	7.60	7.72	7.81	8.77	9.65	10.64
	Q	0.0264	0.068	0.1366	0.2342	0.2592	0.2819	0.4346	0.6269	0.8656
42	V	4.41	5.65	6.88	7.78	7.92	8.00	8.99	9.88	10.90
	Q	0.0271	0.0700	0.1399	0.2400	0.2656	0.2888	0.4453	0.6424	0.8870
44	V	4.51	5.79	7.04	7.97	8.10	8.19	9.20	10.12	11.16
	Q	0.0377	0.0717	0.1432	0.2457	0.2718	0.2956	0.4558	0.6575	0.9078
46	V	4.62	5.92	7.20	8.15	8.28	8.38	9.41	10.34	11.41
	Q	0.0283	0.0733	0.1464	0.2512	0.2780	0.0323	0.4660	0.6423	0.9282
48	V	4.71	6.04	7.35	8.32	8.47	8.56	9.61	10.57	11.65
	Q	0.0289	0.0749	0.1496	0.2566	0.2339	0.3088	0.4761	0.6868	0.9482
50	V	0.81	6.17	7.51	8.49	8.64	8.73	9.81	10.78	11.90
	Q	0.0295	0.0764	0.1527	0.2619	0.2398	0.3151	0.4859	0.7009	0.9678
52	V	4.91	6.29	7.65	8.66	8.81	8.90	10.00	11.00	12.13
	Q	0.0301	0.0779	0.1557	0.2671	0.2955	0.3214	0.4655	0.7148	0.9869
54	V	5.00	6.41	7.80	8.83	8.97	9.07	10.19	11.21	12.36
	Q	0.0307	0.0794	0.1587	0.2722	0.3012	0.3275	0.5055	0.7284	1.006
56	V	5.09	6.53	7.94	8.99	9.14	9.24	10.38	11.41	12.59
	Q	0.0313	0.0809	0.1616	0.2772	0.3067	0.3335	0.5142	0.7413	1.0242
58	V	5.18	6.64	8.08	9.15	9.30	9.40	10.56	11.61	12.81
	Q	0.0318	0.0823	0.1644	0.2821	0.3121	0.3394	0.5233	0.7549	1.0423
60	V	5.27	6.76	8.22	9.30	9.46	9.57	10.74	11.81	13.03
	Q	0.0324	0.0837	0.1672	0.2369	0.3175	0.3452	0.5322	0.7678	1.0601
62	V	5.36	6.87	8.36	9.46	9.62	9.72	10.92	12.01	13.25
	Q	0.0329	5.0851	0.1700	0.2916	0.3227	0.3509	0.5410	0.7805	1.0777
64	V	5.44	6.98	8.49	9.61	9.77	9.88	11.09	12.20	13.46
	Q	0.0334	0.0864	0.1727	0.2963	0.3279	0.3656	0.5497	0.7930	1.0949

Chapter 16. Grassed Waterways

16.1 Definition

Earth watercourses planted with grasses to control soil erosion.

16.2 Objectives

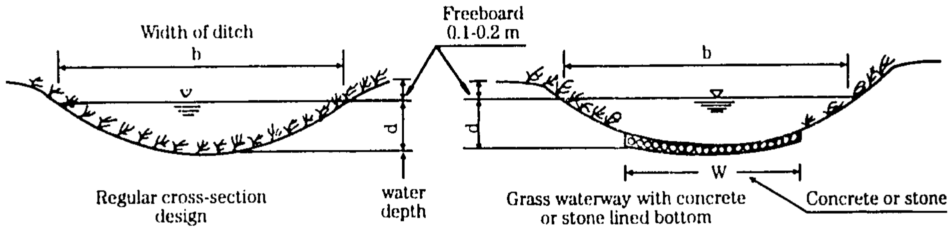
(1) To provide safe outlets for runoff water.

(2) To prevent soil erosion and to stabilize waterways.

(3) To facilitate the operation of farm machinery.

(4) To maintain a stable field environment.

16.3 Diagram



16.4 Application

(1) Suitable for a farm drainage system with a gradient of less than 30%.

(2) If water flow is incessant and its velocity exceeds 1.5 m/sec, the bottom should be lined with concrete or stone.

(3) Places situated in constant shade or where soils are too gravelly to permit normal grass growth are unsuitable for grassed waterways.

(4) With a view to dissipating the energy of waterflow, the grassed waterway should be interrupted at appropriate intervals by small drop spillways.

(5) A grassed waterway should not be used until the grass cover is properly established.

16.5 Design

(1) To estimate the amount of runoff, see 14.5.

(2) The cross-section of a grassed waterway should be a shallow curve.

(3) Bahia grass (Paspalum notatum), Broad-leaf Carpet grass (Axonopus affi..is) and Centipede grass (Eremochloa opiuroides) are suitable cover grasses.

(4) Size of cross-section: When the amount of runoff and the gradient of the waterway bottom are known, the cross-section of the waterway may be decided from Table 16-

75

The size of the waterway may also be decided in the following manner:

a. First assume a size (cross section) for the grassed waterway. In principle, the width should be no less than 2 meters.

b. Estimate the roughness coefficient n

Bahia grass	0.067
Broad-leaf Carpet grass	0.05
Centipede grass	0.055

c. Calculate hydraulic radius R from Fig. 16-1 or use the following formula:

$$R = \frac{b^2 d}{1.5b^2 + 4d}$$

when b=width of waterway (m)

d=depth of water (m)

d. Calculate the average velocity V from Fig. 14-4 in chapter 14, or use the following formula:

$$V = \frac{1}{n} R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} (m/\sec)$$

when V=average velocity (m/sec)

n=roughness coefficient

R=hydraulic radius (m)

S=gradient of the waterway bottom (%)

The value of V derived from the above formula should be within the safety velocity range.

e. Calculate the volume of flow.

$$Q = AV = \frac{2}{3} d \cdot b \cdot V$$

when Q=amount of flow (m^3/sec)

A=cross-section (m^2)

V=velocity (m/sec)

b=width of waterway (m)

d=depth of water (m)

f. The amount of flow thus calculated should be greater than or equal to the amount of runoff in the area, otherwise the size of the waterway should be enlarged; re-calculate the amount of flow until it can cope with the runoff.

(5) When the bottom of the waterway is to be lined with concrete:

a. Width of lining   w = 0.6 - 1m

b. Thickness of lining   t = 0.1 - 0.2m

16.6 Points to be observed during construction

(1) The best site for a waterway is a depression or natural drainage channel.

(2) Place stakes at both ends of the center line of the waterway. Between these two end stakes, place stakes at intervals of 5 - 10 m. If the waterway is straight, all the stakes should stand in line. If the course is curving, the degree of curve should be smoothed out as much as the topography permits. The line of stakes will form the center line of the waterway.

(3) The edges of the waterway may be marked by measuring a distance of half the width of the waterway at each side of, and at right angles to, the center line. Stakes should be placed along both edges.

(4) As soon as the edges are staked, the stakes along the center line may be removed and the excavation of earth can commence, according to the designed shape and depth. Check and correct the depth and width of the waterway from time to time with an engineer's level or a hand level and measuring tape.

(5) When the excavation of the waterway is completed, the surface of the soil in the waterway should be loosened, and covered with fertile soil if necessary. Slits should be cut across the waterway at 10 to 20 cm intervals. Then grass sprigs should be planted in the slits. After planting, the slits should be covered with soil and tramped to make the soil firm.

(6) If suitable grass turf is available, it should be cut into sods 20 to 25cm square. Sodding should commence at the bottom of the slope (downstream) and continue uphill, until the whole of the waterway is covered. Sods should overlap by 2 cm. When the work is completed, the whole of the turfed area should be lightly top dressed with soil and tramped firmly. If insufficient turf is available to cover the whole surface of the waterway, sods may be laid in strips at right angles to the flow of the water.

(7) After the grass is planted, the area should be protected from tramping by livestock.

(8) If the soil is too dry, it should be watered and mulched.

(9) Runoff should be diverted from the newly constructed waterways until the grass cover is established.

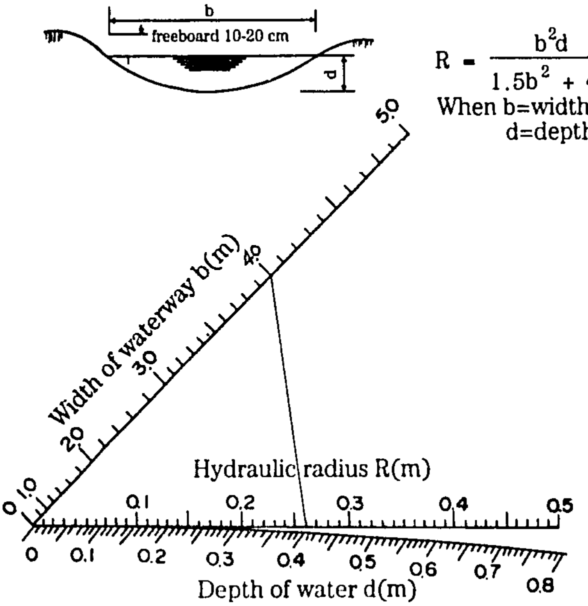
Table 16-1. Volume of flow carried by parabolic-type grassed waterways of various gradients and sizes.

(unit:c.m.s.)

Width of waterway b(m)	Depth of water d(m)	Gradient of waterway bottom (%)							
		0.1	0.5	1	2	3	4	5	6
1	0.10	0.013	0.029	0.041	0.057	0.069	0.081	0.089	0.097
1.2	0.14	0.032	0.073	0.101	0.141	0.172	0.204	0.224	0.244
1.4	0.18	0.067	0.148	0.208	0.293	0.353	0.417	0.459	0.501
1.6	0.22	0.118	0.270	0.377	0.529	0.642	0.754	0.828	0.906
1.8	0.26	0.202	0.446	0.632	0.884	1.069	1.263	1.389	1.507
2.0	0.30	0.312	0.696	0.984	1.380	1.680	1.980	2.172	2.364
2.2	0.34	0.477	1.037	1.465	2.058	2.502	2.946	3.226	3.522
2.4	0.38	0.679	1.489	2.101	2.933	3.563	4.203	4.619	5.035
2.6	0.42	0.937	2.073	2.896	4.06	4.940	5.820	6.388	6.956
2.8	0.46	1.262	2.777	3.931	5.481	6.635	7.825	8.618	9.376
3.0	0.50	1.665	3.645	5.175	7.200	8.775	10.305	11.340	12.375

Width of waterway b(m)	Depth of water d(m)	Gradient of waterway bottom (%)							
		7	8	9	10	12.5	15	17.5	20
1	0.10	0.105	0.113	0.122	0.130	0.142	0.158	0.170	0.182
1.2	0.14	0.265	0.285	0.305	0.325	0.356	0.396	0.426	0.457
1.4	0.18	0.540	0.582	0.625	0.667	0.731	0.812	0.875	0.939
1.6	0.22	0.980	1.058	1.132	1.205	1.323	1.469	1.582	1.700
1.8	0.26	1.633	1.760	1.886	2.012	2.026	2.459	2.644	2.829
2.0	0.30	2.568	2.760	2.964	3.156	3.456	3.852	4.140	
2.2	0.34	3.819	4.115	4.411	4.708	5.136	5.720		
2.4	0.38	5.451	5.867	6.282	6.698	7.333			
2.6	0.42	7.552	8.120	8.716	9.284				
2.8	0.46	10.169	10.962	11.756	12.513				
3.0	0.50	13.410	14.445	15.480					

Note: The figures above or to the left of the heavy lines are within the permissible range
Roughness coefficient n=0.067



$$R = \frac{b^2 d}{1.5b^2 + 4d^2}$$

When b=width of waterway (m)
d=depth of water (m)

Fig. 16-1. Estimate of hydraulic radius for parabolic-type grassed water

Example: If b=4.0m d=0.4m

Find R

Solution: Draw a line connecting b axis (4.0) and d axis (0.4). It intercepts R axis to give the answer: R=0.259~0.26m

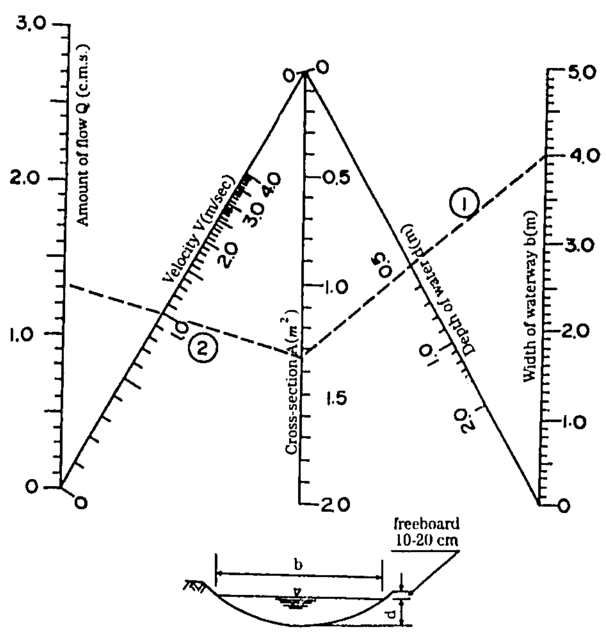


Fig. 16-2. Estimate of volume of flow for parabolic shaped grassed waterway

Example: If d=0.5m b=4.0m V=1.0 m/sec

Find Q

Solution: Draw a line ① to connect b axis (4.0) and d axis (0.5). Project the line to A axis at e, which is the cross section (1.33m²). Draw another line ② to connect A axis (1.33) and V axis (1.0), and project the line to Q axis. Answer: Q=1.33 m³/sec.

79

Chapter 17. Drop Structures

17.1 Definition

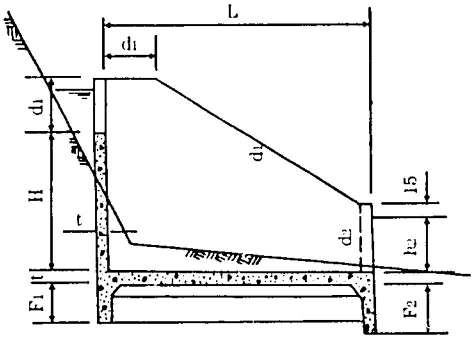
A structure constructed at an appropriate site to reduce the excessive velocity and energy of water flowing down through a steep channel, thereby protecting the channel bottom from damage.

17.2 Objective

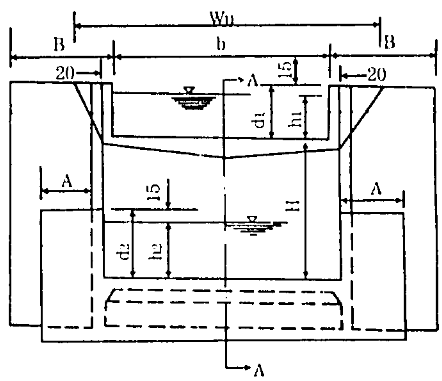
To reduce water flow velocity and energy in the channel, thus reducing erosion on the channel bottom and restraining the current.

17.3 Diagram

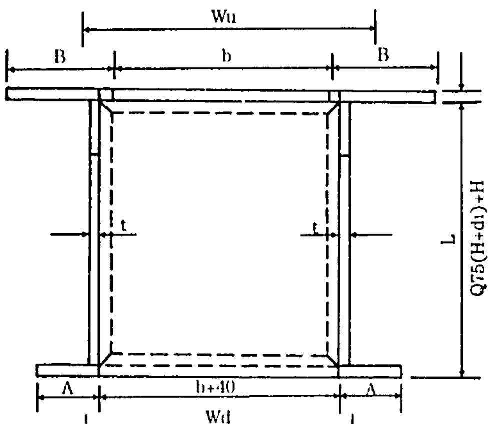
(1) A-type (straight-inlet with apron, made of bricks or reinforced concrete)



A-A section



Front elevation

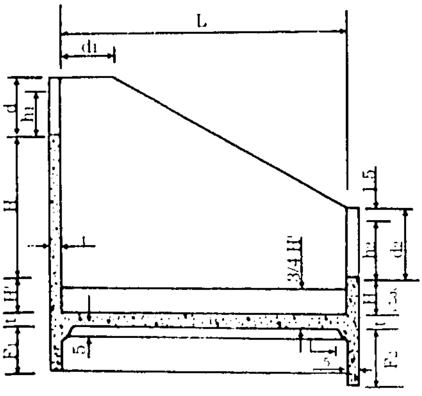


Plan

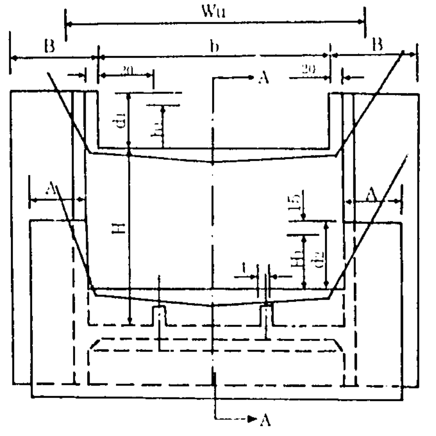
Note: 1. The width of A and B may vary with the width of the channel at the upper side and the lower side. A and B should be set at least 0.5 meter deep into both banks.

2. F_1 and F_2 depend on the soil condition of the channel bottom,
$F_1 \geq 0.4m$, $F_2 \geq 0.5m$

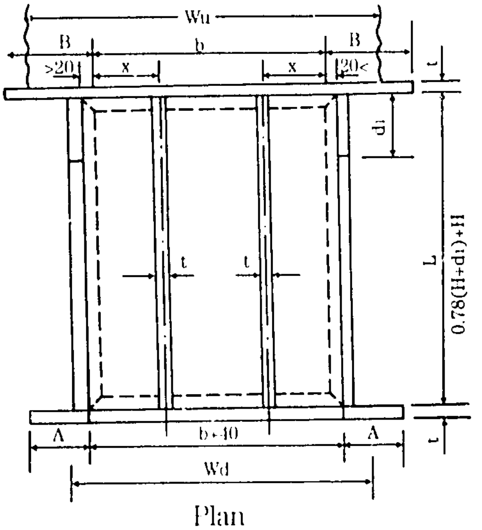
(2) B-type (straight-inlet with stilling basin, made of bricks or reinforced concrete)



A-A section



Front elevation



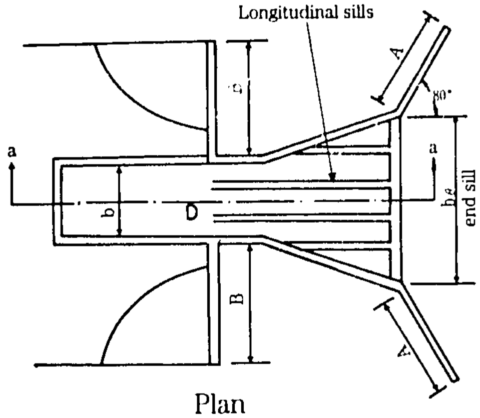
Plan

Note: 1. The width of A and B may vary with the width of the channel at the upper and lower sides. A and B should be set at least 0.5 meter deep in both banks.

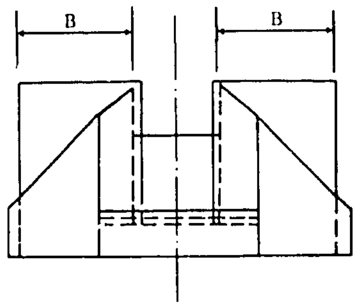
2. F_1 and F_2 value depend on the condition of the soil on the channel bottom,

$F_1 \geq 0.4m$, $F_2 \geq 0.5m$

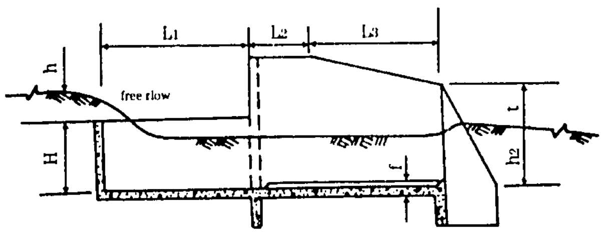
(3) C-type (box-inlet with stilling basin, made of bricks or reinforced concerete)



Plan

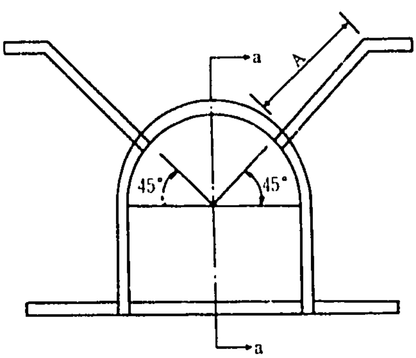


Front elevation

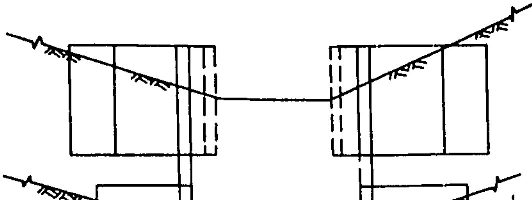


A-A section

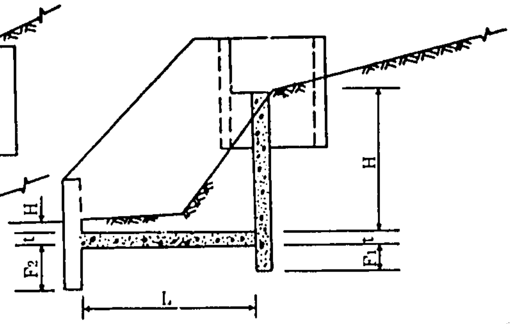
(4) D-type (curved-inlet with stilling basin, made of bricks or reinforced concrete)



Plan



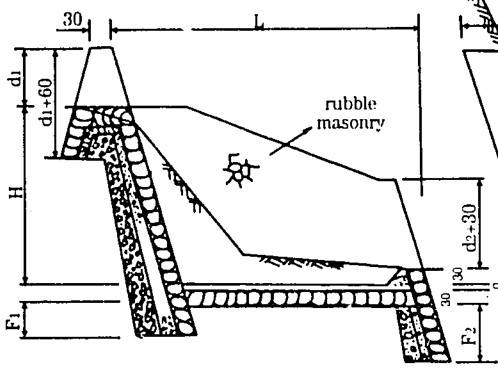
Front elevation



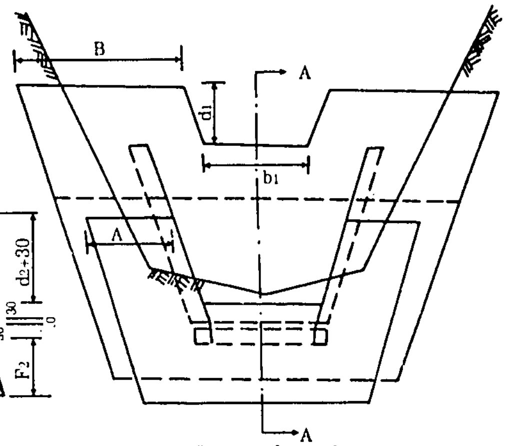
A-A section

87

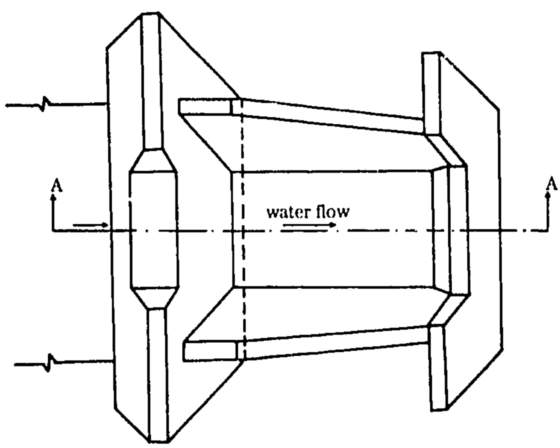
(5) E-type (straight-inlet with stilling basin, made of bricks or reinforced concrete)



A-A section



Front elevation



Plan

17.4 Application

(1) Suitable where a channel has a considerable vertical drop where erosion may occur.

(2) The height of the drop structure is limited to 3m. Special treatment should be given to those more than 3m high.

(3) For brick-made drop structures, the height should not exceed 2m. If the wall is over 1m high, 1B brick should be used.

(4) An A-type drop structure is not suitable where the head and volume of water flow are rather high.

(5) Succession of A-type drop structures may be constructed when necessary.

(6) C-type and D-type drop structures are good for places with a lower head but a large volume of water flow that has to pass through a narrow structure.

(7) For construction of reinforced-concrete drop structures with a height less than 2m, the wall should be 12 cm thick, using 3/8" dia. steel rods less than 25cm apart. For

those with a height over 2 m, the wall should be 25 cm thick, using 3/8" dia. steel rods less than 20 cm apart.

(8) When restricted by terrain, the length of the stilling basin may be shortened, but not less than 80% of the calculated length.

17.5 Design

(1) Estimate of the runoff (Q): Refer to 14.5.1, the design of the diversion ditch, step one.

(2) Determination of the structure type: Based on channel width and gradient, flow head and the runoff volume as well as the materials to be used.

(3) Calculation of the size of the drop inlet: Calculate h and b or b_0 using the following formulas.

a. For straight inlet

(i) Square inlet: $Q=1.767\ bh_1^{3/2}(h_1/b \geq 0.2)$

(ii) Trapezoid inlet: $Q=(1.77\ b_0 + 1.42h_1)h_1^{3/2}$ (side slope 1:1)

$Q=(1.77\ b_0 + 0.71h_1)h_1^{3/2}$ (side slope 1:0.5)

$Q=(1.77\ b_0 + 0.425h_1)h_1^{3/2}$ (side slope 1:0.3)

b. For box-inlet: $Q=1.767\ (b+2L_1)h_1^{3/2}$

c. For curved-inlet: $Q=1.76L_0h^{3/2}$

Where Q=flow discharge (cms)

h_1=water depth at the upper end (m)

b=width of the square inlet (m)

b_0=width of the bottom of the trapezoid inlet (m)

L_1=longitudinal length of the box inlet (m)

L_0=length of the arc of the curved-inlet (m)

Example: If Q=0.2 cms (once for a period of ten years)

b=1.2 m (width of the square inlet)

Find: the size of the square inlet

Solution: Try $h_1=0.2$ b=0.8

$Q=1.767 \times 0.8 \times 0.2^{3/2}$

=0.126 cms (rather small)

Try $h_1=0.25$ b=1.0

$Q=1.767 \times 1.0 \times (0.25)^{3/2}$

=0.22 cms (too large)

Try $h_1=0.24$ b=1.0

$$Q=1.767 \times 1.0 \times (0.24)^{3/2}$$

$$=0.208 \text{ cms (optimum)}$$

(4) Calculation of the length of the apron and the stilling basin

a. For A-type drop structure

Formula: $L = 0.75\,(H+d_1) + H$

where L=length of apron (m)

H=drop head (m)

$d_1=h_1$+freeboard (m)

Example: if: $H=2m$, $h_1=0.24m$

Find: length of apron (L)

Solution: $d_1=h_1+0.15$ (freeboard)$=0.24+0.15=0.39$

$L=0.75\,(2+0.39)+2=3.792m$

b. For B, D and E-type drop structures

(i) First find the inlet critical water depth (dc)

$$dc = \sqrt[3]{\frac{Q^2}{b^2 g}}\,(m)$$

where $g=9.8m/sec^2$

(ii) Then find the length of the stilling basin (L)

$$L = \sqrt{Hdc}\left[2.5 + 1.1\frac{dc}{H} + 0.7\left(\frac{dc}{H}\right)^3\right]$$

Example: if $H=2m$, $h_1=0.24m$,

$Q=0.2$ cms $b=1m$

find length of stilling basin (l)

Solution: First find the inlet critical water depth (d)

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}} = \sqrt[3]{\frac{(0.2)^2}{(1.0)^2 \times 9.8}} = 0.16$$

Then find the length of stilling basin

$$L = \sqrt{2 \times 0.16}\left[2.5 + 1.1 + \frac{0.16}{2.0} + 0.7\left(\frac{0.16}{2.0}\right)^3\right]$$

$$= 0.566 \times 2.5916 = 1.46m$$

c. For the C-type drop structure

The length of the stilling basin (L) can be found out according to the following steps:

(i) Find the inlet critical water depth

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}}$$

(ii) Find the outlet critical water depth

$$d_{ce} = \sqrt[3]{\frac{Q^2}{b_e^2 g}} \quad \text{where } b_e = 0.8W_d$$

(iii) Find the minimum $L_2 = d_c(\frac{0.2b}{L_1}) + 0.3$

(iv) Find the minimum $L_3 = \frac{b + 2L_1}{2\frac{L_1}{b}} \geq 0.25$

Example: If the width of the box inlet b=0.5m

L_1=0.25m, Q=0.2cms (flow discharge)

h_1=0.24m (water depth at the upper end)

W_d=1.2m (width of lower end)

find the length of the stilling basin (L_3)

Solution: (a) $d_c = \sqrt[3]{\frac{Q^2}{b^2 g}} = \sqrt[3]{\frac{(0.2)^2}{(0.5)^2 \times 9.8}} = 0.254m$

(b) $b_e = 0.8W_d = 0.8 \times 1.2 = 0.96m = 1m$

$$\therefore d_{ce} = \sqrt[3]{\frac{Q^2}{b_e^2 g}} = \sqrt[3]{\frac{(0.2)^2}{(1.0)^2 \times 9.8}} = 0.16m$$

(c) $L_2 = d_c(\frac{0.2b}{L_1}) + 0.3 = 0.254(\frac{0.2 \times 0.5}{0.25}) + 0.3 = 0.4M$

(d) $L_3 = \frac{b + 2L_1}{2 \times \frac{L_1}{b}} = \frac{0.5 + 2 \times 0.25}{2 \times \frac{0.25}{0.5}} = 1m$

(5) Calculation of the size of the apron or the stilling basin

a. Length of the head wall at the upper stream (B)

$$B = \frac{1}{2}(Wu - b) + h_1 + 0.2 > 1.0m$$

(applicable to all types)

b. Length of the wing wall (A)

$$A = \frac{1}{2}(W_d - b - 0.4) + h + 0.2 > 1\ m$$

(applicable to A, B, D, and E-types)

$$A = \frac{1}{2}(W_d - b_e)h_2$$

(applicable to C type)

where Wu=channel width (width of water surface) at the upper end (m)

Wd=channel width (width of water surface) at the lower end (m)

c. Size of the sill

(i) For B, D, and E-type drop structures

Height of sill $H' = \frac{1}{2}d_c$

$X = C_x b + 0.45$

C_x value can be found from the following table:

Wd/b	1.0	1.05	1.1	1.15	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2.0
C_x	0	0.075	0.125	0.15	0.17	0.19	0.21	0.23	0.24	0.25	0.26	0.27

(ii) For C-type drop structure

the minimum $h_2 = 1.6\, d_{ce}$

the minimum $t = 1/3\, h_2$

$b_e < 11.5\, d_{ce}$

$$f = \frac{1}{6}h_2$$

$$p = \frac{1}{5}b(\frac{1}{4}b \sim \frac{1}{6}b)$$

17.6 Precautions

(1) The drop structure site should be carefully investigated and attention paid to the alignment of the structure, the inlet and the outlet, especially at a sharp turn, with the dvechon of the current.

(2) During staking and marking of the structure location, keep the apron or the bottom of stilling basin a little lower than the ground line at the downward end.

(3) The excavated earth should be deposited on both sides of the structure, and kept out of the channel.

(4) Refilled earth should be tnoroughly compacted. The compacted earth should be at least 20 cm higher than both side walls, and sloping toward the bottom.

(5) If the earth of the foundation is found to be too loose, the designed depth should be extended.

(6) Spill holes about 3-5 cm in diameter, with one hole per 1 m^2, must be made in the front wall and the both side walls of the drop structure.

Chapter 18. Culverts (small)

18.1 Definition

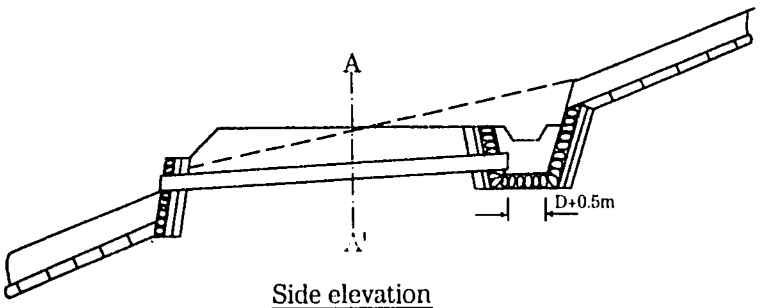
A drainage pipe laid under the ground where a drainage channel intercepts a farm road.

18.2 Objectives

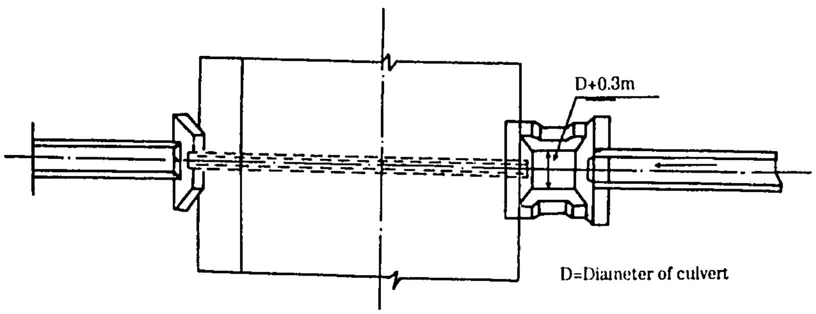
(1) To protect the farm road from erosion by providing a safe channel for runoff water.

(2) To enable farm machinery to cross drains.

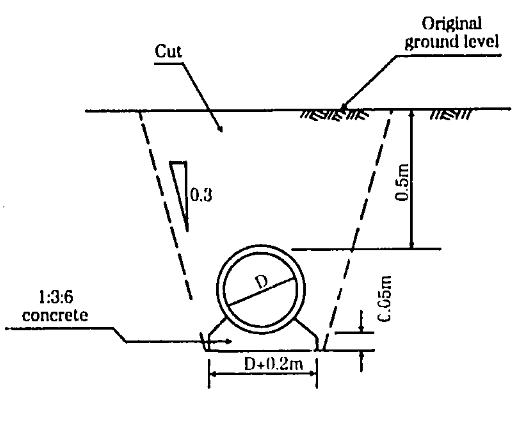
18.3 Diagram



Side elevation



Ground plan



A-A' Cross section

18.4 Application

(1) Applicable for a farm drainage system.

(2) The maximum load on the road is 15 tons.

(3) The size of culvert described in this section should be 30-90 cm in diameter. Over this limit, a special design will be needed.

(4) The slope at the culvert should be greater than 3% but not more than 26%.

(5) The capacity of the culvert should be larger than the volume of flow. The most desirable depth of water is 0.8D, since this will help prevent blockage caused by dirt or twigs.

(6) Shallow and broad dry masonry ditches of parabolic shape or grassed waterways are recommended as substitute for culverts when the volume of flow is small and stones are available, or if there is good soil to support grass growth.

18.5 Design

(1) Estimate the amount of runoff water (see section 14).

(2) The gradient of a culvert is determined according to the slope of the ground, the degree of erosion, the amount of siltation, etc.

(3) The diameter of the culvert is to be calculated with the Manning formula or Table 18-1, on the assumption that the flow is constant.

(4) Design the stilling basin at the inlet of the culvert.

a. Length of the bottom of the basin: D + 0.5m

Width of bottom of the basin: D + 0.3m

Minimum distance between the bottom of the culvert and the bottom of the basin: 0.20m.

D = diameter of culvert

b. Appropriate slope of the sides of a basin built with stones: 1 : 0.3

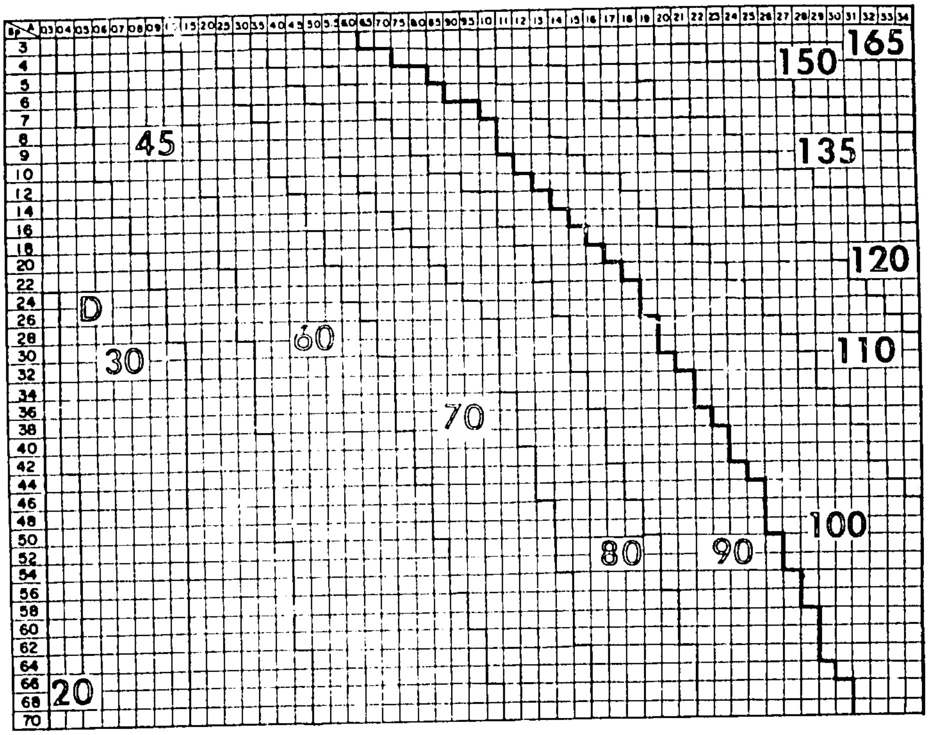
c. When the basin is connected with a roadside ditch, spillways should be provided on the side walls.

d. The stilling basin may be built of concrete slabs.

18.6 Precautions

(1) Regular culvert tubes should be buried at least 50 cm deep, while pressure tubes should be no less than 20 cm below the ground surface. Avoid laying tubes on loosely filled earth.

Table 18-1. Sizes of culvert in relation to the gradient of culvert and the area of watershed.



Sp: gradient of culvert (%)

D: diameter of culvert pipe (cm)

A: area of watershed (ha)

(2) The bottom of the trench in which the culvert is to be laid should be firm and level, and reinforced with a 1:3:6 concrete mixture.

(3) The joints of the culvert pipes should be sealed with a 1:3 cement and sand mixture.

(4) To fill the excavation around the culvert pipes, use a fine loamy soil for the first 30 cm depth, then fill up with any other type of soil which may be available, and pack the soil down firmly.

Chapter 19. L-shaped Roadside Ditches

19.1 Definition

An L-shaped concrete drainage ditch built along the inside of a road.

19.2 Objective

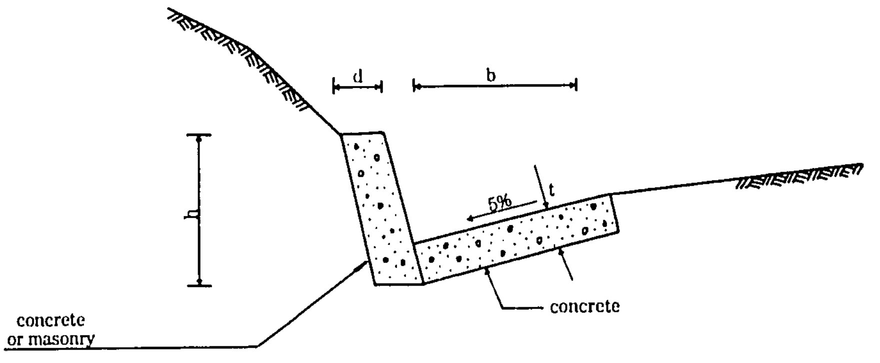
(1) To drain runoff.

(2) To protect the road against erosion.

(3) To keep slopes beside roads from sliding or crumbling.

(4) To facilitate the passage of farm vehicles.

19.3 Diagram



19.4 Application

(1) Suitable for access roads and link roads with small volume of runoff.

(2) At the junction of the L-shaped ditch and a hillside ditch, a dip should be built to facilitate the passage of farm vehicles.

(3) The height of the curb should not exceed 60 cm. Beyond this limit, a retaining wall may be added if necessary.

(4) In principle, this kind of ditch should be built with 1:3:6 concrete. However, if the curb is not under strong stress, masonry may be used.

(5) At those sections of road, where the volume of runoff is rather large, a rectangular or trapezoid drainage ditch should replace the shaped ditch.

19.5 Design

(1) Estimate runoff (See 14.5 (1) Diversion Ditch).

(2) General Specifications: When specifications are made, consideration should be given to the volume of runoff which the ditch is expected to handle, and also the type and size of farm vehicles which will pass along the road.

a. Ditch width b=60 cm

b. Bottom slope S: $10\% \leq S \leq 30\%$

c. Curb height h = 60 cm

d. Curb thickness d = 20 cm - 30 cm

e. Bottom thickness t = 12 cm - 20 cm

(3) Design the cross section (See 14.5 (2))

(4) Estimate materials required (See Appendix 7)

19.6 Precautions

(1) Adequate depth of excavation should be ensured. For better drainage of water on the road, the edge of the ditch should be slightly lower than the road surface.

(2) The road surface should slant slightly toward the ditch to facilitate draining of runoff.

(3) If the road is to be paved with concrete, it is better that the ditch be constructed at the same time as the road.

Chapter 20. Dips

20.1 Definition

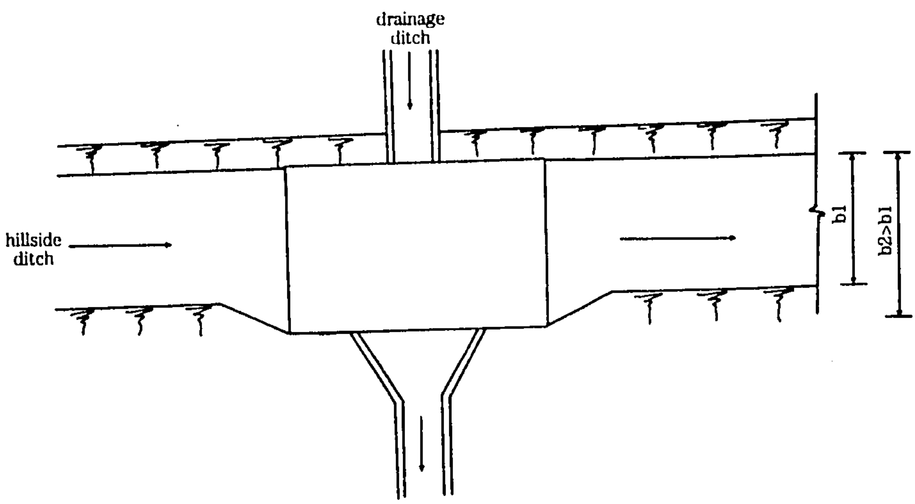
Dips, which serve the dual purpose of drainage and a road way, is a wide, shallow open channel with a curved base, across a road or a hillside ditch, at the point where there is a junction with a drainage ditch. It is covered by grass, stones or bricks. It may also be built of concrete.

20.2 Objective

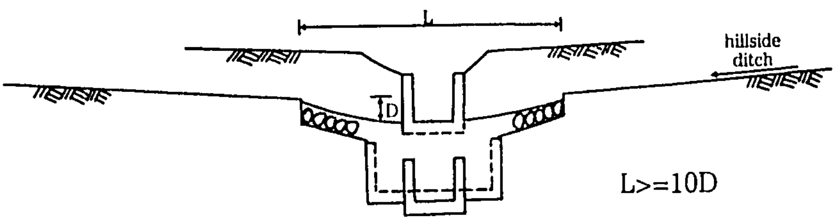
(1) To substitute for a culvert.

(2) To facilitate the passage of farm vehicles.

20.3 Diagram

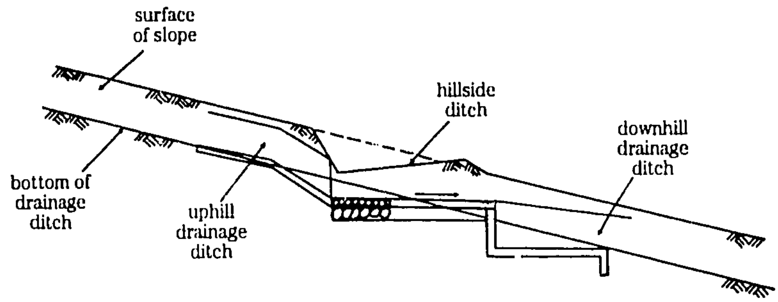


Plan

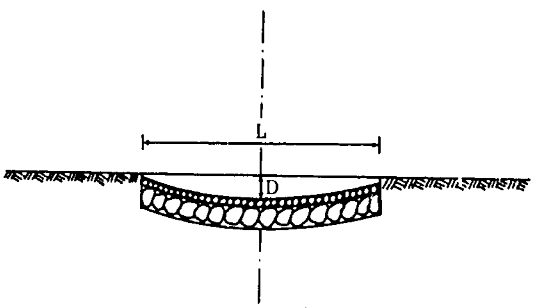


Cross-section

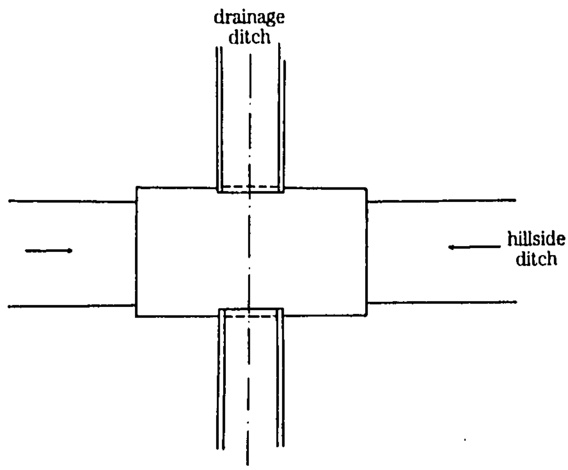
94



Longitudinal Section S $\leqq 10\%$



Cross-section



Plan

20.4 Application

(1) Generally used at junctions of road (or hillside ditches) and drainage ditch, where the volume of runoff is rather small.

(2) When a comparatively large volume of runoff exists, the dip should be paved with concrete, and protective measures should be taken at both the upstream and downstream ends.

20.5 Design

(1) Estimate runoff volume, by referring to 14.5 (1) (Design of Diversion Ditches), or Table 16-1 Volume of flow carried by parabolic type grassed waterways of various gradients and sizes.

(2) In order to satisfactorily fulfill its dual purpose of draining runoff and providing road passage, the width of the dip should be coordinated with the gradient of the road (or hillside ditch) and the drainage ditch. The following principles should be followed:

a. The gradient of the dip should be no more than 10%.

b. The width of the dip should be greater than that of the road (or hillside ditch).

c. The length of the dip should exceed its depth by more than 10 times.

$L \geq 10D$ L = length of dip (m)
D = depth of dip (m)

(3) Design the cross-section with reference to 14.5 (2) Design of Diversion Ditches.

(4) Estimate requirement for materials (See Appendix 7.).

20.6 Precautions

(1) Excavation should closely follow the specifications of depth given in the cross-section design.

(2) If grass cover is to be planted, grasses with suckers as Centipede grass are desirable.

(3) If the pass is to be paved with bricks or concrete, the surface should be made as smooth as possible.

(4) In certain situations, it may be necessary to provide the downstream side of the dip with appropriate protection.

Chapter 21. Access Roads

21.1 Definition

The road leading from a highway or other main road to the cropping area.

21.2 Objectives

To facilitate transportation of crops, supplies and equipment.

21.3 Application

(1) For localities inaccessible by existing highways or main roads.

(2) To be built where a road is needed, but where because of difficult terrain, standards for normal farm roads cannot be met.

21.4 Design

(1) Width 2.5-4m

(2) For other specifications than road width, refer to the Farm Road Design Manual published by the Taiwan Provincial Soil and Water Conservation Bureau.

(3) With a view to compromising with difficult terrain condition, the following specifications may be adopted:

a. Maximum gradient 20%. The length of any section in the 16-20% range of gradient should not exceed 40 meters. Curve radius in relation to road gradient is shown as follows:

Curve Radius (m)	5-8	8-15	15-20	20-25	25-30	30-35
Road Gradient (%)	6	7	8	9	10	11

b. Minimum curve radius allowed: 5 meters

(4) Where a large volume of runoff exists, drainage should be arranged.

21.5 Operational procedures

(1) Investigate the terrain, geological features, and drainage situation of the construction site. Evaluate the feasibility of widening or improvement in the future. Take the result of evaluation into consideration and begin design.

(2) Stake the road line and then start construction.

21.6 Precautions

(1) Ensure that excavation and filling of earth will not bring about any uncalled for damage or disaster.

(2) Take into due consideration the drainage of runoff from the top and sides of the road.

(3) Sections of the road which are subject to the attack of erosion should be reinforced.

5

21.7 Complementary treatment

(1) If the slope on either side of the road is likely to slide, protective structures or vegetative cover should be provided.

(2) Inlets and outlets should be built into road-side ditches at selected points to help collect and drain runoff.

(3) An L-shaped road-side ditch is preferable for this kind of road.

(4) Passing lanes should be set up at suitable points.

Chapter 22. Link Roads

22.1 Definition

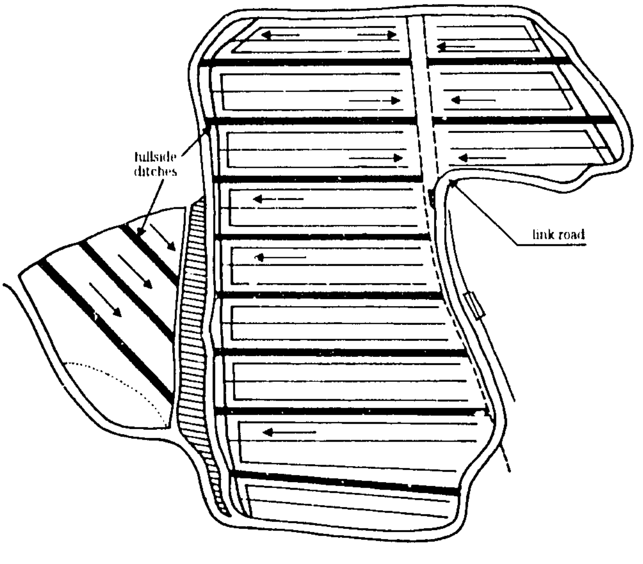
A road connecting hillside ditches or farm paths with a main farm road.

22.2 Objectives

(1) To incorporate hillside ditches or farm paths into a farm road system.

(2) To allow the movement and operation of farm machinery.

22.3 Diagram



22.4 Application

In fields where hillside ditches or farm paths are not connected with minor branch farm roads.

22.5 Design

(1) Longitudinal gradient: The longitudinal gradient of the link road should be no greater than 30%. Where the gradient reaches 20-30%, the length of the section should not exceed 30 meters.

(2) Width: 2 to 3 m.

(3) Radius of curve: The minimum radius of a curve allowed is 5 m.

(4) Drainage along the road should be integrated into the drainage system of the area. At suitable intervals, simple open ditches should be built across the road. Protective measures should be taken where the top or side of the road is subject to erosion.

22.6 Operational procedures

(1) Study the layout of existing farm paths and hillside ditches in the area, and choose the most favorable road line.

(2) Stake out the road lines according to the design and start the construction.

22.7 Precautions

(1) If the road constitutes only part of a project which includes also construction of bench terraces or hillside ditches, the road should be completed before the other construction begins.

(2) It is desirable that the road system for a complete cropping area be completed at one time.

(3) The road surface at all junctions should be kept level and even.

(4) Attention should be paid especially to avoiding disrupting the overall drainage system in the area.

22.8 Complementary treatments

Grass should be planted on link roads as soon as they are constructed, so that they may quickly have the protection against erosion.

Chapter 23. Farm Paths

23.1 Definition

A passage-way which is constructed to facilitate field operations on the farm.

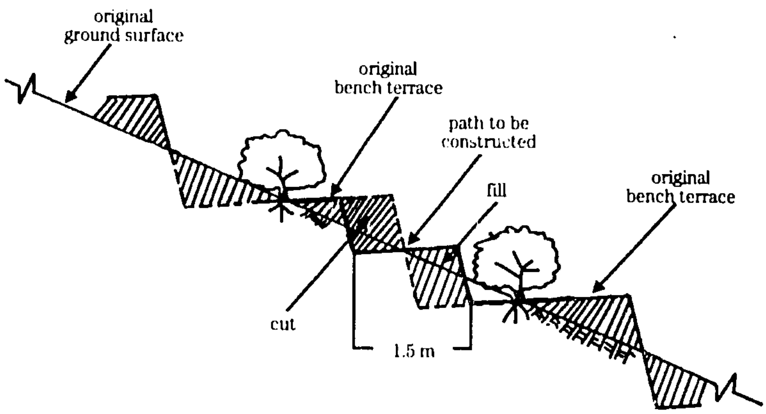
23.2 Objectives

(1) To facilitate farming operations and the passage of small farm machinery.

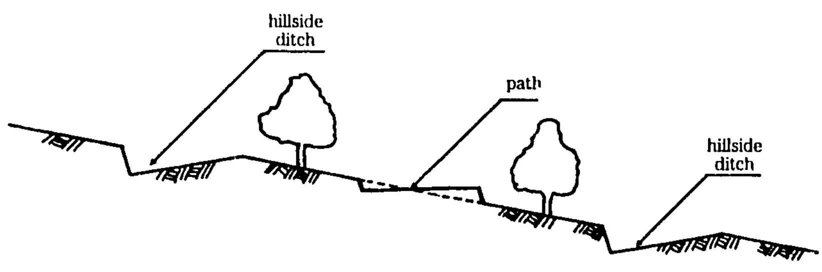
(2) To connect with other roads to form a road system in the farm area.

23.3 Diagram

(1) Paths along bench terraces



(2) Path along hillside ditches



23.4 Application

On slopes and where bench terraces or hillside ditches have been built and mechanized farming is to be carried out.

23.5 Design

(1) Spacing: The spacing of field paths depends on the width of the terraces, the location and size of any fruit trees, the types of farm machinery used and management requirements.

(2) Width: The path is usually 1 to 2 m in width.

23.6 Operational procedures

(1) Construction work is as described for bench terraces.

(2) When a path crosses a drainage ditch, a culvert should be built, or a concrete slab placed over the ditch. Another alternative is to construct a shallow dik through which machines can cross.

(3) Grass should be planted on the top and sids of the path.

23.7 Precautions

(1) Paths should be connected properly with a link road so as to form an efficient farm road network.

(2) When excavating soil, care should be taken to avoid damaging the roots of trees.

(3) Branches blocking the path should be pruned.

Chapter 24. Vegetative Sideslope Stabilization

24.1 Definition

To protect a slope by covering it with vegetation.

24.2 Objective

(1) To stabilize slopes through restraining runoff and reducing erosion.

(2) To reduce slope maintenance cost.

(3) To beautify the landscape.

24.3 Diagram

(See Part III. Vegetative Measures)

24.4 Application

(1) Vegetative cover may be planted by broadcasting, where earth has been filled but the slope gradient is smaller than the angle of repose, or where earth has been excavated and top soil has been transferred from an other location but slope gradient is less than 30%.

(2) Where earth has been excavated or filled but the slope gradient is less than 50%, planting by hydroseeding or sodding is feasible.

(3) Vegetation belt may be used when the slope gradient is less than 45%, and soil hardness is below 25 mm (15 kg/cm) according to a Yamanagka type soil penetrometer.

(4) Contour planting of grass sprigs is desirable for slopes where earth has been either filled or excavated, but where soil is thick and has a gradient of less than 35%.

(5) Transplanting of seedlings growing in containers or plastic bags into individual holes dug in the ground is recommended for excavated slopes with a gradient less than 35%, if the slope falls in any one of the following categories: 1) thin soil cover, 2) soil of high gravel content, 3) seriously eroded ground, 4) debris dumping ground, 5) exposed rock bed, 6) ground unsuitable for plant growth.

(6) In addition to vegetative cover, earth fill slopes may need further protection, e.g. embankments built of stakes and buried twigs, or wattles.

(7) Planting by hydroseeding, under normal conditions, is suitable for either earth fill or excavated slopes. If the thickness of the layer of seed mixture to be sprayed is no more than 3 cm, the seed mixture may be sprayed directly on ground surface. If seed mixture layer is more than 3 cm thick, a wire net should be laid on the ground first.

(8) On a gentle slope with an even surface which is less than 3 meters long, vegetation belts may be laid down the slope. If the slope is longer than 3 meters, the vegetation belt should be laid across the slope.

(9) Containers ıor growing seedlings for transplanting are available in several forms, e.g.

pouchs, trays, tubes and boxes. The pouch is used when a large number of seedlings of the same species are to be planted, as in reforestation. Trays are mainly used for growing seedlings of floral plants. The dibble tube is for growing seedlings of trees and vines from either seeds or cuttings. The box is primarily for landscaping and raising grown trees.

(10) In principle, in a vegetative cover, at least two different kinds of plant should be mixed.

24.5 Design

(1) Establishment of vegetative cover

Methods include: seed broadcasting, hydroseeding, laying of vegetation belt and soil bags, sprig and cuttings planting, sodding, seedling transplantation. For details see Part III. of this manual.

(2) Selection of plants

Grass, preferably of the Gramineae family, is the primary plant for vegetative cover. Species should be chosen for their adaptability to the local environment, and this ability to provide dense cover. Deep rooting and fast growth are also preferred characteristics. If landscaping is necessary, floral plants and vines may be planted together with grass. When trees are used, the species selected should have a high germination rate and tolerance of local conditions. If a sufficient supply of seedlings of one species cannot be secured, two different species may be planted alternately. (For details see Part III. Vegetative Measures)

(3) Grass sprigs may be planted in open ditches or holes.

24.6 Operational Procedures

(1) The ground of the slope should be cleared of all debris, stumps, and unstable rocks, and then leveled.

(2) If the slope is unstable, measures should be taken to stabilize the base of the slope, e.g. construction of an embankment. In addition, the necessary drainage system should be installed.

(3) For seed broadcasting, laying of vegetation belt, contour sprig planting, and sodding, 2 kg. of compost and 0.05 kg. of compound fertilizer should be applied in advance, on each square meter of planted area. A variation of 20% is allowed for the amount of compost and fertilizer used, depending on the fertility of soil.

(4) After broadcasting or hydroseeding, or laying of vegetation belt, attention should be paid to keeping the soil moist. Wire or bamboo sticks may be used to help anchor seeds to the ground.

24.7 Maintenance

(1) At the early stage of establishing a vegetative cover, adequate drainage should be provided for protection against erosion. Any part of the cover that is eroded should

104

be mended promptly.

(2) To help germination of seeds or survival of planted seedlings, appropriate measures should be taken to keep the surface of the slope moist, as dictated by climate conditions.

(3) During the growing stage, irrigation, fertilization and other maintenance and management procedures should be taken as required.

(4) Spring and autumn are the best seasons for planting.

Chapter 25. Grassed Farm Roads

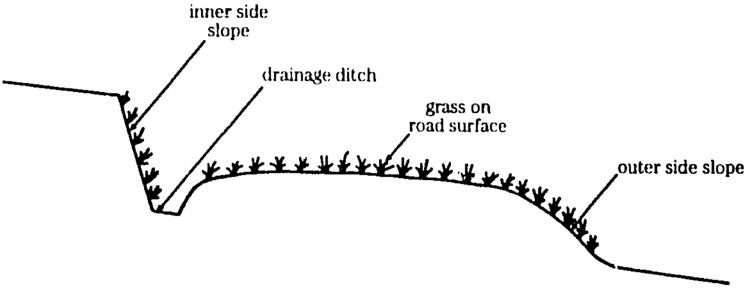
25.1 Definition

To plant grass on the top, shoulder and side slopes of farm roads.

25.2 Objectives

To protect the surface of the road from erosion and save maintenance costs.

25.3 Diagram



25.4 Application

(1) For farm roads with heavier traffic, grass should be planted on side slopes and shoulders as well as in the side ditches.

(2) Grass is planted on the top of those roads only when traffic is relatively light.

(3) Creeping grass adapted to the local environment is most suitable for road tops. For road shoulders and side slopes, Bahia grass, Carpet grass, broad-leaf Carpet grass or Centipede grass, are desirable. Native creeping species may also be used.

25.5 Points to be observed

(1) Planting should be done early in the rainy season. Any plants which do not survive should be immediately replaced.

(2) Undesirable grasses and weeds should be removed.

108

Chapter 26. Gully Control

26.1 Definition

To stabilize active gullies in farmland with vegetative cover and/or engineering measures, for the purpose of preventing anticipated disaster, or restoring land for production.

26.2 Objectives

(1) To stabilize gullies.

(2) To divert discharge of sediment for protection of properties downstream.

(3) To restore the productivity of eroded land.

(4) To provide a green vegetative cover to eroded land, so as to improve the landscape.

26.3 Application

(1) Gullies form on farmland mainly as the result of abusive land use. Prevention of their formation is far less costly than taking remedial measures afterwards.

(2) Control measures vary with the size of gully. When the depth of a gully exceeds 30 cm, which is enough to handicap the passage of farm vehicles, control is compulsory. The measures described in this chapter are especially for gullies no more than 10 meters wide, in a watershed no larger than 10 hectares. Beyond these limits, refer to the chapters of 'Torrent Control' and 'Wild Creek Control' in Part II.

26.4 Planning and design

The preparation of a specific plan for gully control involves many elements, e.g. the size and location of the gullies, the acreage of watershed, gradients of the gullies, soil texture, drainage condition, vegetation, land use, wildlife habitat, landscape maintenance, extent of gully control needed, etc. Only when all these elements are thoroughly evaluated can the most feasible plan be worked out. Further more, a pragmatic approach is essential for ensuring that a reasonable objective is attained at minimum cost. The plan should be integrated with the soil and water conservation measures in headwater watershed areas. Usually it is not feasible to expect any one measure to fulfill the objectives of a gully control project. Nearly always several different measures have to be put together in order to work out the desired effect. These gully control measures are descibed individually as follows:

(1) Adjustment of farming practice: Suitable for small gullies on farmland.

a. Correction of improper land use: The following situations may cause the formation of small gullies:

Routing of farm roads or paths without following soil and water conservation principles; making furrows up and down slopes; bench terraces, hillside ditches and diversion ditches without safe runoff outlets or with runoff outlets in disrepair;

over grazing or trampling by livestock.

b. Elimination of small gullies: To plow over small gullies and level the ground, or fill gullies with debris.

(2) Diversion of runoff: To reduce the amount of runoff discharged into gullies.

a. Diversion ditch or ridge: To be built at the head of the gully or on the upper side of the banks, to direct runoff into a safe course. When it is built at the head, the site should be away from the gully head at a distance three times the depth of the gully. (For details see Chapter 14. Diversion Ditches.)

b. Hillside ditches or terraces

Hillside ditches or inward-sloping terraces may be built at suitable intervals across a gully to divert runoff to a safe collection or drainage point. This measure is particularly desirable for small to medium size gullies on farmland, which do not serve as water courses. The hillside ditches and terraces should be designed as an integral part of the soil and water conservation scheme for gully control. (For details see Chapter 2. Hillside Ditch and Chapter 4. Bench Terraces.)

(3) Vegetative cover

Plants can prevent erosion by providing anchorage for soil and gravels. They may also help in landscaping. Therefore except at those places where plants cannot grow, vegetative cover is the best measure for permanent control of gully erosion.

a. Natural vegetation

Natural vegetative cover can be established by protecting the land with fences or other measures against abuse or ravages, e.g. fires, trampling of livestock, etc. This method is mainly used for rehabilitation of pasture land, and is rarely applied on its own to crop-land.

b. Planted vegetation

This type of vegetative cover is established by planting or encouraging plants in a specific area. Often preparatory procedures are required, e.g. leveling the surface of the slope, staking and wattling etc. Unstable rocks and trees on the banks should be removed, so that they will not fall into the gully and impede runoff flow.

At an appropriate distance from the banks, rows of trees may be planted along the banks to shade plants on the ground so as to help their growth. The shade may help to reduce ambient temperature, maintain soil moisture, minimize temperature variation, and increase relative humidity on the ground. The shade zone should be located on the south side of the gully. The trees are planted at 0.6-1.0 m intervals, in 3 - 10 rows separated by 1 - 1.5 m space.

All trees, big or small, shrubs vines and grasses may be used for gully control. The qualifications are 1) high resistance to acidity, aridity and sterility of soil, 2) highly adapted to local climate, 3) vigorous and deep root system, and 4) strong disease and pest resistance.

(4) Gully surface treatment

This treatment is necessary for gullies with unstable runoff flow, and for those grass waterways which also provide passage for farm vehicles. For the purpose of stabilizing the flow, the slope of the gully should be reduced if possible. Rocks and plants on the sides, which are likely to fall into the gully should be removed to prevent stoppage.

(5) Conversion of a gully to a drainage ditch

a. Grass waterway

On cropland, gullies which are not filled by water all the time may be converted into grass waterways. In doing this, the surface of the gully should first be cleared and leveled, and then planted with grass, preferably Bahia grass. At appropriate intervals, drop structures should be installed to dissipate the energy of runoff. In order to accelerate the formation of grass cover, grass sprigs may be densely planted in strips, as prescribed by the "Expeditious Grass Waterway Construction Procedures". It may be necessary to drive stakes and bury twigs or brushes into the bottom. (For details see Chapter 16. Grassed Waterway.)

b. Lined ditch

This will enable additional useful land to be made available along its sides. (For details see Chapter 15. Drainage Ditches.)

(6) Installation of check dams. Check dams are often installed in gullies for the purpose of: 1) reducing gully gradient, 2) controlling the course of runoff, 3) blocking sediment, 4) stabilizing the gully, and 5) helping vegetation growth. Check dams fall into two categories:

a. Temporary dam

This kind of dam is needed only in the early stage of development of the vegetative cover. It helps in stabilizing the banks of a gully, before vegetative cover becomes fully established. It is easy to build with materials available in the field. Therefore, low cost is its main advantage. However, it is also short-lived and requires frequent maintenance. Generally, the life span of a temporary dam is shorter than one year. For safety, its height should not exceed one meter. The more popular construction materials for this type of check dam are: sandbags, timber, animal skins and rocks. (For details see Chapter 27. Check Dams.)

b. Regular dam

This dam is more durable and built to higher safety standards.

(i) Pervious dam: Built of piled rocks, wire cages, pickets, rubber tires, wood cribs, and precast concrete slabs, etc.

(ii) Impervious dam: Built of concrete and stone or concrete alone, masonry, bricks, or earth. Special care should be taken, if this type of dam is to be built where there are landslides or where land tends to slip or slide.

26.5 Precautions

(1) All work should be coordinated with soil conservation along the gully.

(2) When the working area is inaccessible by road, cable conveyor should be used to transport materials and equipment. Avoid building new roads whenever possible.

(3) Earth work should be done in the dry season.

(4) Planting should be finished before the rainy season arrives.

(5) The leftover excavated earth, that is not needed for earth fill should be dumped in safe places.

(6) During the progress of construction, efforts should be made to avoid damaging the slope surface and vegetation unnecessarily.

(7) Other methods of gully control

Soil stabilizer is an organic or inorganic chemical. A water solution can increase the bonding among soil particles, and consequently reduce detachment of these particles, thus making them more resistant to erosion. It may also be helpful to plant growth, because it can reduce soil moisture evaporation and protect seeds. In addition to soil stabilizer, there are other manufactured products, e.g. fibre pads, plastic mesh, screens, etc., which are useful in soil erosion prevention and gully control.

Chapter 27. Check Dams

27.1 Definition

A structure installed across an active gully to stabilize the gully through control of the erosion of gully bottom and banks.

27.2 Objective

(1) To reduce runoff tractive force by slacking off the gradient of a gully.

(2) To control the course of flow so as to minimize impact on the banks.

(3) To block sediment to keep it from damaging the downstream environment and public utilities.

(4) To maintain the stability of soil when vegetative cover is being established.

27.3 Application

(1) Temporary dam

The purpose of this kind of dam is to temporarily maintain the stability of a gully to make possible the establishment of vegetative cover. It is not durable and needs frequent tending, though it is inexpensive and easy to build. Construction materials are usually available at the site.

a. Types

(i) Timber dam

(a) Brush dam: One or more rows of poles are lined across a gully and driven into the bottom. Behind each row of poles, twigs are packed to form a dam. When there is only a single row of poles, the twigs should be laid crosswise. With more than one row of poles, the twigs should be laid lengthwise.

(b) Plank or log dam: Logs of 15 - 20 cm in diameter or planks more than 5 cm thick are laid one on top of an other horizontally across the gully.

(c) Wood crib dam: A crib is bult of logs, the space in the crib filled with rocks or boulders.

(ii) Wire mesh dam: Wire mesh is stretched along a picket across a gully.

(iii) Sandbag dam: Used nylon or jute fertilizer bags are filled with dirt and stacked into a dam. Grass seeds or roots may be mixed with the dirt, to help the development of a vegetative cover.

(iv) Riprap dam: Piling up boulders or rocks across a gully to form a dam.

b. Application

(i) This type of dam is used for stabilization of a gully before vegetative cover is fully established. Its expectancy of life is no more than one year. Only the riprap dam may last longer.

(ii) It is desirable in places where construction materials are readily available at the site or nearby, and labor is inexpensive. It is also appropriate when no difficult technical problem is involved.

(iii) The height of the dam should not exceed one meter.

(iv) For gullies consisting of large boulders or rocks, only a riprap dam is suitable.

(2) Regular dam: A more durable structure for gully control.

a. Pervious dam

(i) Types

(a) Dry masonry dam: Stones are laid into a dam without mortar.

(b) Gabion dam

i. Wire Sausage dam: A dam consists of horizontally laid sausage-shaped wire cages which are filled with rocks.

ii. Wire Box dam: A dam consists of box-shaped wire cages filled with rocks.

(c) Fence dam

i. Single fence dam: A picket consisting of steel pipes or concrete poles is planted across a gully. Wire is woven between the poles. Rocks are piled up on the upstream side of the fence to form a dam.

ii. Double fence dam: Two rows of pickets are set up across the gully, with a space of 0.6-1.0 meter in between. Wire mesh is stretched along each row. Rocks are filled into the space between the rows.

(d) Tire dam

Scrap-tires are stacked up with a pole of concrete or steel in the center for anchorage. The inner space of the tire is filled with rocks. Stacks of tires closely placed will form a dam.

(e) Concrete slab dam

A dam assembled with concrete poles and slabs.

(f) Concrete crib dam

A crib is built with concrete poles. The space in the crib is filled with rocks.

(ii) Application

(a) Except for concrete crib dam and concrete slab dam, these dams are semi-permanent, with a maximum life span of six years under normal maintenance.

(b) A pervious dam features resiliency. Therefore it is suitable for places where there is potentiality of a landslide.

\\V

(c) With exception of the concrete crib dam, the height of these dams should not exceed 1.5 meters.

(d) For gullies with many large rocks, only a concrete crib dam or a dry masonry dam can be used.

b. Impervious dam

(i) Types

(a) Mortar rubble masonry dam with concrete core

An outer wall is built of mortar rubble masonry.

The space inside of the wall is filled with cobbles mixed with cement.

(b) Mortar masonry dam with rock core

An outer wall is built of mortar rubble masonry.

Space inside is filled with cobbles.

(c) Concrete dam

This type of dam is built of poured concrete.

(d) Brick dam

Built of bricks laid with mortar.

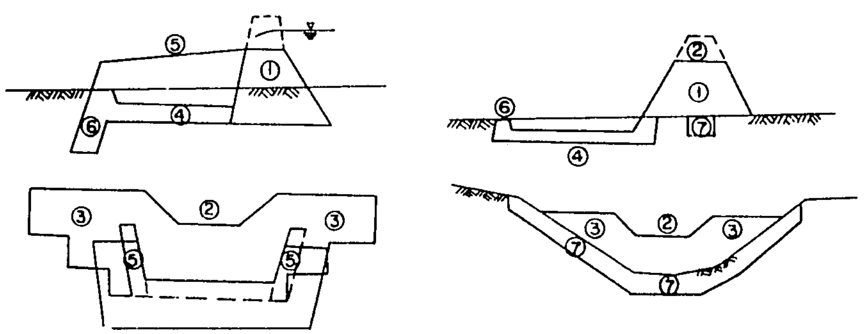
(ii) Application

(a) Since these dams are permanent structures of high safety and need infrequent maintenance, they are constructed to protect housing or other valuable properties along the banks or downstream.

(b) The height of a mortar masonry dam or brick dam should not exceed two meters. Concrete fill mortar masonry dams are not subject to this limitation.

(c) These dams are suitable for any place where land slips are in progress or probable.

Nomenclature of Check Dam Structures

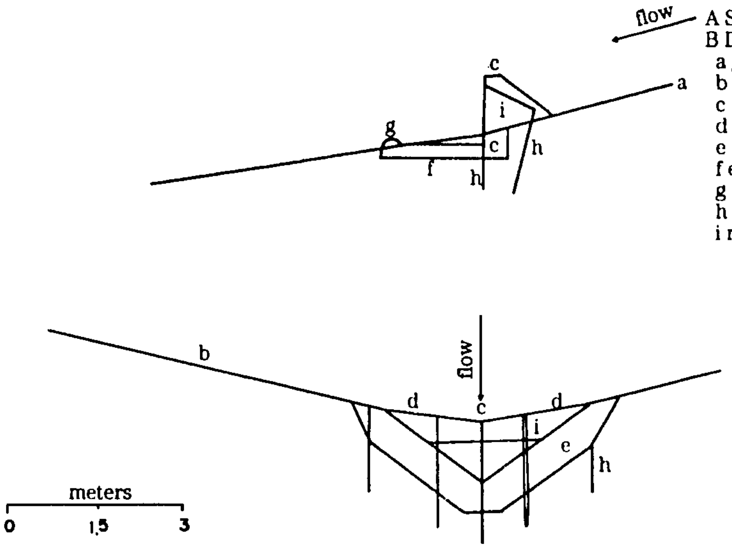


① dam
② spillway
③ wing
④ apron or stilling basin
⑤ side wall
⑥ end wall
⑦ key

27.4 Diagram and illustrations

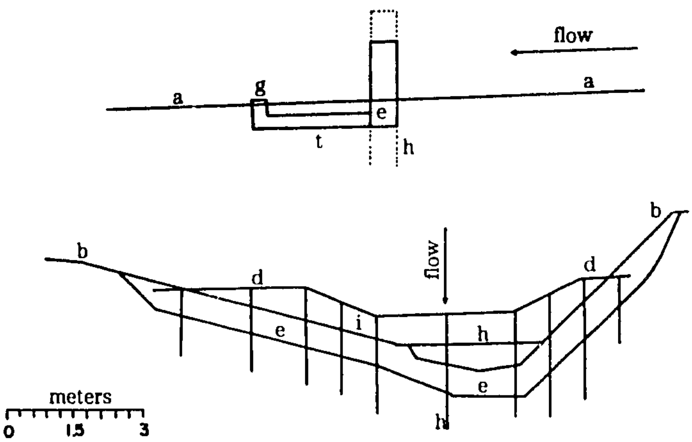
(1) Fence dam

a. Single fence dam



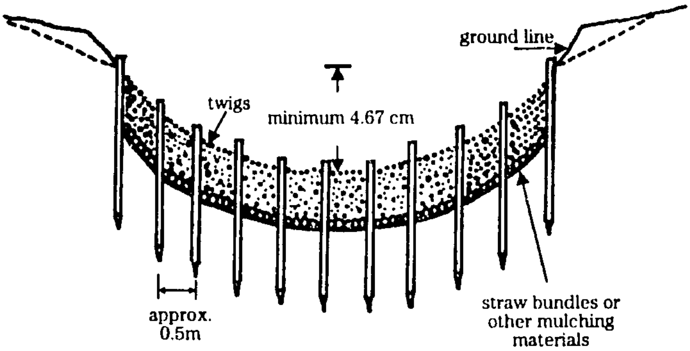
A Section on gully centerline
B Dam cross-section
a gully bottom
b gully cross-section
c spillway
d freeboard top
e excavated for cut-off wall
f excavated for construction of apron
g end sill
h steel picket pole
i rebar

b. Double fence dam

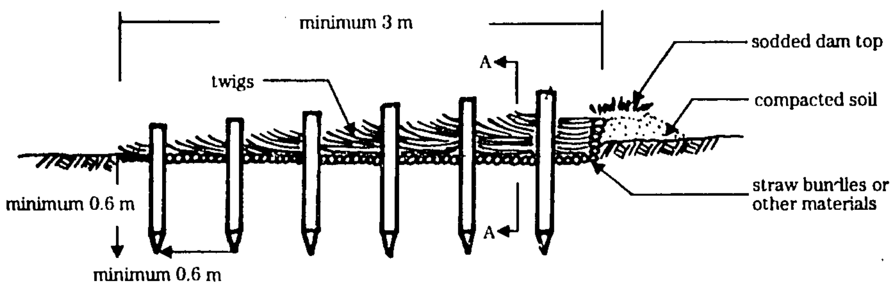


A Section on gully centerline
B Dam cross-section
a gully bottom
b gully cross-section
c spillway
d freeboard top
e excavated for cut-off wall
f excavated for construction of apron
g end sill
h steel picket pole
i rebar

(2) Brush Dam



A-A section



B-B section

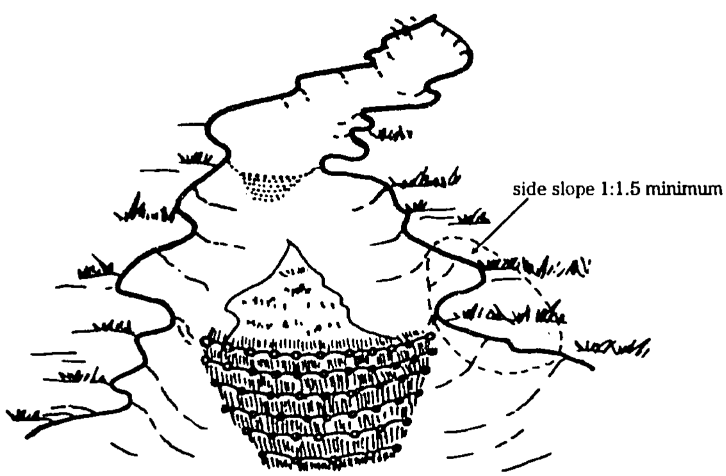
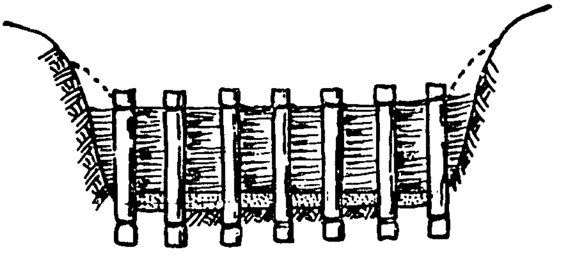
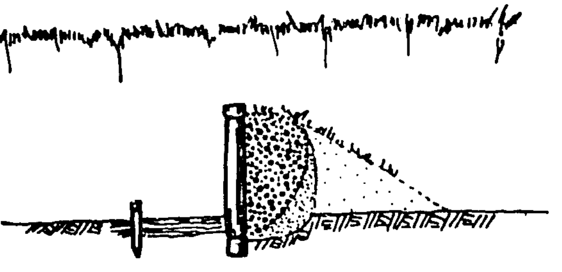


Illustration of Multiple-tier Brush Dam



Cross section



Longitudinal section

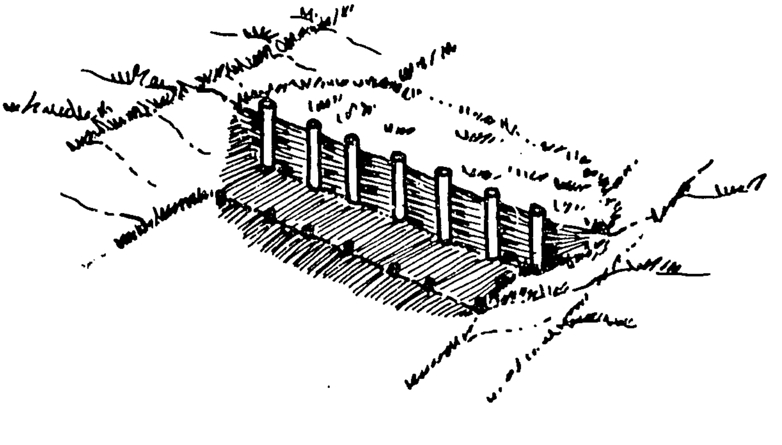
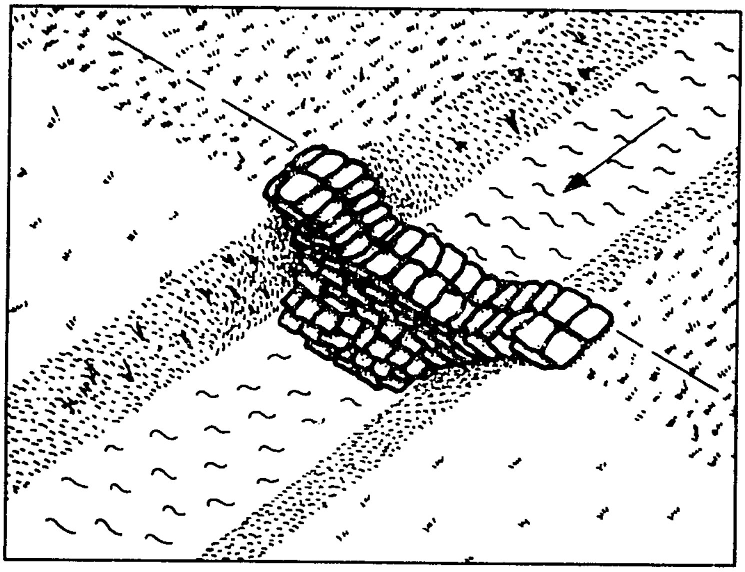
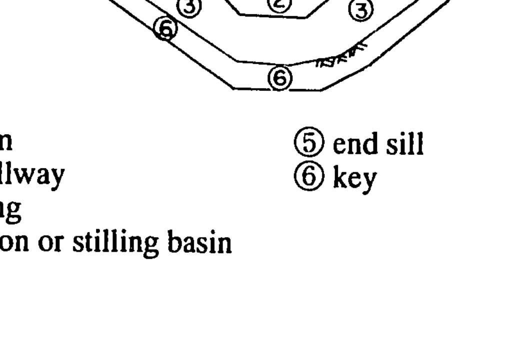


Illustration of Single-tier Brush Dam

(3) Sandbag Dam

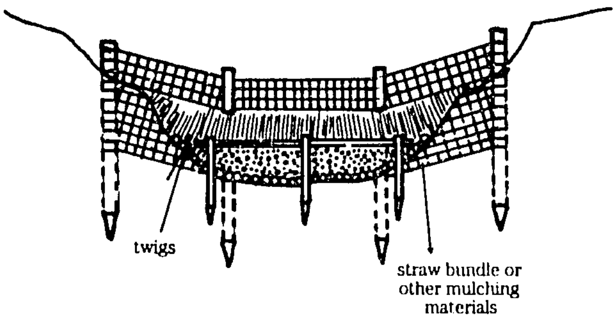


(4) Rock Fill Dam

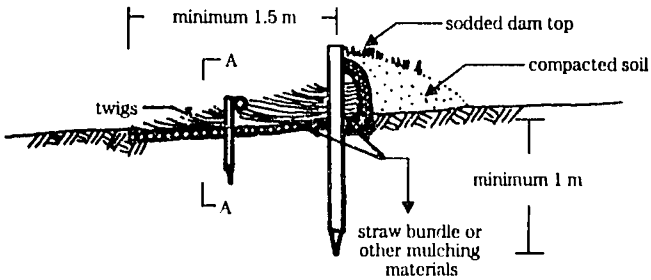


① dam
② spillway
③ wing
④ apron or stilling basin
⑤ end sill
⑥ key

(5) Wire Mesh Dam



A-A section



Longitudinal section

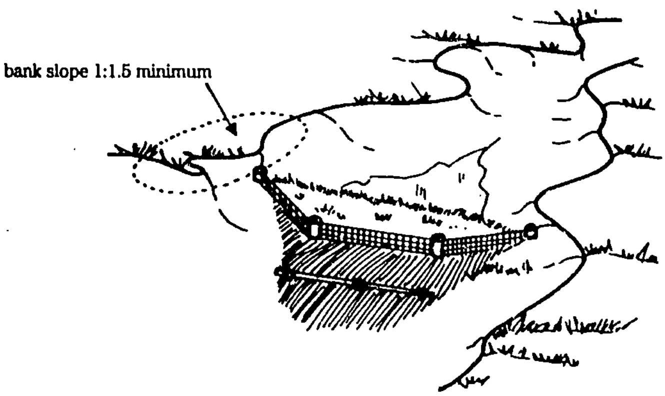
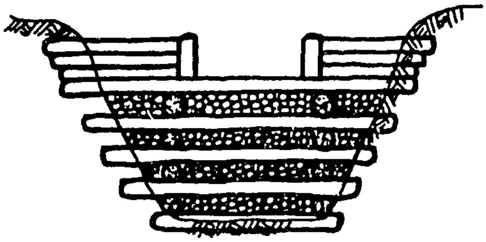


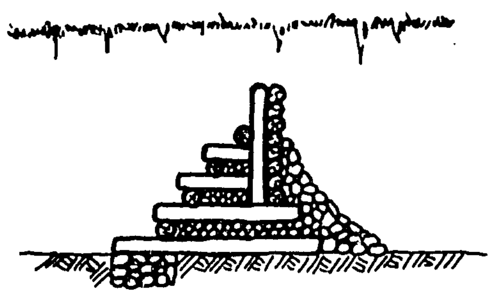
Illustration of Wire Mesh Dam

(6) Timber Dam

a. Wood Crib Dam



Cross section



Longitudinal section

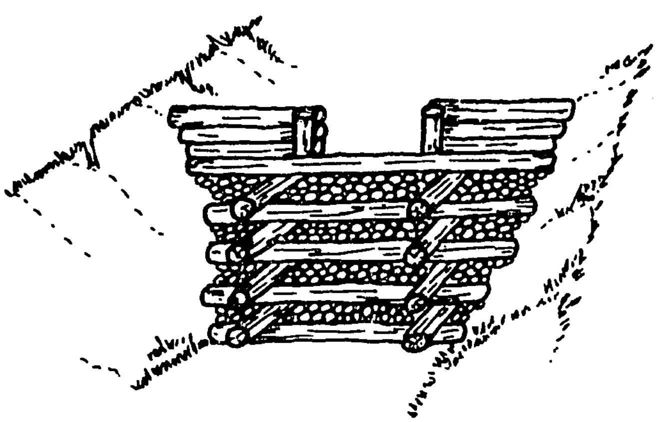
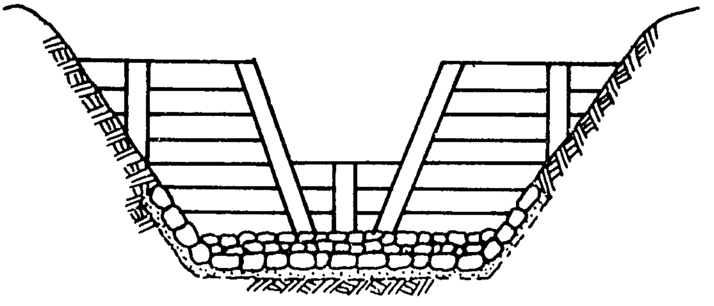
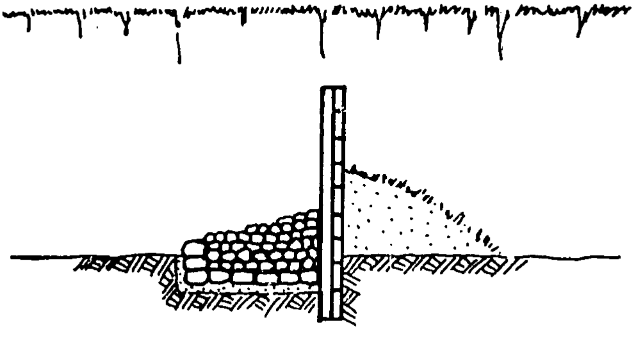


Illustration of Wood Crib Dam Built of Logs and Boulders

b. Plank Dam



Cross section



Longitudinal section

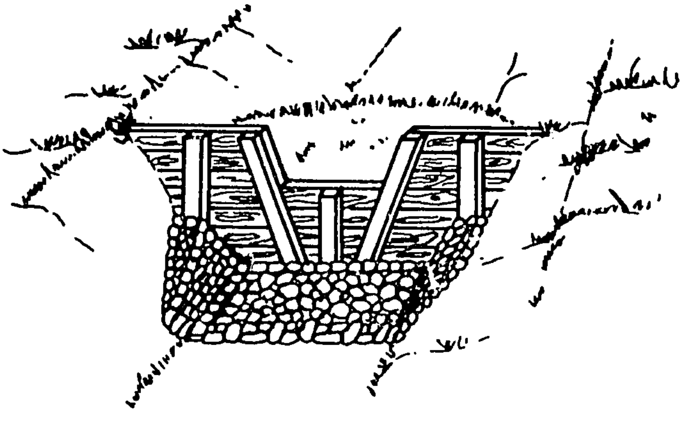
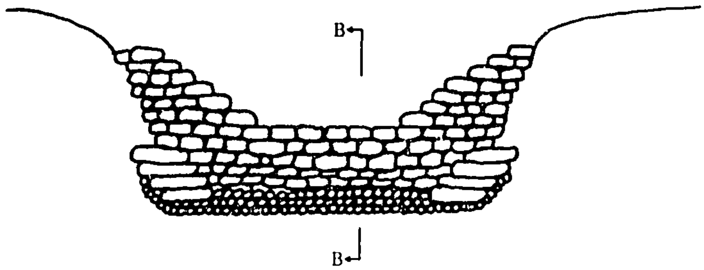


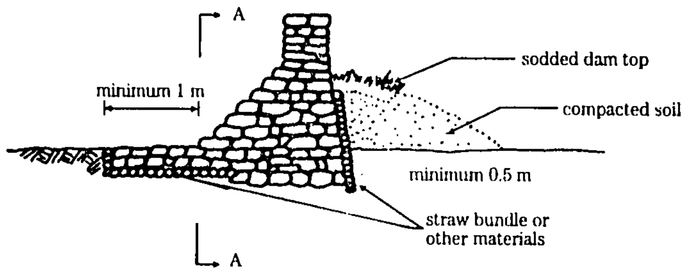
Illustration of Plank Dam with Masonry Apron

120

(7) Masonry Dam



A-A section



B-B section

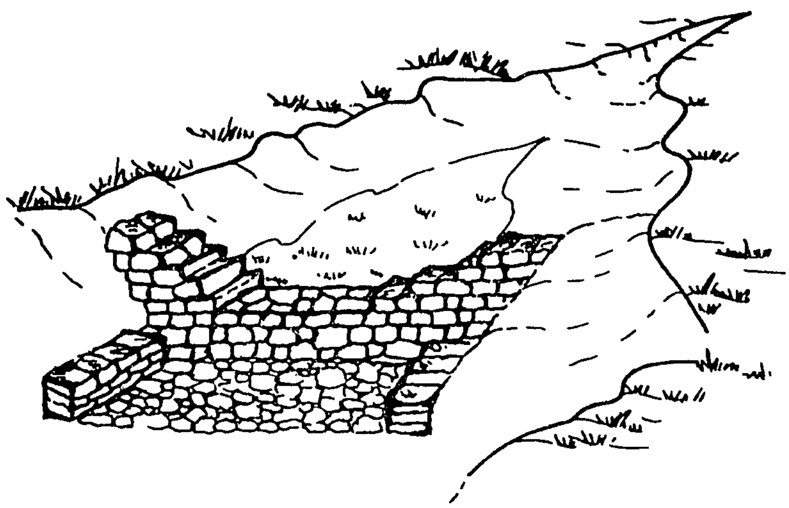
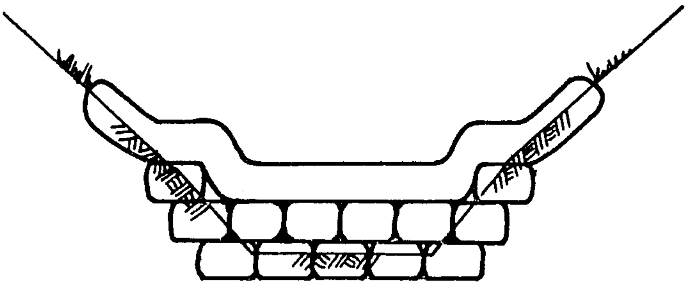


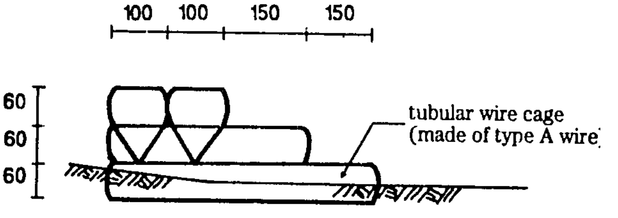
Illustration of Masonry Dam

12

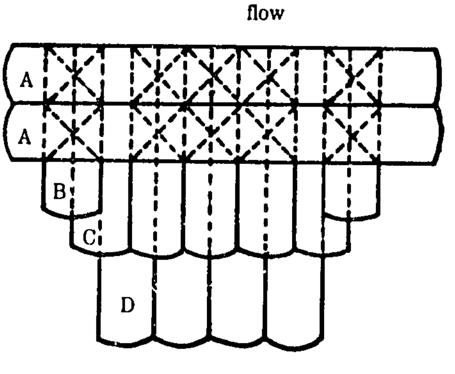
(8) Wire Sausage Dam



A-A section



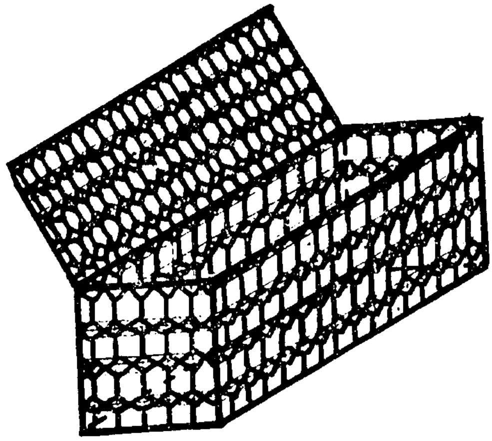
B-B section

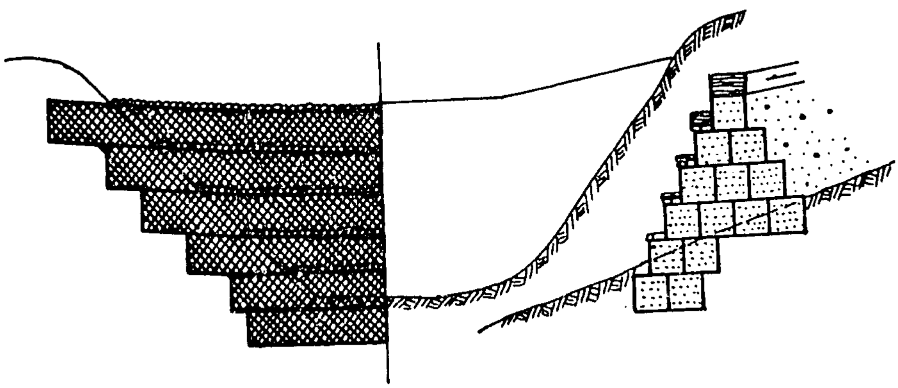


Ground plan

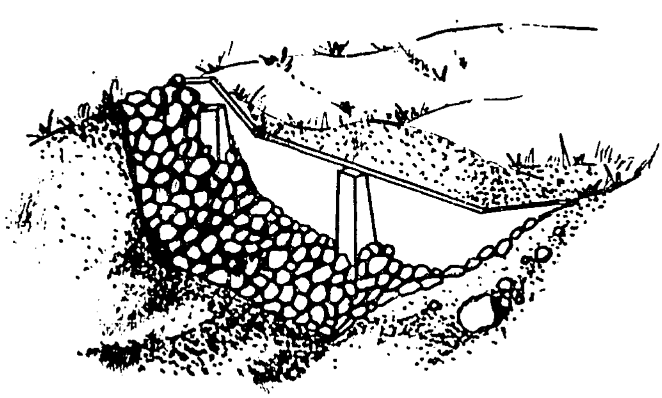
122

(9) Wire Box Dam





(10) Concrete Slab Dam



27.5 Planning and design

(1) General principles

a. Peak flow estimate: For permanent dams, estimate should be based on 25 years' rainfall frequency. For tentative dams, ten years' rainfall frequency will be adequate.

b. Designed silt gradient should be equal to 0.5 - 0.7 gully bottom slope; 0.5 is more frequently used.

c. As a protective measure, such devices as water cushion etc. should be provided for energy dissipation.

d. When there is a choice, the easiest construction method should be adopted. Construction materials available in the vicinity of the dam site should be utilized whenever possible.

(2) Dam site

a. The dam should be located where the gully is narrowest.

b. When a sequence of dams are constructed, the lowest dam should be located at a safe spot, or where the geological features of the banks are sound.

c. A dam should not be built at a bend. When there is a bend, it is better to locate the dam downstream from the bend.

(3) Interval between sequential dams

When several dams are built along a gully at close intervals for erosion control, they are called sequential dams (see diagram below). It is essential that a downward dam should be able to protect the neighbouring upward dam. In order to fulfill the objective of the sequential dams at the lowest cost, the most feasible interval between dams may be determined by the following formula:

$$L = \frac{1}{\tan\alpha - \tan\beta} \times He = \frac{1}{m - n} \times He$$

L = Interval between dams (m)

He = Effective dam height (m)

m = Gully bottom gradient = $\tan\alpha$

n = Planned silt gradient = $\tan\beta$

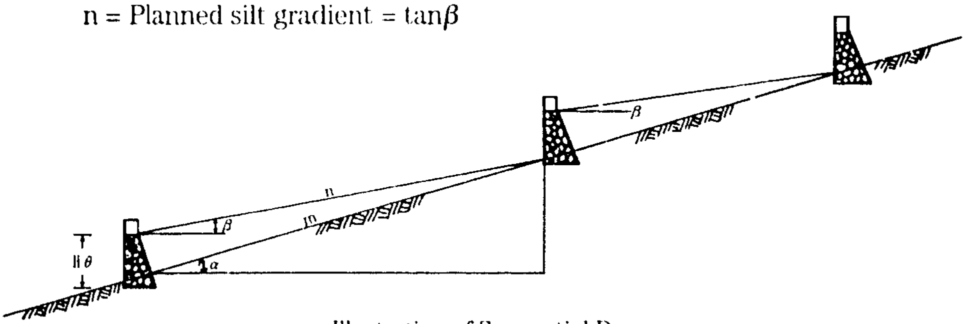


Illustration of Sequential Dams

124

(4) Height of dam

a. Factors which affect the height of a dam include: the shape of the gully, earth characteristics, terrain, land stability, construction costs and expected benefits from the dam.

b. In principle, a low dam is preferred. If a higher dam is needed, it is better to construct a sequence of dams as a substitute.

c. The height of silt is the distance from gully bottom to spillway, which is also known as effective dam height. The most economic effective dam height is 0.6 meters for a riprap dam, 0.7 meter for a single line picket dam and 1.1 meters for a double line picket dam.

(5) Spillway cross-section

a. Direction

(i) The center line of the spillway should be perpendicular to the downstream flow center line. It should also be so aligned that damage or erosion to the banks is minimized.

(ii) At a bend, the spillway center line should be perpendicular as to the tangent of the flow center line.

b. Form: Depending on the type of dam, the following forms are most popular:

(i) Trapezoidal: Usually used on rubble masonry dams filled with concrete mortar, rubble masonry dams and crib dams.

(ii) Rectangular: Suitable for brick dams, box cage dams, crib dams, timber dams and stone dams.

(iii) Parabolic: For brush dams, wire mesh dams, picket dams and sand-bag dams.

(iv) Complex form: Mainly for impervious dams, and dams across very wide gullies.

c. Cross-section

(i) Width of spillway: The width of spillway should be commensurate with the width of the downstream gully bottom, so that the spilt water is kept from damaging the banks.

(ii) Height of spillway: Equal to the depth of overflow at designed peak flow plus freeboard.

(iii) Freeboard: 0.3 - 1.0 meter is appropriate.

(iv) The size of the cross section should be larger, if the amount of floating twigs and debris in the flow is excessive.

d. Calculations related to cross-section

After a specific form is chosen for the spillway, the following equations, which were originally used for the design of broad-crested weirs, may be used to calculate discharge capacity. This should be equal to or larger (by no more than 5%) than the runoff.

(i) Trapezoidal cross-section

At side slope 1:1, $Q = (1.77b + 1.42h)h^{2/3}$

At side slope 1:0.5, $Q = (1.77B + 0.71h)h^{2/3}$

At side slope 1:0.3, $Q = (1.77B + 0.425h)h^{2/3}$

(ii) Rectangular cross-section

$Q = 1.767bh$

Q = Discharge capacity (m^3/sec)

b = Width of spillway bottom (m)

h = Depth of overflow (m)

(6) Thickness of spillway: Spillway thickness depends on the type of dam, materials used in construction, size of rocks and pebbles in the gully bottom, and safety factors.

Table 27-1. Suggested thickness of spillway for various types of dam

Dam type	Gravity dam	Brick dam	Wood crib dam	Wire cage dam	Rock-fill dam	Riprap dam
Spillway thickness	more than 0.8 × spill way depth or 1.5-2m	2b-4b	1-2m	1-1.5m	1-2m	1.5-2m

(7) Slope of dam surfaces

a. In order to prevent damage to the dam from stones and gravel discharged from the spillway, the slope of downstream surface should usually be fairly steep, while the slope of the upstream surface may be moderate.

b. If the dam is quite long, except the section where the spillway is located, the arrangement can be reversed in order to minimize dam volume, i.e. the slope of downstream side may be gentle, while the upstream side is made steep.

c. The gradient of the downstream surface of the gravity dam generally falls in the range of n=0.2 - 0.3, while the upstream slope is larger than 0.45. However the safety of the dam should be considered when these gradients are decided.

d. Gradient of both surfaces of stone dam: 1:1.25 - 1.50.

(8) Apron or stilling basin: Built to protect dam foundation from water erosion on the downstream side, and to prevent collapse of the banks.

a. Calculation of apron length

(i) $L = 1.5(H+h)$, if gully bottom gradient $\leq$ 15%

(ii) $L = 1.75(H+h)$, if gully bottom gradient > 15%

L = Apron length

H = Dam height

h = Depth of spill flow

126

b. Apron thickness: Depending on the type of water coming down the gully, whether it contains, e.g. gravel, boulders, etc. It also depends on whether the apron base or the apron itself possesses any water cushion. The thickness should be sufficient to sustain the impact of the spill flow and the uplifting buoyancy produced by the base. Concrete and gabion are the popular materials for apron construction.

Table 27-2. Apron thickness in relation to materials

Dam Height (m)	Material	Apron Thickness (m)
<2	Concrete	0.20
2-3	Concrete	0.20-0.30
3-5	Concrete	0.30-0.50
<2	Riprap or dry masonry (ϕ 30cm)	>0.30

(9) Endsill

a. The height of the end sill for a pervious dam, e.g. a picket dam or riprap dam, should be 0.15 - 0.25.

b. For permanent impervious dams, the end sill height should be 0.20-0.60m, depending on dam height and length of stilling basin.

(10) Key trench

a. These are rock-filled trenches built crosswise into the banks and bottom of the gully to protect the dam foundation and the banks against water erosion. Pervious dams, e.g. picket dams, riprap dams, dry masonry dams, wire cage dams and brush dams, all need key trenches.

b. Ordinarily the width and depth of key trench are both 0.6m. This maybe extended to 1.2-1.8m, if the banks are unstable.

c. Mixed boulders of various sizes, with 80% of the boulders smaller than 14cm, are the most desirable fill for a key trench.

(11) Stone for pervious dams

a. Stone is the basic material for the construction of pervious dams. Flat rocks and rounded boulders are not suitable for pervious dams, e.g. picket dams, rock-fill dams, etc.

b. Stones used in a pervious dam should not be smaller than 10 cm in diameter, and 25% of the stones should fall in the 10-14cm class.

27.6 Precautions

(1) Try to avoid building any new road for the convenience of construction work, since this will aggravate soil erosion. Instead, materials and machinery should be transported by cable conveyors. Those materials which are available in the vicinity of the construction site should be given first priority.

(2) Construction of sequential dams should begin with the lowest dam, and move up-

stream.

(3) Excess excavated earth, after back fill, should be dumped at a safe spot.

(4) Disturbance to slope surface and vegetation should be reduced to a minimum during the process of construction.

(5) Earth work should be done during the dry season.

(6) Necessary soil conservation measures should be taken during construction.

128

Chapter 28. Farmland Shaping

28.1 Definition

To reduce the gradient and level the surface of slopes with machinery, for the purpose of improving the efficiency of slopeland farming.

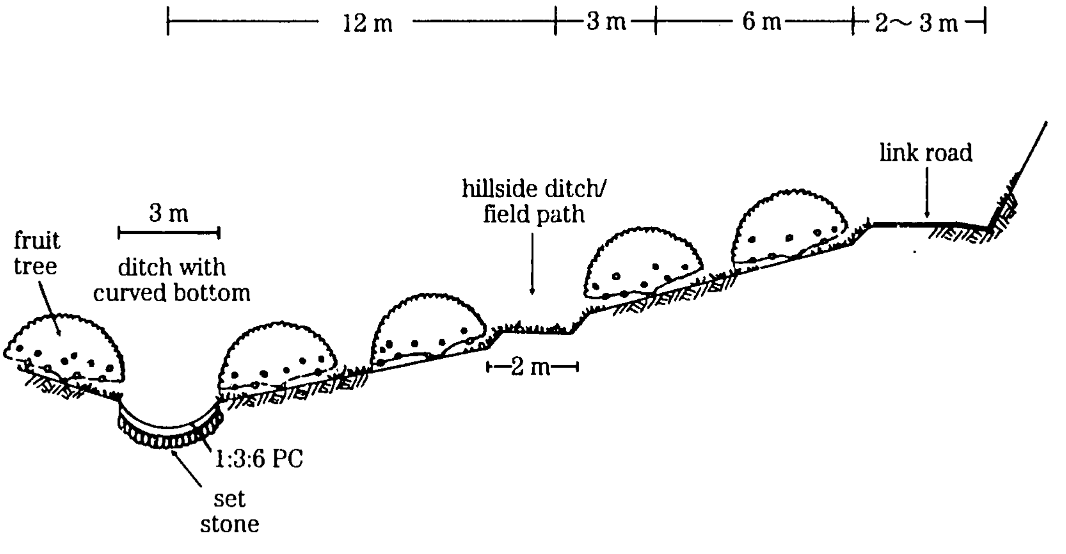
28.2 Objective

(1) To improve farm planning and crop management, by levelling the surface of slopes.

(2) To improve the efficiency of farm machinery operations through slope reduction.

(3) To increase land utilization.

28.3 Diagram



28.4 Application

(1) This treatment may be applied to farmland where the average slope gradient is below 45%, which may be reduced to 20% after treatment. Treatment of forestland is not permitted.

(2) It should not be applied to the watershed of a reservoir, unless authorization is obtained from the agencies concerned.

(3) It is suitable for rolling slopes which are not ideal for cropping.

(4) This treatment should not be attempted in unstable areas where there are landslides, landfalls, faults, consequent slopes, or broken shale.

28.5 Planning and design

(1) Principles

a. According to the ground features, divide the working area into separate slopes. The gradient of each slope should be kept as uniform as possible.

b. Try to adapt to ground features, in order that earth work can be kept to a minimum. It is desirable that the planned volume of cut should approximate the volume of fill.

c. Improvement work should be limited to locations where the gradient is low and the land will permit mechanized cropping after improvement. Places which do not meet these requirements should be allowed to remain undisturbed.

d. Vegetation along the banks of valleys and streams should be maintained. The width of this zone should be decided according to the needs of the site.

(2) Planning

a. Survey the project area to ascertain the extent of improvement work involved and the objective of the project.

b. Roadside drainage system and land utilization.

c. Follow the same principles as are prescribed for the planning of equally spaced hillside ditches.

d. Set up tentative measures for prevention and control of disasters and damage, e.g. check dam, sediment basin etc.

e. Estimate volume of earth work (See Appendix 2.)

(i) Grid system (adopted by USDA.)

(ii) End area system

(iii) Plane system

f. Treatment of top-soil and route of hauling. Try to balance the volume of earth cut and fill.

g. Divide the project area into blocks, and assign working period to each block. Work should progress from one block to another according to the schedule. This can help minimize damage caused by torrential rains.

h. Establish an adequate drainage system.

i. Strengthen the stability of side slopes. Underground drainage pipes should be laid in depressions which are then filled, so as to prevent slipping of soil.

j. Vegetative cover should be developed on all exposed land.

28.6 Operational procedures

(1) Topographic survey: Use 1/500-1/1000 scale and 1-meter contours.

(2) Prepare an earth moving table and job layout chart.

(3) Prepare a soil erosion control scheme, within the limit of the project area, with a view to ensuring safety in the working area. This scheme should be in line with the overall plan of the project.

(4) Foundation work should begin before any other part of the project.

(5) Slope improvement work should begin at the bottom of the slope, and proceed upwards. If the project covers a wide area, the area should first be divided into blocks, and each block worked on separately.

(6) Before excavation starts, vegetation on the site should first be removed. Then topsoil should be taken off and kept at prearranged spots, to be used later for top dressing. Gravel, rocks and poor soil should be buried as earth fill.

28.7 Precautions

(1) All plants growing on the ground should be cleared, since decayed plants in the ground may induce land slips.

(2) Where earth is to be filled, the fill should first accumulate and be piled into a stepped mound at the site. At the time of filling, earth should be laid in layers; each layer should be compacted firmly to ensure stability.

(3) open drains should not be dug into earth, fill.

(4) The schedule of field work should avoid the rainy season.

(5) A large operation area should be divided horizontally into sections. Adjacent sections should not be worked simultaneously.

(6) The optimum distance to the edge of an adjacent stream is 50 meters, measured from any one part of the slope. The minimum distance is 25 meters.

(3)

Chapter 29. Sediment Basin

29.1 Definition

A device installed in a drainage channel or at the junction of drainage ditches to detain silt in runoff.

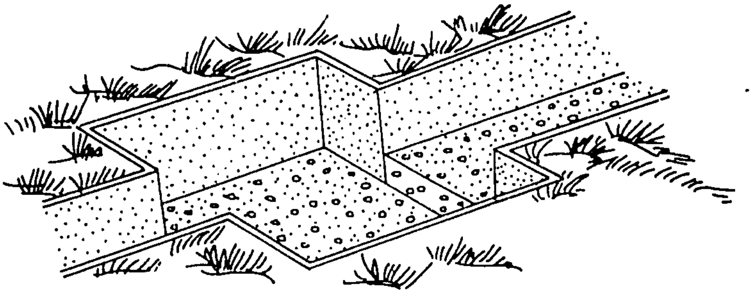
29.2 Objective

(1) To keep silt from damaging land and properties.

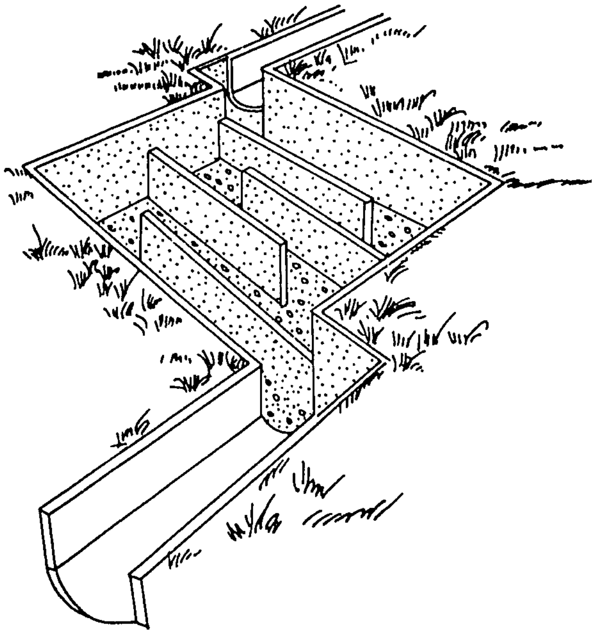
(2) To keep silt from polluting waters.

(3) To utilize silt for top dressing on farmland.

29.3 Diagram



A. Plain Type



B. Basin with Baffles

Fig. 29-1. Temporary Sediment Basin

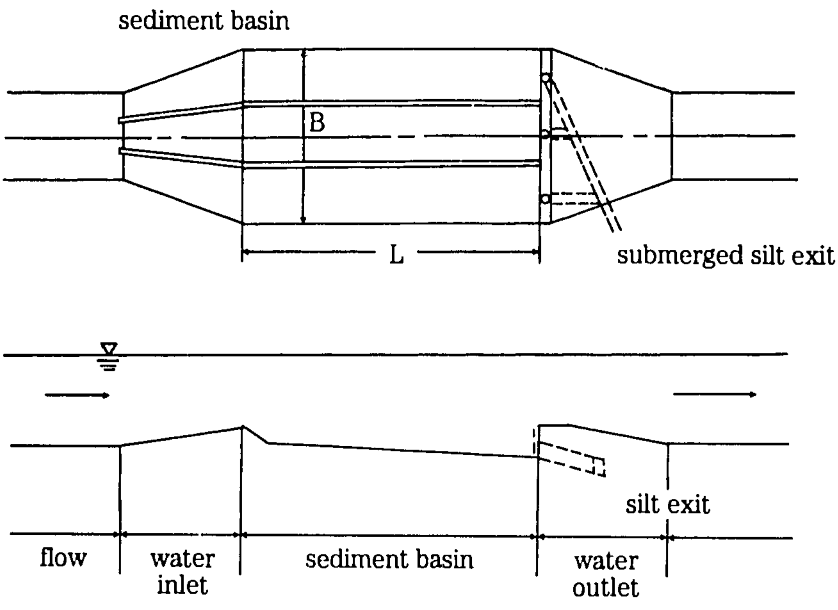


Fig. 29-2. Permanent Sediment Basin

29.4 Application

(1) Temporary sediment basin

This kind of structure is built tentatively with materials available in the project area, during the progress of land levelling or implementation of erosion control. Usually when the project is completed, these basins will be filled and abandoned.

(2) Permanent sediment basin

This is built to intercept silt in an area where erosion control measures have been taken and land utilization has already begun.

29.5 Design

(1) Soil loss may be estimated by any one of the following three methods:

a. Universal soil loss equation (USLE)

(See Appendix 1.)

b. Assume that 500 m^3 of soil per hectare per year will be lost during land levelling.

c. For reclaimed land where erosion control measures have recently been completed, assume soil loss at 200 m^3 per hectare in the first year. For each subsequent year, this rate will be reduced by 50%.

(2) Specification

a. Basin length

$L = K\,(H/Vg).\,V$

L= Basin length

K= Safety coefficient (1.5-2.0)

H= Average water depth in basin

V= Average flow velocity in basin (0.15-0.30 m/sec)

Vg= Critical falling velocity of the smallest particles (m/sec)

Table 29-1. Critical falling velocity of particles in turbid water

Specific gravity of turbid water	Particle diameter (mm)	0.1	0.2	0.3	0.5	1.0	1.2	3.0
1.100	Vg m/s	0.003	0.01	0.01	0.049	0.085	0.14	0.194
1.064	Vg m/s	0.005	0.015	0.015	0.057	0.10	0.192	0.217

b. Capacity of sediment basin

The size of a sediment basin is decided on silt collection speed. A permanent basin should be large enough to require clearing only twice a year. A temporary basin may be cleared 4-10 times a year.

(3) Depth of basin: Ordinarily 1.5-3.0 meters should be adequate.

(4) Shape of basin: A rectangular form is popular. Baffles may be installed on the inside.

(5) For a temporary basin, easily available materials such as earth, stone, logs, or concrete slabs are preferred. A permanent basin may be built of earth and thoroughly covered with vegetation, or durable materials such as concrete.

29.6 Precautions

(1) For earth work, seasons of typhoons and heavy rain should be avoided

(2) Divide the operation area into sections, and sub-sections when necessary, with reference to the total acreage and soil loss rate, and carry out the operation in stages, section (sub-section) by section (sub-section). Land where levelling has been completed should be covered by vegetation as promptly as possible.

(3) Where land smoothing or ditch construction, as part of soil conservation operations, is in progress in upper watershed areas, runoff diversion devices should be set up.

(4) During the progress of earth work or soil conservation operations, in addition to a temporary sediment basin, other temporary damage control facilities should be installed, e.g. drainage systems, earth dams, silt detention fences, etc.

(5) Always remove silt in time to maintain safe capacity of the basin, so as to enable the basin to fulfill its purpose.

(6) The depth and length of the basin should be adequate to prevent overflow of debris.

Example

A construction company is undertaking earthworks on a section of slopeland, under a land development project of the Taipei Municipal Government. What size and number of temporary and permanent sediment basins should be designed?

The environmental conditions and field operation plan are as follows:

a. Watershed area of 50 ha., with silty clay loam, well covered by forests of various species of trees; estimated annual soil loss 1.5 m^3/ha.

b. The watershed is divided into 3 sections. Earth work will be completed in two year to give 30 hectares of the slope a gradient of 14%. The remaining 20 hectares will not be distrubed. Section A, with a total area of 20 ha, will be divided into 20 sub-sections of 1 ha. each. Slope length in this section is 100m. In the second year, Section B will be finished. This section, with a total area of 10 hectares, will be divided into 10 sub-sections of 1 ha. each. Slope length is 60 meters.

c. During the progress of the project, each of the temporary sediment basins will be cleared 10 times a year.

d. Upon completion of the project, the side slopes will be stabilized. Exposed slope surfaces will be sodded to attain a coverage of 80%. All permanent sediment basins will be cleared twice a year.

Solution

A. Temporary sediment basin

i. Soil loss estimation

Step 1: From Appendix 1, Table 1, or Figure 1, find out that Rm=11800 in the area surrounding Taipei City.

Step 2: From Appendix 1, Table 2, or Figure 2, find out Km=0.026 at the project site.

Step 3-4: From Appendix 1., Table 3, or Figure 3, or by equations (5) and (6) in Appendix 1, find out

LS of A Section =4.15

LS of B Section =3.22

Step 5-6: As a rule, land being levelled is considered as exposed land. Therefore C=1, P=1

Step 7: Soil loss during the progress of work

Section A: $T=11800 \times 0.026 \times 4.15 \times 1 \times 1$

$=1273$t/ha/yr

$1273 \div 1.3 = 979$ m^3/ha

1.3=Apparent specific gravity of soil

Section B: $T=11800 \times 0.025 \times 3.22 \times 1 \times 1$

$=988$t/ha/yr

998+1.3=760 m^3/ha

Section C: 1.5 m^3/ha/yr

ii. Capacity of sediment basin

If one sediment basin is built in each sub-section of 1 ha., and each basin is cleared 10 times a year, the minimum basin capacity should be:

Section A: 979 m^3 + 10(times)=98m^3

Section B: 760 m^3 + 10(times)=76m^3

iii. Specifications of the tentative basin

For a tentative basin, which usually is unlined, a depth of 2-3 meters is appropriate. On this basis, the following specifications are recommended:

	Length(m)	Width(m)	Depth(m)	Capacity (m^3)	No. of basins needed
Section A	8	6.2~4.1	2~3	99	20
Section B	8	4.8~3.2	2~3	77	10

B. Permanent sediment basin

i. Soil loss estimation: From Appendix 1, Table 4, it is found that c=0.013. The other parameters are the same as those adopted in the calculations for tentative basins, as shown in the above sections.

Section A: $T=11800 \times 0.026 \times 4.15 \times 0.013 \times 1$

=16.55 t/ha/yr

16.55 t/ha/yr × 20 ha =3 31 t/yr

331 t/yr + 2 times = 165.5 t/yr

165.5 + 1.3 (apparent soil specific gravity)=128 m^3/yr

Section B: $T=11800 \times 0.026 \times 3.22 \times 0.013 \times 1$

=12.8 t/ha/yr

12.8 t/ha/yr × 10ha = 128 t/yr

128 t/yr + 2 times = 64 t/yr

64 + 1.3= 50 m^3/yr

Section C: 1.5 m^3/ha/yr × 20 ha = 30m^3/yr

30 + 2 = 15 m^3/yr

ii. Specifications of the permanent basins

Assume K = 2, H = 2, V = 0.3, Vg = 0.1

Find the minimum length of basin with equation (29.1)

Result: $L=2 \times 2 \times 0.2 + 0.1 = 8$ m

Consequently the numbers and specifications of permanent sediment basins for this project site are recommended as follows:

Table 29-2. Planning of permanent sediment basin construction

	Work section	Sedimentation (m^3)	Basin Specifications (m)			Number of basins required
			Length	Width	Depth	
Basin shared by sections	A	128	10~8	6.4~4	2	1~2
	B	50	8	3.2	2	1
	C	15	8	1	2	1
Basin not shared by sections	A+B	178	9	5	2	2
	A+C	143	9	4	2	2
	B+C	65	8	4	2	1
	A+B+C	193	8	6	2	2

137

Chapter 30. Slopeland Irrigation

30.1 Definition

Slopeland irrigation supplies water by gravity or mechanical devices, to meet the needs of crops, pest and disease control, livestock, and rual people, and to improve the characteristics of the soil.

30.2 Planning and design

(1) Water requirements

Water required by crops equals the total amount of water evaporated from leaves and soil. It varies with soil characteristics, crop types, and weather conditions. Complete local records of water requirements of slopeland crops are gerenally not available. Table 30-1 has been compiled with data from the United States and Japan, in addition to Taiwan; and therefore is of reference value only. Sometimes for planning purposes, water requirements of livestock and people are also taken into consideration. Estimates for such needs may be helped by Table 30-2.

(2) Effective depth of irrigation in each application

The quantity of irrigation water to be applied should be determined with due consideration for variations in soil moisture at different parts of the slope, and the optimum water requirement of crops. The calculation of effective depth of irrigation at each application should be made with reference to 1) the availability of effective moisture in the root zone, and 2) absorption ratio in the root zone. The following equation may be used to find out normal consumption of water in any soil stratum:

$$dm = 1/100\ (Fc\text{-}Wp) \bullet Sa \bullet Ed$$

dm = Effective depth of irrigation (mm)

Fc = Field capacity in the stratum (by weight %)

Wp = Wilting point (by weight %)

Sa = Apparent specific gravity of soil in the stratum

d = Depth of the stratum

Normal water consumption in the stratum=

$$\frac{\text{Effective depth of irrigation(mm)}}{\text{Ratio of water absorption by crops (\%)}} \times 100$$

The stratum which renders the smallest value of water consumption, is the critical stratum. The amount of water consumption of this particular stratum is called total requirement of available moisture (T.R.A.M.). This amount equals to water required for attaining effective irrigation depth at one application.

136

Table 30-1. Peak water requirement of slopeland crops (estimated value)

Unit:mm

Crop	Peak daily water requirement	Estimated daily water requirement for drought and pest control
Citrus fruit	4.0	1.0
Tea	4.0	1.0
Grape	5.7	1.2
Apple	3.0	0.6
Pear	3.5	0.8
Mango	2.5	0.25
Litchi	3.0	0.25
Loquat	3.0	0.25
Banana	4.5	1.0
Papaya	2.5	0.25
Pineapple, Guava	2.0	0.20
Grassland	2.0	0.5

Table 30-2. Daily water requirements of Humans and Livestock

	Peak daily water requirements (liters)
Human	200
Cattle	30
Sheep	2
Hogs	5

Table 30-3. Referential values of field capacity, wilting point and effective moisture of various types of soil

Soil texture	Sand	Sandy loam	Loamy sand	Loam	Sandy clay, loam & clay loam	Silty clay, loam & clay
Field capacity (%)	2.2-3.5	3.5-8.5	8.5-16.0	13.0-22.0	18.0-28.0	25.0-36.0
Wilting point (%)	1.2-1.7	1.5-3.5	3.5-7.0	5.0-10.0	7.5-15.0	14.0-22.0
Effective moisture (%)	1.0-1.8	2.0-5.0	5.0-9.0	8.0-12.0	10.5-13.0	11.0-14.0

(3) Gross depth of irrigation

$$D = \frac{dm}{Ea} \times 100\%$$

D = Gross depth of irrigation at one application

dm = Effective depth of irrigation at each application

Ea = Irrigation efficiency (%)

(4) Watering period

$$N = \frac{dm}{U} \quad \text{or } Nmin = \frac{dm}{U}$$

N = Watering period (day)

dm = Effective depth of irrigation (mm)

U=Daily use of moisture by crops (mm/day)

Umax=Peak daily use of moisture by crops (mm/day)

Umin=Minimum days of interval between watering (day)

(5) Irrigation efficiency

$$E = Ee \times Ea$$

E = Irrigation efficiency

Ee = Water delivery efficiency(%)

Ea = Water supply efficiency(%)

(6) Water supply planning

$$V = \frac{D}{E} \times Au \times 10$$

V = Planned water supply (m^3=ton)

D = Gross depth of irrigation at one application (mm)

E = Irrigation efficiency

Au = Irrigated area (ha)

30.3 Irrigation systems

A variety of irrigation systems have been developed which are adapted to assorted hydrological and climatic conditions, soil characteristics (permeability, field capacity etc.), topography, field sizes, crop types, water sources, and engineering budget. These systems are listed as follows:

Irrigation Method

- Surface irrigation
  - Flood irrigation
    - Border irrigation
    - Basin irrigation
  - Furrow irrigation
    - Furrow irrigation
    - Corrugation irrigation
    - Contour-furrow irrigation
  - Spray irrigation
    - Sprinkler irrigation
    - Perforated pipe irrigation
  - Drip irrigation
  - Others
    - Permanent pipe irrigation
    - Portable pipe irrigation
- Sub-surface irrigation

Table 30-4. Application of various irrigation methods

Irrigation method	Gradient of land (%)	Permeability allowed mm/hr	Crops & conditions	Advantages/disadvantages
Border flooding	below 5	below 75	for densely planted crops, e.g. vegetables, forage crops; requires thorough land levelling	low labor cost, wasteful of water, heavy water consumption
Basin flooding	below 0.2	below 75	for terraced orchards; requires thorough land levelling	low labor cost, wasteful of water, heavy water consumption
Contour-border	5-14	5-100	for densely planted crops, e.g. vegetables, forage crops; grassland; requires contour ridges	heavy water consumption, uneven water distribution, may cause erosion.
Corrugation	below 5	5-100	for terraced vegetable fields; requires thorough land levelling	heavy water consumption, uneven water distribution
Contour-furrow	5-27	5-100	for furrow crops and tree crops	low labor cost, heavy water consumption
Permanent pipe	no limit	above 5	for orchards, no need for land levelling	water thrifty, low labor cost, high equipment cost
Portable pipe	no limit	above 5	for orchards, vegetables, grassland, upland crops	simple equipment, water thrifty, high labor cost.
Sprinklers	no limit	above 5	for all crops, terrains, and soils; requires adequate pressure or elevation	low labor cost, high equipment cost
Perforated pipes	below 5	no limit	for row cropping, vegetables, grassland, terraced orchards	low labor cost, water thrifty, high equipment cost
Drip	no limit	above 5	for orchards	low labor cost, water thrifty, equipment cost rather high
Sub-surface	below 5	above 5	not suitable for slopeland	water thrifty, reduced evaporation loss

Chapter 31. Water Source Facilities

31.1 Definition

Structures for collection and storage of water for slopeland irrigation and farming.

31.2 Objective

To meet the need of crops, pest and disease control, livestock, and rural people for water.

31.3 Types of facilities and their application

(1) Water collection facility: Farm ponds, reservoirs

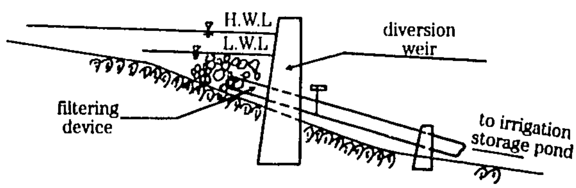
(2) Water conduit: Utilizing existing water source on or under the ground, and conducting the available water by diversion weirs or ditches to the irrigation area. This method can be used only when the water source is located at an elevation higher than that of the irrigation area.

(3) Well: When sufficient underground water is available in the vicinity of the irrigation area, wells may be constructed to supply water by pumping.

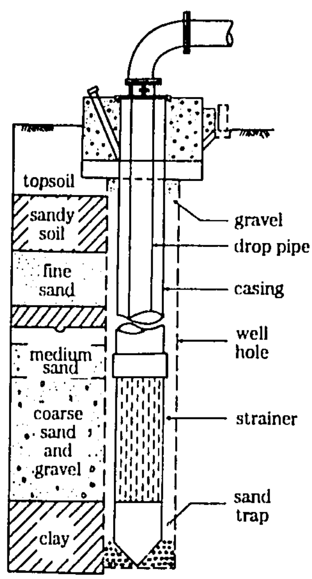
31.4 Diagram

(1) A water collection facility is described in Chapter 34. Farm Ponds.

(2) Water conduits



(3) Well



31.5 Design

(1) Water collection facility: See Chapter 34. Farm Ponds.

(2) Water conduit

a. Diversion weirs or dams may be designed with reference to the design of check dams.

b. A filtering device should be provided at the water inlet.

c. If the water source has a high turbidity or contains large volume of of silt, a sediment basin or sand filtering device should be installed downstream.

(3) Well

Before a well is constructed, test boring should be done to sample and analyse soils and water at various depth. The boring logs should be plotted on the data sheet, to be used in designing the well.

a. Caliber of the casing: The caliber of well casing should be large enough to accommodate the pump.

b. Depth of well: To be determined by the depth and thickness of aquifer (water bearing) stratum. In order to give maximum allowance for water level drop and to obtrain a higher water supply capacity, usually the well should reach the bottom of the water bearing stratum.

c. Length of strainer

(i) The strainer should allow an intake flow velocity of the approximately 0.03 m/sec.

(ii) The length of stariner depends on the thickness of filter bed and the position of strate of coarse sand and fine sand, as well as the still water level.

(iii) The distance from still water level to the top of the stainer is the allowable drop in water level. In other words, when the pump is working, water level should not drop below the top of strainer. Since the maximum pumping capacity equals the product of multiplying the allowable drop in water level by water output, the most desirable length of strainer should be 1/3-1/2 of the thickness of the zone of saturation.

Chapter 32. Pumping Facilities

32.1 Definition

Delivery of water by mechanical means to irrigation areas.

32.2 Objective

To supply water needed by crops, pest and disease control, livestock and rural people in the irrigation area.

32.3 Type and utilization of equipment

The choice of pumping equipment depends mainly on the total water head to be lifted.

Table 32-1. Total head of various types of water pumps

Pump type	Axial flow pump	Diagonal flow pump	Volute pump	Turbine pump		Plunger pump
				Single stage	Multistage	
(m)	above 4	3~15	4~30	18~60	above 20	above 20

The figures given in the above table are a basic reference for the selection of a pump. However, the characteristics of each pump, as well as the essential requirement of the project should also be considered.

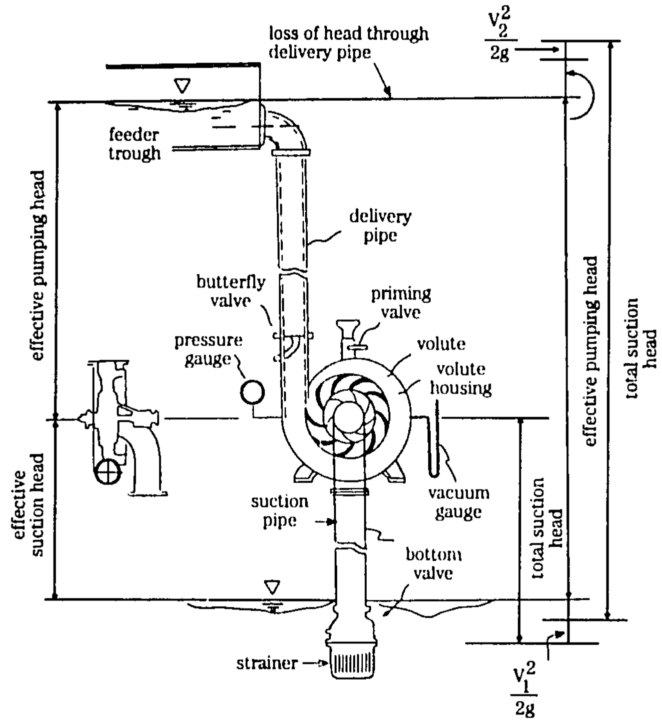
(1) A volute type pump is desirable when the range of water head variation is limited, and only the water output has to be adjusted

(2) Turbine pumps are suitable when the head has more variation, while requirements for water output remain fairly stable.

(3) For delivering small quantities of water, or spraying pesticides with a high head, a plunger pump is better.

144

32.4 Diagram



Single Stage Volute Pump

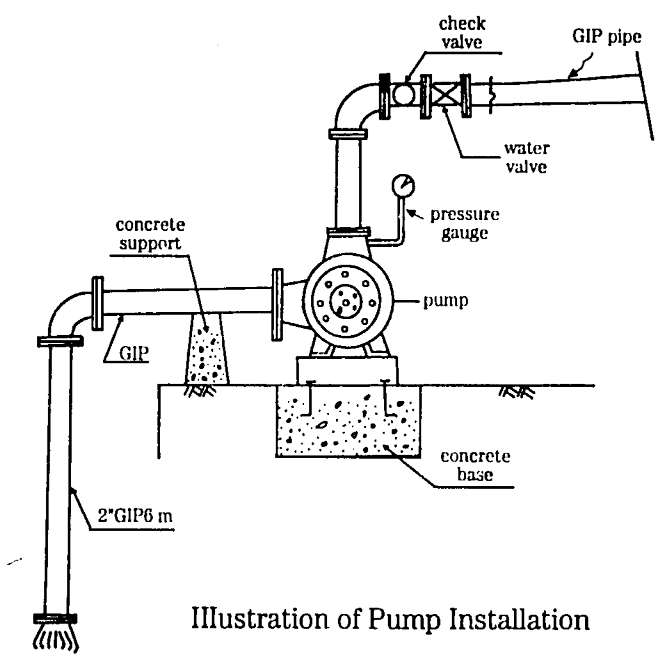


Illustration of Pump Installation

32.5 Design

(1) Pump

a. Caliber of suction port

$$D=146\sqrt{\frac{Q}{V}}$$

D=Caliber of pump suction port

Q=Pumping capacity (m^3/min)

V=Velocity of flow at suction port (m/sec)

(Approximately 1.5-3.0 m/sec)

Table 32-2. Size of suction port in relation to pumping rate

Suction Port size (mm)	40	50	65	75	100	125	150	200	250	300	350	400	500
Pumping rate (m^3/min)	0.11 – 0.22	0.18 – 0.36	0.28 – 0.56	0.45 – 0.9	0.71 – 1.4	1.12 – 2.24	1.8 – 3.35	2.8 – 5.6	4.5 – 9.0	7.1 – 14	9.0 – 18	11.2 – 22.4	18 – 35.3
Standard rate (m^3/min)	0.13	0.23	0.42	0.56	1.10	1.70	2.50	4.80	7.10	11.0	16.0	21.0	33

b. Speed ratio: RPM per 1 meter head per 1 m^3/min output

$$Ns=\frac{NQ^{1/2}}{H^{2/3}}$$

Ns=Speed ratio (rpm)

Q=Pumping capacity (m^3/min)

N=Rotation of pump(rpm)

H=Total head(m)

Table 32-3. Speed ratio of various types of pumps

Pump type	Turbine	Volute	Diagonal flow	Axial flow
Speed ratio	120~250	200~450 Axial flow	700~1,200	1,200~2,000
(m-m3/sec-rev/min)		450~900 Mixed flow		

c. Calculations related to power of pump

(i) Shaft horsepower

SHp = 0.222 QH/Np

SHp = Shaft horsepower

Q=Pumping capacity (m^3/min)

H=Total head(m)

Table 32-4. Efficiency (Np) of small volute type pump

Pumping rate (m^3/min)	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.5	2.0	3.0	4.0
A Efficiency (%)	34	40	44	49	53	55	57	60	62	65	67	70	71
B Efficiency (%)	29	34	37	42	45	47	49	51	53	55	57	59	60

Remark: A = Maximum efficiency

B = Minimum efficiency

(ii) Power requirement

$$RHp = SHp \times \frac{1}{n_i} \times e$$

RHp = Rated power

SHp = Shaft horsepower

n_i = Transmission efficiency:

V belt: 0.93 - 0.95

Flat belt: 0.90 - 0.93

Cross axial spur gear: 0.92 - 0.98

Miter gear: 0.90 - 0.95

Flange coupling: 1

e = Stability coefficient:

For electiric motor: 1.10 - 1.20

For engine: 1.15 - 1.25

Symbol	Nomenclature	Remark
S	service switch	not required when wire smaller than 22 m/m²
K.W.H.	KWH meter	
KWARH	KWARH meter	For motor over 20 Hp
N.F.B	circuit breaker	See Table 32-5
Ⓥ	volt meter	0-300V
Ⓐ	Am meter	See Table 32-5
ⓍVS	3-way switch	
	knife switch	See Table 32-5
M.S	magnetic switch	See Table 32-5
Y.Δ	starter switch	For motor of 7.5 Hp and up
Ⓜ	motor	See Table 32-5
	capacitor	See Table 32-5
	3-wire line	See Table 32-5
	2-wire line	
	ground	

Table 32-5. Specifications of 220V 3-phase motor (under 30 Hp)

Item		Unit	Value						
Power		H	5	7.5	10	15	20	25	30
Minimum wire diameter		m/m²	5.5	5.5	8	14	22	38	38
Circuit breaker N.F.B.	Frame capacity	AF	50	50	50	100	100	225	225
	Trip current	A	40	40	50	70	100	125	125
Magnetic switch	Overload current	A	17.2	25	31	46	60	72	90
Am meter	Reading range	A	30	30	50	75	100	100	150
Knife switch	Rated current	A	30	50	60	100	100	150	200
	Fuse capacity	A	30	30	50	75	75	100	150

Table 32-6. Capacitance and power relations

Power (Hp)	1800 rpm capacitance at max. rated KWAR (single phase)
10	4
15	5
20	5
25	7.5
30	10

KVAR	UF
1.83	100
2.73	150
3.35	200
4.56	250
5.47	300
6.39	350
7.30	400
9.12	450

Single Phase Power Source Wiring

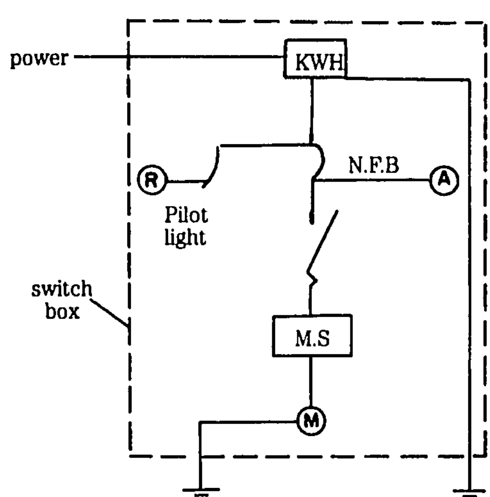


Table 32-7. Specifications of single phase motor (1-5 Hp)

Item		Unit	Value						
Power		H	5	7.5	10	15	20	25	30
Minimum wire diameter		m/m²	5.5	5.5	8	14	22	38	38
Circuit breaker N.F.B.	Frame capacity	AF	50	50	50	100	100	225	225
	Trip current	A	40	40	50	70	100	125	125
Magnetic switch	Overload current	A	17.2	25	31	46	60	72	90
Am meter	Reading range	A	30	30	50	75	100	100	150
Knife switch	Rated current	A	30	50	60	100	100	150	200
	Fuse capacity	A	30	30	50	75	75	100	150

(2) Pumping station

a. Foundation: A pumping station should be built on hard ground, with a foundation no less than 40cm thick. The bolts used to anchor the pump should not be smaller than 16mm in diameter, and should be imbedded in the foundation to a depth of 25-40 times the bolt diameter.

b. Housing: The pump house should be designed with due reference to the size and weight of the machinery, e.g. pump, motor, engine etc. Sufficient space should be provided for maneuverability. Inside the house should be kept dry, well ventilated and adequately lit. The entrance should be wide enough to facilitate the moving of equipment.

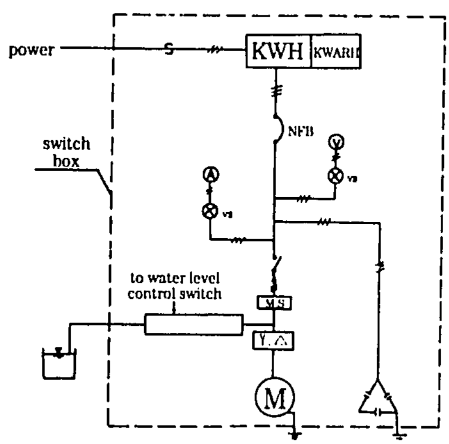
(3) Power supply

a. Electric power

(i) Interior wiring

Three-phase power source

Wiring of Cross Axle Motor Pump



149

(ii) External wiring

To be designed by the power company, and budgeted accordingly.

b. Electric motor

(i) Type of electric motor

(a) On the basis of electrical characteristics

- D.C. Motor
  - Separately excited motor
  - Self excited motor: Shunt motor, Series motor, Compound motor
- A.C. Motor
  - Synchronous motor: Revolving field type, Revolving armature type, Inductor type
  - Asynchronous motor
    - Induction motor
      - Single phase
        - Split phase start type
        - Capacitor start type
        - Capacitance current type
        - Repulsion induction motor
        - Shaded-pole induction motor
      - Three phase
        - Squirrel-cage type
          - Plain squirrel-cage type
          - Notched-pole squrirel-cage type
          - Double squirrel-cage type
          - High impedance squirrel-cage type
        - Wound rotor type
    - Commutator motor
      - Single phase unifilar, Single phase repulsion
      - Three-phase unifilar, Three-phase shunt

(b) On the basis of axial position

Horizontal axle

Vertical axle: Shaft upward, Shaft downward

(c) On the basis of the type of motor housing

Open type: There are openings in the housing.

Therefore the inside of the motor is ventilated.

Hermetically sealed type: No ventilation.

(ii) Rating: The limitations and conditions specified by manufacturers for the use of their product are usually printed on a label plate attached to the motor. The most common ratings for a motor include: Power output, rotation speed, electrical frequency ,voltage, current, temperature tolerance, timing, etc.

c. Engine

(i) Gasoline engine: Rotative speed usually ranges from 1,700 to 3,600 rpm. Small air-cooled gasoline engines are often used on volute type pumps.

(ii) Diesel engine

(a) Small diesel engines: 3-20 hp, 1600-2400 rpm.

(b) Medium diesel engines: 800-1500 rpm, 15-1000 hp. Widely used on pumps of low head and low rotative speed, e.g. axial flow and diagonal flow types.

(c) High speed diesel engines: 15-300 hp, above 2,000 rpm, for volute pump with high head.

32.6 Remarks

(1) A 72-hours performance test should be carried out at the factory before acceptance of the product.

(2) Installation of the pump should be done by the manufacturer whenever possible.

(3) For better economy, electric motors are desirable. If an engine has to be used, diesel engines are preferred. Gasoline engines should be avoided.

(4) For a pump with an electric motor, a water level automatic control, primer, and time switch may be installed when necessary.

(5) Relay pump(s) should be set up when water head exceeds 150 meters.

(6) The efficiency of 3-phase induction motors ranges from 70 to 95%, in proportion to power output, while the efficiency of single phase induction motors is 70-75% (except capacitive current motor). Therefore, when the power output of a motor is less than 2 hp, a single phase engine is desirable; 3-phase system should be adopted when output is over 3 hp.

(7) The pump house should be equipped with a lightning conductor.

Chapter 33. Water Conveyance Facilities

33.1 Definition

Lifting water by mechanical means or sending water by gravitation to the irrigation area.

33.2 Objective

To provide irrigation areas with water when it is needed.

33.3 Mode and application

(1) Open ditches

a. Earth ditch: Easy to build, but owing to high permeability, irrigation efficiency is reduced by heavy water loss.

b. Lined ditch: The ditch is lined with concrete or bricks.

(2) Pipe

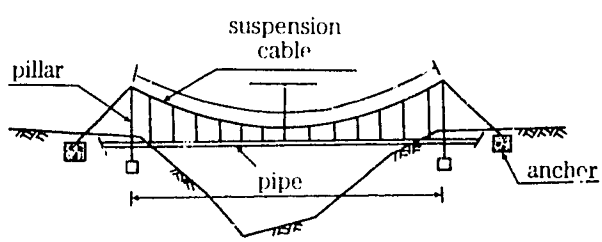
a. PVC pipe: Light-weight, high resistance to corrosion, no deposits, low cost, high plasticity, easy for work, popular in slopeland irrigation.

b. PE pipe: Light-weight, good tolerance to low temperatures, resistant to corrosion, high pliability, easy to work. Suitable for small sized (diameter less than 10 mm), low pressure pipe system.

c. Steel pipe: High pressure tolerance, suitable for any terrain. However, high cost limits its use in slopeland irrigation. Usually it is used only at the water source and where very strong pipe is required.

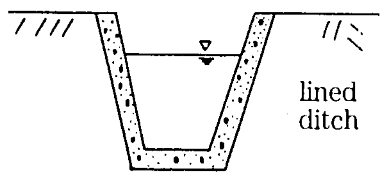
d. Cast iron pipe: High strength, corrosion resistant, easy to work and manage, suitable for a large caliber pipe system. In slopeland irrigation, only cast iron parts are used.

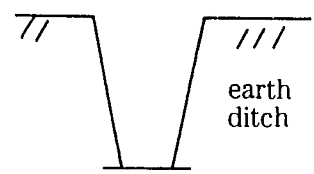
33.4 Diagram



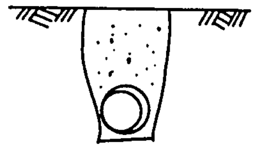
Installation of Suspended Pipe

1. Open irrigation ditch





2. Underground pipe



33.5 Design

(1) Open ditch

Open ditches are comparatively rare in slopeland irrigation water distribution system. For details of the design, see Chapter 30. Slopeland Irrigation.

(2) Pipe system

a. Design of flow: When total planned water requirements have been determined, flow can be computed on the basis of time of water supply.

$$Q=\frac{Q^1}{T}$$

Q=Flow(m^3/sec)

Q^1=Planned daily water requirement (m^3)

T=Time(sec) For gravity flow, the time is 24 hours. For pumping, 16-20 hours are common. Flow in distribution system is calculated on the basis of irrigation time, which is generally 10-12 hours per day.

b. Pipe caliber

(i) Pump pipe: This pipe should be larger than the caliber of the pump outlet by one grade.

(ii) Distribution pipe: With reference to the volume of flow, by trial and error method, calculate head loss by friction and the pressure head between the two ends. Then find out the suitable caliber.

c. Head

(i) Effective head (Ha): The distance from water level to pump outlet.

(ii) Head loss from friction in drop pipe (Ht)

(a) William and Hazen Equation (See chart)

$$Ht=\frac{6.819L\cdot V^{1.852}}{C^{1.852}D^{1.167}}$$

Ht: Head loss from friction (m)

L: Length of drop pipe (m)

V: Average flow velocity in drop pipe (m/sec)

C: Friction coefficient(see chart)

D: Pipe caliber(mm)

(b) Scobey's Equation (See chart)

$$Ht = \frac{2.59Ks \cdot L \cdot V^{1.9}}{1000 \cdot D^{1.1}}$$

K: Friction conefficient (See chart)

Other symbols same as above equation

(c) Darcy's Equation

$$Ht = \lambda \frac{L}{D} \cdot \frac{V^2}{2g}$$

λ=Friction coefficient=0.02+($\frac{1}{2000 + D}$)

Other symbols same as above equation

If D ≤ 50mm,V ≥ 1.5 m/sec, the accuracy of the equation of Williams and Hazen, and that of Scobey, should be watched. When Q = 7600 ℓ/min, and L ≤ 2400 m, Scobey's equation is more suitable. Williams and Hazen should be used when Q and L exceed these figures.

(iii) Miscellaneous head loss (Hf)

(a) Bottom valve loss

(b) Control valve loss

(c) Check valve loss

(d) Pipe bend loss

(e) Pipe diametrical variance loss

(f) T joint loss

(g) Residual velocity loss

Total miscellanceous loss may be assumed to equal 5% of the drop pipe loss.

(iv) Total head (H)=Ha + Ht + Hf

(1) Suspended pipe

At the crossing of a stream or gully, if it is impractical to lay a pipe line on or under the ground, the line may be suspended.

a. Maximum tensile load

$$Hmax = \frac{WL^2}{8d}$$

W=Weight to be suspended (Cable weight + Water weight + Pipe Weight)

Hmax=Maximum horizontal stress

$$T = Hmax\left[1 + \left(\frac{4d}{L}\right)^2\right]^{\frac{1}{2}}$$

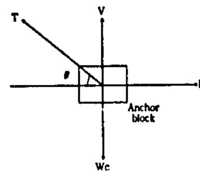
$$\ell = L\left[1 + \frac{8}{3}\left(\frac{d}{L}\right)^2\right]$$

b. Anchor block

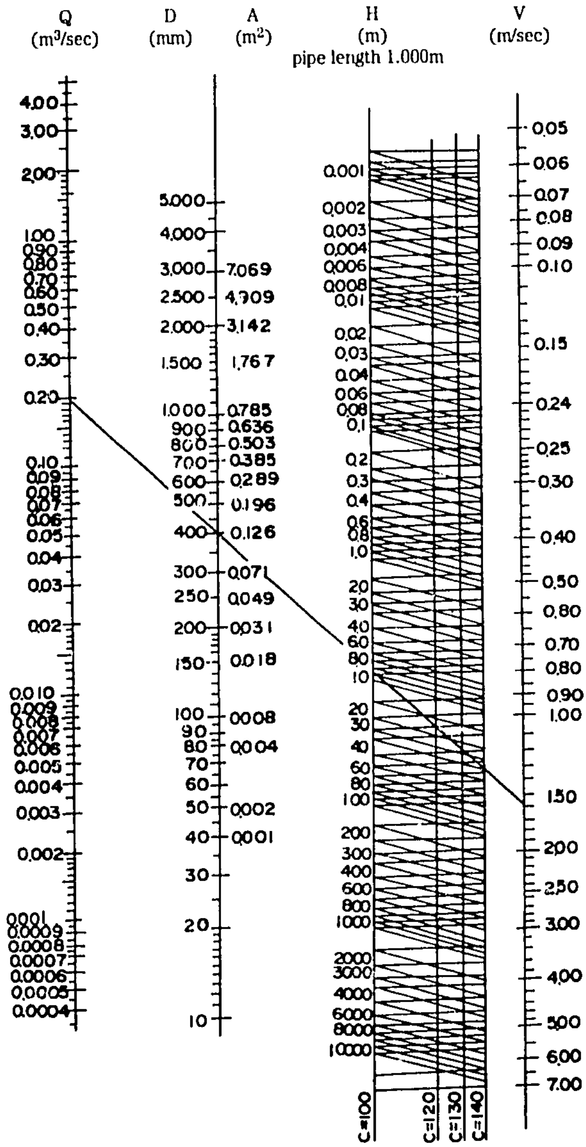
V = T • Cosθ < Wc

V = Uplift force

Wc= Weight of anchor block



Head Loss for Internal Friction of Pipe

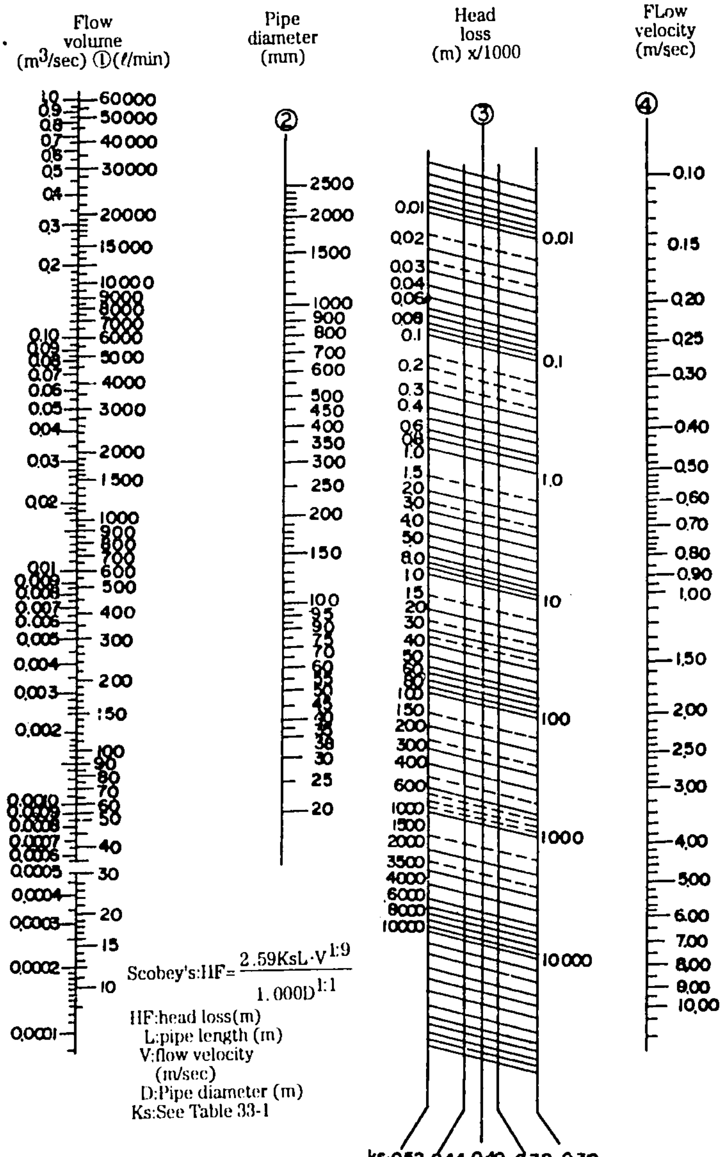


Willioms & Hazen

$$H = \frac{6.819LV^{1.852}}{C^{1.852}D^{1.167}}$$

H:head loss
L:pipe length (m)
C:friction coefficient (variable with pipe material)
D:pipe internal diameter
V:flow velocity
A:cross section area of water flow in pipe
Q:volume of water flow

Head Loss from Internal Friction of Pipe



Scobey's: $HF = \frac{2.59 Ks L \cdot V^{1.9}}{1.000 D^{1.1}}$

HF: head loss (m)
L: pipe length (m)
V: flow velocity (m/sec)
D: Pipe diameter (m)
Ks: See Table 33-1

To be used when:
Q=7000 ℓ/min
C=2400 m or less

150

Table 33-1. Pipe Ks and C Coefficients

	Ks (Scobey)	C(Williams & Hazen)
Smooth steel spiral welded (new)	0.32	140
New aluminium	0.32	140
Steel spiral welded (15 yr. old)	0.40	120
Riveted steel (10 yr. old)	0.44	110
Re-manufactured	0.52	95
Lead	0.28~0.32	150~140
Wood (new)	0.40	120
Wood (15 years old)	0.44	110
Rubber (inside lined with rubber)	0.32~0.44	140~110
Portable aluminium pipe and coupling	0.40	120
Portable plastic pipe & coupling	0.42	115
Portable plastic pipe & coupling	0.32~0.38	140~125
Asbestos cement	0.32~0.36	140~130
Centrifugal reinforced concrete	0.36	130
Concrete or clay	0.40	120

33.6 Remarks

(1) In order to prevent water hammer effect which may damage the pipe, check valves should be installed at appropriate points along any section of a pipe line which climbs a long slope.

(2) Width and depth of pipe trench

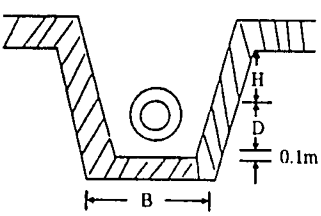


Table 33-2. Cross-section of Pipe Trench

Pipe caliber (mm)	13~38	50~63	80~300
B (m)	0.30	D+15	D+15
H (m)	0.45	0.80	1.00

(3) Glued slip-over connection of plastic pipes: The length of overlap should follow the specifications in the following table.

Table 33-3. Overlap length of glued slip-over connection of plastic pipe

Pipe caliber (mm)	9	13	19	25	38	50	63	80	100	150 above
Overlap length (mm)	20	25	35	40	60	70	90	100	130	180

(4) Bending of plastic pipe: The minimum radius allowed is specified in Table 33-4. When pipes mount a crest in the terrain, vent valves should be installed. Where pipes are laid in a depression, drainage channels or waste discharge tubes should be provided.

Table 33-4. Minimum bend radius of plastic pipe

Pipe caliber (mm)	9	13	19	25	38	50	63	80	100	150	200	250	300
Band radius (mm)	40	60	85	110	190	250	300	350	450	650	900	1,200	1,500

(5) If flexible connections are to be used, specifications and directions given by the project sponsor should be observed.

(6) Spoils of pipe trench excavation may be left on the ground beside the trench. However, the bank formed by spoil should be kept as narrow as possible, and not obstruct traffic.

(7) Sand or sandy soil should be used as backfill for the first 10cm from the top of the pipe. After that, unless it is otherwise specified, the excavated earth may be backfilled. However, within 30 cm of the top of the pipe no rocks or similar debris should be used.

(8) If a pipe line has to cross a roadway, permission should be secured from the authorities responsible.

Chapter 34. Farm Ponds

34.1 Definition

To build a reservoir in a depression or along a stream, by excavation or with a dam, for storage of runoff.

34.2 Objectives

(1) To supply water for irrigation, pest control, aquacultuse, fire fighting etc.

(2) To provide recreational area.

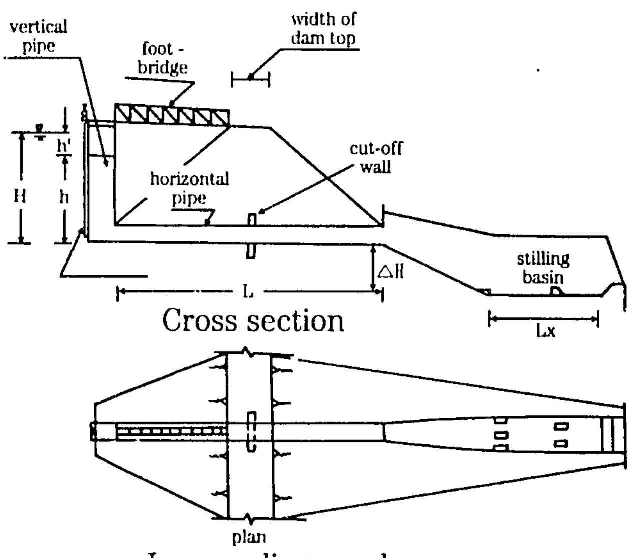
(3) To improve the environment and landscape.

34.3 Applications

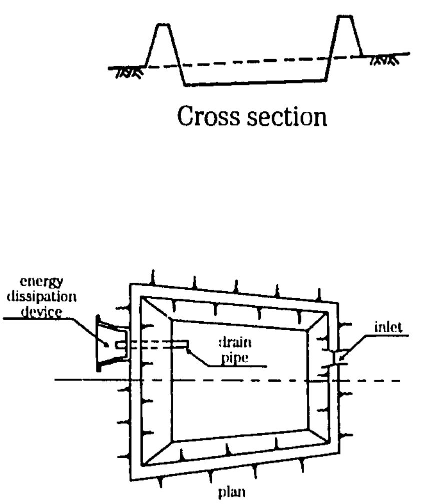
(1) Impounding pond: At a selected point, a dam is built across a stream or gully to impound water coming from upstream.

(2) Excavated pond: A cut is made in the ground to form a hollow, for the purpose of collecting runoff from the watershed.

34.4 Diagram



Impounding pond



Excavated pond

34.5 Design

(1) For design of the dam and spillway of an impounding pond, refer to Chapter 37. Check Dams. However, a foot bridge and a sand gate should be added. The sand gate, which is made of steel and other metals, consists of a winch, a drivescrew, and a gate.

(2) Excavated or off-channel pond

a. The height of the embankment should not exceed 3 meters.

b. The width of the top of earth embankment should not be less than one meter. The slope of both sides of the embankment should be less than 1:1.5. For protection of the embankment surface, see Chapter Earth Dams in Part II.

c. If concrete is used, the embankment should be built in the form of a revetment, with a top width of 0.3-0.5m. Water pressure should be taken into consideration.

d. Freeboard: 0.4-1.0m.

e. The outlet should be lower than the top of embankment by 0.4 - 1.0m. The cross-section of the outlet should be large enough to relieve the maximum intake. For off-channel ponds, the runoff volume in the watershed should be calculated.

34.6 Precautions: See Chapter Earth Dams in Part II.

160

Chapter 35. Water Storage Tanks

35.1 Definition

Structures constructed in a irrigation system for the purpose of regulating water supply at the terminals.

35.2 Objective

To ensure a timely supply of adequate irrigation water.

35.3 Application

(1) Brick tank: Square or round in shape, maximum capacity 20 metric tons, suitable for pesticide spray.

(2) Concrete tank: Round in shape, capacity over 30 metric tons, suitable for irrigation.

35.4 Diagram

See "Storage Tank Designs", published by the Taiwan Provincial Soil and Water Conservation Bureau.

35.5 Design

$Q = Q' / E \times 10 \text{ Au} (T_1 - T_2 / T_1)$

Q = Tank capacity (m^3)

Q'=Daily irrigation water requirement

E = Irrigation eficiency

Au = Irrigation area (ha)

T_1 = Pumping time per day (hour)

T_2 = Irrigation time per day (hr)

Chapter 36. Conservation Farm Planning

36.1 Definition

Systematic planning and layout of measures and facilities related to soil erosion control, safe drainage, roadways and water supply etc., for a slopeland farm.

36.2 Objective

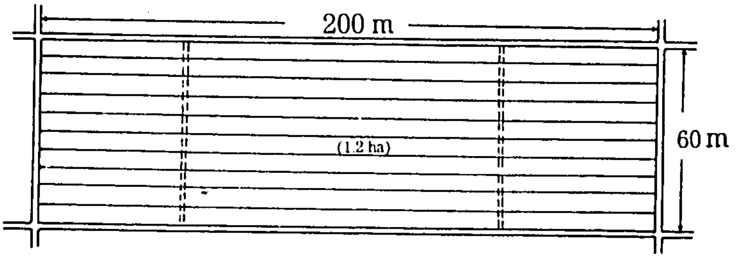
(1) To achieve erosion control and efficient farm management through integration of soil conservation and labor saving practices.

(2) To lay out a slopeland farm for the convenient operation of farm machinery, with a view to saving labor costs.

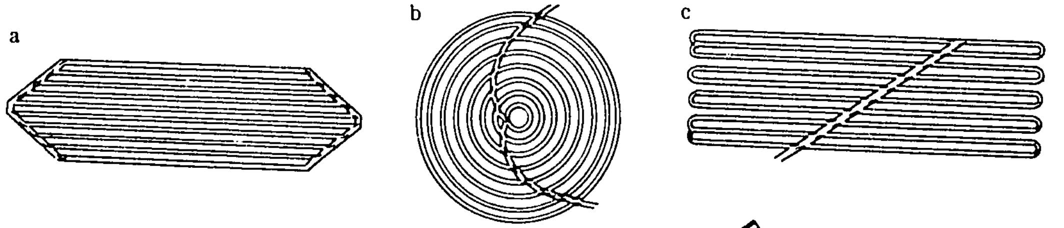
(3) To improve the environment and the physical arrangement of slopeland farms to facilitate their modernization.

36.3 Diagram

For a moderate slope (Gradient less than 15%): Rectangular plots are desirable.



For steep slopes (over 15%): Depending on the terrain, any one of the following three patterns may be adopted, a) Hexagonal, b) Concentric circles, c) Switch-back.



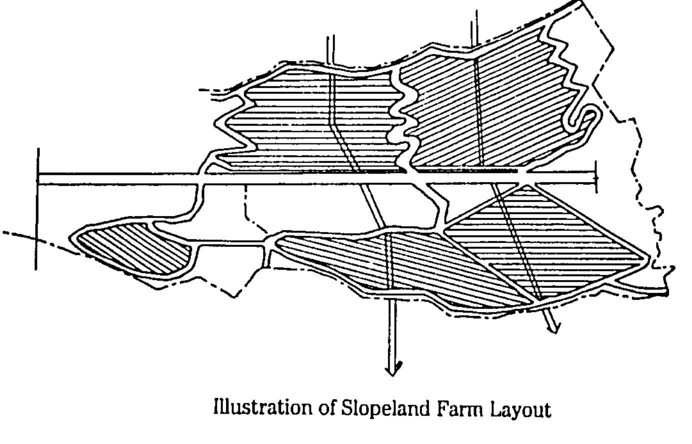


Illustration of Slopeland Farm Layout

36.4 Application: For slopeland farms

36.5 Planning

(1) Primary facilities and relevant planning criteria

a. Farm roads: Including main roads and secondary roads. Follow the Farm Road Design Manual published by the Soil and Water Conservation Bureau.

b. Soil and water conservation: Including soil erosion control, safe drainage, farm paths, link roads, gully control, windbreaks. See related chapters of this handbook.

c. Water supply: Consideration should be given to the availability of water sources, condition of the farm, crops grown, and management system.

d. Other practices: The pest control system and harvest collection stations, etc. should be incorporated into the management plan.

e. Within the planning area, forest land, unstable land, and water sources in forested land should be treated as an integral part of the overall plan. Trees which provide protection to water source or have windbreak effect should be preserved.

(2) Principles of layout

a. Farm roads

(i) Road density

On average, 30-80 meters per hectare; horizontal interval between two roads approximately 200 meters. In peripheral areas, where construction of roads is difficult, farm paths may substitute for roads.

(ii) Route

(a) Maximum utility should be achieved by the shortest route.

(b) A route should be convenient for the transportation of farm inputs and outputs along the line. It should also be helpful for other parts of the farm.

(c) The gradient of roads should be so planned that the roads can be connected with hillside ditches and farm paths on the farm without difficulty.

(d) For safety, unstable areas should be avoided.

b. Erosion control and safe drainage

(i) Erosion control: Measures should be taken on the basis of the types of crops to be grown, and the field management pattern.

(ii) Safe drainage

(a) Natural drainage channels should be utilized, with due attention to the stability of the channels. When necessary, gully control measures should be taken.

(b) When a drainage ditch is to be constructed, it should be located in natural depressions of the ground, in order to facilitate collection of runoff. Whenever possible a ditch should be built on firm ground. Unstabilized

163

fill, of the type which may be found on levelled slopes, should be avoided.

(c) Location and arrangement of drainage ditches: Drainage ditches should be so arranged that as to intercept the drainage system of bench terraces and hillside ditches at proper intervals, to ensure that the length of drainage channels on bench terraces and hillside-ditches will not exceed 100 meters in one direction.

(d) Type and cross section of drainage ditches: Depending on slope gradient, soil characteristics, size of watershed, and cropping systems. Availability of construction materials and system of mechanical operations should also be considered.

c. Traffic system

(i) All roads, paths and hillside ditches in the farm area should be intgrated into one traffic network to give access by farm machinery to the entire farm.

(ii) Where drainage ditches meet a farm road, a farm path, or a hillside ditch, culverts or dips should be built.

(iii) Link roads should be built at the ends of hillside ditches and farm paths, to facilitate the movement of farm machinery.

d. Water supply

(a) Development of water source: On the basis of the type of water source available, a water supply system may be developed by drilling wells, building impounding dams, digging ponds etc. Delivery pipe lines, storage tanks, and regulatory tanks should be built as required.

(b) Irrigation installations: Irrigation system should be designed in accordance with crop needs and soil characteristics.

(c) Pest control system: Pesticide mixing tank, spray pipe line and control mechanism.

e. Windbreaks

(a) Selection of trees or grass for establishment of windbreaks: Trees or grasses planted as windbreaks should be adapted to the local climate and soil conditions. They should not compete with crops for nutrition or water. Also, they should not be vectors of pests or diseases that threaten the crops.

(b) Arrangement of windbreak forest belt: The windbreak belt should be at a right angle to the direction of the prevailing wind. The interval between two wind break belts should be approximately equal to five to ten times the height of the windbreak. It is preferable to plant windbreaks along ridges or at the top of slopes. Whenever possible, roadside slopes and field borders should be utilized. If practicable, vegetation should be planted under the trees, and the trees should be planted in multiple rows.

(3) Coordination of erosion control measures and facilities

a. Road and erosion control

(i) Roads should not serve the purpose of diverting or draining runoff from up slopes. When necessary concrete L-shaped side ditches should be built along roads to prevent erosion of the top of the road and its side ditches.

(ii) Drainage on the lower side slope of road should not be channeled toward the road. Instead, it should be directed away from the road.

(iii) When hillside ditches are to be built on a steep slope along both sides of a road, where these is a switchback, it is feasible to have hillside ditches built on the outside of the bend. However, the inside of the bend should be avoided, and kept as interval between the upward and the downward hillside ditches.

b. Road and drainage

(i) The drainage system should be well coordinated with the road system. The location and layout of the drainage system should be so arranged that the rules concerning maximum permissible length of drainage channel in one direction will be fulfilled.

(ii) Drainage across the road should be properly positioned so that it is coordinated with the road drainage system.

(iii) Special attention should be paid to the drainage problem of roadside ditches at a switchback.

c. For the benefit of farm machinery, efforts should be made to ensure that the junctions of roads, paths, hillside ditches, and bench terraces are as smooth as possible. Drainage at these junctions should be properly arranged. When necessary, suitable structures may be built to prevent soil erosion.

d. Utilization of land at farm boundries and plot borders: Drainage system, water supply lines, windbreak belts, and roads should be compatible with each other. Land at the boundries of the farm and borders of a plot should be fully utilized in developing these facilities.

36.6 Operation procedures

(1) Collection of topographic data from files or field survey: Available topographic and soil maps and records of referential value to the planning work should be collected. Topographic maps of 1:5000, or larger scale are preferable. A topographic survey may be conducted to obtain data which are not readily available.

(2) Field inspection: Including farm boundaries, surroundings, land use, soil depth, soil characteristics, soil gravel content, extent of erosion, location of gullies, terrain, transportation, water sources, as well as the utilization of existing facilities. Observations should be marked on the base map used in planning.

(3) Preliminary planning on base map: Mark on the base map the location of various facilities and farming activities.

a. Scope of planning area and farm boundaries.

b. Location of existing facilities, gullies and ditches, and present land use situation

c. Planned land use and management pattern

d. Anticipated soil and water conservation measures, e.g. hillside ditches, bench terraces etc.

e. Anticipated road lines

f. Drainage systems

g. Lay out link roads with reference to planned land use, secondary roads and drainage system.

h. Decide the direction of drainage, in line with the principles of erosion control and the layout of roads and the drainage system.

i. Make a comprehensive review of the planned layout of roads and drainage system, and the direction of drainage; revise Items e and f, until they are satisfactory.

j. On the basis of the planned direction of drainage, the size of watershed, and the gradients of drainage ditches, decide the type and cross section of drainage ditches. For a very long drainage ditch that runs through a large watershed consisting of catchment areas of widely different sizes, it should be divided into sections. Each section should be designed in accordance with the situation of the appropiate part of the watershed.

k. Arrangement of water supply, windbreak and other necessary facilities.

l. Make an overall review of the propriety of all items listed above, i.e. access roads link roads, drainage, soil erosion control, water supply, windbreaks, etc. Make whatever revisions are necessary.

(4) Field check and survey

a. Check all items marked on the base map with the actual situation in the field, through survey and staking.

b. Rectify discrepancies discovered during the field check.

(5) Ask the farmers concerned for their comments on the plan.

(6) Calculate the quantity and cost of various planned facilities and structures. Make a clear copy of all drawings and maps.

a. On the basis of the maps, drawings and survey records, list all facilities and structures in categories, according to their purposes and specifications.

b. Calculate the unit costs and construction expenditure.

c. Make clear copies of drawings and maps.

36.7 Compilation of planning report

A planning report should include the following sections:

(1) Background and general description of the planning area

(2) Base map showing land use and existing facilities.

(3) Outline of the plan

(4) Layout of the plan

(5) Drawings of the plan

(6) Tables of unit costs

(7) Tables of materials and expenditure required

(8) Recommendations on the execution of the plan and field work

Appendix 1. Soil Loss Estimation

1. Universal Soil Loss Equation (USLE)

T = Rm Km L S C P --(1)

T = Soil loss (t/ha/y)

Rm = Rainfall erosivity index (Mj.mm/ha.hr.y)

Km = Soil erodibility index (t.ha.y/ha.Mj.mm)

L = Slope length factor

S = Slope steepness factor

C = Cropping management factor

P = Erosion control practice factor

2. Procedures for soil loss estimation

Step 1. Find Rm value from Table 1 or Figure 1. If data from the project site are not shown, an average value may be obtained from the Rm values of two or three spots in the vicinity of project site.

Step 2. Find Km value from Table 2. If higher accuracy of Km is desired, the following parameters should be obtained from soil analysis:

a. Content of organic matter (%)

b. Soil structure parameters

Parameter	Soil Structure	Grain Size
1	Very fine silt	< 1.0 mm
2	Fine grain	1 - 2 mm
3	Medium or large particies	2 - 10 mm
4	Lumpy, flaky soil, or with large particies	> 10 mm

c. Soil permeability parameters

Parameter	Permeability	mm/hr
6	Very slow	< 1.25
5	Slow	1.25 - 5.0
4	Medium slow	5.0 - 20.0
3	Medium	20.00 - 62.5
2	Fast	62.50 - 125.0
1	Very fast	> 125.0

d. Percentage of silt and very fine sand (0.002 - 0.1mm)

e. Percentage of coarse sand (0.1 - 2.0 mm)

After the a, b, c, d, e, parameters are found through soil analysis, Km value may be obtained from the following equations:

$$Km = K \times 0.317 \quad \text{------------} (2)$$

$$K = [2.1M^{1.14}(10^{-4})(12 - a) + 3.25(b - 2) + 2.5(c - 3)]/100 \quad \text{----} (3)$$

$$M = d(d - e) \quad \text{------------} (4)$$

K value can also be found in the attached Table 2.

Step 3. Find slope length factor L

First find out the actual length of slope

$$\text{Then } L = (\ell / 22.13)^{0.5} \quad \text{------------} (5)$$

L = Slope length factor

ℓ = Slope length (m)

Step 4. Find slope steepness factor S

Find out the actual slope steepness

$$\text{Then } S = 65.4 \sin^2\theta + 4.56 \sin\theta + 0.0654 \quad \text{------------} (6)$$

Note: L and S may be calculated together or found from Table 3. or Chart 3.

Step 5. Find vegetative cover index C.

The value of C varies with the type and growth condition of vegetation, seasonal changes and extent of coverage. The C value of exposed land is 1. C values of various types of vegetative cover may be found in Table 4.

Step 6. Find erosion control practice factor P.

P values for contour cropping at specific maximum slope length are as follows:

Slope gradient %	P Value	Slope length(m)
1 - 2	0.6	120
3 - 5	0.5	90
6 - 8	0.5	60
9 - 12	0.6	36
13 - 16	0.7	24
17 - 20	0.8	18
21 - 25	0.9	15

For land under levelling or without any erosion control practice, P=1

Step 7. Find total soil loss (T) in project area.

Put values obtained from Step 1 through Step 6 into Equation (1). The product is then multiplied by the total area. The result will be the total weight of annual soil loss in the project area.

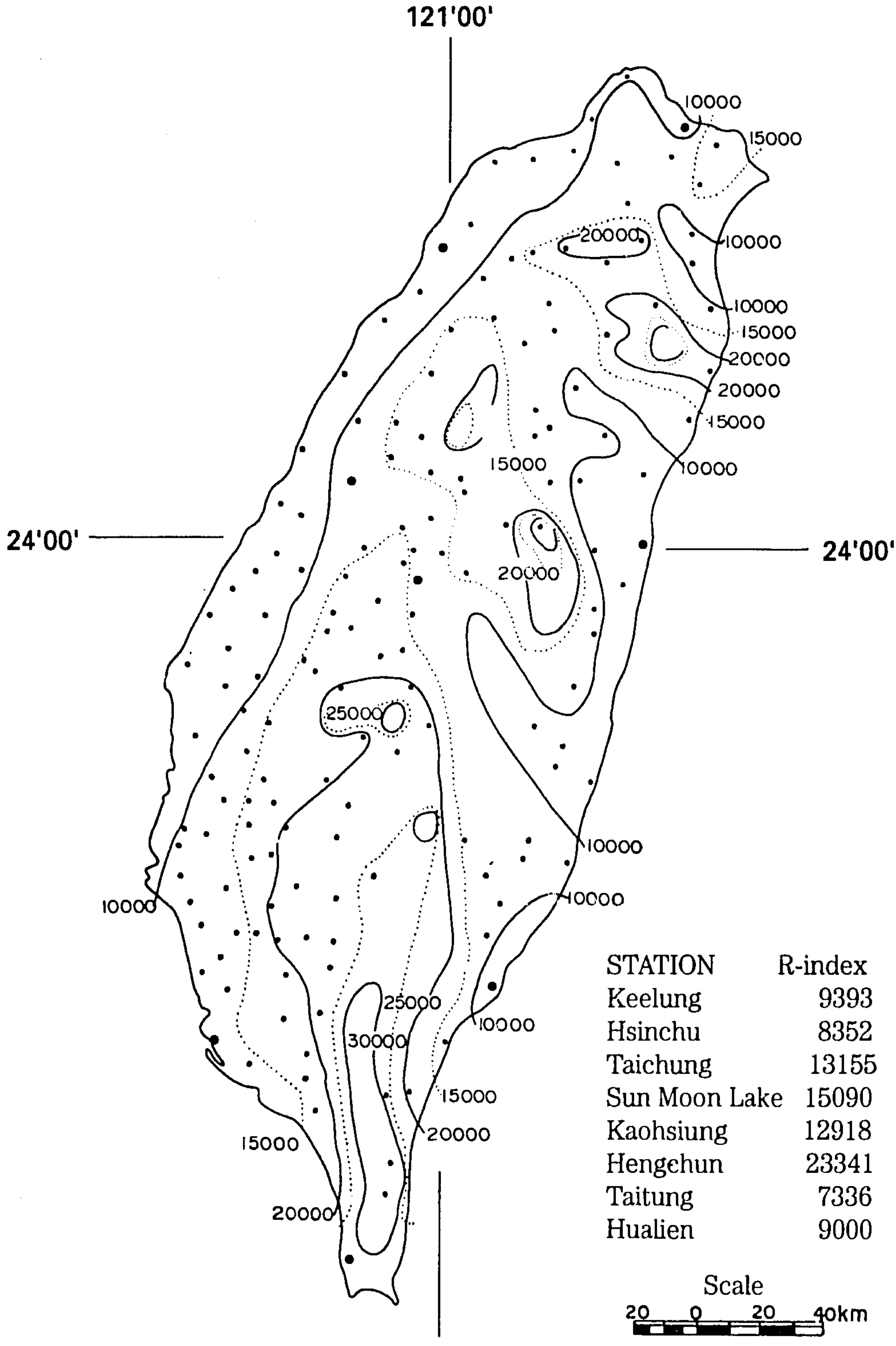


Fig. 1. Taiwan rainfall erosivity indices (Unit: $\frac{\text{Mj mm}}{\text{ha-hr,y}}$)

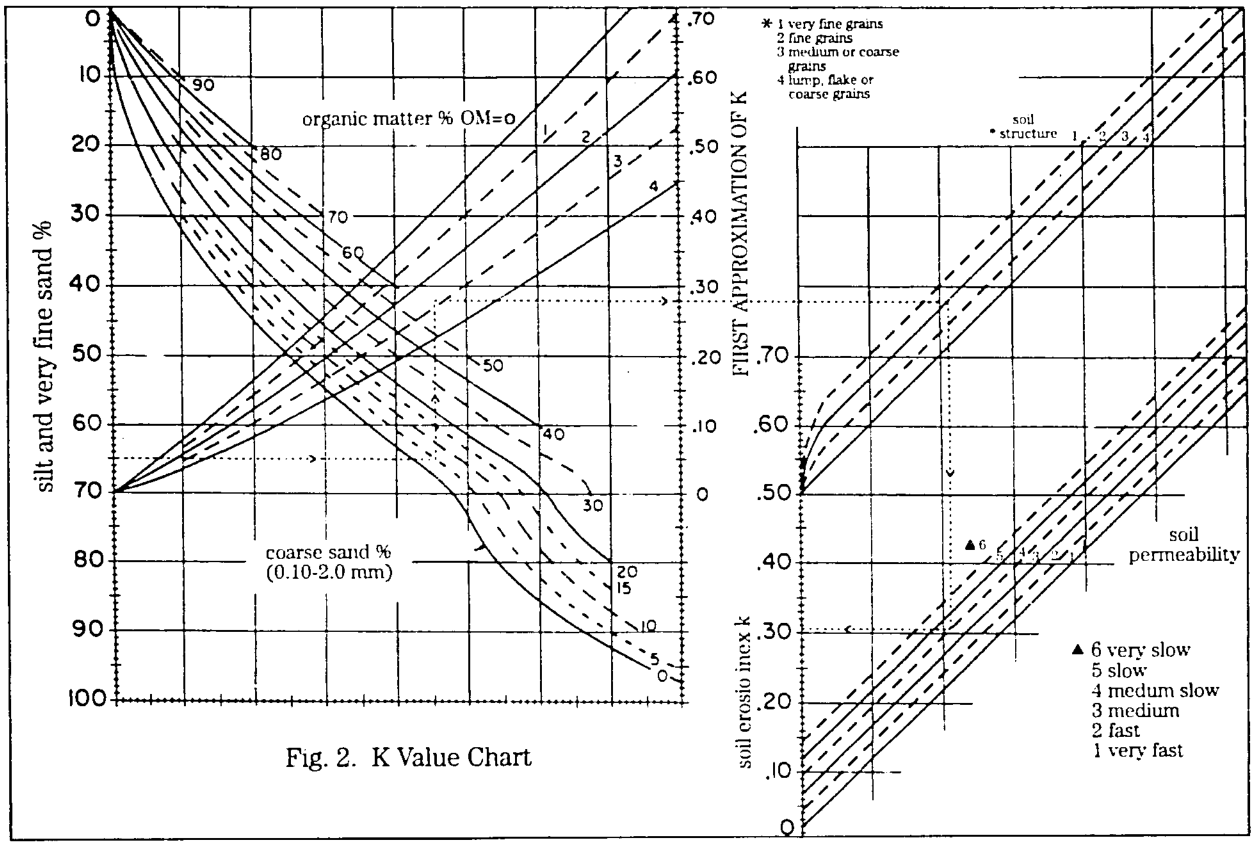


Fig. 2. K Value Chart

Example: If silt and very fine sand si+vfs=65%, coarse sand=5%, organic matter OM=2.8%, soil structure parameter=2, permeability=4, soil erosion index K=?
Solution:1)Draw a horizontal line from si+vfs=65%, until the line intercepts 'coarse sand=5% curve', 2) Turn up vertically to meet 'OM= 2.8% curve', 3) Turn right and run horizontally again to soil structure parameter=2. 4) Turn downward vertically and come to soil permeability parameter 4. 5) Finally turn left horizontally to connect soil erodibility index line at K=0.31.

171

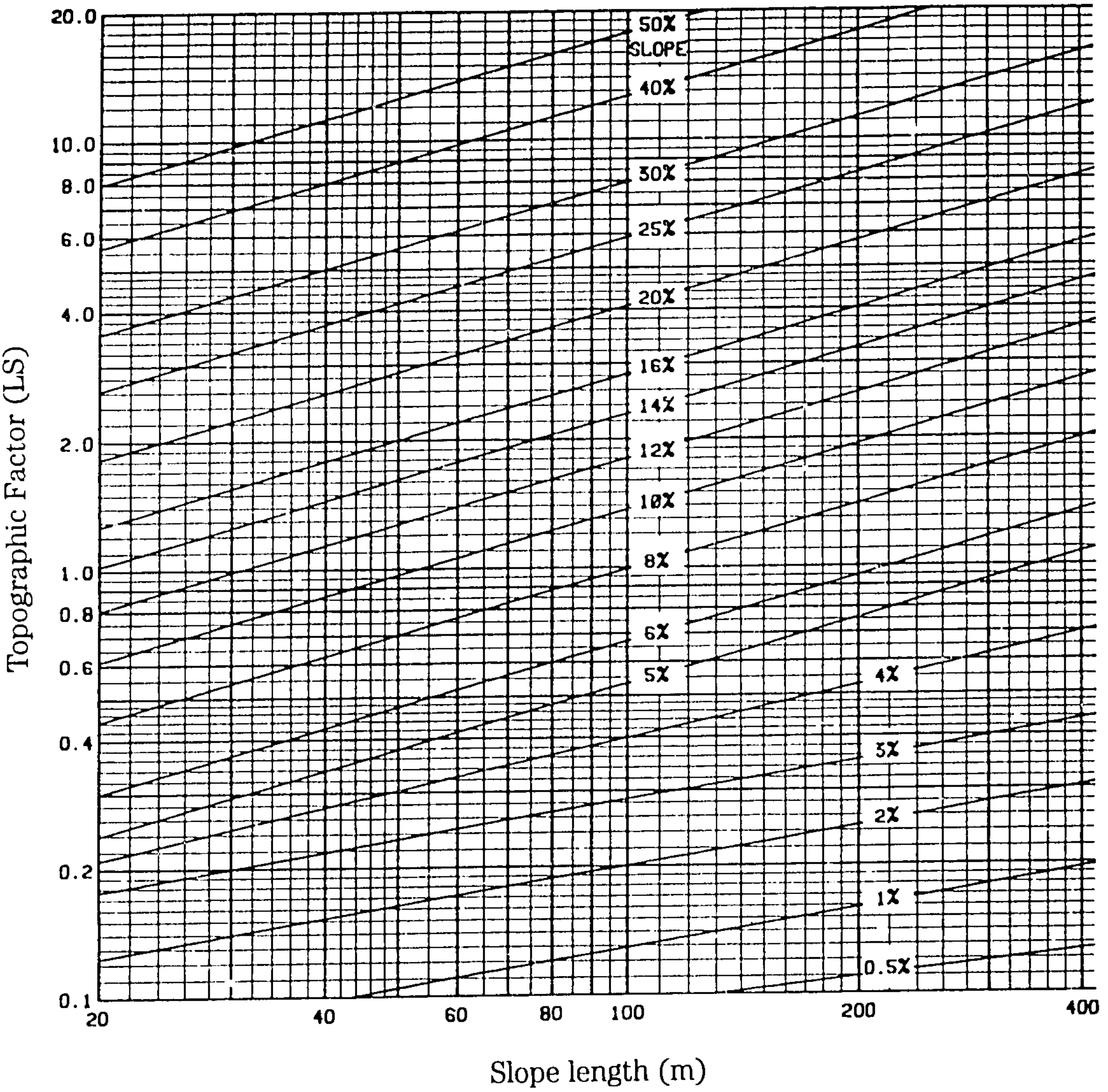


Fig. 3. LS Chart

172

Table 1. Rainfall erosivity indices of Taiwan

Location	Rm	Location	Rm	Location	Rm
基隆Keelung	9395	月眉Yueh Mei	11815	八仙新山Pa Hsien Hsin Shan	16028
乾溝Kan Kou	8842	土城Tu Cheng	16069	天輪Tien Lun	15080
四堵Szu Tu	10335	番子寮Pan Tzu Liao	12037	大南Ta Nan	13676
竹子湖Chu Tzu Hu	14035	台中Taichung	13145	鞍馬山An Ma Shan	26192
瑞芳Shui Fang	15568	橫山Heng Shan	10326	翠巒Tsui Luan	14879
五堵Wu Tu	11674	南投Nan Tou	14201	清流Ching Liu	13250
火燒寮Huo Shao Liao	17030	大城Ta Cheng	6560	國姓Kuo Hsing	13677
宜蘭I Lan	8015	萬合Wan Ho	8352	埔里Pu Lil	3305
冬山Tung Shan	11191	溪湖Chi Hu	8171	北山Pei Shan	12198
富貴角Fu Kwei Chiao	10226	永靖Yung Ching	10105	天池Tien Chih	48008
台北Taipei	11800	員林Yuan Lin	9441	盧山Lu Shan	17936
淡水Tan Shui	10898	彰化Chang Hua	9519	武界Wu Chieh	16320
西林Hsi Lin	8343	二水Erh Shui	17165	奧萬大Ao Wan Ta	14504
竹圍Chu Wei	9133	太義Ta I	8183	開化Kai Hua	9262
三峽San Hsia	12808	鹿港Lu Kang	4982	和社Ho She	10095
大溪Ta Chi	12176	後安寮Hou An Liao	5737	集集Chi Chi	15135
八德Pa Te	8821	林內Lin Nei	17195	明潭Ming Tan	15090
平鎮Ping Chen	11208	飛沙Fei Sha	8042	溪頭Chi Tou	19582
復興Fu Hsing	17861	褒忠Pao Chung	8241	玉山Yu Shan	24830
石門Shih Men	15737	斗南Tou Nan	12440	阿里山A Li Shan	40191
觀音Kwan Yin	7855	北港Pei Kang	9398	竹山Chu Shan	14658
關西Kwan Hsi	13817	溪口Chi Kou	9638	龍神橋Lung Shen Chiao	11240
湖口Hu Kou	7429	永和Yung Ho	9084	望鄉Wang Hsiang	16618
新竹Hsin Chu	8352	馬稠後Ma Chou Hou	9276	草嶺Tsao Ling	17558
竹東Chu Tung	10985	義竹I Chu	10600	卡跨托灣Ka Kwa To Wan	8401
大閣南Ta Ko Nan	14205	南莊Nan Chuang	15100	大湖山Ta Hu Shan	26880
竹南Chu Nan	5908	橫龍山Heng Lung Shan	16777	中埔Chung Pu	22696
後龍Hou Lung	6449	天狗Tien Kou	15796	達邦Ta Pang	18637
大湖Ta Hu	11509	雙崎Shuang Chi	17997	大埔Ta Pu	17175
三義San I	11276	雪嶺Hsueh Ling	29465	照興Chao Hsing	18082
苑裡Yuan Li	4485	馬達拉Ma Ta La	21115	土場Tu Chang	24470
新店Hsin Tien	13041	環山Huan Shan	13459	新豐Hsin Feng	22873
卓蘭Chuo Lan	16593	梨山Li Shan	13670	古夏Ku Hsia	24500
台中港Taichung Harbour	7521	達見Ta Chien	16744	甲仙Chia Hsien	21028

Location	Rm	Location	Rm	Location	Rm
美濃Mei Nung	23191	鳳山Feng Shan	13650	溪畔Chi Pan	9172
小林Hsiao Lin	21294	高雄Kaohsiung	12918	合歡啞口Ho Hwan Ya Kou	13100
馬里山Ma Li Shan	30197	旗山Chi Shan	20305	托博闊To Po Kou	9521
表湖Piao Hu	24511	屏東Pingtung	19301	陶塞Tao Se	11654
三地門San Ti Men	24556	林園Lin Yuan	12135	花蓮Hualien	900
阿禮A Li	39890	四林Szu Lin	18501	大觀Ta Kwan	34882
水山Shui Shan	20531	萬丹Wan Tan	15318	鳳林Feng Lin	11284
龍泉Lung Chuan	18909	東港Tung Kang	13888	清水第一Ching Shiu Ti I	8787
向陽Hsiang Yang	35551	泰武Tai Wu	44712	壽豐Shou Feng	7365
嘉義Chia I	16407	來義Lai I	21854	高嶺Kao Ling	20826
南靖Nan Ching	13020	里港Li Kang	19539	西林Hsi Lin	11189
崁子頭Kan Tzu Tou	16288	大響營Ta Hsiang Ying	17258	玉里Yu li	9906
西口Hsi Kou	19641	加祿堂Chia Lu Tan	14773	富源Fu Yuan	14307
柳營Liu Ying	11420	紹家Shao Chia	32661	立山Li Shan	10011
尖山埤Chien Shan Pi	13293	大武Ta Wu	29239	三民San Min	8983
麻豆Ma Tou	13310	大武(壽卡)Ta Wu(Shou Ka)	46819	忠勇Chung Yung	9679
漚汪Ou Wang	11165	大漢山Ta Han Shan	53259	新港Hsin Kang	11495
將軍Chiang Chun	11182	牡丹Mu Tan	38310	奇萊Chi Lai	17360
玉井Yu Ching	20850	恆春Heng Chun	23341	鎮西堡Cheng Hsi Pao	10120
二溪Erh Chi	16067	福山Fu Shan	16918	池上Chih Shang	11659
左鎮Tso Chen	18177	孝義Hsiao I	24220	富里Fu Li	11982
烏山頭Wu Shan Tou	15931	精坑Ching Keng	13907	霧鹿Wu Lu	10331
溪海Chi Hai	12253	白石Pai Shih	11533	瑞豐Shui Feng	12492
新化Hsin Hua	14229	鞍部An Pu	15447	鹿野Lu Yeh	11471
崎頂Chi Ting	14773	嘎拉賀 Ka La Ho	11017	台東Taitung	7336
台南Tainan	13088	南山Nan Shan	9410	里20林班	
木柵Mu Cha	18603	太平山Tai Ping Shan	19884	Li20 Forest Compartment	16254
古亭坑Ku Tin Keng	13361	土場Tu Chang	15306	里40林班	
阿蓮A Lien	12237	地端Chih Tuan	30110	Li40 Forest Compartment	20662
車路Che Lu	13361	天埤Tien Pi	21158	大南Ta Nan	15663
前鋒子Chien Feng Tzu	13037	南澳Nan Ao	21144	林班Lin Pan	16595
本洲Pen Chou	13208	山腳Shan Chiao	52250	太麻里Tai Ma Li	13378
楠梓Nan Tzu	14773	大濁水Ta Chu Shui	12854	大武Ta Wu	16560

Data source: 'A study of the Rainfall Erosivity Index in Taiwan (1979)' by Huang, Chun-teh

174

Table 2. Soil erodibility indices of the slopeland of Taiwan

Location	Km
台北石碇小格頭 Hsiao Ke Tou, Shih Tin, Taipei	0.0277
坪林石槽 Shih Taso, Ping Lin	0.0342
貢寮三紹角 San Tiao Chiao, Kung Liao	0.0448
貢寮望造坑 Wang Tsao Keng, Kung Liao	0.0514
雙溪牡丹 Mu Tan, Shuang Chi	0.0132
瑞芳九份 Chiu Fen, Shui Fang	0.0408
瑞芳中坑 Chung Keng, Shui Fang	0.0263
平溪十分寮 Shih Fen Liao, Ping Chi	0.0250
石碇永定 Yung Ting, Shih Ting	0.0408
深坑土庫 Tu Ku, Sheng Keng	0.0474
汐止 Hsi Chih	0.0527
萬里大坪 Ta Ping, Wan Li	0.0316
萬里磺潭 Huang Tan, Wan Li	0.0250
金山三界 San Chieh, Chin Shan	0.0250
石門草埔尾 Tsao Pu Wei, Shih Men	0.0290
石門白沙灣 Pai Sha Wan, Shih Men	0.0184
三芝八賢 Pa Hsien, San Chih	0.0198
三芝北新莊 Pei Hsin Chuang, San Chih	0.0224
水小坪頂 Shui Hsiao Ping Ting	0.0079
八里埤頭 Pi Tou, Pa Li	0.0119
五股成仔寮 Cheng Tzu Liao, Wu Ku	0.0211
林口 Lin Kou	0.0224
新店屈尺 Chu Chih, Hsin Tien	0.0211
烏林 Wu Lin	0.0184
烏林孝義 Hsiao I, Wu Lin	0.0421
新店雙城 Shuang Cheng, Hsin Tien	0.0395
泰山崎子腳 Chi Tzu Chiao, Tai Shan	0.0356
樹林 Shu Lin	0.0237
鶯歌中湖社區 Chung Hu Community, Yin Ke	0.0369
三峽忠孝山莊 Chung I Heights, San Hsia	0.0382
三峽插角 Cha Chiao, San Hsia	0.0237

Location	Km
林口下福　Hsia Fu, Lin Kou	0.0461
林口頂福　Ting Fu, Lin Kou	0.0198
林口　Lin Kou	0.0237
八里觀音山麓　Kwan Yin Shan (Foot), Pa Li	0.0369
淡水　Tan Shui	0.0329
土城清水　Ching Shui, Tu Chen	0.0540
桃園龍潭銅鑼台地　Tung Lo Plateau, Lung Tan, Taoyuan	0.0329
龍潭二角林　Erh Chiao Lin, Lung Tan	0.0211
後潭二坪　Erh Ping, Hou Tan	0.0435
復興水源地　Shui Yuan Ti, Fu Hsing	0.0053
復興三民　San Min, Fu Hsing	0.0040
楊梅　Yang Mei	0.0237
龜山下湖　Hsia Hu, Kwei Shan	0.0356
龜山　Kwei Shan	0.0079
龜山大湖頂　Ta Hu Ting, Kwei Shan	0.0329
龜山兔坑國小　Tu Keng Elementary School, Kwei Shan	0.0184
八德仁善　Jen Shan, Pa Te	0.0158
大溪三層　San Tseng, Ta Chi	0.0158
大溪慈湖　Tzu Hu, Ta Chi	0.0171
竹東二重　Erh Chung, Chu Tung	0.0210
香山元培醫專　Yuan Pei Medical Institute, Hsiang Shan	0.0435
寶山寶豐牧場　Pao Feng Ranch, Pao Shan	0.0237
新竹市關東橋　Kwan Tung Chiao, Hsin Chu	0.0250
新豐明新工專　Ming Hsin Institute, Hsin Feng	0.0250
芎林　Chiung Lin	0.0277
新埔昭門　Chao Men, Hsin Pu	0.0289
竹北義民廟旁　I Min Temple, Chu Pei	0.0276
關西馬武督　Ma Wu Tu, Kwan Hsi	0.0039
新豐新庄子　Hsin Chuang Tzu, Hsin Feng	0.0434
新竹青草湖　Ching Tsao Hu, Hsin Chu	0.0158
台中龍井東海大學　Tung Hai University, Taichung	0.0356

Location	Km
霧峰　Wu Feng	0.0421
大里塗城　Tu Cheng, Ta Li	0.0421
外茅埔　Wai Mou Pu	0.0448
北屯大坑　Ta Keng, Pei Tun	0.0487
新社中興嶺　Chung Hsing Ling, Hsin She	0.0421
新社水井村　Shui Ching Tsun, Shin She	0.0395
石岡意興村　I Hsing Tsun, Shih Kang	0.0487
東勢新伯公　Hsin Pai Kung, Tung Shih	0.0395
東勢中坑坪　Chung Keng Ping, Tung Shih	0.0553
豐原南嵩里　Nan Sung Li, Feng Yuan	0.0382
后里毘盧寺　Pi Lu Temple, Hou Li	0.0303
后里仁里村　Jen Li Tsun, Hou Li	0.0474
后里月眉　Yueh Mei, Hou Li	0.0395
清水海風里　Hai Feng Li, Ching Shui	0.0342
南投國姓大旗村　Ta Chi Tsun, Kuo Hsing, Nan Tou	0.0474
大坪頂　Ta Ping Ting	0.0132
埔里虎仔山　Hu Tzu Shan, Pu Li	0.0329
東光　Tung Kwang	0.0158
過溪仙水農場　Hsien Shui Farm, Kuo Chi	0.0461
水頭山隧道口　Shui Tou Shan Tunnel Entrance	0.0290
南投武東　Wu Tung, Nan Tou	0.0369
南投横山　Heng Shan, Nan Tou	0.0395
赤水　Chih Shui	0.0342
名間松柏坑　Sung Pai Keng, Ming Chien	0.0329
名間頂南仔　Ting Nan Tzu, Ming Chien	0.0303
竹山外田　Wai Tien, Chu Shan	0.0395
延平照鏡山　Chao Ching Shan, Yen Ping	0.0369
鹿谷廣興　Kwang Hsing, Lu Ku	0.0277
鹿谷永隆　Yung Lung, Lu Ku	0.0382
中寮包尾　Pao Wei, Chung Liao	0.0619
中寮社區　Chung Liao Community	0.0632

Location	Km
中寮挑米坑　Tiao Mi Keng, Chung Liao	0.0579
集集北勢坑　Pei Shih Keng, Chi Chi	0.0369
水里民和村　Min Ho Tsun, Shui Li	0.0211
魚池太平村　Tai Ping Tsun, Yu Chih	0.0316
魚池茶場　Yu Chih Tea Farm	0.0132
中埔魚池新城　Hsin Cheng, Yu Chih	0.0435
彰化縣芬園下樟　Hsia Chang, Fen Yuan, Chang Hua	0.0500
芬園八股　Pa Ku, Feng Yuan	0.0603
花壇橋頭　Chiao Tou, Hua Tan	0.0461
嘉義梅山安靖　An Ching, Mei Shan, Chia I	0.0553
竹崎大履寮　Mu Lu Liao, Chu Chi	0.0421
竹崎　Chu Chi	0.0500
民雄三興　San Hsing, Min Hsiung	0.0356
民雄寶林寺　Pao Lin Temple, Min Hsiung	0.0566
竹崎　Chu Chi	0.0514
嘉義市蘭潭水庫　Lan Tan Reservoir, Chia I	0.0290
嘉義番路江西　Chiang Hsi, Pan Lu, Chia I	0.0487
番路半天岩　Pan Tien Yen, Pan Lu	0.0408
中埔鹿腳　Lu Chiao, Chung Pu	0.0421
番路下路行　Hsia Lu Hsing, Pan Lu	0.0566
中埔　Chung Pu	0.0257
中埔沄水　Yun Shui, Chung Fu	0.0514
中埔　Chung Pu	0.0659
水上檳榔樹腳　Pin Lang Shu Chiao, Shui Shang	0.0474
民和　Min Ho	0.0356
大埔　Ta Pu	0.0527
台南白河內角　Nei Chiao, Pai Ho, Tainan	0.0395
白河白河水庫　Pai Ho Reservoir, Pai Ho	0.0514
東山六重溪　Liu Chung Chi, Tung Shan	0.0593
東山仙公廟　Hsien Kung Temple, Tung Shan	0.0421
東山青山　Ching Shan, Tung Shan	0.0527

178

Location	Km
東山枋仔林　Fang Tzu Lin, Tung Shan	0.0685
東山牛山礦場　Niu Shan Mine, Tung Shan	0.0435
官田　Kwan Tien	0.0421
大內烏頭　Ta Nei Wu Tou	0.0527
官田鎮安宮旁　Cheng An Temple, Kwan Tien	0.0369
柳營王爺宮旁　Wang Yeh Temple, Liu Ying	0.0435
六甲大丘園　Ta Chiu Yuan, Liu Chia	0.0527
楠西烏山嶺　Wu Shan Ling, Nan Hsi	0.0290
楠西曾文水庫　Tsen Wen Reservoir, Nan Hsi	0.0408
楠西　Nan Hsi	0.0421
楠西龜甲溫泉　Kwei Chia Spa, Nan Hsi	0.0553
南化水寮　Shui Liao, Nan Hua	0.0711
南化　Nan Hua	0.0395
南化　Nan Hua	0.0487
玉井九層林　Chiu Tsen Lin, Yu Ching	0.0500
關廟八里寮　Pa Li Liao, Kwan Miao	0.0527
龍崎　Lung Chi	0.0369
關廟　Kwan Miao	0.0448
新北新化林場　Hsin Hua Forest, Hsin Pei	0.0474
左鎮岡林　Kang Lin, Tso Cheng	0.0540
高雄內門萊仔坑　Lai Tzu Keng, Nei Men, Kaohsiung	0.0435
旗山觀亭　Kwan Ting, Chi Shan	0.0514
杉林愛丁寮　Ai Ting Liao, Shan Lin	0.0461
甲仙埔尾　Pu Wei, Chia Hsien	0.0329
甲仙　Chia Hsien	0.0421
六龜　Liu Kwei	0.0408
六龜　Liu Kwei	0.0.448
旗山　Chi Shan	0.0303
旗山花旗山　Hua Chi Heights, Chi Shan	0.0448
田寮崇德　Chung Te, Tien Liao	0.0395
阿蓮小岡山　Hsiao Kang Shan, A Lien	0.0316

571

Location	Km
阿蓮　A Lien	0.0474
小港　Hsiao Kang	0.0369
大寮新莊　Hsin Chuang, Ta Liao	0.0158
大寮義仁　I Jen, Ta Liao	0.0329
大寮內坑　Nei Keng, Ta Liao	0.0250
大樹　Ta Shu	0.0408
旗山　Chi Shan	0.0316
嶺口　Ling Kou	0.0250
燕巢深水　Sheng Shui, Yen Tsao	0.0250
大社觀音山麓　Kwan Win Shan (Foot), Ta She	0.0487
仁武　Jen Wu	0.0408
鳳山　Feng Shan	0.0421
屏東車城射寮龜山　She Liao Kwei Shan, Che Cheng, Ping Tung	0.0158
恆春社頂　She Ting, Heng Chun	0.0119
恆春鵝鑾鼻　Ou Luan Pi, Heng Chun	0.0158
墾丁畜牧分場　Ken Ting Livestock Experiment Station	0.0079
恆春龍子埔　Lung Tzu Pu, Heng Chun	0.0211
墾丁公園　Ken Ting National Park	0.0132
墾丁公園　Ken Ting National Park	0.0119
恆春核電場旁　Nuclear Power Station, Heng Chun	0.0171
楠西烏山嶺　Wu Shan Ling, Nan Hsi	0.0290
恆春貓鼻頭　Mou Pi Tou, Heng Chun	0.0092
恆春白沙　Pai Sha, Heng Chun	0.0132
滿洲港乾橋旁　Kang Chien Chiao, Man Chou	0.0079
滿州　Man Chou	0.0277
滿州　Man Chou	0.0290
牡丹　Mu Tan	0.0290
壽卡　Shou Ka	0.0329
楓港　Feng Kang	0.0303
楓林　Feng Lin	0.0316
春日　Chun Jih	0.0277

Location	Km
新開　Hsin Kai	0.0198
新埤　Hsin Pi	0.0263
餉潭　Hsiang Tan	0.0250
來義丹林主社區　Tan Lin Chu Community, Lai I	0.0224
來義古樓國小　Ku Lou Elementary School, Lai I	0.0303
內埔老埤農場　Lao Pi Farm, Nei Pu	0.0290
山地門　Shan Ti Men	0.0171
高樹廣興　Kwang Hsing, Kao Shu	0.0303
高樹大烏　Ta Wu, Kao Shu	0.0290
基隆八堵　Pa Tu, Keelung	0.0435
七堵東勢中股　Chung Ku, Tung Shih, Chi Tu	0.0369
宜蘭南澳金岳　Chin Yo, Nan Ao, I Lan	0.0290
蘇澳東澳　Tung Ao, Su Ao	0.0250
蘇澳猴猴坑　Hou Hou Keng, Su Ao	0.0158
蘇澳後湖　Hou Hu, Su A	0.0158
冬山新寮　Hsin Chiu, Tung Shan	0.0171
冬山得安　Te An, Tung Shan	0.0119
大同寒溪　Han Chi, Ta Tung	0.0263
大同松羅　Sung Lo, Ta Tung	0.0132
員山頭圳　Tou Chun, Yuan Shan	0.0263
員山枕山　Chen Shan, Yuan Shan	0.0250
礁溪匏崙　Pao Lun, Chiao Chi	0.0277
礁溪大忠　Ta Chung, Chiao Chi	0.0250
頭城金面　Chin Mien, Tou Cheng	0.0342
頭城大溪　Ta Chi, Tou Cheng	0.0593
花蓮新城　Hsin Cheng, Hua Lien	0.0303
吉安　Chi An	0.0448
秀林　Hsiu Lin	0.0277
壽豐　Shou Feng	0.0263
鳳林　Feng Lin	0.0342
萬榮　Wan Yung	0.0342

Location	Km
光復 Kwang Fu	0.0250
瑞穗舞鶴 Wu Ho, Shui Sui	
卓溪太平 Tai Ping, Cho Chi	
玉里樂合 Lo Ho, Yu Li	0.0198
富里東里 Tung Li, Fu Li	0.0184
富里石牌 Shih Pai, Fu Li	0.0250
光復海岸山脈 Kuang Fu Coastal Mountain Range	0.0237
豐濱 Feng Pin	0.0158
台東富岡 Fu Kang, Tai Tung	0.0290
東河興昌 Hsing Chang, Tung Ho	0.0277
東河 Tung Ho	0.0277
成功 Cheng Kung	0.0171
長濱 Chang Pin	0.0211
池上 Chih Shang	0.0237
海端新武 Hsin Wu, Hai Tuan	0.0145
關山 Kwan Shan	0.0369
達仁 Ta Jen	0.0211
大武尚武 Shang Wu, Ta Wu	0.0158
大武大竹 Ta Chu, Ta Wu	0.0198
太麻里金崙 Chin Lun, Tai Ma Li	0.0263
金鋒 Chin Feng	0.0263
太麻里南坑 Nan Keng, Tai Ma Li	0.0237
卑南初鹿 Chu Lu, Pi Nan	0.0250
延平紅葉 Hung Yeh, Yen Ping	0.0263
鹿野 Lu Yeh	0.0250
鹿野新豐 Hsin Feng, Lu Yeh	0.0342
關山月眉 Yueh Mei, Kwan Shan	0.0342

Data Source: 'Soil Erosion of Slopeland in Taiwan (1989)' by Wan, Hsin-Shen and Huang, Chun-I

Table 3. Topographic factor (LS) for different slope length and slope steepness

Slope S	Slope length, L (m)									
%	5	10	15	20	30	40	50	60	80	100
5	0.216	0.307	0.376	0.434	0.531	0.613	0.686	0.751	0.868	0.970
6	0.270	0.385	0.471	0.543	0.666	0.769	0.860	0.942	1.089	1.217
8	0.040	0.57	0.69	0.80	0.98	1.13	1.27	1.39	1.60	1.79
10	0.55	0.78	0.96	1.11	1.36	1.57	1.75	1.92	2.22	2.48
12	0.72	1.02	1.27	1.46	1.78	2.07	2.31	2.53	2.92	3.27
14	0.93	1.31	1.61	1.86	2.28	2.63	2.94	3.22	3.72	4.15
16	1.51	1.63	1.99	2.30	2.82	3.25	3.64	3.98	4.60	5.14
18	1.39	1.93	2.41	2.78	3.41	3.93	4.40	4.82	5.56	6.22
20	1.65	2.34	2.86	3.30	4.05	4.67	5.22	5.73	6.61	7.39
25	2.36	3.34	4.09	4.72	5.78	6.67	7.46	8.18	9.44	10.55
30	3.18	4.51	5.52	6.37	7.80	9.00	10.07	11.03	12.73	14.24

Table 4. C value at various patterns of vegetation coverage

Vegetation		Plant Coverage %					
Pattern of growth & plant height	Coverage %	0	20	40	60	80	95
No visible canopy	0	0.45	0.20	0.10	0.042	0.013	0.003
Tall grass or shrubs, average fall of raindrop high	25	0.36	0.17	0.09	0.038	0.013	0.003
Tall grass or shrubs, average fall of raindrop high	50	0.26	0.13	0.07	0.035	0.012	0.003
Tall grass or shrubs, average fall of raindrop high	75	0.17	0.10	0.06	0.032	0.011	0.003
Shrubs or brushes, average fall of raindrop 2m	25	0.40	0.18	0.09	0.04	0.013	0.003
Shrubs or brushes, average fall of raindrop 2m	50	0.34	0.16	0.08	0.038	0.012	0.003
Shrubs or brushes, average fall of raindrop 2m	75	0.28	0.14	0.08	0.036	0.012	0.003
Shrubs w/o brushes, average fail of raindrop 4m	25	0.42	0.19	0.10	0.041	0.013	0.003
Shrubs w/o brushes, average fall of raindrop 4m	50	0.39	0.18	0.09	0.04	0.013	0.003
Shrubs w/o brushes, average fall of raindrop 4m	75	0.36	0.17	0.09	0.039	0.012	0.003

163

Appendix 2. Farmland Shaping – Earth Volume Calculation

1. Grid method

The plot is to be staked into grids of 10 - 30m (20m is considered more convenient for calculation). If 0.01m accuracy is to be attained, each plot should have a total of 60 - 100 stakes.

$$Vc = \frac{L^2}{4} \times \frac{(\Sigma C)^2}{(\Sigma C + \Sigma F)} \quad \text{-------- (1)}$$

$$Vf = \frac{L^2}{4} \times \frac{(\Sigma F)^2}{(\Sigma C + \Sigma F)} \quad \text{-------- (2)}$$

Vc = Volume of cut (m^3)

Vf = Volume of fill (m^3)

L = Length of each side of a grid (m)

C = Depth of cut at a stake (m)

F = Depth of fill at a stake (m)

C = Total depth of cut in a grid (m)

F = Total depth of fill in a grid (m)

2. End area method

$$y = A + bx \quad \text{-------- (3)}$$

$$A = \frac{1}{n}(\Sigma y - b\Sigma x) \quad \text{-------- (4)}$$

$$b = \frac{\Sigma xy - 1/n\Sigma x \times \Sigma y}{\Sigma x^2 - 1/n(\Sigma x)^2} = \frac{\Sigma xy - \bar{x} \times \Sigma y}{\Sigma x^2 - \bar{x} \times \Sigma x^2}$$

y = Design elevation

A, b = Constant

x = Coordinate of a stake

3. Plane method

By this method it is assumed that the whole plot is to be levelled into an imagined plane. First calculate the average elevation of the plot and set this elevation at the center of the plot. If the plot is in an irregular form, this center point may be found by utilizing the vertical and horizontal coordinates, and the moment of force equation (as shown in Fig. 1). The design elevation of each stake may be calculated by the following quadratic equation (plane equation):

$$h = A + bx + cy \quad \text{-------- (5)}$$

h = Design elevation of any stake

A = Original elevation

b,c = Gradient on X axis and Y axis respectively

x,y = Coordinates of the stake

The gradient on X or Y axis in a plane may be calculated by least square method. This method is not required to produce the most suitable gradient for flooding irrigation. The design gradient may be calculated by the following simultaneous equations.

$$(\Sigma x^2 - nx_c^2)b + [\Sigma(xy) - nx_c y_c]c = \Sigma(xh) - nx_c h_c \quad \text{------(6)}$$

$$(\Sigma y^2 - ny_c^2)c + [\Sigma(xy) - nx_c y_c]b = \Sigma(yh) - ny_c h_c \quad \text{------(7)}$$

n = Total number of grids

$x_c y_c$ = Coordinates of the centroid (distances to respective axis)

h_c = Centroid elevation (average elevation of all stake points)

When (6) and (7) are combined, the gradient (b) along X axis may be obtained.

When the x and y in (6)(7)exchange their positions, the combination of these two equations may produce gradient (c) along Y axis.

Consequently plane equation h = A + bx + cy is fulfilled.

As the imagined plane is on the level with the centroid, the values of h, x, y,b, and c of the centroid may be used in the plane equation to secure the value of A. Then the position of the imagined plane can be ascertained with the plane equation. The design elevation of the stake points may be obtained the same way.

Note: Free hand plotting: With any of these three methods, the chart of design may be plotted by free hand, to obtain nearly balanced curves of cut and fill volume. However, it requires adequate experience and more revisions to accomplish. Besides, the accuracy is lower.

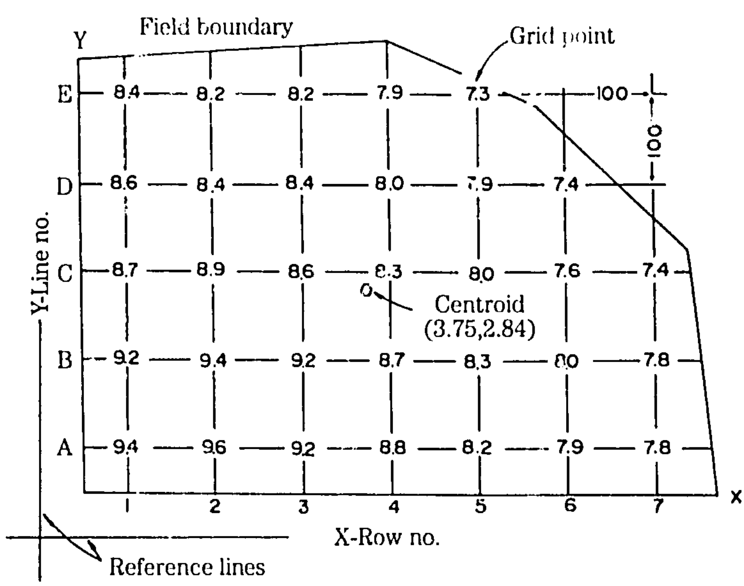
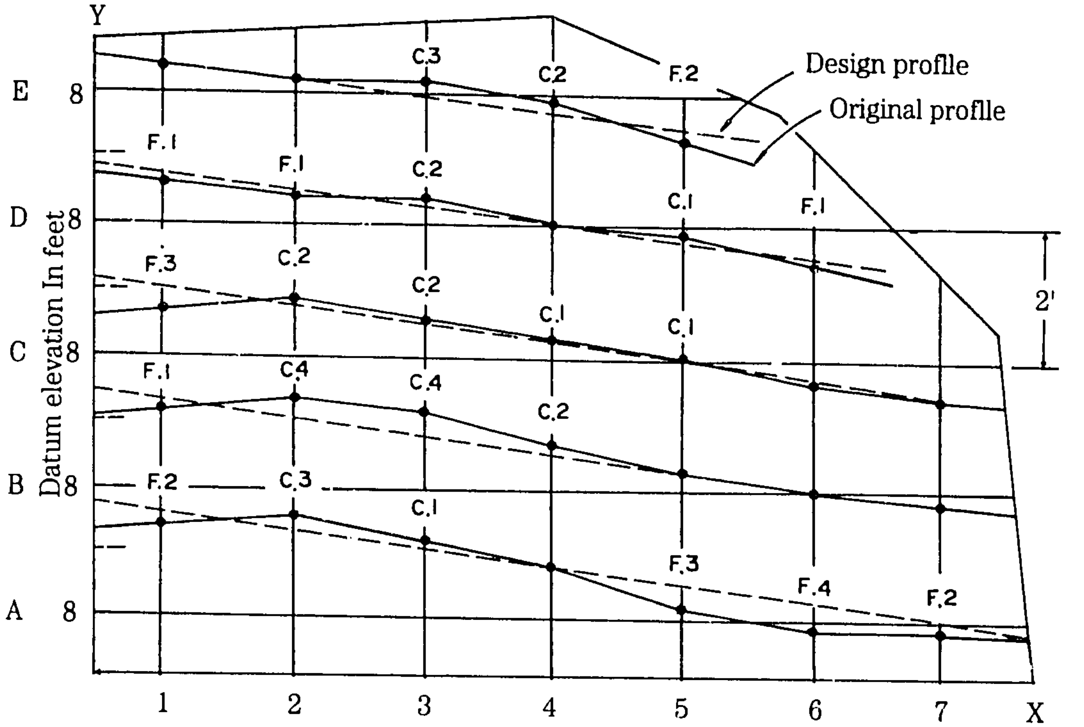


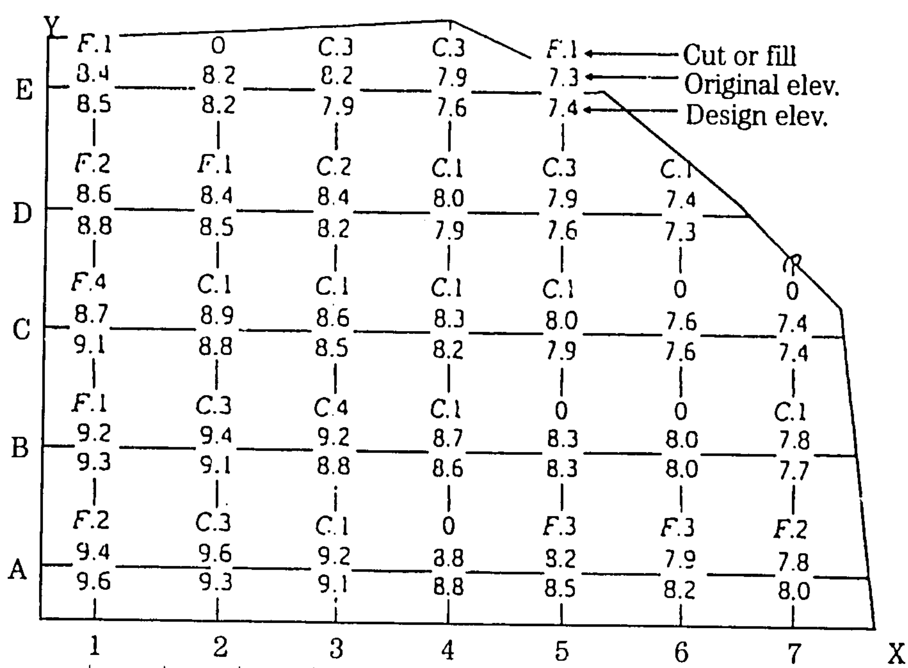
Fig. 1. Illustration of topographic survey by gridding

183



Example 1. Computation of design profile, height of fill and depth of cut by end area method

Example 2. By plane method find design profile of the plot and the design elevations of each stake point



								Total
Cut	0	0.7	1.1	0.6	0.4	0.1	0.1	3.0
Fill	1.0	0.1	0	0	0.4	0.3	0.2	2.0

$n=32 \quad X=3.75$, and $Y=2.84$

$h_c=(9.4+9.2+8.7+\ldots\ldots\ldots+7.8+7.4)/32=8.37$

$\Sigma x^2=1^2+1^2+1^2+1^2+1^2+\ldots\ldots\ldots+6^2+7^2+7^2+7^2=566$

$nX_c^2=32 \times 3.752=450$

$\Sigma(XY)=(1 \times 1)+(1 \times 2)+(1 \times 3)+\ldots\ldots\ldots+(7 \times 1)+(7 \times 2)+(7 \times 3)=327$

$nX_cY_c=32 \times 3.75 \times 2.84=340.8$

$\Sigma(Xh)=(1 \times 9.4)+(1 \times 9.2)+(1 \times 8.7)+\ldots\ldots\ldots+(7 \times 7.8)+(7 \times 7.4)=975.80$

$nX_ch_c=32 \times 3.75 \times 8.37=1004.40$

$(327 - 340.8)b+(319 - 258.1)c=749.40- 760.27$

$(566 - 450)b+(327 - 340.8)c=975.80 - 1003.87$

$b=-0.27/100$

$c=-0.24/100$

$A=8.37 - (-0.27)3.75 - (-0.24)2.84=10.07$

$h=10.07 - 0.27X - 0.24Y$

Appendix 3. Slopeland Use Capability Classification

Approved by Executive Yuan Memorandum No. Tai-66-Chin-7641, 9 Septement 1977

Promulgated by Ministry of Economic Affairs Order No. Chin (66) Nung-288853, 30 September 1977, and Council of Agriculture Order No. Nung-Lin-6101096, June 1987

1. Standards for classification of slopeland for crop, pasture and forest use and for intensive conservation treatment are stipulated as follows:

(1) Gradient: The average ratio of slope of a land lot, expressed by percentage. Slopes are divided into the following classes, according to their gradient.

Class	Gradient range
I	Less than 5%
II	5-15%
III	15-30%
IV	30-40%
V	40 - 55%
VI	Over 55%

(2) Effective soil depth: The depth from ground surface to the stratum where root development is handicapped; expressed by centimeters.

Class	Depth
Very deep	over 90cm
Deep	50-90cm
Shallow	20-50cm
Very Shallow	Less than 20 cm

(3) Extent of soil erosion: Measured by erosion forms and soil loss

Extent of erosion	Erosion form and soil loss
Light	Rills invisible on the grounds; loss of surface soil less than 25%
Medium	Rills and gullies visible; content of gravel and broken stones in soil less than 20%; loss of surface soil 25-75%
Severe	Plenty of gullies; sheet erosion active; soil color bright, content of gravel and broken stones in soil 20-40%; loss of subsoil less than 50%
Very severe	Palm-shaped gullies spreading criss-cross; content of stones in soil over 40%; loss of subsoil over 50%, exposed bedrock occasional; landslides sporadic.

(4) Type of bed rock: Classified according to its penetrability by roots and farm machinery.

Type	Characteristics
Soft bed rock	Soft and loose, or gravelly, root penetrable, no handicap to farm machinery
Hard bed rock	Hard and unbroken, unpenetrable by root, handicapping farm machinery

2. Slopeland use capability classification and corresponding conservation treatments

Land use designation	Land class	Land characteristics	Remarks
Crop and Pasture	I	Class I slope with very deep or deep soil	Soil and water conservation to be practiced as prescribed by the Soil Conservation Handbook issued by responsible provincial and municipal authorities
	II	Class II and III slope with very deep soil Class II slope with deep soil Class I slope with shallow soil	
	III	Class IV slope with very deep soil Class III slope with deep soil Class II slope with shallow soil	
	IV-1	Class V slope with very deep soil Class IV and V slope with deep soil Class III and IV slope with shallow soil Class I, II, III slope with shallow soil	
	IV-2	Class V slope with shallow soil Class IV slope with very shallow soil	1. Only for perennial fruit trees and pasture which provide year round vegetative cover with minimum tillage. 2. Erosion control measures should be dictated by local authority, if crops requiring frequent tillage are to be planted.
Forest land	V	Class VI slope with very deep, deep, or shallow soil Class V and VI slope with very shallow soil Class V slope with shallow soil and severe erosion Class IV slope with very shallow soil and severe erosion or hard bed-rock	Natural forest cover should be maintained, or reforestation be enforced. Severe erosion may take place at the early stage of reforestation. Necessary erosion control measures should be taken.
Land requiring intensive conservation treatment	VI	Very unstable, very severe erosion in evidence, e.g. landslide, landslip, brittle bed rock, exposed bed rock.	Special conservation measures should be prescribed by local authority.

3. The provincial and municipal authorities may designate, under the following situations, an area as forest land, disregarding the stipulations in previous sections.

   (1) When forest is needed for prevention of disaster, conservation of water resources, and protection of public safety, or when the land is used for forest experiment, or for conservation of important tree species, or when the land is covered by forests of historical value.

   (2) When forest is needed to maintain landscape of cultural value or to protect natural ecological environment; or if forests in a specific area are essential to the preservation of certain views, historical relics, or public health.

   (3) The watersheds of reservoirs and the protected land along rivers.

   (4) Land designated as forest land in a regional multipurpose development and conservation plan.

Appendix 3-1. Soil Conservation Treatment for Slopeland Classified as Crop and Pasture Land

Land classified as crop and pasture land under the Rules of Slopeland Use Capability Classification should be given the following water and soil conservation treatment, in addition to the practice of contour planting.

1. Class I crop and pasture land: Broad-based terraces or hillside ditches.
2. Class II crop and pasture land:
   a. When planted with short period crops requiring frequent tillage: Bench terraces, grass barriers, or stone walls.
   b. When planted with long period crops requiring frequent tillage: Hillside ditches, grass barriers, or stone walls.
   c. When fruit trees are grown: Hillside ditches, grass barriers, or stone walls.
   d. When used for pasturing: Hillside ditches.
3. Class III crop and pasture land
   a. When planted with short period crops requiring frequent tillage: Bench terraces, grass barriers, or stone walls.
   b. When planted with long period crops requiring frequent tillage: Hillside ditches, grass barriers, or stone walls.
   c. When fruit trees are grown: Hillside ditches, grass barriers, or stone walls.
   d. When used for pasturing: Hillside ditches. Grass barriers should be set up at the new seeding stage and when pasture is being rehabilitated.
4. Class IV crop and pasture land
   a. Sub-class 1 land
      (i) When planted with short period crops requiring frequent tillage: Bench terraces, grass barriers, or stone walls.
      (ii) When planted with long period crops requiring frequent tillage: Hillside ditches, grass barriers, or stone walls.
      (iii) When fruit trees are grown: Hillside ditches, grass barriers, or stone walls.
      (iv) When used for pasturing: Hillside ditches. Grass barriers should be set up at the new seeding stage and when pasture is being rehabilitated.
   b. Sub-class 2 land: Land use and conservation measures must be prescribed by authorities responsible for soil and water conservation, after field insoection.
      (i) When planted with short period crops requiring frequent tillage: Bench terraces.
      (ii) When planted with long period crops requiring frequent tillage: Bench terraces.

(iii) When fruit trees are grown: Bench terraces, hillside ditches, or stone walls.

(iv) When used for pasturing: Hillside ditches and grass barriers. Grazing should be controlled to avoid overgrazing.

5. Safe drainage should be provided to dispose runoff which is concentrated as an aftermath of soil erosion control treatment, to prevent gully erosion.

6. Land which is classified as suitable for crop and pasture use, but is presently covered by forests, may be restored to cropping or pasturing, provided the above stipulations are observed.

Appendix 3-2. Diagram of Slopeland Use Capability Classification

Average slope steepness / Effective soil depth	Class I slope	Class II slope	Class III slope	Class IV slope	Class V slope	Class VI slope
	5% (2°51.7')	15% (8°31.8')	30% (16°42')	40% (21°48.2')	55% (28°48.6')	
Very deep	Class I crop and pasture land	Class II crop and pasture land	Class II crop and pasture land	Class III crop and pasture land	Class IV-1 crop and pasture land	Class V Forest land
90 cm						
deep	Class I crop and pasture land	Class II crop and pasture land	Class III crop and pasture land	Class IV-1 crop and pasture land	Class IV-1 crop and pasture land	Class V Forest land
50 cm						
Shallow	Class II crop and pasture land	Class III crop and pasture land	Class IV-1 crop and pasture land	Class IV-1 crop and pasture land	Class IV-2 Crop and pasture land / Class V Forest land with severe erosion	Class V Forest land
20 cm						
Very Shallow	Class IV-1 crop and pasture land	Class IV-1 crop and pasture land	Class IV-1 crop and pasture land	Class IV-2 Crop and pasture land / Class V Forest land with severe erosion or hard bed rock	Class V Forest land	Class V Forest land
Class VI requiring intensive conservation treatment	Erosion very severe; land slide, landslip, and exposed brittle bed rock in evidence. Intensive conservation measures needed for prevention of disasters.					

Appendix 4. Table of Slope Degree / Gradient Conversion

Slope			Slope		
%	Degree		Degree		%
	(°)	(')	(°)	(')	
1	0	34.4	0	30	0.8
2	1	8.7	1		1.7
3	1	43.1	1	30	2.6
4	2	17.4	2		3.5
5	2	51.7	2	30	4.4
6	3	26.0	3		5.2
7	4	0.3	3	30	6.1
8	4	34.4	4		7.0
9	5	8.6	4	30	7.9
10	5	42.6	5		8.7
11	6	16.6	5	30	9.6
12	6	50.6	6		10.5
13	7	24.4	6	30	11.3
14	7	58.2	7		12.3
15	8	31.8	7	30	13.2
16	9	5.4	8		14.1
17	9	38.9	8	30	14.9
18	10	12.2	9		15.8
19	10	45.5	9	30	16.7
20	11	18.6	10		17.6
21	11	51.6	11		19.4
22	11	24.4	12		21.3
23	12	57.2	13		23.1
24	13	29.7	14		24.9
25	14	2.2	15		26.8
30	16	42.0	16		28.7
35	19	17.4	17		30.6
40	21	48.2	18		32.5
45	24	13.7	19		34.4
50	26	33.9	20		36.4
55	28	48.6	22		40.4
60	30	57.8	25		46.6
65	33	1.4	30		57.7
70	34	59.5	40		83.9
75	36	52.5	45		100.0
80	38	39.6			
85	40	21.9			
90	41	59.2			
95	43	31.9			
100	45	0			

Appendix 5. Runoff Estimation

Drainage is a problem to be encountered with in any planning or design work related to soil and water conservation. Water to be drained under this situation comes mostly from rainfall excess. The overland flow often affects the safety and cost of structures, that it has to be discreetly estimated. The methods and procedures are as follows:

1. Estimation of the time of concentration (t)

The time of concentration means the time required for runoff at the remotest point of the watershed to reach the drainage outlet. Figure 1. has been prepared with data provided in the paper " Time of Concentration of Small Agricultural Watershed" of P. Z. Kirpich. Time of concentration can be obtained by first finding the distance (L) between the drainage outlet and the fartherest point in the watershed, and the elevation (H) between these two points. Then connect L and H in the chart, where the line intercept the time line indicates the time of concentration (t). Table 1. which is transcribed from "California Culvert Practice", shows in watersheds of various gradients and sizes, the approximate time of concentration, on the assumption that the length of each watershed is three fold of it width.

Figures in Table 2, which is taken from the "Wood Highway Engineering Handbook", are estimates under the assurnption that the gradient is 5%. Since the time of concentration in these tables are all estimates, adjustment according to the actual field condition may be necessary.

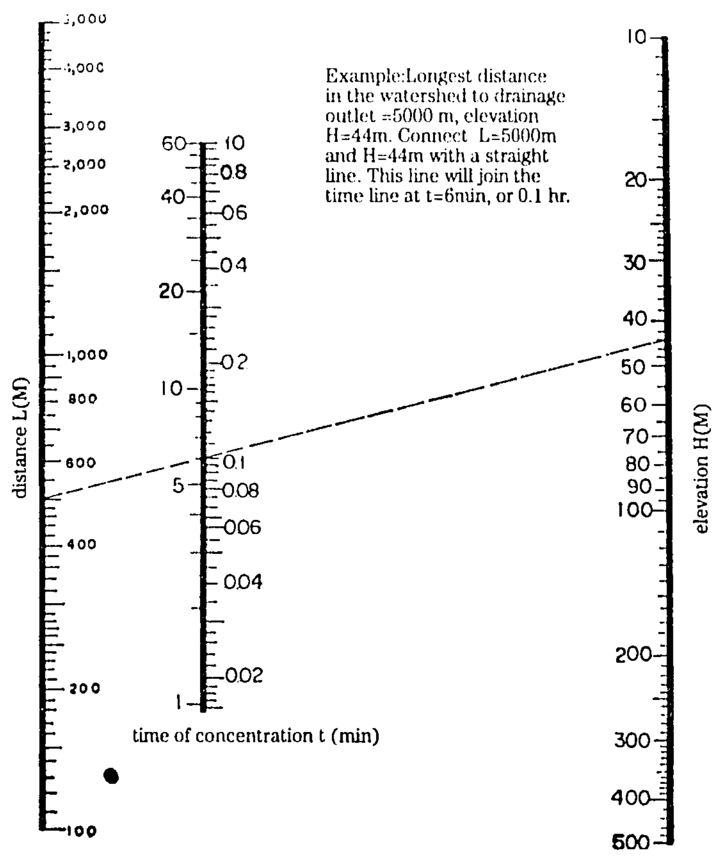


Fig. 1. Chart of time of concentration

Table 1. Time of Concentration

Unit: Minute

Watershed area (ha)	Watershed length (m)	Slope of land			
		1%	5%	10%	20%
12.5	610	16	9	7	5
28.0	915	22	12	9	7
49.5	1,220	27	15	11	9
77.5	1,525	32	17	13	10
174.0	2,280	44	24	18	14
310.0	3,050	55	30	23	17
700.0	4,570	76	41	31	24
1,235.0	6,100	94	51	39	30

Table 2. Time of Concentration at 5% Slope

Watershed area (ha)	0.5	1	2	4	8
Time of concentration(min)	1.6	2.6	3.5	4.0	4.8
Watershed area (ha)	12	20	40	80	100
Time of concentration(min)	8	12	17	23	26

2. Estimation of hour rainfall intensity (i)

This estimate may be made, on the basis of 10 years rainfall frequency, from the chart in Fig. 2, or from the following equations. However, each of these equations is applicable only to a designated area. Therefore, the equation for an area nearest to the project site should be used.

Keelung : $i = \dfrac{699}{(t+7)^{0.5518}}$ (mm/hr)

Kaohsiung : $i = \dfrac{1690}{(t+43)^{0.6096}}$

Taipei : $i = \dfrac{1688}{(t+21)^{0.6914}}$

Hengchun : $i = \dfrac{798}{(t+8)^{0.5851}}$

Hsinchu : $i = \dfrac{1575}{(t+32)^{0.6796}}$

Taitung : $i = \dfrac{545}{(t+1)^{0.5224}}$

Taichung : $i = \dfrac{947}{(t+17)^{0.5649}}$

Hualien : $i = \dfrac{877}{(t+18)^{0.5519}}$

Tainan : $i = \dfrac{2891}{(t+36)^{0.7268}}$

Ilan : $i = \dfrac{358}{t^{0.3790}}$

If data of daily rain fally intensity at 10 years frequency is available, hour rain fall may be found by the chart in Fig. 3, or calculated by the following equation.

$$i = \frac{R}{24}\left(\frac{24}{t}\right)^{0.6}$$

190

R = Daily rainfall (mm)

t = Time of concentration (hr)

i = Hour rainfall intensity (mm/hr)

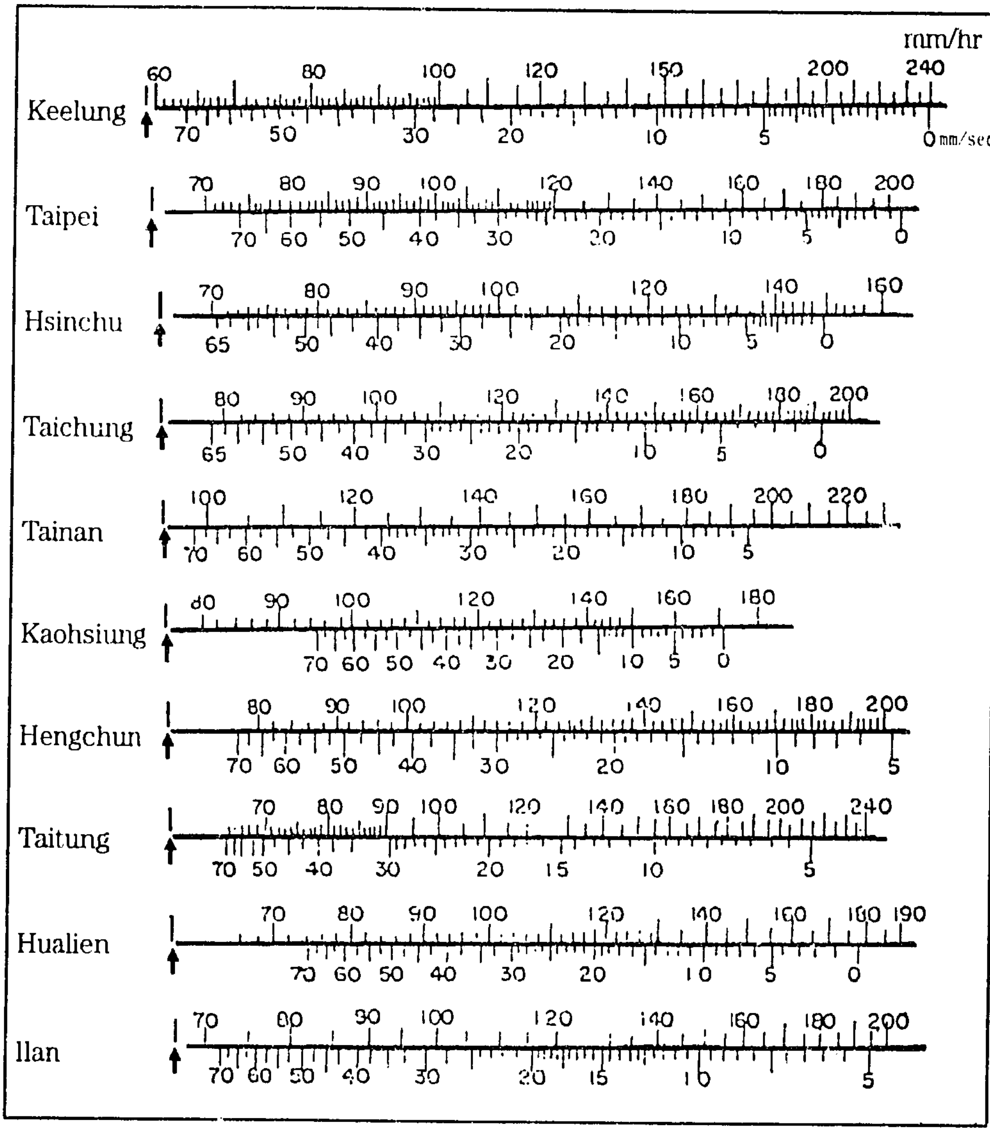


Fig. 2. Hour rainfall intensity at 10-ye..r frequency

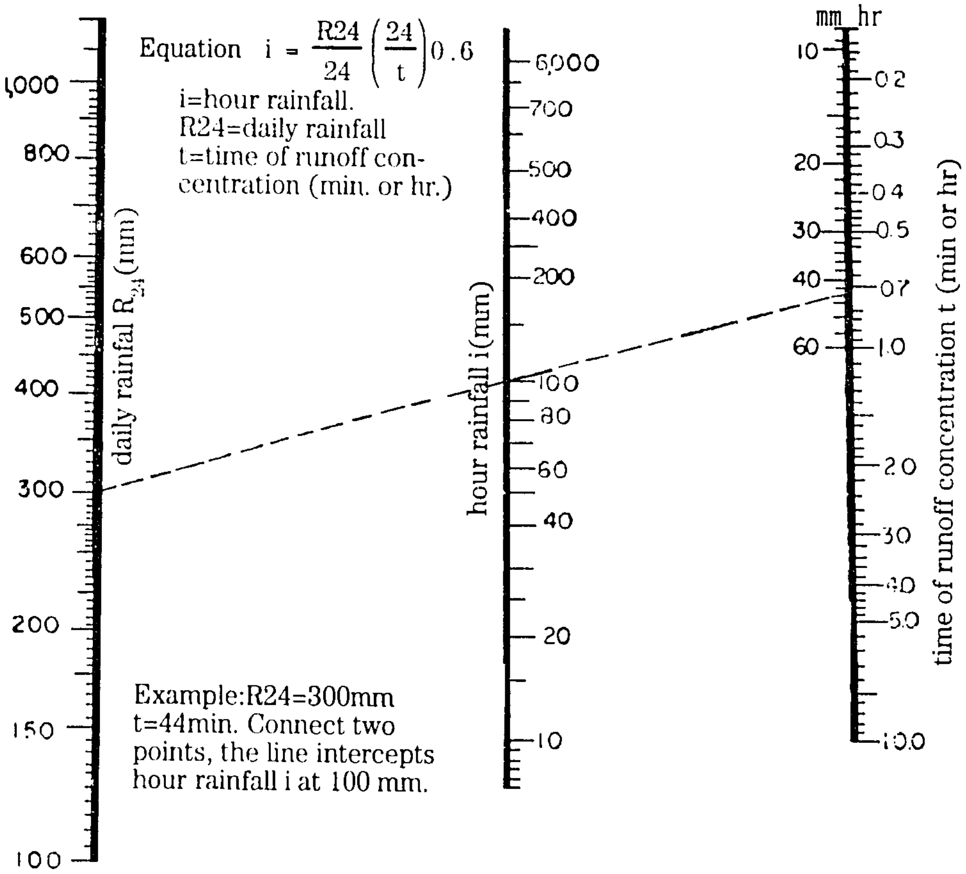


Fig. 3. Calculation of hour rainfall from daily rainfall

3. Estimation of runoff coefficient

In a storm, the runoff coefficient varies in the range of 0.8 - 0.9, depending on the gradient, soil characteristics, vegetative coverage, rainfall intensity and duration. For the time being, accurate data are still not available. It is suggested that the average value of 0.85 be used.

4. Estimation of runoff volume (Q) may be made with the help of Fig. 4, or the following equation.

$$Q = \frac{1}{360} C \cdot i \cdot a$$

Q = Runoff volume (m^3/sec)

C = Runoff coefficient

i = Hour rainfall intensity (mm/hr)

A = Watershed area (ha)

158

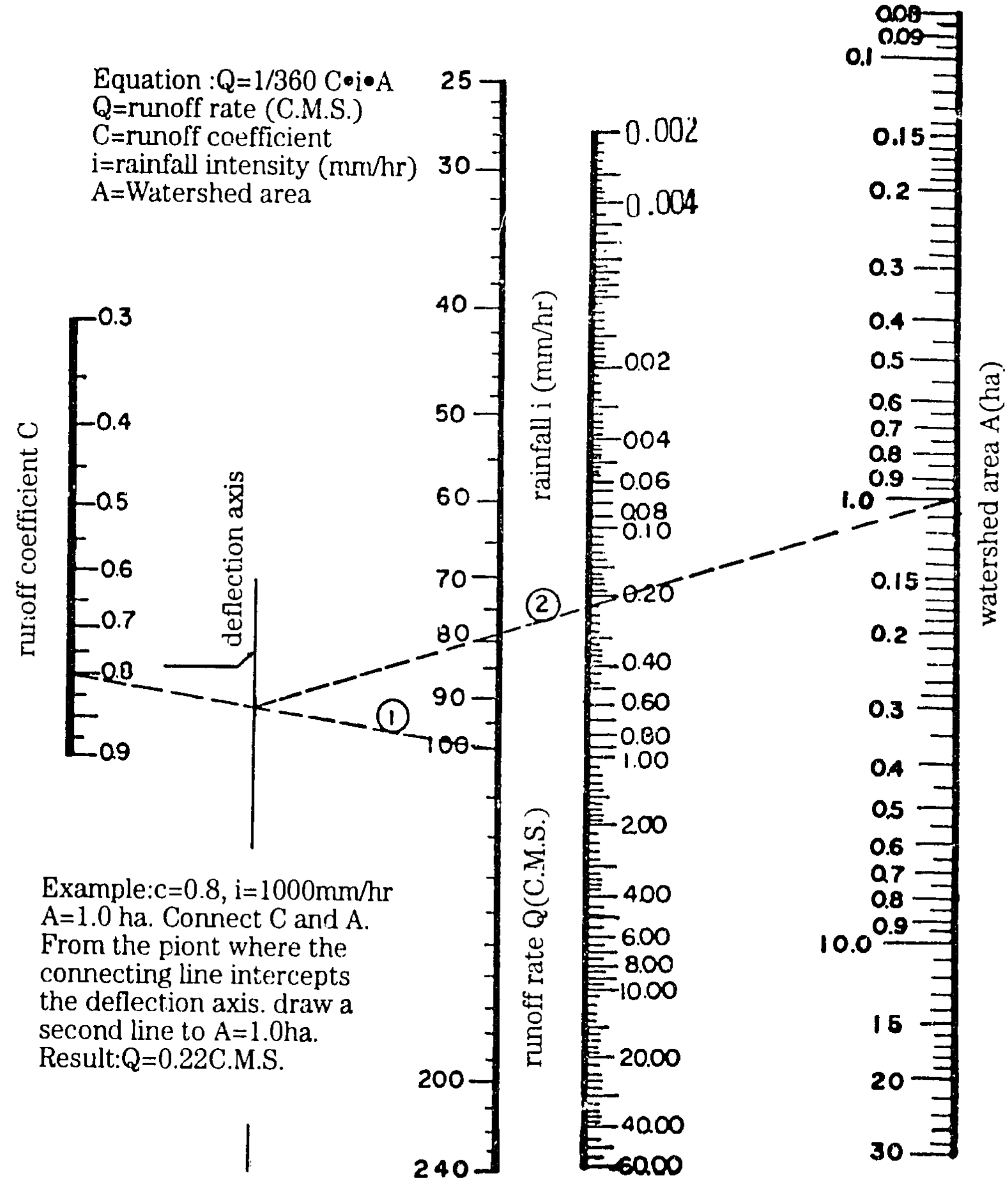


Fig. 4. Calculation of runoff

155

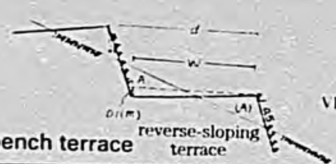
Appendix 6. Table of Bench Terracing Earth Volume

level bench terrace

$VI = \frac{W.S}{100 - S \cdot \mu}$ $d = W + \frac{VI}{2} = \frac{100VI}{S}$ $A = \frac{W.VI}{8}$ $V = A \times \frac{100^2}{d}$ $\mu = \frac{1}{2}$ (riser slope ratio)

6-1 Level bench terrace

W(m)	θ(0)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Remark
	s(%)	3.49	5.24	6.99	8.75	10.51	12.28	14.05	15.84	17.63	19.44	21.26	23.09	24.93	26.80	26.67	30.57	32.49	34.43	36.40	38.39	40.50	42.45	44.52	46.63	48.77	50.95	53.17	55.43	57.74	
1.00	VI(m)	0.036	0.054	0.072	0.092	0.111	0.131	0.151	0.172	0.193	0.215	0.238	0.261	0.285	0.310	0.335	0.361	0.388	0.416	0.445	0.475	0.506	0.539	0.573	0.608	0.645	0.684	0.724	0.767	0.812	Earth work of the ridge along the side is excluded
	d(m)	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.13	1.15	1.16	1.17	1.18	1.19	1.21	1.22	1.24	1.25	1.27	1.29	1.30	1.32	1.34	1.36	1.38	1.46	
	A(m²)	0.004	0.007	0.009	0.011	0.014	0.016	0.019	0.022	0.024	0.027	0.030	0.033	0.036	0.039	0.042	0.045	0.049	0.052	0.056	0.059	0.063	0.067	0.072	0.076	0.081	0.856	0.091	0.096	0.101	
	V(m³)	43.6	65.5	87.3	109.4	131.3	153.3	175.6	198.0	222.5	245.4	265.8	288.6	311.6	334.9	358.4	882.1	406.1	430.4	455.0	479.4	506.1	530.6	556.5	582.9	608.7	636.9	664.6	692.9	721.8	
1.50	VI	0.054	0.081	0.109	0.137	0.166	0.196	0.227	0.258	0.290	0.323	0.357	0.392	0.427	0.464	0.502	0.541	0.582	0.624	0.667	0.712	0.759	0.808	0.859	0.912	0.967	1,025	1,086	1,150	1,217	
	d	1.53	1.54	1.55	1.57	1.58	1.60	1.61	1.63	1.65	1.66	1.68	1.70	1.71	1.73	1.75	1.77	1.79	1.81	1.83	1.86	1.88	1.90	1.93	1.96	1.98	2.01	2.04	2.08	2.11	
	A	0.010	0.015	0.020	0.026	0.031	0.037	0.043	0.048	0.054	0.061	0.067	0.073	0.080	0.087	0.094	0.102	0.109	0.117	0.125	0.133	0.142	0.152	0.161	0.171	0.181	0.192	0.204	0.216	0.228	
	V	65.4	98.2	130.9	164.1	197.0	230.2	263.4	297.0	333.7	368.1	398.7	432.9	467.4	502.4	337.6	573.2	609.1	645.6	682.5	719.1	759.2	795.9	834.7	874.4	913.1	955.3	996.9	1,039	1,083	
2.00	VI	0.071	0.108	0.145	0.183	0.222	0.262	0.302	0.344	0.387	0.431	0.476	0.522	0.570	0.619	0.669	0.722	0.776	0.832	0.890	0.949	0.013	1,078	1,145	1,216	1,290	1,367	1,448	1,534	1,624	
	d	2.04	2.05	2.07	2.09	2.11	2.13	2.15	2.17	2.19	2.22	2.24	2.26	2.29	2.31	2.33	2.36	2.39	2.42	2.45	2.47	2.51	2.54	2.57	2.61	2.65	2.68	2.72	2.77	2.81	
	A	0.018	0.027	0.036	0.046	0.056	0.065	0.076	0.086	0.097	0.107	0.119	0.131	0.142	0.155	0.167	0.180	0.194	0.208	0.222	0.237	0.253	0.269	0.286	0.304	0.322	0.342	0.362	0.383	0.406	
	V	87.3	131.0	174.5	218.7	262.7	306.9	351.2	395.9	445.0	490.8	31.5	577.2	623.3	669.9	716.7	764.2	812.1	860.7	910.0	958.8	1,012	1,061	1,113	1,166	1,217	1,274	1,329	1,386	1,446	
2.50	VI	0.089	0.135	0.181	0.229	0.277	0.327	0.378	0.430	0.483	0.538	0.595	0.653	0.712	0.774	0.837	0.902	0.970	1,040	1,112	1,186	1,266	1,347	1,432	1,520	1,612	1,709	1,811	1,917	2,029	
	d	2.55	2.57	2.59	2.61	2.64	2.66	2.69	2.72	2.74	2.77	2.80	2.83	2.86	2.89	2.92	2.95	2.99	3.02	3.06	3.09	3.13	3.17	3.22	3.26	3.31	3.35	3.41	3.46	3.51	
	A	0.028	0.042	0.057	0.071	0.087	0.102	0.118	0.134	0.151	0.168	0.187	0.204	0.223	0.242	0.261	0.282	0.303	0.325	0.348	0.371	0.396	0.421	0.447	0.475	0.504	0.534	0.566	0.599	0.634	
	V	109.1	163.7	218.2	273.4	328.4	383.7	439.0	494.9	556.2	613.5	664.1	721.5	779.1	837.3	895.9	955.3	1,015	1,076	1,137	1,198	1,265	1,327	1,391	1,457	1,522	1,592	1,662	1,732	1,804	
3.00	VI	0.106	0.161	0.217	0.275	0.333	0.392	0.453	0.516	0.580	0.646	0.714	0.783	0.854	0.928	1,004	1,083	1,163	1,248	1,335	1,424	1,519	1,617	1,718	1,820	1,935	2,051	2,173	2,300	2,435	
	d	3.05	3.08	3.11	3.14	3.17	3.20	3.23	3.26	3.29	3.32	3.36	3.39	3.43	3.46	3.50	3.54	3.58	3.62	3.67	3.71	3.76	3.81	3.86	3.91	3.97	4.03	4.09	4.15	4.22	
	A	0.040	0.061	0.081	0.103	0.125	0.147	0.170	0.194	0.218	0.242	0.268	0.294	0.320	0.348	0.377	0.406	0.437	0.468	0.500	0.537	0.570	0.293	0.644	0.684	0.726	0.769	0.815	0.863	0.914	
	V	130.9	196	261.8	328.1	394.0	460.4	526.8	593.9	667.5	736.2	797.3	865.8	934.9	1,005	1,075	1,146	1,218	1,291	1,365	1,438	1,518	1,592	1,669	1,749	1,826	1,911	1,994	2,079	2,165	
4.00	VI	0.142	0.215	0.289	0.366	0.444	0.23	0.604	0.688	0.773	0.861	0.952	1,044	1,139	1,238	1,339	1,444	1,551	1,664	1,780	1,898	2,025	2,156	2,291	2,432	2,580	2,734	2,897	3,067	3,247	
	d	4.07	4.11	4.14	4.18	4.22	4.26	4.30	4.34	4.39	4.43	4.48	4.52	4.57	4.62	4.67	4.72	4.78	4.83	4.89	4.95	5.01	5.08	5.15	5.22	5.29	5.37	5.45	5.53	5.62	
	A	0.071	0.108	0.145	0.183	0.222	0.262	0.302	0.344	0.387	0.431	0.476	0.522	0.570	0.619	0.669	0.722	0.776	0.832	0.890	0.949	1,012	1,078	1,145	1,216	1,290	1,367	1,448	1,534	1,624	
	V	174.5	262.0	349.1	437.5	525.4	613.9	702.4	791.9	890.0	981.6	1,063	1,154	1,247	1,340	1,433	1,528	1,624	1,721	1,820	1,918	2,024	2,122	2,226	2,332	2,435	2,548	2,659	2,772	2,887	
5.00	VI	0.178	0.269	0.362	0.458	0.555	0.654	0.756	0.860	0.967	1,077	1,189	1,305	1,424	1,547	1,673	1,805	1,939	2,080	2,225	2,373	2,532	2,694	2,864	3,041	3,225	3,418	3,621	3,834	4,059	
	d	5.09	5.13	5.18	5.23	5.28	5.33	5.38	5.43	5.48	5.04	5.59	5.65	5.71	5.77	5.84	5.90	5.97	6.04	6.11	6.19	6.27	6.35	6.43	6.52	6.61	6.71	6.81	6.92	7.03	
	A	0.111	0.168	0.226	0.286	0.347	0.409	0.472	0.538	0.604	0.673	0.743	0.816	0.890	0.967	1,046	1,128	1,213	1,300	1,390	1,483	1,582	1,684	1,790	1,900	2,016	2,137	2,263	2,396	2,538	
	V	218.1	327.4	436.3	546.9	656.7	767.3	878.0	989.9	1,112	1,227	1,329	1,443	1,558	1,675	1,792	1,911	2,030	2,152	2,275	2,397	2,531	2,653	2,782	2,915	3,044	3,184	3,323	3,464	3,609	
6.00	VI	0.213	0.323	0.434	0.549	0.665	0.785	0.907	1,032	1,160	1,292	1,427	1,566	1,709	1,857	2,008	2,165	2,327	2,495	2,670	2,847	3,078	3,233	3,436	3,648	3,869	4,102	4,345	4,601	4,871	
	d	6.11	6.16	6.22	6.27	6.33	6.39	6.45	6.52	6.58	6.65	6.71	6.78	6.85	6.93	7.00	7.08	7.16	7.25	7.34	7.42	7.54	7.62	7.72	7.82	7.93	8.05	8.17	8.30	8.44	
	A	0.160	0.242	0.326	0.412	0.499	0.589	0.680	0.774	0.870	0.969	1,071	1,175	1,282	1,393	1,506	1,624	1,746	1,872	2,002	2,135	2,278	2,425	2,577	2,736	2,902	3,077	3,259	3,451	3,654	
	V	261.8	392.9	523.6	656.2	778.1	920.8	1,054	1,188	1,335	1,472	1,595	1,732	1,870	2,010	2,150	2,292	2,436	2,582	2,730	2,876	3,037	3,194	3,339	3,497	3,652	3,821	3,988	4,157	4,331	
7.00	VI	0.248	0.377	0.504	0.641	0.776	0.916	1,058	1,204	1,353	1,507	1,665	1,827	1,994	2,166	2,343	2,526	2,715	2,911	3,115	3,322	3,544	3,772	4,009	4,257	4,514	4,785	5,069	5,368	5,683	
	d	7.13	7.19	7.25	7.32	7.39	7.46	7.53	7.60	7.67	7.75	7.83	7.91	8.00	8.08	8.17	8.26	8.36	8.46	8.56	8.66	8.77	8.88	9.00	9.13	9.26	9.39	9.53	9.68	9.84	
	A	0.218	0.330	0.443	0.560	0.679	0.801	0.926	1,054	1,184	1,319	1,457	1,599	1,744	1,896	2,050	2,210	2,377	2,548	2,724	2,906	3,101	3,301	3,507	3,724	3,950	4,188	4,436	4,697	4,974	
	V	305.4	458.4	610.9	765.6	919.4	1,074	1,229	1,386	1,557	1,718	1,860	2,020	2,181	2,345	2,509	2,675	2,842	3,031	3,185	3,356	3,543	3,714	3,895	1,080	4,261	4,450	4,652	4,851	5,052	
8.00	VI	0.284	0.430	0.579	0.732	0.887	10.46	12.08	13.76	15.47	17.22	1,903	2,088	2,278	2,476	2,677	2,886	3,102	3,327	3,560	3,795	4,050	4,311	4,582	4,865	5,159	5,469	5,794	6,134	6,494	
	d	8.14	8.22	8.29	8.37	8.44	8.52	8.60	8.69	8.77	8.86	8.95	9.04	9.14	9.24	9.34	9.44	9.55	9.66	9.78	9.90	10.03	10.16	10.29	10.43	10.58	10.73	10.90	11.07	11.25	
	A	0.284	0.430	0.579	0.732	0.887	1,046	1,209	1,376	1,546	1,723	1,903	2,088	2,278	2,476	2,677	2,886	3,104	3,328	3,558	3,795	4,050	4,244	4,581	4,789	5,079	5,469	5,794	6,134	6,496	
	V	349.0	523.9	698.1	875.0	1,051	1,288	1,405	1,584	1,780	1,963	2,126	2,309	2,493	2,680	2,867	3,057	3,248	3,443	3,640	3,835	4,049	4,245	4,452	4,663	4,862	5,095	5,317	5,543	5,774	
10.00	VI	0.355	0.538	0.732	0.915	1,109	1,308	1,511	1,720	1,933	2,153	2,379	2,610	2,848	3,095	3,347	3,609	3,878	4,159	4,450	4,745	5,063	5,389	5,727	6,081	6,449	6,836	7,242	7,669	8,118	
	d	10.18	10.27	10.36	10.46	10.55	10.65	10.76	10.86	10.97	11.08	11.19	11.31	11.42	11.48	11.67	11.80	11.94	12.03	12.23	12.37	12.53	12.69	12.86	13.04	13.22	13.42	13.62	13.83	14.06	
	A	0.444	0.673	0.904	1,114	1,386	1,635	1,889	2,150	2,416	2,692	2,974	3,263	3,560	3,868	4,183	4,510	4,850	5,200	5,560	5,931	6,328	6,736	7,158	7,601	8,062	8,546	9,053	9,585	10.15	
	V	436.3	654.9	872.7	1,094	1,313	1,535	1,756	1,980	2,225	2,454	2,658	2,886	3,116	3,349	3,584	3,821	4,061	4,304	4,550	4,794	5,061	5,306	5,565	5,829	6,087	6,369	6,646	6,929	7,218	
12.00	VI	0.426	0.646	0.868	1,098	1,331	1,569	1,813	2,064	2,320	2,584	2,855	3,132	3,418	3,714	4,016	4,331	4,654	4,991	5,340	5,694	6,076	6,407	6,872	8,308	7,739	8,203	8,690	9,202	9,741	
	d	12.22	12.32	12.43	12.50	12.67	12.78	12.91	13.03	13.16	13.29	13.43	13.57	13.71	13.86	14.01	14.17	14.33	14.50	14.67	14.85	15.04	15.23	15.43	15.65	15.87	16.10	16.43	16.60	16.87	
	A	0.639	0.968	1,302	1,647	1,996	2,354	2,720	3,096	3,477	3,876	4,282	4,699	5,126	5,570	6,024	6,494	6,984	7,488	8,006	9,539	9,112	9,700	10.31	10.95	11.61	12.31	13.04	13.80	14.62	
	V	523.5	785.9	1,047	1,313	1,576	1,842	2,107	2,376	2,670	2,945	3,189	3,463	3,740	4,019	4,300	4,585	4,873	5,164	5,460	5,753	9,073	6,367	6,678	6,995	7,305	7,643	7,976	8,314	[illegible]	
15.00	VI	0.532	0.807	1,085	1,373	1,664	1,962	2,267	2,580	2,900	3,230	3,568	3,916	4,272	4,642	5,020	5,414	5,817	6,239	6,675	7,118	7,595	8,084	8,591	9,122	9,674	10.25	10.86	11.50	12.17	
	d	15.27	15.40	1.54	15.69	15.83	15.98	16.13	16.29	16.45	16.62	16.78	16.91	17.14	17.32	17.51	17.71	17.91	18.12	18.34	18.56	18.80	19.04	19.30	19.56	19.84	20.13	20.43	20.75	21.09	
	A	0.999	1.513	2,035	2,573	3,119	3,679	4,249	4,838	5,437	6,056	6,691	7,342	8,010	8,704	9,413	10.15	10.91	11.70	12.51	13.34	14.24	15.16	16.11	17.10	18.14	19.23	20.37	21.51	22.84	
	V	6,544	982.3	1,309	1,641	1,970	2,302	2,634	2,970	3,337	3,681	3,986	4,329	4,674	5,024	5,376	5,732	6,091	6,456	6,825	7,191	7,592	7,959	8,347	8,744	9,131	9,553	9,969	10.39	10.83	



6-2 Reverse-sloping bench terrace

$VI = \frac{W.S+(0.1)S\mu}{100-S\mu}$ $d = W + \frac{VI+0.1}{2}$ $A = \frac{W.VI+(0.1)d}{8}$ $V/ha = A \times \frac{100^2}{d}$ $\mu = \frac{1}{2}$ (riser slope ratio)

W(m)	θ(0)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	s(%)	3.49	5.24	0.99	8.75	10.51	12.28	14.05	15.84	17.63	19.44	21.26	23.09	24.93	26.80	26.67	30.57	32.49	34.43	36.40	38.39	40.40	42.45	44.52	46.63	48.77	50.95	53.17	55.43	57.74
1.00	VI(m)	0.037	0.057	0.076	0.096	0.117	0.137	0.159	0.181	0.203	0.226	0.250	0.274	0.299	0.325	0.351	0.378	0.407	0.437	0.467	0.498	0.532	0.566	0.601	0.639	0.677	0.718	0.761	0.805	0.852
	d(m)	1.07	1.08	1.09	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.18	1.19	1.20	1.21	1.23	1.24	1.25	1.27	1.28	1.30	1.32	1.33	1.35	1.37	1.39	1.40	1.43	1.45	1.48
	A(m^2)	0.018	0.021	0.023	0.026	0.028	0.031	0.034	0.037	0.040	0.043	0.046	0.049	0.052	0.056	0.059	0.003	0.067	0.070	0.074	0.079	0.083	0.087	0.092	0.097	0.102	0.507	0.113	0.119	0.125
	V(m^3)	168	190.5	212.4	234.4	256.4	278.5	300.7	323.0	345.4	368.0	390.6	413.8	436.6	460.0	483.4	507.1	531.1	555.4	580.0	604.4	630.0	655.6	681.5	707.6	734.6	761.8	789.7	818.9	846.7
1.50	VI	0.056	0.083	0.112	0.142	0.172	0.203	0.234	0.267	0.300	0.334	0.369	0.405	0.441	0.480	0.519	0.559	0.601	0.645	0.689	0.736	0.785	0.835	0.888	0.943	1,000	1,060	1,123	1,189	1,258
	d	1.58	1.59	1.60	1.62	1.64	1.65	1.67	1.68	1.70	1.72	1.74	1.75	1.77	1.79	1.81	1.83	1.85	1.87	1.89	1.92	1.94	1.97	1.99	2.02	2.05	2.08	2.11	2.14	2.18
	A	0.030	0.036	0.041	0.047	0.053	0.059	0.065	0.071	0.077	0.084	0.091	0.098	0.105	0.112	0.120	0.128	0.136	0.144	0.153	0.162	0.171	0.181	0.191	0.202	0.213	0.225	0.237	0.250	0.290
	V	191.5	223.2	255.9	289.1	322.1	355.2	388.5	422.0	455.6	489.5	523.4	558.2	592.4	627.5	662.5	697.8	733.9	770.9	806.8	844.6	882.6	921.0	959.8	999.0	1,039	1,080	1,122	1,166	1,333
2.00	VI	0.074	0.110	0.148	0.188	0.227	0.268	0.309	0.353	0.396	0.442	0.488	0.535	0.584	0.634	0.686	0.740	0.795	0.853	0.912	0.973	1,038	1,105	1,174	1,247	1,322	1,401	1,485	1,572	1,664
	d	2.09	2.11	2.12	2.14	2.16	2.18	2.20	2.23	2.25	2.27	2.29	2.32	2.34	2.37	2.39	2.42	2.45	2.48	2.51	2.54	2.57	2.60	2.64	2.67	2.71	2.75	2.79	2.83	2.88
	A	0.045	0.054	0.064	0.074	0.084	0.094	0.105	0.116	0.127	0.139	0.151	0.163	0.175	0.188	0.201	0.215	0.229	0.244	0.259	0.275	0.292	0.308	0.326	0.345	0.364	0.385	0.406	0.428	0.452
	V	214.4	256.0	299.5	343.8	387.7	431.9	475.6	520.9	565.8	611.1	654.3	702.5	748.2	795.0	841.8	889.5	937.0	986.2	1,035	1,084	1,135	1,171	1,239	1,290	1,344	1,399	1,454	1,513	1,569
2.50	VI	0.092	0.137	0.185	0.233	0.283	0.334	0.385	0.439	0.493	0.549	0.607	0.666	0.726	0.789	0.853	0.920	0.989	1,001	1,134	1,210	1,291	1,374	1,460	1,551	1,645	1,743	1,847	1,955	2,070
	d	2.60	2.62	2.64	2.67	2.69	2.72	2.74	2.77	2.80	2.82	2.85	2.88	2.91	2.94	2.98	3.01	3.04	3.08	3.12	3.15	3.20	3.24	3.28	3.33	3.37	3.42	3.47	3.52	3.58
	A	0.061	0.076	0.091	0.106	0.122	0.138	0.155	0.172	0.189	0.207	0.225	0.224	0.263	0.282	0.304	0.325	0.347	0.370	0.393	0.418	0.443	0.470	0.497	0.526	0.556	0.587	0.621	0.655	0.692
	V	235.8	288.7	343.2	398.5	453.5	508.6	564.1	620.0	676.0	732.8	789.1	846.8	904.0	962.5	1,021	1,080	1,114	1,201	1,262	1,324	1,388	1,452	1,516	1,582	1,649	1,717	1,787	1,860	1,929
3.00	VI	0.110	0.164	0.221	0.279	0.338	0.399	0.460	0.525	0.590	0.657	0.726	0.796	0.869	0.944	1,021	1,101	1,182	1,269	1,357	1,448	1,544	1,644	1,747	1,855	1,967	2,085	2,209	2,339	2,476
	d	3.10	3.13	3.16	3.19	3.22	3.25	3.28	3.31	3.34	3.38	3.41	3.45	3.48	3.52	3.56	3.60	3.64	3.68	3.73	3.77	3.82	3.87	3.92	3.98	4.03	4.09	4.15	4.22	4.29
	A	0.080	0.101	0.122	0.145	0.167	0.190	0.213	0.238	0.263	0.289	0.318	0.342	0.369	0.398	0.427	0.450	0.489	0.522	0.555	0.590	0.628	0.665	0.704	0.745	0.788	0.833	0.880	0.930	0.982
	V	257.9	321.5	386.8	453.1	519.1	585.3	650.7	719.0	786.1	854.0	922.1	991.1	1,060	1,130	1,200	1,272	1,342	1,417	1,490	1,564	1,642	1,717	1,795	1,873	1,954	2,036	1,119	2,206	2,290
4.00	VI	0.146	0.218	0.293	0.371	0.449	0.530	0.621	0.697	0.783	0.872	0.963	1,057	1,153	1,253	1,355	1,462	1,570	1,685	1,802	1,922	2,051	2,183	2,319	2,463	2,612	2,269	2,933	3,106	3,288
	d	4.12	4.16	4.20	4.24	4.27	4.31	4.36	4.40	4.44	4.49	4.53	4.58	4.63	4.68	4.73	4.78	4.84	4.89	4.95	5.01	5.08	5.14	5.21	5.28	5.36	5.43	5.52	5.59	6.69
	A	0.125	0.161	0.199	0.238	0.278	0.319	0.360	0.403	0.447	0.492	0.538	0.586	0.635	0.685	0.737	0.791	0.845	0.904	0.963	1,024	1,089	1,156	1,225	1,297	1,373	1,452	1,536	1,623	1,715
	V	302.1	386.7	474.1	562.5	650.4	738.8	827.5	917.0	1,006	1,097	1,188	1,280	1,372	1,465	1,559	1,654	1,749	1,847	1,945	2,043	2,145	2,250	2,351	2,456	2,563	2,672	2,784	2,902	3,012
5.00	VI	0.182	0.272	0.365	0.462	0.560	0.661	0.763	0.869	0.976	1,088	1,201	1,318	1,438	1,563	1,690	1,823	1,958	2,101	2,247	2,397	2,557	2,721	2,892	3,071	3,257	3,452	3,657	3,873	4,099
	d	5.14	5.19	5.23	5.28	5.33	5.38	5.43	5.48	5.53	5.59	5.65	5.71	5.77	5.83	5.90	5.96	6.03	6.10	6.17	6.25	6.33	6.41	6.50	6.59	6.68	6.78	6.88	6.98	7.10
	A	0.178	0.235	0.294	0.355	1,417	0.480	0.545	0.611	0.679	0.750	0.821	0.895	0.971	1,050	1,130	1,214	1,299	1,389	1,382	1,576	1,677	1,781	1,899	2,002	2,119	2,242	2,372	2,508	2,651
	V	346.3	452.4	561.3	671.9	781.7	892.3	1003.2	1,115	1,227	1,340	1,453	1,568	1,683	1,800	1,917	2,036	2,155	2,278	2,400	2,523	2,650	2,778	2,908	2,038	3,173	3,309	3,448	3,595	3,734
6.00	VI	0.218	0.326	0.438	0.554	0.671	0.791	0.914	1,041	1,170	1,303	1,439	1,579	1,723	1,873	2,025	2,183	2,346	2,516	2,692	2,871	3,063	3,260	3,465	3,679	3,902	4,136	4,382	4,639	4,911
	d	6.16	6.21	6.27	6.33	6.39	6.45	6.51	6.57	6.63	6.70	6.77	6.84	6.91	6.99	7.06	7.14	7.22	7.31	7.40	7.49	7.58	7.68	7.78	7.89	8.00	8.12	8.24	8.36	8.51
	A	0.240	0.322	0.407	0.494	0.583	0.674	0.767	0.863	0.960	1,061	1,164	1,270	1,379	1,492	1,607	1,727	1,850	1,978	2,112	2,247	2,392	2,541	2,696	2,858	2,026	3,203	3,389	3,584	3,790
	V	390.5	518.1	648.5	781.3	913.9	1,046	1,779	1,313	1,447	1,583	1,719	1,857	1,995	2,136	2,275	2,418	2,561	2,707	2,855	2,002	3,155	3,309	3,464	3,621	3,782	3,946	3,113	4,289	4,456
7.00	VI	0.254	0.380	0.507	0.645	0.782	0.922	1,065	1,213	1,363	1,518	1,677	1,840	2,008	2,182	2,359	2,544	2,734	2,932	3,137	3,346	3,569	3,799	4,038	4,287	4,547	4,819	5,106	5,406	5,723
	d	7.18	7.24	7.31	7.37	7.44	7.51	7.58	7.66	7.73	7.81	7.89	7.97	8.05	8.14	8.23	8.32	8.42	8.52	8.62	8.72	8.83	8.95	9.07	9.20	9.32	9.36	9.60	9.74	9.91
	A	0.312	0.423	0.525	0.637	0.777	0.901	1,027	1,157	1,289	1,426	1,566	1,710	1,857	2,011	2,167	2,330	2,497	2,672	2,853	2,037	3,234	3,436	3,646	3,866	3,095	4,335	4,588	4,825	5,131
	V	434.7	583.9	726.1	890.6	1,044	1,199	1,354	1,511	1,668	1,826	1,985	2,146	2,306	2,470	2,634	2,800	2,967	3,138	3,310	3,482	3,660	3,840	4,021	4,203	4,392	4,583	4,771	4,982	5,177
8.00	VI	0.290	0.433	0.582	0.737	0.893	1,053	1,217	1,385	1,556	1,733	1,915	2,102	2,293	2,491	2,694	2,903	3,121	3,348	3,582	3,819	4,076	4,338	4,610	4,895	5,192	5,503	5,830	6,173	6,535
	d	8.20	8.26	8.34	8.42	8.50	8.58	8.66	8.74	8.83	8.92	9.01	9.10	9.20	9.30	9.40	9.50	9.61	9.72	9.84	9.96	10.09	10.22	10.36	10.50	10.65	10.81	10.96	11.12	11.32
	A	0.392	0.536	0.687	0.842	0.999	1,160	1,325	1,494	1,667	1,845	2,028	2,216	2,408	2,607	2,812	3,024	3,241	3,470	3,705	3,943	4,202	4,466	4,740	5,026	5,325	5,638	5,967	6,312	6,676
	V	478.9	649.0	823.1	1,000	1,176	1,353	1,530	1,704	1,880	2,069	2,251	2,435	2,618	2,805	2,992	3,182	3,372	3,568	3,765	3,949	4,165	4,370	4,577	4,786	5,002	5,220	5,442	5,67[illegible]	[illegible],899
10.00	VI	0.362	0.541	0.727	0.920	1,115	1,315	1,519	1,729	1,943	2,164	2,391	2,624	2,862	3,110	3,364	3,627	3,897	4,170	4,472	4,769	5,088	5,416	5,756	6,111	6,481	6,870	7,279	7,76[illegible]	8,158
	d	10.23	10.32	10.41	10.51	10.61	10.71	10.81	10.91	11.02	11.13	11.25	11.36	11.48	11.60	11.73	11.86	12.00	12.14	12.29	12.43	12.59	12.53	12.93	13.11	13.29	13.49	13.65	13.88	14.13
	A	0.606	0.805	1,049	1,281	1,526	1,777	2,034	2,310	2,567	2,844	3,129	3,421	3,721	4,033	4,351	4,682	5,021	5,364	5,744	6,117	6,517	6,927	7,356	7,803	8,268	8,756	9,269	9,807	10.734
	V	592.7	779.8	977.6	1,219	1,438	1,660	1,881	1,116	2,329	2,555	2,782	3,012	3,241	3,475	3,709	3,947	4,185	4,419	4,675	4,919	5,175	5,507	5,690	5,951	6,221	6,493	6,771	7,064	7,034

6-3 Outward-sloping bench terrace

$VI = \frac{W \cdot S - W \cdot \mu \cdot S/10}{100 - 9S}$ $d = W - \frac{VI - W/10}{2}$ $A = \frac{W \cdot VI - d \cdot W/10}{8}$ $V/ha = A \times \frac{100^2}{d}$ $\mu = \frac{1}{2}$ (riser slope ratio)

W(m)	θ(0)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	s(%)	12.28	14.05	1.84	17.63	19.44	21.26	23.09	24.93	26.80	28.67	30.57	32.49	34.43	36.40	38.39	40.40	42.45	44.52	46.63	48.63	50.95	53.17	55.43	57.74
1.00	VI(m)	0.125	0.144	0.163	0.184	0.205	0.226	0.248	0.271	0.294	0.318	0.343	0.369	0.395	0.423	0.451	0.481	0.512	0.544	0.578	0.613	0.649	0.688	0.728	0.771
	d(m)	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.12	1.13	1.15	1.16	1.17	1.19	1.21	1.22	1.24	1.26	1.27	1.29	1.31	1.34
	A(m²)	0.003	0.005	0.008	0.010	0.012	0.015	0.018	0.020	0.023	0.026	0.029	0.032	0.035	0.038	0.042	0.045	0.049	0.053	0.057	0.061	0.065	0.070	0.075	0.080
	V(m³)	28.5	50.6	73.0	93.4	118.0	140.7	163.6	186.6	210.0	233.4	257.1	282.1	305.4	330.0	354.9	880.0	405.6	431.5	457.9	484.6	511.9	539.6	567.9	596.8
1.50	VI	0.190	0.215	0.245	0.276	0.307	0.339	0.372	0.406	0.441	0.477	0.514	0.553	0.593	0.634	0.676	0.721	0.768	0.816	0.867	0.919	0.974	1,032	1,971	1,157
	d	1.52	1.53	1.55	1.56	1.58	1.60	1.61	1.63	1.65	1.66	1.68	1.70	1.72	1.74	1.76	1.79	1.81	1.83	1.86	1.89	1.91	1.94	1.97	2.00
	A	0.006	0.012	0.017	0.022	0.028	0.033	0.040	0.046	0.052	0.058	0.065	0.072	0.079	0.086	0.094	0.102	0.110	0.119	0.128	0.137	0.147	0.155	0.168	0.179
	V	42.8	25.9	109.5	143.1	177.0	211.1	245.4	279.9	315.0	350.1	385.7	421.7	458.1	495.0	532.3	570.0	608.4	647.3	686.8	726.9	767.8	809.4	851.8	895.1
2.00	VI	0.248	0.287	0.326	0.367	0.409	0.453	0.492	0.541	0.588	0.636	0.686	0.737	0.790	0.845	0.902	0.962	1,024	1,088	1,155	1,225	1,299	1,376	1,457	1,542
	d	2.02	2.04	2.06	2.08	2.10	2.13	2.25	2.17	2.19	2.22	2.24	2.27	2.30	2.32	2.35	2.38	2.41	2.44	2.48	2.51	2.55	2.59	2.63	2.67
	A	0.0.12	0.021	0.030	0.040	0.050	0.060	0.070	0.081	0.092	0.104	0.115	0.128	0.140	0.153	0.167	0.181	0.196	0.211	0.227	0.244	0.261	0.276	0.299	0.319
	V	57.7	10.13	146.0	190.8	236.0	281.5	327.3	373.3	420.0	466.8	514.3	562.3	610.8	660.0	709.7	760.0	811.2	863.0	915.8	969.2	1,023	1,079	1,136	1,194
2.50	VI	0.310	0.359	0.409	0.459	0.511	0.566	0.620	0.676	0.735	0.795	0.857	0.921	0.988	1,057	0.127	1,202	1,280	1,360	1,444	1,532	1,624	1,720	1,821	1,928
	d	2.53	2.55	2.58	2.61	2.63	2.66	2.69	2.71	2.74	2.77	2.80	2.84	2.87	2.90	2.94	2.98	3.02	3.06	3.10	3.14	3.19	3.24	3.29	3.34
	A	0.018	0.032	0.047	0.062	0.078	0.094	0.110	0.127	0.144	0.162	1.180	0.199	0.219	0.240	0.260	0.283	0.306	0.330	0.354	0.381	0.408	0.431	0.466	0.498
	V	71.3	126.6	182.5	238.4	295.0	351.9	409.1	466.6	525.0	583.4	624.8	702.8	763.4	825.0	887.2	950.0	1,014	1,079	1,145	1,212	1,280	1,349	1,420	1,492
3.00	VI	0.370	0.431	0.490	0.551	0.614	0.679	0.744	0.812	0.882	0.954	1,028	1,106	1,185	1,268	1,352	1,443	1,536	1,632	1,733	1,838	1,948	2,064	2,185	2,313
	d	3.04	3.06	3.10	3.13	3.16	3.19	3.22	3.26	3.29	3.33	3.36	3.40	3.44	3.48	3.52	3.57	3.62	3.67	7.72	3.77	3.82	3.88	3.94	4.01
	A	0.026	0.047	0.068	0.089	0.112	0.135	0.158	0.182	0.207	0.233	0.260	0.287	0.315	0.345	0.375	0.407	0.440	0.475	0.511	0.548	0.587	0.620	0.672	0.717
	V	85.5	151.9	219.0	286.1	354.0	422.4	490.0	559.9	630.0	700.1	771.4	843.4	916.1	990.0	1,065	1,140	1,217	1,295	1,374	1,454	1,536	1,619	1,704	1,790
4.00	VI	0.500	0.574	0.654	0.735	0.818	0.905	0.992	1,082	1,176	1,272	1,371	1,474	1,580	1,691	1,803	1,923	2,048	2,176	2,311	2,451	2,598	2,752	2,914	3,085
	d	4.05	4.09	4.13	4.17	4.21	4.26	4.30	4.34	4.39	4.44	4.49	4.54	4.59	4.65	4.70	4.76	4.82	4.89	4.96	5.03	5.10	5.18	5.26	5.34
	A	0.046	0.083	0.121	0.159	0.199	0.240	0.281	0.324	0.369	0.414	0.461	0.510	0.561	0.613	0.667	0.724	0.783	0.844	0.908	0.974	1,044	1,103	1,194	1,275
	V	114.0	202.5	292.0	381.5	472.0	563.0	654.5	746.5	840.0	933.5	1,029	1,125	1,222	1,320	1,420	1,520	1,623	1,726	1,832	1,938	2,048	2,159	2,272	2,387
5.00	VI	0.620	0.718	0.817	0.918	1,023	1,131	1,240	1,535	1,470	1,590	1,714	1,843	1,976	2,114	2,254	2,405	2,560	2,720	2,881	3,064	3,247	3,440	3,642	3,856
	d	5.06	5.11	5.16	5.21	5.26	5.32	5.37	5.43	5.49	5.55	5.61	5.67	5.74	5.81	5.87	5.95	6.03	6.11	6.20	6.28	6.37	6.47	6.57	6.68
	A	0.072	0.129	0.188	0.248	0.310	0.375	0.439	0.506	0.576	0.647	0.721	0.797	0.876	0.958	1,042	1,131	1,223	1,318	1,418	1,522	1,631	1,743	1,866	1,993
	V	142.5	253.1	365.0	476.9	590.0	703.7	818.1	933.1	1,050	1,169	1,286	1,406	1,527	1,650	1,774	1,900	2,028	2,158	2,289	2,423	2,559	2,698	2,839	2,984
6.00	VI	0.746	0.861	0.981	1,102	1,227	1,358	1,488	1,623	1,764	1,907	2,057	2,211	2,371	2,536	2,704	2,886	3,071	3,264	3,466	3,676	3,897	4,128	4,371	4,627
	d	6.07	6.13	6.19	6.25	6.31	6.39	6.44	6.51	6.58	6.65	6.73	6.81	6.89	6.97	7.04	7.14	7.24	7.33	7.43	7.54	7.65	7.76	7.89	8.01
	A	0.104	0.186	0.271	0.358	0.447	0.539	0.633	0.729	0.829	0.932	1,038	1,148	1,261	1,380	1,506	1,629	1,761	1,989	2,042	2,192	2,349	2,488	2,687	2,869
	V	121.0	303.8	438.0	572.3	708.0	844.5	981.8	1,120	1,260	1,400	1,543	1,687	1,832	1,980	2,129	2,280	2,343	2,589	2,747	2,908	3,071	3,238	3,407	3,581
7.00	VI	0.870	1,004	1,144	1,286	1,432	1,584	1,736	1,894	2,058	2,225	2,400	2,580	2,776	2,959	3,155	3,367	3,583	3,808	4,044	4,289	4,546	4,816	5,099	5,398
	d	7.08	7.15	7.22	7.29	7.37	7.45	7.52	7.60	7.68	7.76	7.85	7.94	8.03	8.13	8.22	8.33	8.44	8.55	8.67	8.80	8.92	9.06	9.20	9.35
	A	0.141	0.253	0.369	0.487	0.608	0.734	0.861	0.992	1,129	1,268	1,413	1,562	1,717	1,878	2,042	2,217	2,397	2,583	2,780	2,983	3,197	3,378	3,657	3,905
	V	199.5	354.4	511.0	667.6	826.0	985.2	1,145	1,396	1,470	1,634	1,800	1,968	2,138	2,310	2,484	2,660	2,839	3,021	3,205	3,392	3,583	3,777	3,975	4,177
8.00	VI	0.994	1,148	1,307	1,469	1,637	1,810	1,984	2,164	2,352	2,543	2,742	2,948	3,161	3,382	3,606	3,848	4,095	4,352	4,621	4,901	5,196	5,504	5,828	6,169
	d	8.09	8.17	8.25	8.33	8.42	8.51	8.59	8.68	8.78	8.87	8.97	9.08	9.18	9.29	9.39	9.52	9.65	9.78	9.91	10.05	10.20	10.35	10.51	10.69
	A	0.185	9.331	0.482	0.636	0.795	0.959	1,125	1,296	1,474	1,656	1,845	2,041	2,243	2,453	2,667	2,895	3,131	3,427	3,687	3,897	4,176	4,412	4,776	5,101
	V	228.0	405.0	584.0	763.0	944.0	1,126	1,309	1,493	1,680	1,867	2,057	2,249	2,443	2,640	2,839	3,040	3,245	3,452	3,663	3,877	4,095	4,317	4,543	4,774
10.00	VI	1,243	1,436	1,634	1,837	2,046	2,262	2,480	2,706	2,940	3,179	3,428	3,685	3,951	4,227	4,508	4,810	5,119	5,440	5,777	6,127	6,495	6,888	7,285	7,712
	d	10.12	10.22	10.32	10.42	10.52	10.64	10.74	10.85	10.97	11.09	11.21	11.34	11.48	11.61	11.74	11.90	12.06	12.22	12.39	12.56	12.75	12.95	13.14	13.36
	A	0.289	0.517	0.753	0.994	1,242	1,498	1,757	2,025	2,300	2,588	2,883	3,189	3,504	3,833	4,167	4,524	4,892	5,273	5,673	6,089	6,525	6,983	7,463	7,970
	V	285.0	506.3	730.0	953.8	1,180	1,407	1,636	1,866	2,100	2,344	2,571	2,811	3,054	3,300	3,549	3,800	4,056	4,315	4,579	4,846	5,119	5,396	3,679	5,968
12.00	VI	1,491	1,723	1,961	2,024	2,455	2,715	2,976	3,247	3,528	3,815	4,114	4,422	4,741	5,072	5,409	5,771	6,143	6,528	6,932	7,352	7,794	8,256	8,742	9,254
	d	12.14	12.26	12.38	12.50	12.63	12.77	12.89	13.02	13.16	13.31	13.46	13.61	13.77	13.94	14.09	14.29	14.47	14.66	14.87	15.08	15.30	15.53	15.77	16.07
	A	0.415	0.745	1,084	1,431	1,788	2,157	2,531	2,917	3,317	3,726	4,152	4,592	5,046	5,519	6,000	6,515	7,044	7,593	8,169	8,768	9,396	1,926	10.75	11.48
	V	342.1	607.5	876.0	1,146	1,416	1,689	1,964	2,240	2,520	3,361	3,086	3,374	3,665	3,960	4,259	4,560	4,865	5,178	5,495	5,815	6,148	6,476	6,815	7,161
15.00	VI	1,864	2,153	2,457	2,775	3,068	3,394	3,720	4,058	4,410	4,769	5,142	5,528	5,927	6,341	6,672	7,214	7,679	8,160	8,666	9,191	9,742	10.32	16.92	11.57
	d	15.18	15.33	15.48	15.63	15.78	15.96	16.11	16.24	16.46	16.63	16.82	17.01	17.21	17.42	17.61	17.86	18.09	18.33	18.58	18.85	19.12	19.41	19.71	20.03
	A	0.649	1,164	1,695	2,236	2,794	3,370	3,954	4,557	5,183	5,823	6,487	7,175	7,884	8,623	9,376	10.17	11.01	11.88	12.76	13.70	14.68	15.51	16.79	17.93
	V	427.6	759.4	1,095	1,431	1,770	2,112	2,454	2,799	3,150	3,501	3,857	4,217	4,58[illegible]	4,950	5,32[illegible]	5,700	6,084	6,473	6,868	7,269	7,678	8,095	8,518	8,951

Appendix 7. Table of Calculation of Requirements for Construction Materials

For the construction of any structure for soil and water conservation purpose, after its dimensions are decided, materials requirement should be calculated, according to its volume, area and other relevant specifications.

1. Birch lined ditch: The number of bricks required may be found from the following chart and equation:

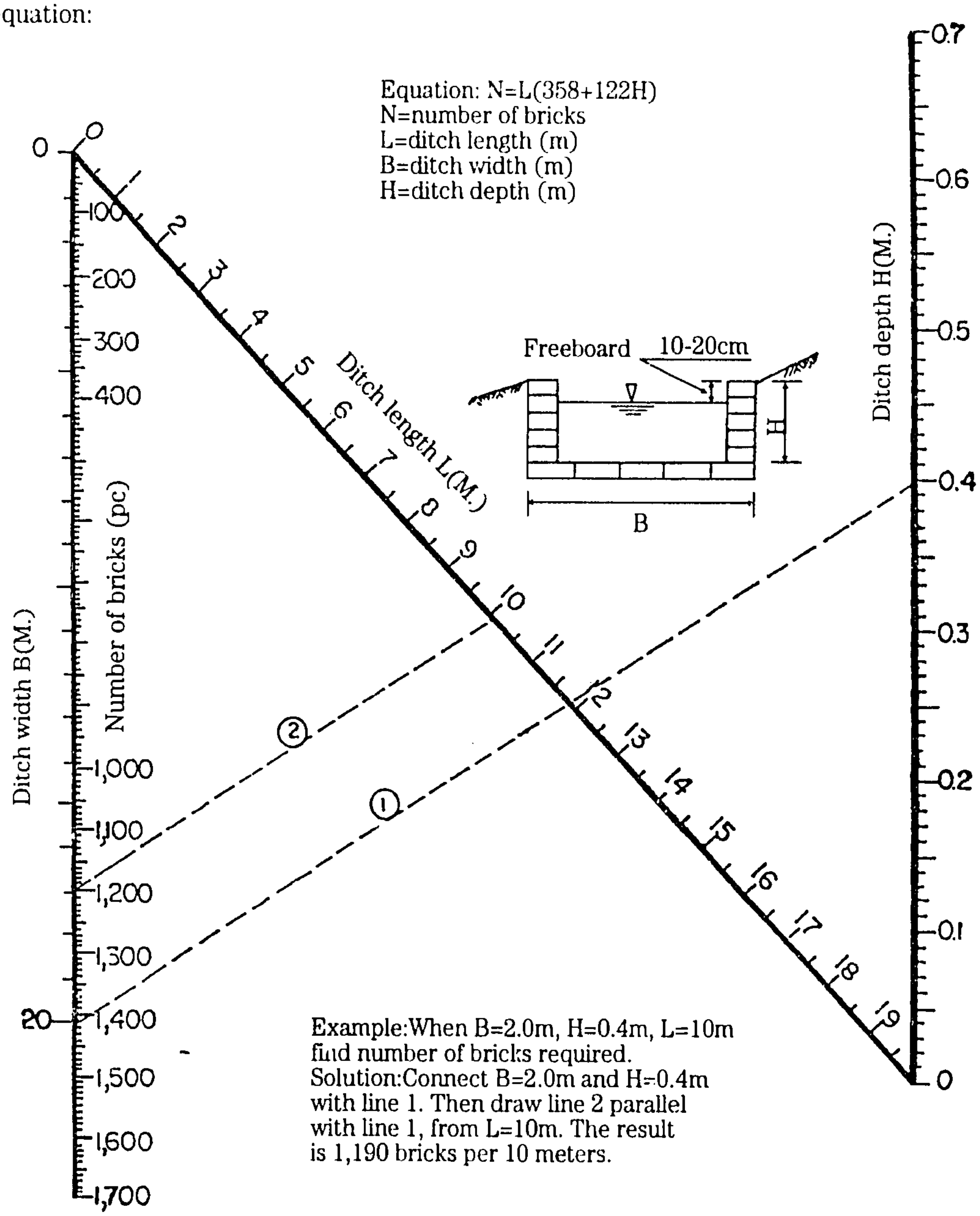


Fig. 1. Bricks required for diversion and drainage ditches with rectangular cross section

Table 1. Mortar Materials per 1000 Bricks

Materiais \ Cement mortar / Mix ratio	0.3 m³	
	1 : 3	1 : 4
Bricks (pc)	1000	1000
Cement (bag)	3	2.4
Sand (m^3)	0.3	0.3

2. Masonry ditch: Materials for masonry work are calculated on the basis of the area of masonry to be constructed. Masonry work is divided into dry masonry, concrete masonry, mortar masonry, and concrete or cement pointed masonry. The crevices and joints in dry masonry should be filled with 1-3 cm pebbles. For concrete or cement pointed masonry, the crevices and joints are filled with 1-3 cm pebbles first, then pointed with concrete or cement. After the dimensions of the cross section are decided, the area of masonry may be found by adding ditch width to ditch depth, and multiply the total by ditch length.

Table 2. Materials for stone masonry (per sq.m.)

Mortar type	Materials \ Stone size (cm)	30	25	20	15
Dry masonry	Cobbles (m^3)	0.30	0.25	0.20	0.15
	Pebbles for filling (m^3)	0.070	0.065	0.055	0.040
Concrete or cement masonry	Cobbles (m^3)	0.30	0.25	0.20	0.15
	Concrete/cement mortar (m^3)	0.085	0.075	0.065	0.045
Cement or concrete pointed dry masonry	Cobbls (m^3)	0.30	0.25	0.20	0.15
	Pebbles for filling (m^3)	0.05	0.045	0.040	0.030
	Cement mortar/concrete (m^3)	0.035	0.030	0.025	0.015

Table 3. Materials per cubic meter of cement mortar

Mortar type	Mix ratio \ Materials	Cement (bag)	Sand (m^3)	Pebbles (m^3)
Cement motar	1 : 3	10.00	1.00	-
	1: 4	8.00	1.00	-
Concrete	1 : 3.5 : 7	3.95	0.48	0.94
	1 : 4 : 8	3.45	0.48	0.95

3. Grass ditch: The area of grass to be planted may be calculated in the same way as in the case of masonry ditch, i.e. multiplying the total length of the ditch by the total length of the sides of cross section. Square meter is commonly used as the unit of measurement.

Table 4. Materials and Labor for Construction of Grassed Waterway (per square meter)(m^2)

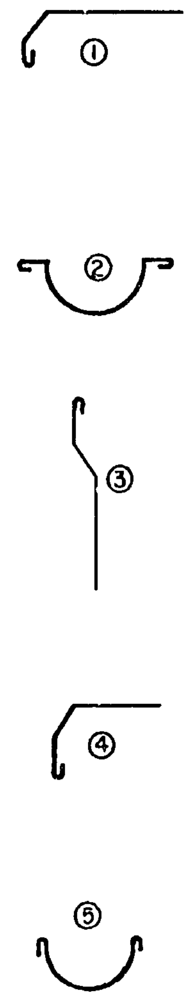
Item	Unit	Quantity	Remark
Grass seed	kg	0.003-0.01	
Planting Labor	man/day	0.1	
Fertilizer	kg	0.08	

4. Precast ditch: For easy handling, the most appropriate length of each section of a precast ditch is 60 cm.

Sizes and Materials for semi-circular precast concrete ditches

60 cm per section

Ditch width b (cm)	Ditch depth d (cm)	Wall thickness t (cm)	1 : 2 : 4 Concrete (m^3)	Cement (bag)	8 # Wire (0.1064 kg per m) No.	Length	Pcs.	Total length	Total weigth	Grand total of weight	Remark
						m	ea.	m	kg	kg	
20	10	4	0.014	0.09	①	0.75	1	0.75	0.08	0.61	
					②	0.56	4	2.24	0.24		
					③	0.7	2	1.4	0.15		
					④	0.36	2	0.72	0.08		
					⑤	0.06	1	0.6	0.06		
25	12.5	4	0.017	0.11	①	0.76	2	1.5	0.16	0.76	
					②	0.64	4	2.56	0.27		
					③	0.7	2	1.4	0.15		
					④	0.36	3	1.08	0.11		
					⑤	0.68	1	0.68	0.07		
30	15	4	0.019	0.12	①	0.75	2	1.5	0.16	0.80	
					②	0.71	4	2.84	0.30		
					③	0.7	2	1.4	0.15		
					④	0.36	3	1.08	0.11		
					⑤	0.76	1	0.76	0.08		
35	17.5	5	0.030	0.19	①	0.75	2	1.5	0.16	0.86	
					②	0.83	4	3.32	0.35		
					③	0.7	2	1.4	0.15		
					④	0.36	3	1.08	0.11		
					⑤	0.89	1	0.89	0.09		
40	20	5	0.033	0.21	①	0.75	3	2.25	0.24	0.93	
					②	0.91	4	3.64	0.39		
					③	0.7	2	1.4	0.15		
					④	0.36	4	1.44	0.15		
					⑤	0.96	1	0.96	0.10		
45	22.5	5	0.036	0.23	①	0.75	4	3.00	0.32	1.19	
					②	0.99	4	3.96	0.42		
					③	0.7	2	1.4	0.15		
					④	0.36	5	1.80	0.19		
					⑤	1.04	1	1.04	0.11		



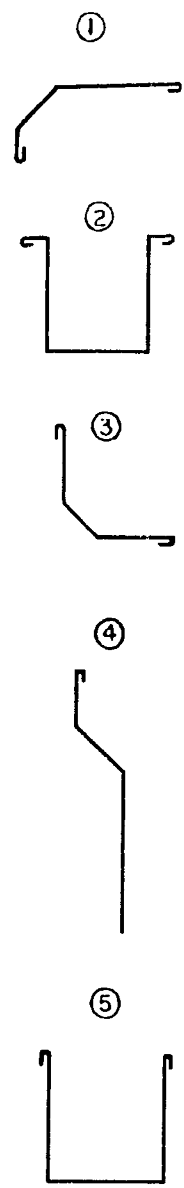
60 cm per section

Ditch width b (cm)	Ditch depth d (cm)	Wall thickness t (cm)	1 : 2 : 4 Concrete (m^3)	Cement (bag)	8 # Wire (0.1064 kg per m)						Remark
					No.	Length	Pcs.	Total length	Total weigth	Grand total of weight	
						m	ea.	m	kg	kg	
50	25	6	0.051	0.33	①	0.75	4	3.0	0.32	1.25	
					②	1.10	4	4.4	0.47		
					③	0.7	2	1.4	0.15		
					④	0.36	5	1.8	0.19		
					⑤	1.17	1	1.17	0.12		
55	27.5	6	0.025	0.35	①	0.75	5	3.75	0.40	1.41	
					②	1.18	4	4.72	0.50		
					③	0.7	2	1.4	0.15		
					④	0.36	6	2.16	0.23		
					⑤	1.25	1	1.25	0.13		
60	30	6	0.059	0.38	①	0.75	5	3.75	0.40	1.49	
					②	1.26	4	5.04	0.54		
					③	0.7	2	1.4	0.15		
					④	0.36	6	2.4	0.26		
					⑤	1.33	1	1.33	0.14		

Sizes and materials for U-shape precast concrete ditches

60 cm per section

Ditch width b (cm)	Ditch depth d (cm)	Wall thickness t (cm)	1 : 2 : 4 Concrete (m³)	Cement (bag)	8 # Wire (0.1064 kg per m) No.	Length	Pcs.	Total length	Total weigth	Grand total of weight	Remark
						m	ea.	m	kg	kg	
20	25	4	0.025	0.16	①	0.75	2	1.5	0.16	1.15	
					②	0.92	4	3.48	0.39		
					③	0.30	6	1.80	0.19		
					④	0.70	4	2.8	0.30		
					⑤	1.08	1	1.08	0.11		
25	30	4	0.029	0.19	①	0.75	2	1.50	0.16	1.25	
					②	1.07	4	4.28	0.46		
					③	0.32	6	1.92	0.20		
					④	0.70	4	2.80	0.30		
					⑤	1.23	1	1.23	0.13		
30	40	4	0.036	0.23	①	0.75	3	2.25	0.24	1.65	
					②	1.32	4	5.28	0.56		
					③	0.37	6	2.22	0.24		
					④	0.70	6	4.2	0.45		
					⑤	1.48	1	1.48	0.16		
35	45	5	0.054	0.35	①	0.75	3	2.25	0.24	1.77	
					②	1.50	4	6.0	0.64		
					③	0.40	6	2.40	0.26		
					④	0.70	6	4.2	0.45		
					⑤	1.70	1	1.70	0.18		
40	50	5	0.059	0.38	①	0.75	4	3.0	0.32	1.94	
					②	1.65	4	6.6	0.70		
					③	0.42	6	2.52	0.27		
					④	0.70	6	4.2	0.45		
					⑤	1.85	1	1.85	0.20		
45	55	5	0.065	0.42	①	0.75	4	3.00	0.32	2.19	
					②	1.80	4	7.20	0.77		
					③	0.45	6	2.70	0.29		
					④	0.70	8	5.60	0.60		
					⑤	2.00	1	2.00	0.21		



60 cm per section

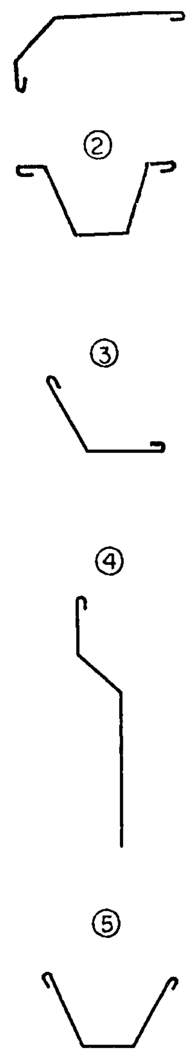
Ditch width b (cm)	Ditch depth d (cm)	Wall thickness t (cm)	1 : 2 : 4 Concrete (m^3)	Cement (bag)	8 # Wire (0.1064 kg per m)						Remark
					No.	Length	Pcs.	Total length	Total weigth	Grand total of weight	
						m	ea.	m	kg	kg	
					①	0.75	4	3.00	0.32		
					②	1.98	4	7.92	0.84		
50	60	6	0.089	0.58	③	0.47	6	2.82	0.30	2.30	
					④	0.70	8	5.60	0.60		
					⑤	2.22	1	2.22	0.24		
					①	0.75	5	3.75	0.40		
					②	2.13	4	8.52	0.91		
55	65	6	0.096	0.62	③	0.50	6	3.00	0.32	2.48	
					④	0.70	8	5.60	0.60		
					⑤	2.37	1	2.37	0.25		
					①	0.75	5	3.76	0.40		
					②	2.28	4	9.12	0.97		
60	70	6	0.103	0.67	③	0.52	6	3.12	0.33	2.71	
					④	0.70	10	7.00	0.74		
					⑤	2.52	1	2.52	0.27		

201

Sizes and materials for trapezoidal-shape precast concrete ditches

60 cm per section

Ditch width b (cm)	Ditch depth d (cm)	Wall thickness t (cm)	1 : 2 : 4 Concrete (m^3)	Cement (bag)	8 # Wire (0.1064 kg per m)						Remark
					No.	Length	Pcs.	Total length	Total weigth	Grand total of weight	
						m	ea.	m	kg	kg	
20	15	4	0.0216	0.140	①	0.75	2	1.50	0.16	0.93	
					②	0.76	4	3.04	0.32		
					③	0.40	6	2.20	0.26		
					④	0.70	2	1.40	0.15		
					⑤	0.68	1	0.68	0.44		
25	17.5	4	0.0250	0.163	①	0.75	3	2.25	0.24	1.11	
					②	0.86	4	3.44	0.37		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	0.82	1	0.82	0.09		
30	20	4	0.0253	0.184	①	0.75	4	3.00	0.32	1.24	
					②	0.97	4	3.88	0.41		
					③	0.40	6	2.4	0.26		
					④	0.70	2	1.4	0.15		
					⑤	0.93	1	0.93	0.10		
35	25	5	0.0458	0.298	①	0.75	5	3.75	0.40	1.41	
					②	1.16	4	4.64	0.49		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.06	1	1.06	0.11		
40	30	5	0.0524	0.341	①	0.76	6	4.50	0.48	1.59	
					②	1.32	4	5.23	0.56		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.27	1	1.27	0.14		
45	32.5	5	0.0569	0.370	①	0.75	7	5.25	0.56	1.73	
					②	1.43	4	5.72	0.61		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.38	1	1.38	0.15		



60 cm per section

Ditch width b (cm)	Ditch depth d (cm)	Wall thickness t (cm)	1 : 2 : 4 Concrete (m^3)	Cement (bag)	8 # Wire (0.1064 kg per m)						Remark
					No.	Length	Pcs.	Total length	Total weigth	Grand total of weight	
						m	ea.	m	kg	kg	
50	35	6	0.0796	0.517	①	0.75	7	5.25	0.56	1.79	
					②	1.56	4	6.24	0.66		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.50	1	1.60	0.16		
55	37.5	6	0.0852	0.554	①	0.75	8	6.00	0.64	1.93	
					②	1.67	4	6.63	0.71		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.61	1	1.61	0.17		
60	40	6	0.0916	0.595	①	0.75	8	6.00	0.64	1.98	
					②	1.77	4	7.08	0.75		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.71	1	1.71	0.18		

Appendix 8. Conversion of Weights and Measures

1. Long Measure

Cemti-meter	Metey	Kilo-meter	Inch	Foot	Yard	Mile	Shaku*
1	0.01	0.00001	0.3937	0.032808	0.010936		0.033
100	1	0.001	39.37	3.280833	1.09361	0.000621	3.3
100,000	1,000	1	39,370	3,280.83	109.363	0.62137	3.300
2.540005	0.0254		1	0.083333	0.02778		0.08382
30.48006	0.304801	0.000305	12	1	0.333333	0.000189	1.00582
91.44018	0.914402	0.000914	36	3	1	0.000568	3.017746
	1,609.347	1.609347		5.280	1.760		15,310.878
30.303	0.30303		11.9303	0.99419	0.3314		1

2. Square Measure

Sq. centi-menter	Sq.meter	Sq. Kio-meter	Are	Hectare	Chia	Acre
1	0.0001					
10,000	1	0.000001			0.0001031	0.000247
1,000,000	1,000,000	1	10,000	100	103,102	247,104
1,000,000	100	0.0001	1	0.01	0.01031	0.02471
	10,000	0.001	100	1	1.03102	2.471044
	9,699.2	0.0096992	96,992	0.96992	1	2.39680
0.0015625	4,046.87	0.004070	40.4630	0.404687	0.41724	1

3. Cubic Measure and Capacity

Cu.centi-meter	Cu.meter	Liter	Hecto-liter	Cu.inch	Cu.foot	Imperial gallon	U.S. gallon
1	0.000001	0.001		0.061023	0.0000353	0.000220	0.00026417
1,000,000	1	999.973	9.99973	61,023.38	35.3145	219.97	264.17
1,000,027	0.01	1	0.01	61.025	0.035315	0.21997	0.264178
	0.1	100	1	6,102.5	3.53145	21.997	26.4178
16.3872	0.0000164	0.016387	0.000164	1	0.000579	0.00360	0.0043289
28.317	0.028317	28.316	0.28316	1.728	1	6.229	7.48052
	0.00456	4.5460	0.04543	277.418	0.16054	1	1.20094
3,785.43	0.0037854	3.7854	0.03785	231	0.133681	0.8327	1

4. Weights

Milligram	Gram	Kilogram	Metric ton	Catty*
1	0.001	0.000001		
1,000	1	0.001	0.000001	0.001667
1,000,000	1,000	1	0.001	0.16667
	1,000,000	1.000	1	1,666.67
600,000	600	0.6	0.0006	1
28,349.5	28.3495	0.0283495		0.047249
	453,592	0.453592	0.000454	0.756
		1,016.05	1.01605	1,693.4167
	907,184.9	907.1849	0.90718	1,511.97

Ounce	Pound	Long ton	Short ton
0.0353	0.002205	0.00000098	0.0000011
3.27395	2.204622	0.000984	0.0011023
	2,204.6	0.9842	1.1023
21.164	1.3228	0.0005905	0.0006614
1	0.0625	0.0000279	0.0000313
16	1	0.00045	0.0005
35,840	2,240	1	1.12
32,000	12,000	0.89298	1

5. Velocity

Meter/Sec	Foot/Sec	Meter/Min	Foot/Min	Km/Hr	Mile/Hr	Knot/Hr
1	3.2808	60.0	196.848	3.6	2.237	1.9438
0.3048	1	18.288	60.0	1.0973	0.6818	0.5935
0.01667	0.05468	1	3.2808	0.06	0.037282	0.32396
0.00508	0.01667	0.3048	1	10.018288	0.0113636	0.09875
0.2778	0.911348	161.667	54.6824	1	0.6217	0.540
0.46704	1.6532275	26.8223	87.9993	1.60934	1	0.069
0.5144	1.6878	30.864	101.264	1.8520	1.508	1

6. Flow

M^3/Sec	M^3/Min	Liter/Sec	Liter/Min	Cu.ft./Sec	Cu.ft./Min	US gallon /Sec	Imp.gallon /Sec
1	60.00	1,000.0	60,000.0	35.31	21.9	264.2	220.00
0.016667	1	16.667	1,000.0	0.5886	35.31	4.403	3.667
0.$_{0}^{2}$1000	0.0600	1	60.0	0.03531	2.1189	0.2642	0.2200
0.$_{0}^{4}$16667	0.$_{0}^{2}$1000	0.016667	1	0.$_{0}^{3}$5886	0.03532	0.$_{0}^{2}$4403	0.$_{0}^{2}$3667
0.02832	1.6990	28.32	1,699.0	1	60.00	7.481	6.229
0.$_{0}^{3}$04719	0.02832	0.4720	28.32	0.016667	1	0.12468	0.10382
0.$_{0}^{2}$3785	0.2271	3.785	277.13	0.13368	8.0208	1	0.8327
0.$_{0}^{2}$4546	0.2728	4.546	272.8	0.16054	9.6324	1.2009	1

7. Pressure

Atmospheric Pres sure	Mercury Column	Water Column		Metric ton/ sq. meter	Kg./Sq. centimeter	Lb./Sq. foot	Lb./Sq. inch
	Millimeter	Foot	Meter				
1	760	33.9014	10.33296	10.33296	1,033296	2116.335	14.6966
0.0013158	1	0.044607	0.013596	0.013596	0.0013596	2.784651	0.0193376
0.029497	22.4179	1	0.30479	0.030479	0.030479	62.42618	0.43351
0.0967777	73.55104	3.2809	1	1	0.1	204.814	1.4223
0.967777	735.5104	32.809	10	10	1	2,048.14	14.223
0.004725	0.35911	0.0160189	0.0048825	0.00448825	0.00048825	1	0.00694436
0.068043	51.71264	2.30675	0.70308	0.70308	0.070303	144.0	1

*Measures of Taiwan

Appendix 9. Distribution of Slopelands at Various Elevations in Taiwan

Unit: Hectare

	Total			Below 100 m			100 - 1,000 m			Above 1,500 m			Total		
	Area	Percentage		Area	Percentage		Area	Percentage		Area	Percentage		Area	Percentage	
		A%	B%		A%	B%		A%	B%		A%	B%		A%	B%
Taipei City	27,214	100	–	16,759	61.95	–	10,361	38.07	–	94	0.35	–	–	–	–
Kao hsiung City	15,361	100	–	14,742	95.97	–	619	4.03	–	–	–	–	–	–	–
Taiwan Province	3,556,401	100	100	992,257	27.90	100	1,384,771	38.94	100	424,777	11.90	100	754,596	21.13	100
Keelung City	13,276	100	0.37	7,613	57.24	0.77	5,663	42.76	0.41	–	–	–	–	–	–
Taipei County	205,233	100	5.77	45,908	22.37	4.63	142,632	69.50	10.30	14,869	7.24	3.50	1,824	0.89	0.24
Ilan County	213,746	100	6.01	33,132	15.50	3.34	102,757	48.08	7.42	41,134	19.24	9.68	36,723	17.18	4.87
Taoyuan County	122,089	100	3.43	37,006	30.31	3.73	65,051	53.28	4.70	13,344	10.93	3.14	6,688	5.48	0.89
Hsinchu County	153,169	100	4.31	25,962	16.95	2.62	71,207	46.49	5.14	19,634	12.82	4.62	36,366	23.74	4.82
Miaoli County	182,031	100	5.12	42,829	23.53	4.32	80,758	30.87	4.57	15,9832	7.79	3.76	72,869	20.28	4.89
Taichung County	205,147	100	5.77	52,975	25.82	5.34	63,320	44.37	5.83	21,520	11.82	5.07	36,924	45.52	9.66
Taichung City	16,342	100	0.46	6,437	39.39	0.65	9,905	60.61	0.72	–	–	–	–	–	–
Changhua County	107,440	100	0.46	6,437	39.39	0.65	9,905	60.61	0.72	–	–	–	–	–	–
Nantou County	410,644	100	11.55	29,198	7.11	2.94	111,931	47.26	8.08	93,078	22.67	21.91	176,437	42.36	23.38
Yunlin County	129,084	100	3.63	94,132	72.92	9.49	33,604	26.03	2.43	1,062	0.83	0.25	286	0.22	0.04
Chia-I County	195,139	100	5.49	52,962	27.14	5.34	98,203	50.32	7.09	19,512	10.00	4.59	24,462	12.54	3.42
Tainan County	201,601	100	5.67	158,052	78.40	15.93	43,344	21.50	3.13	205	0.10	0.05	–	–	–
Kao hsiung County	279,266	100	7.85	82,204	29.44	8.28	86,539	30.99	6.25	36,201	12.96	8.52	74,322	26.61	9.85
Ping tung County	277,560	100	7.80	116,842	42.10	11.78	118,989	42.87	8.59	23,577	8.49	5.56	18,152	6.54	2.40
Taitung County	351,525	100	9.88	32,966	9.39	3.33	174,664	49.69	12.61	56,315	16.02	13.26	87,550	24.90	11.60
Hualien County	462,857	100	13.01	41,541	8.97	4.19	170,981	36.94	12.35	68,343	14.77	16.09	181,992	39.32	24.12
Penghu County	12,686	100	0.36	12,686	100	1.28	–	–	–	–	–	–	–	–	–
Tainan City	17,565	100	0.49	17,565	100	1.77	–	–	–	–	–	–	–	–	–
Taiwan's Total	3,598,976	100	–	1,023,758	28.44	–	1,395,751	38.78	–	424,871	11.81	–	754,596	20.97	–

Remark: A% Percentage of the total area of the city or county
B% Percentage of Taiwan's total area at that elevation

SOIL CONSERVATION HANDBOOK

Part II

Engineering Work

1995

2/6

CONTENT

page

218

Tables

III. Engineering Construction and Maintenance

VI. Appendices

SOIL CONSERVATION HANDBOOK

Part II. Engineering Work

I. General Description

Chapter 1. Control of Wild Creeks

1.1 Introduction

Wild Creek Control is to provide engineering control practices in turbulent unstable river channels where banks or beds are eroded, scoured or collapsed, or where debris has been deposited, due to natural factors or the effects or human development in the middle or upstream reaches of ordinary rivers or small creeks along the edges of rolling land. Its purpose is to prevent or reduce river channel erosion, scouring and collapsing, and to efficiently control moving debris, for stabilization of the river flow line in order to reduce flood and sediment damage. The primary objective is to practise efficient and economical control measures, mainly with regard to debris source and damage areas.

1.2 Planning and Design Principles

(1) Determination of control areas: With reference to local social, economic and environmental conditions, seriously eroded or collapsed areas, areas where debris has been deposited, potentially dangerous areas and planned protection areas, are demarcated as control areas according to actual survey information. As the selection of control areas has a close relation to investment, benefits, construction and maintenance of engineering work, it is necessary to survey the control areas in detail.

(2) Overall control plan: It is necessary to work out the entire control plan, applying system concept and theory and regarding the watershed area as a unit.

(3) The control plan has to establish priorities in order of importance.

(4) It is necessary to consider the correlation between the control plan and neighboring watershed areas.

1.3 Methods and Measures

(1) As damage factors of a creek in a watershed area are very complex, not only must the selection of engineering methods meet the technical requirements, but it is necessary to select a suitable control method according to the local natural environment, engineering circumstances and socio-economic conditions.

The damage control objects and their related engineering control works are listed in the following table for reference in planning.

22

Table 1-1. Damage Control Objects and Related Control Works

Control Objects	Related Control Works
1. Slope erosion, serious gully-erosion area	Reforestation, vegetation, gully control, longitudinal and lateral drainage, hillside works, check dam.
2. Bank collapsing area	Runoff dam, bed fixing works, submerged dam revetment, spurdike, vegetation, drainage.
3. Turbulent flow river section	Submerged dam, regulation works, check dam, levee, spurdike
4. River with serious deposition	Check dam, submerged dam, sediment detention works, earth dam
5. Longitudinal erosion	Check dam, bed fixing works, submerged dam
6. Debris flow area	Check dam, bed fixing works, continuous dams, sediment detention works
7. Runoff detention (area)	Runoff detention dam

The control of wild creeks through engineering work in watershed areas is not usually achieved by a single item of treatment. In order to attain the purpose of the control plan, application of a combination of different methods is often necessary.

(2) Criteria for Flood Estimation

a. For check and submerged dams, rainfall intensity with a frequency of once in 50 years is used for flood computation.

b. For regulation works, levees, revetment, spurdikes etc., rainfall intensity with a frequency of once in 25-30 years is used for design. A 25-year-frequency is generally adopted for small gullies. For the upstream watershed of areas with a dense population or important installations, rainfall intensity with a frequency of once in more than 50 years may be used for flood computation.

c. The flood discharge cross-sectional area of a structure is to be enlarged by 10-50% (depending on the type of a structure) considering debris flow and drifting timber. Sites of individual construction works are to be properly analyzed and selected according to survey records, topographical and geological conditions, creek characteristics and construction purposes etc.,

d. It is more effective and economical to adopt a series of low check dams rather than a single high dam (more than 5 meters) in a steep and narrow creek, so that the riverbed is adjusted into a stair shape.

e. It is preferable to construct a check dam or submerged dam at the upstream end of regulation work. Facilities to stabilize river bed and dissipate water energy must be provided at the downstream end of regulation work. At the same time, careful consideration and review must be made for the safety of the downstream area, so that there is coordination with any downstream control work, in order to achieve the best result.

f. Levees and revetments are generally provided with spurdikes. However, these should not to be used in a creek less than 30 meters wide. In designing a spurdike to divert river flow, special attention must be paid to the safety of the opposite bank.

g. Levees, revetments and regulation works are designed to be in a straight line as far as possible. In a curved section, the concave bank must be heightened and strengthened. The curvature may be more than 10-20 times the creek width, or the creek width may be increased by 10%-20% in the curved section of the channel.

1.4 Precautions

(1) Construction of access roads must be carefully arranged so as to minimize excavation and keep the danger of soil erosion and environmental damage to a minimum.

(2) Excess earth left by excavation and embankment must be properly placed and treated with soil conservation measures in order not to block water flow.

(3) If explosives are used to excavate the foundations of dam and wing walls, the amount of explosive must be carefully regulated to avoid moving adjacent stones and earth, in order to maintain the strength of the foundation.

(4) Banks filled with earth must be thoroughly compacted. Concrete or cobble paving may be used to give extra strength.

(5) If the soil is soft and weak in bearing capacity beyond the designed depth of foundation excavation, the design should be revised to allow the foundation to be deeper or to provide piles for strengthening.

(6) Attention must be paid to drainage for sudden rainstorms during construction, so that the runoff does not bury the foundation or wash construction materials away.

Chapter 2. Torrent Control

2.1 Introduction

Torrent control is a treatment which uses engineering methods to stabilize active gullies and prevent further deterioration.

Gullies grow wider and deeper with accelerated erosion due to natural factors or improper use of land. If active gullies are not controlled at an early stage, they will continue to deteriorate, and will not only damage the area they are in, but also harm property and public installations in downstream area by causing sedimentation and floods.

This chaper deals with gullies which are less than 20 meters in width and which be within a watershed area of 5-20 ha. If a gully exceeds this limit, refer to the chapter on "Wild Creek Control".

2.2 Planning and Design Principles

The method of torrent control is to be properly selected, depending on the topographic situation, the purpose of treatment, gully size, watershed area, gully slope, soil properties, drainage conditions, vegetation status, land use, construction equipment and materials as well as the required degree of control etc. Torrent control is to be systematically planned and designed according to its requirements, economic conditions, and soil conservation treatments on both banks. It should also be coordinated with any wild creek control downstream.

In general, a single method of torrent control cannot achieve this purpose. Usually several methods of control must be applied simultaneously.

2.3 Methods and Measures

(1) Runoff diversion

This is based on the construction of water interception work to reduce runoff flowing into the gully.

a. Interception ditch

This is a ditch to divert all or some of the runoff to a safe point in the gully. In the gully head treatment, ditches must be properly located upstream.

b. Adjustment of sloping faces

This is to adjust the sloping faces of the gully to a relatively flat slope in order to stabilize water flow. Dangerous escarpments and moving stones, as well as trees and weeds along the bank, must be removed in order to avoid clogging in the gully. This measure is usually adopted for gullies with unstable water flows, especially when use of construction equipment is permissible.

(2) Revetment construction

In order to prevent widening of the channel, revetments should be provided in the curved section of a gully.

(3) Flow control

Regulation work may be provided to control water flow and prevent it from deflecting, in order to avoid widening the gully.

(4) Fixing work on riverbeds, check dams etc.

This is done to adjust the slope of the riverbed, to fix the channel, and to deposit debris so as to stabilize the gully.

(5) Runoff detention dams and reservoirs

The purpose of these is to reduce the peak of flood water and slow its movement.

(6) Check dams

Check dams are built in places where excessive amount of debris are carried in the flow.

2.4 Precautions:

(1) Erosion control treatments must be provided on both banks of the gully.

(2) In remote areas, cables may be used for transport in stead of constructing access road for transport of construction equipment and materials.

(3) Earth work is preferably to be done during the dry season.

(4) Excess earth should be deposited in a safe place.

(5) Construction of earth, masonry and structures must minimize damage to slopeland and vegetation.

Chapter 3. Investigation and Treatment of Landslides

3.1 Introduction

Landslide treatments are to stabilize collapsing lands by engineering and vegetation methods. In Taiwan, landslides may be classified into five categories: avalanches, landslips, creeps, debris flows, and gully erosion. In an avalanche, the moving body, of earth causes great destruction, present in a disunited collapsing form. In landslips, the moving body may not have great destructive power and still maintains its original relation to the non-slipping body. In substratal landslips, the moving body moves at a very low velocity and its sliding surface is not obvious. Debris flow consists of a mixture of water and solid materials such as silt, sand, gravel and large rocks, moving at a fast speed generated by the force of gravity. The gully erosion features the collapse of sloping surfaces following formation of gullies through erosion. For landslide treatment, the primary procedures are firstly to investigate the cause and type of the landslide, and then to analize the stability of land, according to topographic and geological conditions and soil characteristics, and finally to adopt proper protection measures.

3.2 Planning and Design Principles

(1) Investigation and treatment of landslides must follow the flow chart shown in Figure 3-1.

(2) Before investigation into a landslide begins, it is necessary to find out first the natural and human environment of the landslide and its neighboring areas. The required information includes topography, buildings, geology, soils, meteorology, hydrology, land use history, air photographs taken on different dates, documents and reports (technical and historical publications etc.), newspaper records of any past damage, existing damage prevention measures, etc.

(3) Investigation should cover an area larger than the projected watershed and damage area related to the landslide. Investigation should be made of its type, scale, cause and influence, with on-site investigation (topography, buildings, geology, vegetation, land use and actual damage investigation), survey (topography, longitudinal profile and cross section), physical tests, geological survey and groundwater exploration (groundwater level, pore pressure, groundwater aquifers, permeability, water quality analysis), slip surface survey, and ground surface and underground movement observation etc..

During the process of investigation, preliminary treatment measures may be taken according to the actual situation.

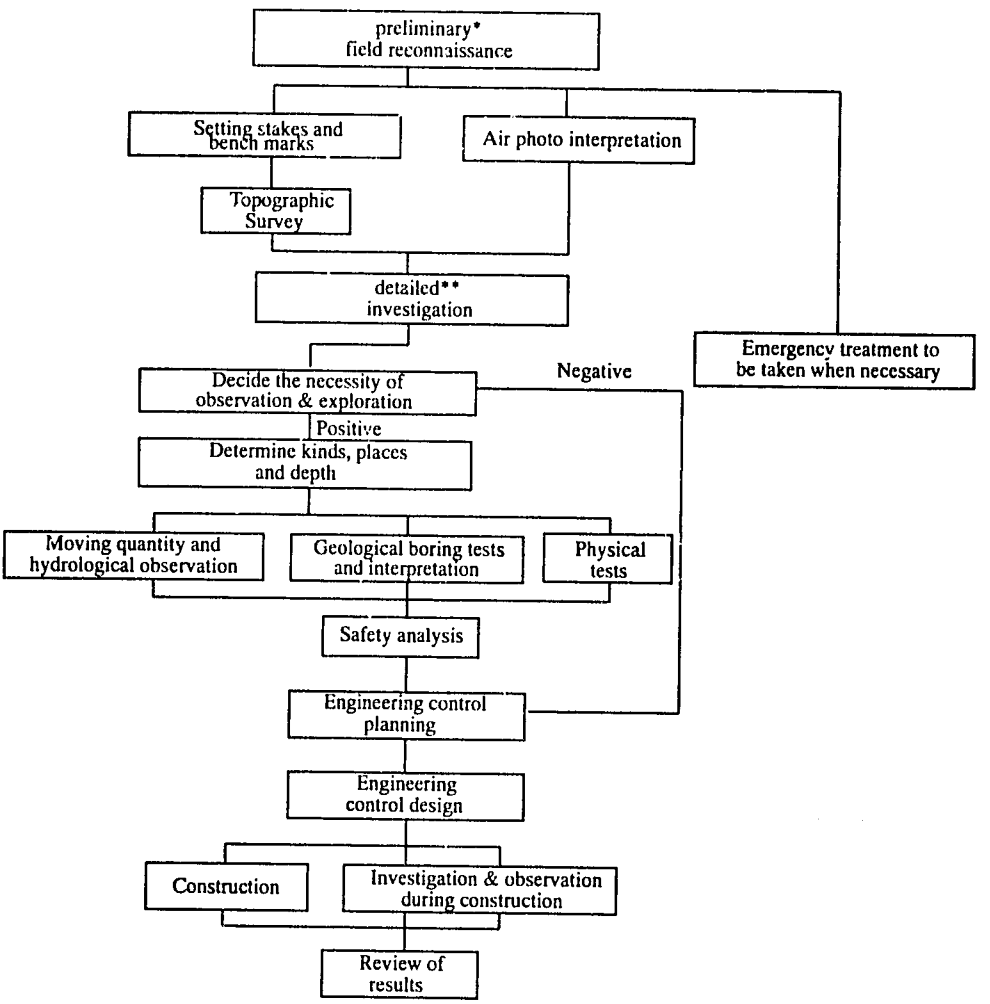
(4) Preliminary treatment measures include warning signs, temporary drainage facilities, prevention of surface water seepage (using plastic sheets or by filling cracks with clay for example), strengthening of hillsides (as with the use of earth dikes or wire sausages). Precise observation on the movement of sideslopes should be made.

(5) The scale of engineering control work depends on the seriousness of the collapse, the

importance of protected objects and financial conditions.

(6) If the landslide is serious, the object to be protected is important and financial resources are available, a survey of the sliding mechanism should be conducted. This survey includes a three dimensional investigation of factors in the sliding area, such as geological formations of the slipping body, depth of the slipping surface, slipping type and scale, slipping layer, hydrologic conditions etc.. The survey method usually includes the setting of survey base lines, boring tests, mechanical experiments and slope stabilization analysis.

(7) During construction, continued investigation is necessary. Proper precautionary measures may have to be taken depending on the situation.



* Topography, geology, hydrology etc.
**Topography, geology, natural and social environment, vegetation, hydrology etc.

Fig. 3-1. Landslide investigation and treatment flow chart

3.3 Methods and Measures

Engineering work to control landslide can be classified into two classes, control work and prevention works. Control work covers various engineering measures to stabilize sideslopes by changing sloping topography, groundwater or other parts of the natural environment, such as slope adjustment, drainage etc.

Prevention work is to prevent landslides by the use of engineering structures such as piles, retaining walls etc. for immediate effect, on the basis of the priority of the work plan and the maximum rate of return. A single method or a combination of methods should be chosen for the most efficient performance.

(1) Surface drainage

Drains (using impervious structures, and flexible materials in possible landslide areas) and seepage prevention works (using clay, plastic sheets, asphalt, etc.) are employed.

(2) Removal of groundwater

This includes the use of culverts, drainage holes, collecting wells, groundwater interception work etc. Culverts are usually placed beneath the sliding part where the topography changes, or under the face of concave slopes where water easily accumulates. Drainage holes are driven into the aquifer to an appropriate depth, at an inclining angle greater than 5° (to facilitate draining of groundwater). In some cases, collecting wells are used, depending on groundwater conditions.

(3) Earth excavation

It is necessary to try to minimize energy consumption, at the time when the area and depth of earth excavation is being determined.

Also, maintenance of the stability of the upper slopes should be considered. In principle, sloping land should be excavated in steps so that the slope is not too long. Furthermore, the excavated slope surface should be protected against erosion.

(4) Earth embankments

The foundation is not to be damaged by the earth embankment. Before the embankment is built, vegetative cover must be removed. For slope treatment, refer to the chapter on Sideslope Stabilization.

(5) Retaining walls

There are many kinds of retaining wall. They should be built in places where the excavation of wall's foundations will not cause a landslide.

(6) Piles

These include steel piles, synthetic piles, H steel piles and reinforced concrete piles. Piles must be placed along the lower edge of the hillside where sufficent bearing force exists.

(7) Deep foundation piles

Deep foundation piles are cast in place to resist earth movement. These piles are used in places where driven piles are not effective or pile driving machines are not feasible due to topographic conditions. There are two kinds of deep foundation piles, namely steel casing plate piles and reinforced concrete piles. Since these piles are expensive, there should be a comparison with other methods before the decision is made to use them.

(8) Anchors

In general, anchors are set 1.5-3 meters apart, using the most economical and efficient angle of boring.

(9) Protection of slope surfaces

These include agronomic, vegetative and engineering methods, to be adopted individually or in combination. Please refer to Section 5-3.

3.4 Precautions

(1) It is necessary to decide on the location of retaining facilities with care, especially when there are several combined sliding faces, in order to avoid increasing the load on the lower face of the silde.

(2) In studies of vegetation, special attention should be paid to unusual phenomena, such as withered, trees, cracks or bends in tree trunks, fallen trees etc..

(3) The base line of a topographic survey must be set in the stable area outside the sliding land.

(4) The main line of measurement must pass through the represientive point of a body of sliding land.

(5) In general, boring tests must reach a sufficient depth to pass through the sliding face or stable foundation soil.

(6) Safety factors must be determined according to the importance of objects to be protected, and their distance, location and risk of damage.

(7) Retaining walls, piles, caisson foundations, and anchors should be placed on firm bedrock.

Chapter 4. Control of Debris Flow

4.1 Introduction

Debris flow is a mixture of silt, sand, gravel and large rocks, its movement generated by the force of gravity. In a broad sense, debris flow have complex mechanical characteristics and their type and mechanism of movement are outside Newton's fluid category, since they contain a mixture of water and solid substances. Research and observation have shown that debris flows generally have the following characteristics:

(1) The distribution of particle size of gravel which are the component materials of debris flows is affected by geological and weathering conditions. It covers a wide range from several meters to less than 0.01 millimeters in size.

(2) According to the distribution of different component materials, debris flows may be classified as follows:

Gravel type debris flows: Contains less than 10% micro particles 0.1 millimeters in size.

Silt type debris flows: Contains more than 50% micro particles 0.1 millimeters in size.

Those with a micro particle content of between 10% and 50% are called common debris flows.

(3) The unit weight of debris flows (in motion) is in the range of 1400-2,300 kg/m^3.

(4) A debris flow usually moves intermittently. When the flow front stops, the following portion builds up as a result of inertia, increasing the pressure on the front and making it flow again.

(5) The front portion of a debris flow presents a wave form and accumulates rubble, as shown in Figure 4-1. In comparison with the large quantity of rubble in the front portion, both the size and density of gravels in the following portion of the debris flows is much lower.

(6) A cross-section of a debris flow in motion shows a convex shape at the front and a concave shape in the following portion as shown in Figure 4-1.

(7) The velocity of the surface of a debris flow is obviously greater than its mean velocity. Also, its velocity on the surface is higher than that at the bottom.

(8) The velocity of a debris flow is affected by the size and density of debris carried and the slope of the creek. The velocity of a gravel type debris flow is about 3-10 m/s, while that of a silt type debris flow is about 2-20 m/s.

(9) A debris flow forms an alluvial fan at the outlet of the creek, where its slope becomes flat and its width is extended.

(10) Debris flows occur mostly in places with a slope ranging from 15° to 30° , while the slopes of alluvial fans are mostly in the range of 3–6° .

In addition to these characteristics, debris flows have four stages of development, namely the intial stage, the flowing stage, the deposition stage and the treminal stage.

Each stage has to meet certain physical conditions (density, slope etc.) to be sustained. If planning and design work for devris flow control takes these into account, prevention of damage can be achieved efficiently and economically, and human lives, properties, and public facilities, as well as the natural environment, can be protected.

4.2 Planning and Design Principles

Planning and design of debris flow control measures should follow the principles listed below:

(1) Identification of creeks and areas endangered by debris flow: Creeks and areas endangered by debris flow can be identified by the use of topographical maps and air photographs, together with field surveys. Precise identification of dangerous creeks may help planning and design workers in adopting better preventive measures.

(2) After creeks or areas with potentially dangerous debris flow are identified, warning systems must be established before control engineering works are implemented. Even after the completion of control engineering works, any removal of these warning systems should be made with due care.

(3) Engineering measures to control debris flow:

These include methods to suppress, check, divert, or buffer debris flow to promote deposition.

(4) These methods should be properly integrated to fulfill the overall requirements of the project, according to the characteristics of each stage of debris flow development (initial, flowing, deposition and treminal).

(5) Estimating the quantity of various contents of a debris flow:

Before planning of work to control debris flow is begun, values related to debris quantities, as required by the following equation, are to be estimated, in order to determine the size, number, distribution and procedures of the control work.

$$Q - E - (C + D + B) = 0$$

Q=design outflow quantity; to be estimated on be basis of the quantity of debris flowing out of the creek in the past, and debris deposited on the river bed.

E=allowable discharge quantity ; safe to the downstream area.

C=planned check quantity; quantity of debris to be trapped by the checking method.

D=planned deposit quantity; debris quantity to be deposited by the depositing method.

B=planned suppressed quantity; the debris quantity reduced by the suppressing method.

From the above equation, it is known that the residual of the debris outflow quantity (Q) minus the allowable discharge quantity (E), is the amount of debris to be controlled by various control methods.

4.3 Methods and Measures

(1) Suppressing flow

This is applied to the upstream section of a creek. Since this section is steep, debris flows occur quite often. Scouring is so serious on the bed and banks of a creek during the initial stage that debris content will increase to such an extent that the debris will soon attain the density of abnormal debris flow. Therefore, in the upstream steep slope section, debris flow control is to protect the creek bed and banks from scouring and to stop the supply of debris materials to the flow. This kind of control method includes the fixing of river beds, submerged dams, serial dams, and hillside works.

(2) Checking flow

This method is mainly used in the mid-upstream section of a creek when the density of a debris flow which carries sufficient debris materials from the upstream section reaches saturation, and the scouring power of the flow has decreased. However, the flow still has great inertia, and its front containing rubble and drifting timber still has a strong destructive force.

(3) Promoting deposition

This method mainly consists of widening the creek bed or reducing the bed slope in particular places, to promote the deposition of debris in properly designed silting basin.

(4) Diverting flow

This is mainly applied to a downstream section or an alluvial fan area, to divert debris flow along a safe route using a canal or leading dike.

(5) Buffer forest zone

This is mainly used on an alluvial fan area in the course of a debris flow, to prevent direct intrusion of debris flow by using a forest belt as a buffer.

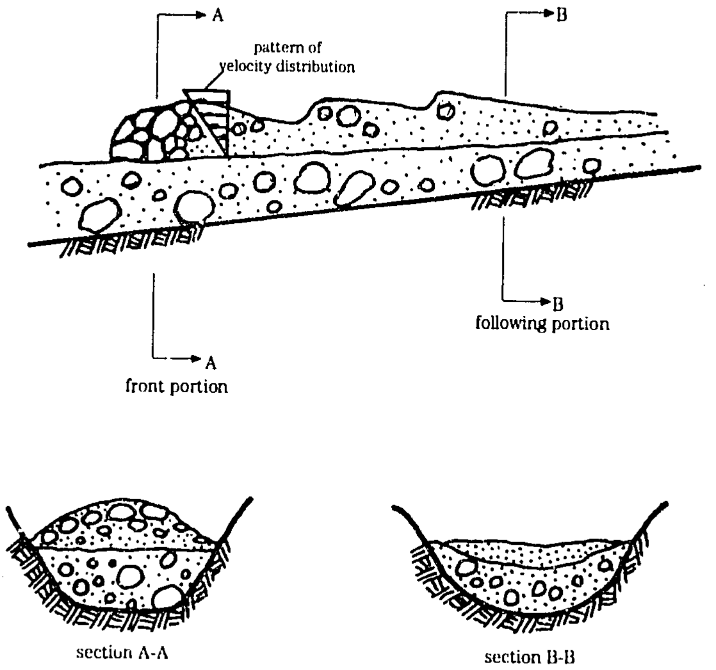


Fig. 4-1. Longitudinal and cross sections of debris flow in motion

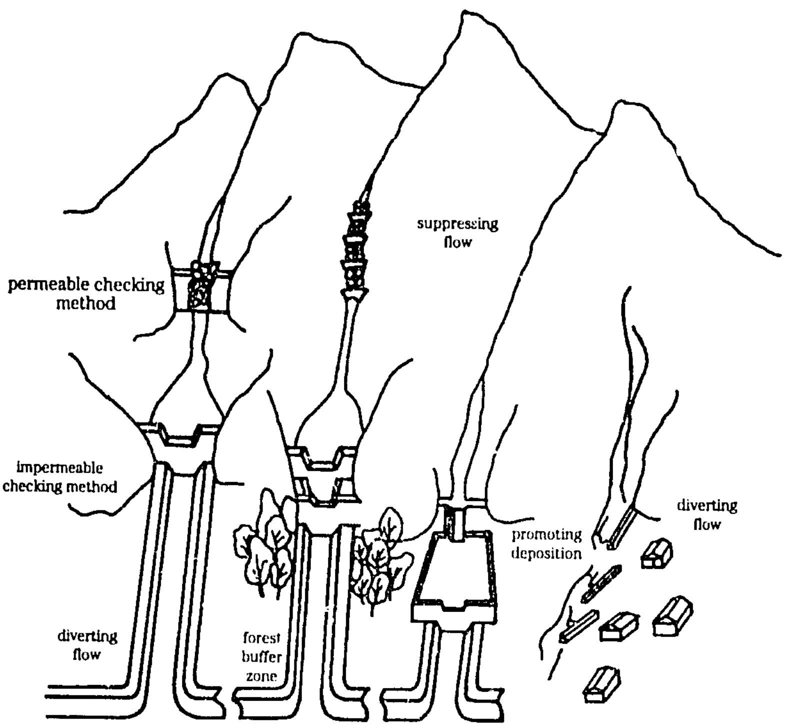


Fig. 4-2. Layout of various control methods

233

4.4 Precautions

(1) Special consideration should be made of the possible impact of large rocks, in addition to the mean load, in any safety analysis of structures to control debris flow.

(2) The width of a canal or the distance between two leading dikes for debris flow diversion must be determined according to the maximum size of debris, in order to avoid overflowing due to blocking by huge rocks.

(3) Attention has to be paid to the velocity and the maximum curvature of a debris flow in planning and designing the super-elevation and the curve radius of a canal for diverting a debris flow.

(4) Checking is not a suitable control method in places like alluvial fan areas, where sufficient storage capacity is not available.

(5) A high density of reforestation in a buffer zone is preferred, as long as this it will not affect the growth of trees.

(6) Since debris flows wear away the surface of concrete structures, buffer and rub resisting facilities have to be adopted in the design of debris flow control work.

(7) It is necessary to inspect and clear debris control work periodically so as to keep the facilities functioning.

Chapter 5. Sideslope Stabilization

5.1 Introduction

Sideslope destruction, which is affected by natural and human factors, has two causes, namely an increase in the activating force or a decrease in the resisting force. An increase in the activating force is usually induced by earth filling, constructionof structures, increase in groundwater, earthquakes etc; a decrease in the resisting force may be due to the removal of lateral structures, river bank erosion, excavation, etc. In view of these two causes, sideslope stabilization may use two types of control methods, the suppressive and preventive. Selection of methods for sideslope stabilization depends on the locality. In general, a sideslope should be provided with longitudinal and lateral drains; should be covered with vegetation; and should be stabilized at the foot by appropriate engineering measures. Needless to say, all these measures have to be properly maintained and managed.

5.2 Planning and Design Principles

(1) Slope

If the hill slope is too high, it may be divided into sections when the stabilization methods are designed. The gradient of each section must coincide with the best stabilizing angle. For embankments, attention must be paid to earth filling materials, and topographic, geological and meteorological conditions etc. For excavation, special consideration must be made of geological formations and the height of the hill. Table 5-1 and Table 5-2 may be applied where no detailed data from investigation and analysis are available.

(2) Drainage

The purpose of drainage is to intercept and drain out surface water or groundwater, so as to protect the sideslope from damage due to the effect of water, e.g. soil pore pressure increase, shear stress resistance decrease and water content increase. Drainage work should be planned and designed in the most efficient and economical way, after thorough investigation of the topography, geology (especially ground formations) and groundwater.

(3) Retaining walls

Retaining walls are structures used mainly to resist sliding. They are usually combined with excavation, embankment and drainage works.

(4) Slope protection

Work on slope protection is to protect side slopes from weathering and erosion and is generally carried out using vegetative measures with due consideration for the landscape and engineering costs. On a rocky side slope or in a debris deposit area where no soil is available for vegetation growth, borrowed soil (with a slope of less than 1:0.8) may be applied. Structures for slope stabilization may be added if necessary. A sound drainage system is also indispensable for slope protection.

Table 5-1. Reference slopes for embankment sideslopes

Filling material	height of fill (meter)	Side slope (vert:hori.)	Soil classification
Mixture of well graded gravels, coarse sand and sand	0~6	1:1.25~1:1.5	GW、SW、GM、GC
	6~15	1:1.5~1:2	
Poorly graded gravels	0~10	1:1.5~1:2	GP
Broken rock deposits	0~10	1:1.25~1:1.5	GW、GP、GM
	10~20	1:1.5~1:2	
Sandy soil, hard clay soil, silt sand	0~6	1:1.25~1:1.5	SM、SC、CL、OL
	6~10	1:1.5~1:2	
Soft clay soil	0~6	1:1.5~1:2	CH、MH

Table 5-2. Reference slopes for excavated sideslopes

Geological conditions	Cutting height (meter)	Side slope (vert:hori.)	Soil classification
Hard rock		1:0~1:0.5	
Soft rock		1:0.25~1:0.8	
Sand		1:1.5 or flatter	SW、SP
Sandy clay, tight	0~5	1:0.8	SM、SC
	5~10	1:0.8~1:1.0	
Sandy clay, soft	0~5	1:1.0~1:1.2	
	5~10	1:1.2~1:1.5	
Gravels or gravelly soil including fine materials, Tight or well graded	0~10	1:0.5~1:0.8	CW、GM、GC、GP
	10~15	1:0.8~1:1.0	
Gravels or gravelly soil including fine materials, Soft or not well graded	0~10	1:0.8~1:1.0	
	10~15	1:1.0~1:1.5	
Clay or clay soil	0~10	1:0.8~1:1.2	ML、MH、CL、CH、OL、OH
Clay soil including rocks or gravels	0~5	1:1.0~1:1.2	
	5~10	1:1.2~1:1.5	

Remarks: Soil classification notations represent:
G-gravel, C-clay, S-sand, O-organic matter, M-sediment silt, W-well graded, P-poorly graded, L-liquid limit less than 50 and low compressibility, H-liquid limit more than 50, and high compressibility.

5.3 Methods and Measures

There are many methods of slope stabilization. This chapter introduces only those which are in generally use. As to others, please refer to related chapters and sections in this Manual.

(1) Open channels

The layout of open channels is to be properly made to collect water efficiently and lead it to safe places in order to avoid infiltration and percolation into the ground.

(2) Culverts

Materials used for culverts are preferrably pliable and not easy to break in case of land sliding. Under the bottom of a culvert, an impervious sheet should be placed.

For surface drainage, the space over the top of a culvert should be filled with gravel, crushed stones and sand.

(3) Retaining walls

There are many types of retaining walls, including the sandwich type, gravity type, semi-gravity type, aggregate type, buttress type, sheet-pile type and anchor type. In principle, retaining walls with better flexibility and less excavation should be used in places where there is a possibility of landslides.

(4) Slope protection

Vegetative methods include planting of grass sprigs or vegetation belts, hydroseeding, hole planting with top dressing of borrowed soil and the use of netting, wattling and frames (including prefabricated frames and free frames). For details see Part III of this Manual. Structural methods include spraying with cement mortar, concrete structures, frameworks, anchors or masonry (For details, refer to Part III of this Manual)

5.4 Precautions

(1) Proper vegetative methods have to be selected according to natural and physical conditions, especially the hardness of the soil.

(2) Suitable planting periods are spring and autumn.

(3) Before earth fill, the plants and topsoil on the ground must be cleared, and debris should be removed. Filled soil should be wedged into the original sloping ground.

(4) Earth filling must be done layer by layer.

(5) Excavated rock formations, when subject to accelerated weathering, should be treated as soon as possible.

(6) After completion of the work, continued maintenance should be enforced with a view to keeping the slope in good condition.

Chapter 6. Erosion Control for Roads

6.1 Introduction

Due to the movement of large amounts of earth and rock in the construction of mountain roads, there may be damage to land, houses and various public facilities along the road or downstream creeks and gullies during and after construction, if special consideration is not taken during planning, design and construction. Therefore, special attention should be paid to soil conservation in order to avoid inducing man-made destruction.

Erosion control for roads includes road sideslope stabilization, drainage, treatment of abandoned earth and construction damage prevention, etc. Major soil conservation problems involved in mountain road construction may be described as follows:

(1) Sideslope exposure, erosion and collapsing

Excavation easily induces sideslope exposure, collapsing, sliding and erosion especially in those road construction sections where unfavorable topographic and geological conditions exist. Improper construction methods, such as excessive use of explosives, may cause weakening and alteration of ground formations and thus induce rock falls or the future collapse of sideslopes.

(2) Improper treatment of abandoned earth

Dumping rocks and earth directly along the slope at the construction site will damage vegetation cover, and accelerate soil erosion. Piling up excess earth without proper treatment will cause reservoir sedimentation, water source pollution, burying of houses and clogging in river channels and culverts, which in turn will induce relocation of the waterway, resulting in serious damage in times of heavy rainfall.

(3) Insufficient drainage facilities

Destruction of natural drainage systems without providing sufficient and effective drainage to drain out concentrated runoff will cause land erosion and collapse. Insufficien lateral drainage and inadequate size of culverts will cause the erosion of road surfaces and collaspe of sideslope.

(4) Lack of proper damage prevention measures

Lack of temporary measures for damage prevention during construction, such as bamboo and timber fences, deposit detention facilities etc., will result in falling of rocks and earth which might hurt human being and animals, pollute water sources and damage farmland and houses.

6.2 Planning and Design Principles

(1) Road alignment

Topographical and geological conditions should be taken into consideration, in addition to economic benefits for road alignment. In areas with difficult topographical conditions and unfavorable geological formations, road construction may have a destructive effect on the environment and cause damage due to falling rocks and earth. Furthermore, road maintenance will not be easy after construction. Therefore, precise topographical and geological surveys are necessary for road alignment.

(2) Road design criteria

Construction and maintenance will be exceptionally difficult, for a road located in an area with steep slopes and difficult geological formations. Consequently, design standards on the longitudinal slope, curvature, radius, and width of roads in these areas should be lowered so as to reduce the need for excavation. However safety measures, such as protective fences, warning signs, etc., should be strengthened.

(3) Filling and cutting

It is necessary to limit the cross-section of cutting. An effort should be made to balance cutting and filling so as to minimize the amount of excess earth. Excess rocks and earth must be piled at a dumping site and given proper treatment.

(4) Drainage facilities

At a place where the road crosses a natural drain, a culvert or a pipe of an adequate size must be installed. Ordinary lateral drains should be built at suitable intervals in order to avoid concentration of runoff.

(5) Sideslope stabilization

Slope protection, retaining walls and vegetation should be planned, and executed simultaneously with road construction.

(6) If a road is constructed along a river bank, intrusion into the waterway must be avoided.

6.3 Methods and Measures

(1) Roads should avoid passing through slope face of poor geological formations in which excavation induces land slides and collapse, especially on dip slopes. If such a situation cannot be avoided, excavation of the section in question must be reduced to a minimum.

(2) Roads should also not pass through slopes which are so steep, bumpy or fragmented that construction and maintenance are very difficult.

(3) Switchback routes should be located where slopes are smooth in order to minimize earthworks, Two consecutive switchbacks must be separated and located as far apart as possible in order to widen the interval between the upper and lower road routes, so as to minmize destruction of the slope face.

(4) Excess earth after cutting and filling must be properly treated. It must be:

a. Conveyed to a safe dumping site.

b. Provided with soil conservation measure at the dumping site.

(5) Drainage facilities

235

a. Side ditches

(i) These ditches should have a lining on steep slopes, where there is a danger of erosion.

(ii) They should have a lining in sections where the road foundation is wet and drainage is poor.

(iii) They should have a minimum slope of 0.5%.

(iv) Slope protection work should be provided with lined ditches.

(v) Switchbacks should be provided with lined ditches.

(vi) Unlined ditches can be used in places where there is free of erosion hazard, because of rocky formations or good soil properties.

(vii) L-shaped ditch with a shallow, wide triangular shape should be used in places where the slope face is unstable. Regular ditches are difficult to clean when they are blocked by earth and rock. Under normal conditions, ditches with a trapezoidal or rectangular cross section should be used; however, the width and depth should be no less than 30 cm.

b. Lateral drains

(i) Lateral drainage facilities are provided in places where natural ditches or canals cross the road.

(ii) Lateral drains should be provided in depressions in the longitudinal section of the road.

(iii) In addition to (1) and (2), lateral drains should be provided at intervals of 150 meters.

(iv) At the outlet of a lateral drain, there should be a protection device or energy dissipator such as a stilling basin; and a drainage ditch must be connected with the outlet to lead water to a safe place in order to protect the road from erosion.

(v) The slope of a lateral pipe or culvert hsould be more than 3%.

(vi) If there is much sediment, timber, or leaves flowing from upstream which may plug the lateral drain, the cross-sectional area of a pipe or culvert must be enlarged by 30-50% depending on actual conditions.

(6) Side slope stabilization

a. Filling to reduce the gradient of slopes (See Table 5-1, the Chapter on Sideslope Stabilization)

b. Cutting into the slope face (See Table 5-2, the Chapter on Sideslope Stabilization)

c. In principle, excavation should be carried out in steps if the excavated height is over 5 meters.

d. On slope faces where erosion is in progress and restoration of natural vegetative cover is difficult, wattles should be set up and vegetation planted.

e. Retaining walls are to be used for sideslopes which are not stable and may collapse.

f. Sideslopes constructed in steps have to be provided with slope face drainage facilities.

(7) The base of a road should not occupy a river bed. If this is inevitable, the cross section area of the river channel where water flows must be examined, and proper arrangements be made during planning to reserve sufficient space for water flow. The possibility of scouring of the riverbed, and collapse of the opposite bank due to the impact of the current should be considered.

6.4 Precautions

(1) A large amount of explosive should not be used at any one time, in order to avoid weakening earth and rocks.

(2) Machines are preferable to explosives for excavation of rock formations. The use of explosives should be avoided as much as possible.

(3) If the slope is too steep, facilities such as earth dikes, bamboo or timber fences, etc. may be used to prevent earth and rocks from falling down.

(4) Slope faces must be cleared of debris and made into steps before filling with earth. Earth fill should be thoroughly compacted.

(5) If there are dangerous objects such as weakened rocks or leaning trees on the top of a sideslope, they must be cleared during construction.

Chapter 7. Erosion and Sediment Control in Mining Areas

7.1 Introduction

As mining causes rapid changes in topography and ground configuration, improper mining methods will not only shorten the life of a mine, but cause damage when large amounts of earth and rocks (mine slags) collapse and wash away. Erosion and sediment control in mining areas is an integrated treatment, including vegetative and engineering methods, combined with adjustment of the mining process. These measures make possible reasonable and effective development and utilization of mining resources, and help in the environmental rehabilitation of abandoned mining areas.

Soil erosion and sedimentation problems vary in different mining areas, in close relation with the type of mine dominant in that area (as shown in Table 7-1). At present, typical problems of soil erosion and sedimentation in Taiwan's mining areas may be listed as follows:

(1) Poorly designed mining processes result in wasting of mineral resources and destruction of landscapes.

(2) Mine slag is not properly treated. Collapsing and flushing away of dumped slags cause so called 'mine damage' to downstream areas.

(3) Mineral washing without waste water treatment facilities causes water pollution and degrades the quality of water sources.

(4) Lack of drainage systems results in surface runoff, scouring and soil erosion.

(5) Improper planning, design and maintenance of roads in mining areas makes the watershed a source of silt and sand that endangers areas downstream.

(6) Delayed and improper execution of rehabilitation programs in mining areas causes deterioration of the landscape and wasting of land resources.

Table 7-1. Soil erosion and sedimentation problems caused by mining in Taiwan

	Mineral	Mining area	Major soil erosion and sedimentation problems
Energy minerals	Coal	Keelung, Taipei, Taoyuan, Hsinchu, Miaoli	Slag flushing, water pollution
	Crude oil	Hsinchu, Miaoli	
	Natural gas	Hsinchu, Miaoli	
Heavy metallic minerals	Gold	Taipei	Slag flushing, water pollution, heavy metal pollution etc.
	Silver	Taipei	ditto
	Iron sand	Northern coast	ditto
Non-metallic minerals	Pyrrhotite	Kaohsiung (mainly for recollection)	
	Marble(industrial use)	Ilan, Hualien, Taitung	Slag flushing, unstable excavated slopes, devastated mining areas and scarps, water pollution, roads causing erosion
	Marble(art use)		
	Limestone	Hsinchu, Chiayi, Tainan Kaohsiung, fossil lime -stone in East Taiwan	ditto
	Dolomite	Hualien, Ilan, Taitung	ditto
	Soapstone	Hualien, Ilan	ditto
	Asbestos	Hualien (Fengtien)	
	Mica	Taitung (Hsiangyang)	
	Clay	Taipei, Miaoli, Ilan, Nantou, Hualien	Same as 'Marble'
	Spinel	Hualien (Wanyung, Shui -sui, Chuochi)	ditto
	Feldspar	Ilan, Hualien	ditto
	Gemstones	Hualien, Taitung (incl, chalcedony, soft jade, iron quartz)	Slag flushing
	Crystal	Ilan, Hualien	
	Gypsum	Hualien, Taitung (mainly deposited gypsum & salt field gypsum)	

7.2 Planning and Design Principles

(1) Boundary of mine affected areas

The location, area and range of each affected area (mining site, dumping site, storage space, washing and screening facilities, cable way etc.) should be described in a work plan.

(2) Coordination with mining work plans

A mining work plan shall be carefully made according to the results of mine geological survey and the precise exploration of mineral veins. On the basis of this, the geological status and condition of mine layers are described, and the optimum safe quantity of output estimated. From this work plan, the amount of ore, earth and stones to be excavated can be estimated, in order to determinate methods and procedures of control treatments.

(3) Preventive measures against soil erosion and collapse

a. Prevention of collapse of mine faces and untreated banks:

The dimensions (width and height) of the excavated steps or terraces, stabilization work for remaining banks and sideslopes, and vegetative measures to be adopted for protection of slopes, should be clearly described.

b. Planning and layout of runoff interception and drainage systems: This should describe the layout and hydraulic properties (especially section flood discharge and system capacity) of interception ditches as well as main and lateral drainage systems in the work plan.

c. Items and quantities of various engineering structures and facilities.

(4) Treatment methods and pollution control of mine slag or spoil

a. Safety conditions of dumping sites: Dumping sites must be examined, including, topographic conditions, available dumping capacity and yearly mineral production, as well as the possibility of clogging of natural waterways or flushing away of dumped earth and stones.

b. Treatment facilities for earth and stone dumps: To include footing stabilization facilities for the dumps; types, methods and operation procedures of dumping; measurements of the sideslopes of dumps and stabilization treatments for these slopes etc..

c. Pollution control facilities: To include location, criteria, material quality, design capacity and connecting waterways for the silting basin, and operation procedures, facitlities and methods of mineral washing and screening.

d. Type and quantity of each facility or structure.

(5) When roads are constructed in a mining area, road criteria and standards should be clearly described and their related soil erosion control plan be worked out (For details of planning and design, refer to the Chapter on Erosion Control for Roads).

(6) A damage prevention plan shall describe the possibility of damage due to collapse of earth and rocks during mining operations; preventive measures against damage from

typhoons and floods; protection against earthquakes, etc.

(7) The estimated quantities of facilities and their expense are to be included in a soil erosion and sediment control plan.

(8) Basic data for design include:

a. Hydraulic computation: To include the computation process and estimated flood and drainage discharge, for which a frequency of once in 25 years should be adopted in rainfall intensity analysis. However, other frequencies should be used if they are prescibed by the authorities.

b. Mechanical computation and checking of important structures.

c. Drawing: If standard drawings are used, their names and origin should be quoted, with samples attached. Regarding the scale of these drawings, stipulations under various relevant regulations should be observed.

(9) Deadline of work project:

The anticipated date of completion of soil erosion and sediment control work in a mining area shall be clearly specified and supported with a work progress schedule.

7.3 Methods and Measures

The primary methods and measures related to soil conservation and land classification in mining areas are described in Table 7-2.

7.4 Precautions

(1) Reference should be made to the Chapters on Slopeland Drainage Systems, Erosion Control for Roads, and Sideslope Stabilization.

(2) For implementation of vegetative measures, it is preferable to prepare the slope in the dry season for planting in the rainy season; spring and autumn are the most desirable seasons.

(3) Spoil in the mining area should be dumped in safe places. The possibility of utilization of the waste materials should be considered.

(4) In execution of a mining plan, destruction of slope faces and vegetation outside the designated area must be kept to a minimum.

Table 7-2. Measures to control soil erosion in mining areas in Taiwan

Location of treatment	Mining area soil conservation measures	
	Engineering methods	Vegetative methods
Excavated steps	1. Slope face stabilization 2. Temporary drainage facilities	
Excavated remains (incl. the last remaining walls)	1. Slope face stabilization 2. Longitudinal and lateral drainage	1. Vegetation materials: Chinese wedelia, Taiwan kudzu-bean, Japanese silver grass, pedent reed etc. 2. Vegetative method: planting seadlings in holes, dibbling, netting with borrowed soil top dressing or hydromulching
Dumping area	1. Slope face stabilizing treatment 2. Slope face drainage 3. Footing stability treatment 4. Subsurface drainage	1. Vegetation materials: Japanese silver grass, pedent reed, Japanese mallotus, paniculate-flowered mallotus, Roxburgh sumac, Formosan alder, charcoal tree etc. 2. Vegetation method: sowing seed in holes, planting seedlings in soil bags, wattling, netting with borrowed soil top dressing or hydromulching.
Mineral storage area	1. Temporary drainage facilities 2. Temporary slope face stabilizing treatment 3. Footing stabilizing treatment	
Washing and screening area	1. Waste washing water effluent control 2. Silting basin 3. Drainage system 4. Silt deposit facilities	
Mine roads	1. Road drainage 2. Upper and lower slope stabilizing treatment 3. Road foundation stabilizing treatment	Vegetation materials and methods, see Part III of this manual
Remarks	1. For details of various methods, see related chapters of this Manual. 2. In designing silting basins and detention facilities for integrated soil erosion control of an entire mining area, refer to the Chapters on Silting Basins and Runoff Detention Dams.	

(5) In order to carry out rehabilitation of vegetation and slope stabilization in mining and dumping areas, it is necessary to take samples in field surveys, in order to test mechanical characteristics, general physical properties, and soil fertility .

(6) Removal of soil from slope faces should be completed during the dry season. During terrace excavation, tentative drainage systems should be installed.

(7) It is preferable to use cable conveyors to transport ore, in order to minimize road construction.

(8) A waste water treatment plant should be attached to the ore washing and screening facilities in order to meet the effluent water quality criteria.

(9) For dumping of mine slag or excavation spoil, attention should be paid to the appropriateness of the site and its environmental impact.

(10) Open-pit mining should be compartmented. The compartments should be mined in different periods, in coordination with soil erosion control work.

(11) The capacity and life span of the dumping site for mine spoil and slag should be determined according to the mining plan and annual ore output.

(12) If there is any possibility of damage to the mine or an increase in flood damage, check dams or runoff detention facilities should be provided.

(13) Evaluation should be made of the potential value of the land in a mining area for future utilization after mining operations are discontinued, with reference to the remaining life span of the mine as indicated in the mining plan.

(14) For other related matters, other relevant chapters of this Manual should be consulted.

247

Chapter 8. Slopeland Drainage Systems

8.1 Introduction

When slopeland is subected to continuous rainfall or a storm, part of the rainwater evaporates or penetrates underground or is absorbed by plants. The remaining rainwater flows down along the slope face as runoff. Exposed ground surface or soft soil is easily scoured by runoff, thus causing erosion. Runoff will collect in ground depressions and gullies. Its energy and destructive force will keep increasing, and if no measures are taken to control this situation, it may bring about a serious disaster. On the other hand, seepage water flowing above the impervious layer underground may cause landslides.

The purpose of slopeland drainage is to lead, divert or drain out runoff or underground seepage water to safe places downstream, thus reducing the destructive force of excess water to a minimum.

Factors affecting slopeland drainage are: topography, terrain, soil, geology, vegetative cover, slope, rainfall intensity and volume, watershed size and shape etc. Prior to the planning of a drainage system, basic data should be collected, analyzed and compared. Data of appropriate accuracy and generality should be carefully selected for estimation of runoff flows, from which the required cross-sectional area and controlled velocity are determined for the design of an effective safe drainage system that will reduce erosion and sedimentation.

8.2 Planning and Design Principles

(1) The design capacity of a drainage ditch is determined as follows:

a. The rainfall intensity of a 10-year frequency is adopted for design of drainage systems on slopeland farms.

b. The rainfall intensity of a 25-year frequency is adopted for drainage systems in mining areas, excavated areas, or for road construction and slopeland communities.

(2) Determining the cross-section of drainage ditches follows the principles below:

a. The most advantageous cross-section should be used, to make the ditch free of scouring and silting.

b. The ditch should be economic, safe and easy to construction.

(3) If the length of a cut and filled slope equals the interval between hillside ditches (see Chapter 2. Hillside Ditches, Part I) lateral drainage must be provided.

(4) If the length of a lateral drainage ditch approaches 100 meters in one direction, a longitudinal drainage ditch must be provided. If a lateral drainage ditch exceeds 100 meters in length, it should be so arranged that water in the ditch will drain in two directions. Otherwise, a longitudinal drainage ditch should be built to meet the middle of the lateral ditches.

(5) The water flow velocity in a longitudinal drainage must be within the maximum

safety limit. If it exeeds this limit, drop structures and energy dissipators are required.

8.3 Methods and Measures

(1) The location of a drainage ditch should be in the lowest possible place.

(2) Drainage ditches specially provided for the purpose of farmland soil conservation, should ensure that the direction of drainage and intervals between the ditches will meet farming requirements.

(3) If a drainage ditch changes direction, the outside bank must be protected and heightened, or a drop structure be provided when necessary.

(4) The cross section of a drainage ditch should be made larger from upstream to downstream in accordance with the increase in discharge.

(5) The gradient of the sideslopes of a drainage ditch should be determined with reference to contruction materials used.

(6) The inlet of a drainage ditch should be properly arranged in accordance with topographic conditions of the drainage area, and in coordination with the water outlets of other soil conservation works.

(7) A drainage structure should have enough freeboard.

(8) A diversion ditch should be provided along the uphill side of buildings on a slope face, if these might be damaged by runoff.

(9) Whenever possible, a drainage ditch should be straight. Sharp curves should be avoided.

(10) The longitudinal slope of a drainage ditch should be as smooth as possible, without sudden changes.

(11) If the longitudinal slope of a drainage ditch is greater than 10%, cross walls should be provided at intervals of 10-40 meters. This interval may be adjusted under special geological conditions, or when the ditch is located in a mudstone area.

(12) It is preferable not to have a drainage system on filled earth. If this is inevitable, the foundations must be strengthened.

(13) A culvert accommodates not only the passage of water, but also a volume of sediment and drifting matters. Therefore its cross-sectional area should be designed accordingly. The water level at the inlet should not be above the top of the culvert.

(14) If a culvert crosses a road or a major facility, its crossing angle should be 90 degrees whenever possible.

(15) A culvert should not be too long. Its inlet should be installed with a silting basin, trash racks or a transition.

(16) For treatment of seepage water in landslide areas, it is necessary firstly to observe the source of groundwater and its flow direction and study the sliding face, then to install culvert drainage and water collecting facilities.

(17) A drainage ditch should have expansion joints at an interval of 30-50 meters.

8.4 Precautions

(1) Before excavation of a foundation, trees, weeds and other matter should be removed.

(2) Before construction of a drainage structure, the depth of the foundation must be specially checked in relation to the ground surface in order that the top edges of the banks will not be higher than the ground, lest drainage will be handicapped.

(3) Back filled earth should be well compacted. Excess amounts of earth should be dumped in a safe place, or spread along both sides of the ditch to form a little slope .

(4) If the earth foundation at the design depth is found to be too soft, it should be deepened or strengthened.

(5) In excavation of a foundation, large rocks or ledge rocks should be broken and removed manually if possible. It is preferable not to use explosives so as to avoid weakening the foundations.

(6) Cobbles and bricks must be washed and thoroughly wetted before betting them in cement mortar.

(7) Cobble pitching slope protection work must start at the footing, layer by layer, with larger cobbles in the lower part, in order to give sufficient strength to the footing. If it is made in sections, each section should not be too short, and preferably longer than 10 meters. The joints where the sections will connect should be in a stair form to ensure tight connection.

(8) In laying cobbles, each cobble must be laid with its longer diameter perpendicular to the slope face, and laid interactively and firmly. The paved surface must be a plane. The larger surface of a cobble should not be on the slope face. Clearance of the cobbles should to be in a triangular shape.

(9) The vertical joints of pitched bricks must be in a zig-zag pattern Layers of brick should be parallel.

(10) In brick paving, avoid adding excessive water in 1:3 mortar, in order to keep mortar in place to ensure complete jointing. The joint of each layer must be thoroughly filled with cement mortar.

Chapter 9. Erosion and Sediment Control for Development Sites

9.1 Introduction

Construction of golf courses, recreation areas, community areas and other slopeland development activities will degrade slope stability, and increase runoff and soil erosion, as excavation and land preparation break the natural environmental balance and vegetative cover. The main soil conservation problems encountered are as follows:

(1) Flushing of earth and stones

Earth surfaces exposed and loosened due to excavation and land preparaticn are an easy prey of erosion. Washed away soil and rubble will clog drainage waterways or even change river courses. Neighboring residential areas might be buried by debris in rainstorms during the construction period.

(2) Expanded flood peaks

As an aftermath of land development, runoff rate increases and the time of concentration reduces, consequently flood peaks expand considerably. As a result, river banks are eroded and destroyed, resulting in inundation when downstream river channels cannot accommodate the increased flood safely.

(3) Landslides and collapse of sideslopes

Landslides and collapse of sideslopes are apt to occur in developing areas if improper construction procedures are applied on slopes. This is particularly likely in unstable areas with landslide formations, clastic fault zones or talus.

(4) Degradation of soil conservation effectiveness and disturbance to downstream ecosystems

In the course of land development, the water retention and filter capability of forests and other vegetation in the area will deteriorate. When this is added to the movement of large amounts of sediments, downstream arees suffer from water pollution and ecological disturbance.

It is necessary to emphasize at the planning stage, data collection and interpretation, field survey, experimenttion and analysis, etc., in order to identify damage problems in developing areas in advance, and to gather necessary data on topographical and geological conditions in order to determine and review construction methods and damage prevention measures.

9.2 Planning and Design Principles

Control of erosion and sediments is based on the following principles:

(1) Avoiding unstable areas

a. Avoid any excavation of lower slopes in areas prone to landslides, clastic fault zones, dip slope or talus areas in order to prevent land movement.

b. Avoid placing embankments on the top of talus or landslide areas.

c. Designate such unstable areas as nondevelopment or protective zones, on condition that the original purpose of the development project will not be affected.

(2) Minimizing destruction by skillful adaptation to topography and terrain

Following the principles of minimizing disturbance, excavation and land preparation should be adapted to the topography and terrains with a view to reducing exposures of the soil surface or loosening of earth, and to reducing construction and maintenance costs.

(3) Balancing earth cutting and filling

Cutting and filling of earth should be minimized and balanced against each other. The objective is to avoid borrowing earth for fill or dumping excess earth from cuts, since both borrowing and dumping will cause soil erosion and sediment problems. In general, earth cutting and filling should be concentrated in specific sections.

(4) Reducing slope gradient and length

Slope gradient and length are directly related to the extent of erosion. The longer and steeper the slope, the more rapid runoff flow will be, and consequently the greater the scouring force. Therefore, reducing slope gradient and length will curtail surface erosion and prevent the collapse of sideslopes.

(5) Dividing work into stages and separate zones

a. Avoid typhoons and rainy seasons as much as possible, in order to eliminate damage caused by debris flow and sideslope collapse due to storms.

b. If excavation covers a large area, it shall be carried out separately in individual small watershed or drainage areas, with proper damage prevention measures.

(6) Drainage systems

a. The temporary or permanent drainage systems on the project site should be able to drain out surface and ground water efficiently and safely from the site. In practice, the site should be drained by sections, with due consideration for drainage capability within the section and its surrounding area.

b. For safety, runoff coeficient 1 should be adopted for computation of flood peaks occurring during the period of the project.

c. During the progress of a development project, proper control of flood peaks should be applied:

(i) Flood peak discharge during and after the development shall not exceed that found before development took place.

(ii) The flood peak discharge of the neighbouring watershed area should not increase during or after development.

(7) Sideslope stabilization (refer to the Chapter on Sideslope Stabilization)

In general, engineering and vegetation methods are incorporated into sideslope stabilization and other soil erosion control treatments, for the purpose of reducing run-off and erosion after the development of the project area.

(8) Damage prevention measures during the development period

a. Damage prevention facilities in the project area should be capable of preventing damage due to debris flows, and collapse and flooding of land during excavation.

b. For the purpose of damage prevention, facilities for runoff detention, sand trapping and prevention of landslides may be incorporated with excavation and land preparation operations.

9.3 Methods and Measures

(1) Slope face protection

a. Exposed soil surfaces shall be planted with vegetation or covered by other materials. They shall be well maintained in order to minimize soil erosion caused by development.

b. If a sideslope can not be stabilized solely by means of vegetation, it is necessary to use special measures or structures, e.g. hydroseeding, wattling, netting, troughs, free frames etc.

c. For stabilization of high sideslopes, refer to the Chapter on Sideslope Stabilization.

(2) Stabilization of slope footings

Retaining walls may be used to strengthen the unstable footings of a slope, when slope face protection work is carried out on the slope. (Refer to the Chaper on Retaining Walls). If the retaining wall is inadequate to stabilize the footing of the sideslope because of excessive sliding force, other engineering work should be added (such as anchors).

(3) On a sideslope, mortar spray should be applied on rocks which are prone to acute weathering. Particularly, excavated sideslopes on shale formations should be sprayed to prevent them from collapsing.

(4) Drainage of surface and ground water (refer to the Chapter on Slopeland Drainage Systems)

a. Select a proper rainfall frequency for computation of runoff, design velocity and cross-sectional area of water flow, and for selection of drainage construction materials.

b. Following the prescribed procedures of construction, drainage ditches should be provided on the top of the slope above the place where earth cutting or filling meets the natural ground, and along the footing of the excavated slope. If the slope is too long, it may be divided into sections, and a separate drainage ditch be provided to each section. Otherwise, hill-side works should be provided.

c. During the progress of earth excavation, temporary drainage ditches should to be provided when necessary, to drain out excess rainwater in order to protect the completed sideslope from erosion by runoff.

d. During earth back-filling in valleys or in land depressions, water collection wells or culverts may be provided in combination with drainage, sand traps, and runoff detention facilities, in order to ensure the safety of back-filling and to prevent piping.

(5) Detention facilities (Refer to the Chapters on Runoff Detention Facilities and Runoff Detention Dams)

a. To provide detention ponds upstream from drainage systems, for storage and detention of runoff and delay flood peaks.

b. To design the capacity of a detention pond according to the difference in water discharge at flood peaks before and after the area is developed, and to determine the maximum safe water discharge according to the flood release capacity of the downstream river channel.

(6) Sand traps and facilities to prevent slope collapse.

Depending on the extent of erosion damage caused by excavation and land preparation, the following temporary and permanent sand traps as well as other related facilities may be incorporated.

a. Silting basin: To be located between the development area and the water way, or at the downstream confluence point, for settling silt and sand carried by water. The capacity of a silting basin may be determined on the basis of soil loss of 500 m^3 per hectare from the cutting and filling area.

b. Retaining fence: To be provided mostly as a temporary facility. It is usually located on the boundary between the development area and the neighboring land, and is made of logs, bamboo or planks for prevention of soil losses.

c. Prevention, of darmage to earth dikes: To be located along the lower edge of the boundary or on the steep slopes in the development area for diversion of eroded soils into the silting basing and alleviation of slope face erosion, so as to prevent silt and sand from flowing directly into downstream ditches. The height of a dike should not be more than one meter.

d. Simple retaining wall: To be constructed in a river valley for land preparation and embankment. Construction materials are : sand bags, wire sausages, used tires etc..

e. Check dams: To be provided at a proper location in the main drainage of the development area. Check dams are used to check debris, and may be constructed individually at the proper sections of a river valley, depending on the embankment quantity and the estimated amount of eroded soil.

9.4 Precautions

(1) The vegetative cover should be thoroughly cleared before embankment, to reduce the hazard of surface sliding.

(2) Embankments should be made layer by layer horizontally and be thoroughly compacted .

(3) Drainage facilities are to be strengthened at the footing of a cut or fill side slope where

groundwater is abundant.

(4) Retaining facilities and protection nets should be provided in places where working personnel or neigboring houses might be endangered by collapsing or falling earth and rocks in times of excavation and land preparation.

(5) If there is excess earth in cutting and filling operations, the dumping site should be properly provided with drainage and retaining and other protective facilities before the spoil is dumped.

Chapter 10. Runoff Detention Facilities

10.1 Introdcution

Flood damage is due to the flood peak of runoff and the amount of transported silt, sand and other debris, when there is a rain storm. The runoff at flood peak increases because of slopeland development, and in most cases exceeds the flood release capacity of the downstream regional drainage system. Furthermore, silt, sand and floating matter such as trees and bamboo will block drainage structures, thus causing flood damage as the result of inundation. Measures aiming at decreasing flood peaks and the runoff coefficient are called detention facilities.

Detention dams, detention lakes and pocket-type detention river secticns are used to reduce flood peaks and to adjust transportation of silt and sand. The so-called detention dam is a traditional check dam with rectangular or circular openings, the function of which is to cut down flood peaks and adjust the amount of silt and sand in the flow. Other facilities are: permeable drainage structures, permeable pavement on roads or parking lots, wetland plants which absorb and evaporate a large amount of water, and densely planted grass which increases ground surface roughness and helps detain runoff.

10.2 Planning and Design Principles

A protection area is to be selected according to data and information collected in a field survey. The area is divided into specific regulation zones, based on geological and topographical conditions, land use, and social, economic and environmental aspects as well as the priority of engineering work. In general, a regulation zone consists of a single watershed which is treated as a unit for integrated planning with least waste of manpower and financial resources. If the watershed is small, flood control may be achieved with a series of detention dams with low elevation diference.

10.3 Methods and Measures

(1) On the basis of the degree of importance of a zone where flood regulation facilities are to be constructed, the discharge of a particular flood frequency is to be selected as a criterion for design. In general there are two categories of regulation zone as follows:

a. Forest land and wild creeks.

The purpose of flood detention facilities in such areas is to delay flood peaks and to adjust the amount of silt and sand flowing out of the area, to ensure the safety of people downstream and their property. Therefore, detention lakes, detention dams and pocket-type sand traps in rivers may be adopted.

b. Urban areas.

The primary method of flood detention in this area is to reduce runoff by increasing seepage and soil intake. For instance, parking lots and sidewalks may be paved with hollow concrete blocks; a space is kept between the blocks and planted in grasses. Furthermore, a permeable layer may be laid beneath the pavement, to increase seepage. This arrangement also helps greening and landscaping. In depressions in urban areas, lawns and grassland may be established.

(2) After a traditional check dam is filled with debris, it is no longer useful. However, it may serve the purpose of runoff detention and flood peak reduction, if it is provided with an outlet at the bottom of the dam to release runoff. For a dam with a large watershed area, a rectangular opening should be used to allow a larger volume of flow (as shown in Figure 10-1). For a small dam, the outlet may be a semi-circular structure made of concrete and protected with iron nets (as shown in Figure 10-2). If necessary, the outlet should be protected by buttress walls on the downstream side. A cobbled protection apron may be added.

(3) An open-type detention dam in a forest or wild creek area should be constructed with reinforced concrete to make it more durable. For the benefit of landscaping, dams in the vicinity of towns or villages, should be built with a reinforced concrete corewall covered with earth i.e., an earth dam with a R.C. corewall (shown in Figure 10-3). The outlet of the dam should be built with reinforced concrete and covered with a steel trashrack on the upstream side. In order to make the dam harmonize with the landscape, the top of the emergency overflow spillway may be covered with earth and vegetation.

(4) Runoff detention lakes in slopeland areas should be dredged in case sediments preclude the function of detaining runoff after floods.

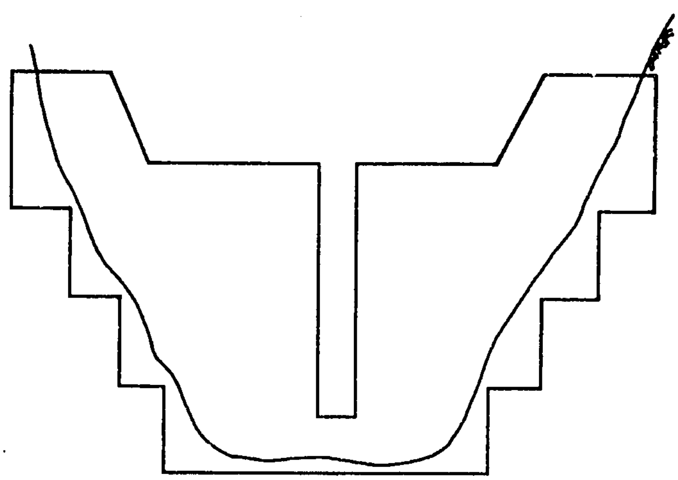
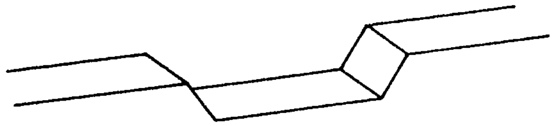


Fig. 10-1. Runoff detention dam with a rectangular opening on the upstream side



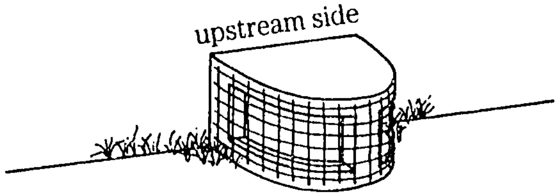


Fig. 10-2. Flood detention dam with semi-circular opening and steel trashrack

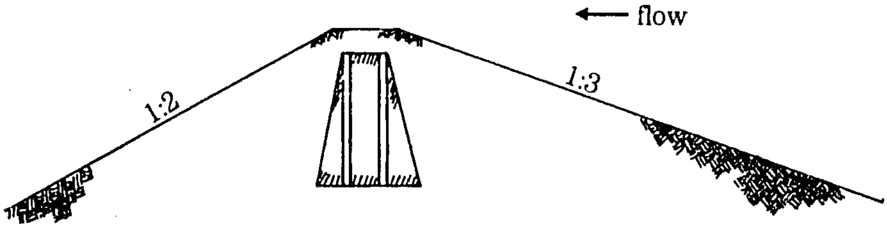


Fig. 10-3. Reinforced corewall covered with earth

10.4 Precautions

(1) A detention lake should be made in accordance with natural and environmental conditions. It should not be made in a region where land is limited.

(2) After flood, trash which has accumulated in front of the trashrack installed on the upstream side of the outlet of a detention dam should be removed.

(3) Permeable materials are preferred for bed and bank protection in drainage systems in urban and countryside areas, with a view to increasing intake rates and reducing runoff coefficients.

(4) The opening width of an open-type detention dam should be so designed so as to prevent scouring and cutting of either wing wall.

(5) If a detention dam is constructed where debris flows cause a serious problem, it is preferable to construct a stone-checking facility or check dam farther upstream, in order to prevent plugging at the opening of the dam by large rocks, since plugging results in loss of the effectiveness of the dam.

(6) Grasses may be planted in a detention lake, so that it may serve as a recreation ground in non-flood seasons.

II Specifications of Individual Structures

Chapter 1. Check Dams

1.1 Definition

A check dam is a structure more than five meters high designed to check silt and sand, adjust sediment transportation, stabilize the river bed and banks, prevent scouring and erosion, and suppress debris flow in a river channel.

1.2 Purpose

(1) To check and adjust silt and sand in a river.

(2) To reduce the rate of fall of a river and prevent longitudinal scouring.

(3) To control water flow to prevent eddies and lateral scouring.

(4) To stabilize the footings of hillsides to prevent collapse.

(5) To suppress debris flow in order to minimze damage.

1.3 Types of dams and their purposes.

(1) Classification according to dam form and construction materials used.

a. Earth dam: Applicable to a small drainage area, with a small amount of runoff, especially when the dam site is in poor geological conditions but has abundant earth and stone materials suitable for construction nearby.

b. Timber dam: Applicable to an area with abundant timber, where transportation is inconvenient and runoff is limited. It is used as a temporary structure to meet emergency requirements.

c. Wire sausage dam: Applicable to a devastated small gully or creek, an area with poor transportation or land slides. It is also used for emergency repairs.

d. Rock-fill dam: Applicable to a site where there are abundant rocks suitable for construction and emergency reparis.

e. Concrete dam: To be adopted when a large volume of runoff exists, or when construction of a permanent structure for river regulation is desirable.

f. Reinforced concrete dam (including a semi-gravity reinforced concrete dam): Useful when tensile reinforcement is to be provided at a lower cost.

g. Cobble concrete dam: Applicable to a site where abundant cobbles suitable for construction are available.

h. Concrete crib dam: Applicable to an area with limited runoff but poor geological conditions, espiecially when the construction period is short. It is a permeable permanent structure.

i. Comb dam: This dam is permeable, and is used to check rapid movement of debris

25

and to intercept coarse sand and large stones.

(2) Classification according to dam structure

a. Gravity dam

b. Arch dam

c. Semi-gravity dam

d. Permeable dam

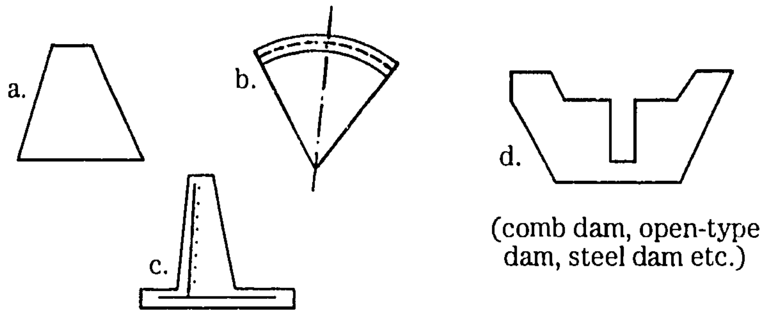


Fig. 1-1. Schematic diagrams of check dams

1.4 Diagram

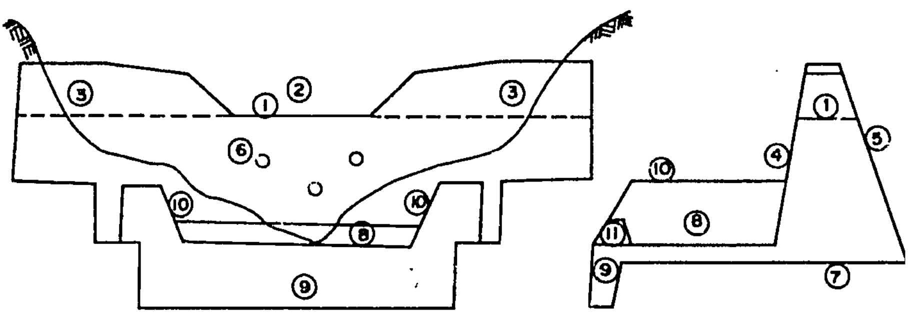


Fig. 1-2. Features of check dam

(1) Effective top width of dam

(2) Spillway

(3) Wing wall

(4) Downstream face of dam

(5) Upstream face of dam

(6) Drainage hole

(7) Bottom of dam (or dam base)

(8) Apron, water cushion

(9) Cutoff wall

(10) Side wall

(11) End sill

1.5 Design Criteria

(1) Selection of location

The location of a check dam shall be selected according to the purpose of its construction.

a. In principle, a check dam is located at a place where of collapsing land needs to be stabilized or where creek erosion may cause collapse of the banks. If the length of land collapsing along a creek is extended or the river bed slope is too steep, two or more dams may be required.

b. A series of consecutive dams are required in sections where longitudinal and lateral erosion of the creek are serious or banks have collapsed for some distance along the creek.

c. It is preferable to have bedrock at the site of the last of a series of dams from upstream to downstream. If not, the downstream river bed of the last dam should be properly protected.

d. For the purpose of stabilizing the river bed against longitudinal erosion, a dam should be located at a place which is deeply scoured or downstream from a scoured place.

e. In sections where there is erosion at the foot of a bank due to eddies, which easily occur in a wide river bed downstream from a curve, riverbed fixing and regulation work should be done to control water flow.

f. For the purpose of trapping sand and stones, a dam should be located in a narrow passage where there is a wide, flat space upstream.

g. In order to avoid erosion downstream and to ensure the safety of the dam, a dam should be located in a place where the riverbed and both banks are a rock formation. If a dam is to be constructed on gravel, protection will have to be strengthened.

h. Where there is a confluence of two creeks, a dam should be located slightly downstream from the confluence so that it can help stabilize the beds of both creeks.

(2) Direction of axis of dam

a. In a straight section of a creek, the axis of a dam should be perpendicular to the flood flow line, and the center of the spillway should be on the center line of the channel.

b. A dam should not be located on the curve of a creek. If this is inevitable, the axis of the dam should be perpendicular to the tangent of the flood flow line, and the wing walls should be strengthened.

(3) Planned sedimentation slope

In general, a planned slope should be $\frac{1}{2}$-$\frac{2}{3}$ of the original slope of a creek, of which $\frac{2}{3}$ is for a river bed with large sized particles and $\frac{1}{2}$ for a river bed with smaller size particles. For sand and mudstone, a planned slope may be nearly flat or entirely flat for sedimentation.

(4) Dam height

The height of a dam depends on its purpose and sedimentation slope, as well as the condition of the dam site, including both banks and the area upstream. It should be the most effective and economical height.

a. Dam height depends on the geological conditions.

b. Dam height should be designed with reference to land use conditions in the sedimentation area upstream.

c. For the purpose of protecting the foot of a collapsing slope and the foundation of an existing engineering structure from scouring, the dam height is to be determined by the design height of sediments, that is required to achieve this purpose.

d. For the purpose of trapping sand and stones, dam height is to be determined according to topographical and geological conditions of the dam site and the upstream sedimentation area.

(5) Spillway and wing walls

a. Spillway

(i) Location: In principle, the center of a spillway should be located in the middle of a river bed, with reference to topographical, geological, and river bank condition, as well as water flow direction and other related factors at the dam site. However, avoiding scouring and collapse of river banks is the primary requirement.

(a) If the river bed and both banks of the dam site are made of bedrock, a spillway may be provided in the middle of the river channel without any need for wing walls.

(b) If the bedrock of two banks have different properties, or if one bank is not made of bedrock, the spillway should be moved towards the harder bank.

(c) If the geological conditions of the two banks are different, the wing wall on the side with poorer conditions should be heightened.

(d) The spillway should be located far from unstable land.

(ii) Shape: These include rectangular, trapezoidal and parabola shapes.

(a) In general, a spillway is built with a trapezoidal section and a flat base. It may be designed according to special purposes.

(b) If the river bed is wide with a considerable amount of sediment, causing eddy flows upstream, it is preferable to design a double-trapezoidal section for the spillway.

(iii) Cross section: The cross section of a spillway should be adequate to release the designed flood discharge. However, the base of the section may be enlarged as much as possible within the allowed limit.

(a) The free board is to be determined according to the designed flood discharge. It should be more than 0.6 meter, but may be heightened by 30-50%

262

if there is likely to be debris such as drifting timber.

Table 1-1. Freeboard and flood discharge

Flood Discharge m^3/s	<200	200-500	>500
Freeboard	0.6	0.8	1.5

(b) The water depth of the overflow should preferably be less than 3 meters. It may be up to 4 meters, if the bedrock is good.

(iv) Cross section computation

(a) The computation of the flood discharge is based on a frequency of once in 50 years. Details are given in Appendix 1.

(b) Computation formula in common use

i. Rectangular section

$Q=1.767\ bh^{3/2}$

Where

Q=Flood discharge (c.m.s.)

b=Spillway base width (m)

h=Overflow depth (m)

ii. Trapezoidal section

$$Q = \frac{2}{15}\left(2b_u + 3b_o\right)ch\sqrt{2gh}$$

$$= \frac{2}{15}\left(2b_u + 3b_o\right)ch^{\frac{3}{2}}\sqrt{2g}$$

Where

b_u: Trapezoid top length (m)

h: Overflow depth (m)

b_o: Trapezoid bottom length (m)

Q: Flood discharge (c.m.s.)

g: Gravity acceleration 9.8 m/sec^2

c: Discharge coefficient 0.6

Side slope of trapezoid 1:1

$Q=(1.77b_o+1.42h)h^{3/2}$

Side slope of trapezoid 1:0.5

$Q=(1.77b_o+0.71h)h^{3/2}$

Example 1

Q=10(cms) Both side slopes=1:0.5, h=1.0 (m)

To find bottom width b_o

2ا3

$$10=(1.77b_o+0.71\times 1)\,1^{3/2}$$

$$b_o=\frac{10-0.71}{1.77}=\frac{9.29}{1.77}=5.24m \fallingdotseq 5.5m$$

$b_o=5.5m$

The spillway cross-section is determined as:

H=1.6m, which is (1+0.6); where 0.6 m is for freeboard

Example 2

Q_o=10cms, width of river bed=20m

b_o=14m, side slope =1:0.5, to find h

$$Q=(1.77b_o+0.71h)h^{3/2}$$

$$=1.77\times 14h^{3/2}+0.71h^{5/2}$$

Try h=0.5

$Q=8.76+0.125=8.885<Q_0=10$, not suitable

Try again h=0.6

$Q=11.522+0.198=11.72>Q_0=10$ O.K.

The spillway cross-section is :

H=(0.6+0.6)=1.2m

b_o=14m

(v) Protection of spillway

In order to avoid abrasion or destruction of a spillway crest, high strength concrete, steel rails, steel plates or a special design method may be used to protect the spillway.

b. Wing walls

(i) Top face

Wing walls shall be inserted into the banks. The top face of a wing wall should have a slope equal to, or greater than, the sediment slope, and extend upwards into the bank (V:H=1:10, and 1:20 at the minimum), under the following conditions.

a. Debris flow on a large scale

b. Collapsing land and drifting timber upstream

c. Dam located on the curve of a creek.

(ii) Height

The height of a wing wall is the sum of the overflow depth and the freeboard. If it is located on the concave side of a creek, its height shall be added in accordance with to the following formula:

$$\triangle h=2.3\ \frac{V^2}{g}(\log R_2-\log R_1)$$

$\triangle h$=height to be added (m)

where

R_1=Radius of the convex (inner) bank (m)

R_2=Radius of the concave (outer) bank (m)

g= Gravity acceleration (m/sec^2)

V=Water flow velocity(m/sec)

(iii) Inserted depth

The depth the wing wall should be inserted into the bank is determined according to the geological conditions of the bank. If the bank consists of bed-rock, the depth is 1-2 meters. If it is a gravel or sedimentary soil, the depth should be more than 3 meters (perpendicular to the slope face of the bank). Protection should be strengthened where there is earth cutting or filling.

(6) Drainage hole

The major function of a drainage hole is to release seepage pressure and adjust the outflow of silt and sand. It also has a drainage effect during construction.

a. The lowest row of drainage holes should be set at the elevation of the river bed. The top row should be 1.5-2 meters below the spillway. Their range should not exceed the width of the spillway.

b. Holes should be clustered in threes to form in a triangle, while the space between the holes should be 2-3 meters.

c. Cross section of drainage holes

(i) Circle

(ii) Rectangle

(iii) Horse shoe

In general, circular pipes are used.

(iv) Diameter of drainage pipe

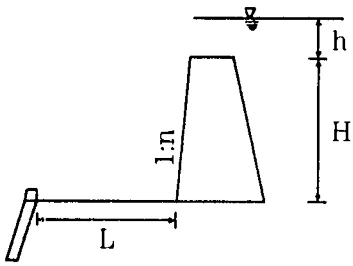
The size of pipes should be 30-60 cm in diameter.

(7) Energy dissipator

The energy dissipator is a structure to ensure the safety of a dam. If may take the form of a stilling basin (water cushion), apron, secondary dam etc. If necessary, riprap or concrete blocks may be placed below the dowstream cutoff wall to prevent scouring.

a. Water cushions: Water cushions are effective for a dam over 7 meters in height, with a high overflow head, particularly when the river bed downstream is subject to accelerated erosion.

(i) Length



General empirical equation

L=c(H+h-nH)

L:Length of water cushion (m)

H:Effective dam height(m)

h:Overflow depth (m)

n:Dam dowstream face slope

c:Coefficient 1.5~2

Coefficient c=1.5 for a high dam of over 15 meters; c=2.0 for a low dam of less than 15 meters.

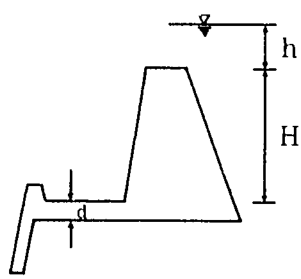
(ii) Thickness

The thickness of a water cushion is determined according to the following criteria.

When H+h<10 m, d=0.5~1.0m

When H+h=10-15m, d=1.0~1.2m

When H+h>15m, d is determined by the following empirical formula:



$d=\alpha\,(0.6h+3-1.0)$

d=Thickness of water cushion floor (m)

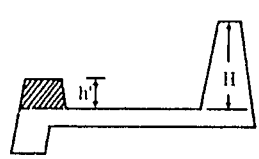
α =Coefficient≒0.1-0.2(0.1 for a dam with a stilling basing and 0.2 for one without a stilling basin)

H=Effective dam heigh, i.e., the total height deducted by the thickness of the floor of the water cushion

h:Overflow depth (m)

(iii) Slope: The floor of a water cushion should be level.

(iv) End sill: No formula is available to determine the height of the end sill. It is usually 20% of the main dam height, i.e. h'=0.2H



(v) Cutoff wall

A cutoff wall is to be provided at the end of the water cushion. Its thickness is 0.5-1.0 meter. Both ends of the cutoff wall shall be inserted into both banks or extended into safe areas. The depth of the cutoff wall should be determined by the estimated scoured depth of the downstream river bed.

(vi) Side walls

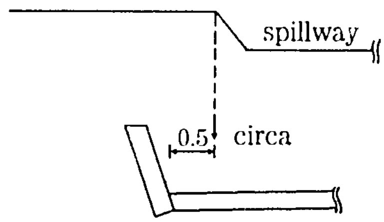
Side walls are to be provided when both banks are soft and weak, or when a water cushion is required to control water flow.

(a) Height

The height of the end of the side wall is to be determined by the height of the spillway. The top of the side wall should extend gradually upwards from the end to the dam body.

(b) Connection with the main dam

The position of the footing of the side wall should be outside the plumb-line extended from the top of the spillway, and 0.5 meter from the line.



b. Aprons

If a dam is less than 7 meters in height with a low spillway head and is located on an easily eroded river bed, an apron may be a more economic and effective means of conrolling water damage.

Features concerning the length, thickness, slope, cutoff wall depth and side wall height as well as connection with the main dam, are the same as those of water cushions.

c. Secondary dams

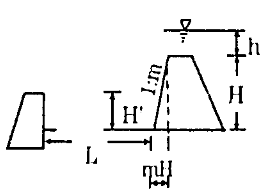
In order to prevent the toe of a dam from scouring, a low dam can be construcled downstream from a dam, espacially when the river has a large flow discharge.

(i) Structure

Refer to the design of main dams.

(ii) Overlap height

The overlap height of a secondary dam may be determined by the following empirical equations.



H'=Overlap height (m)

$=(\frac{1}{3}\sim\frac{1}{4})H$

L =Distance between main dam and secondary dam

$=(1.5\sim2.0)(H+h)$

(8) Forces involved in dam design

Forces applied to a dam include the dam weight, water pressure, earth pressure, foundation bearing force, uplift force, possible earthquakes, expansion and shrinkage, debris flow impact, etc.

a. Dam weight

Dam weight is calculated on the basis of the materials used. Concrete weight is 2.3-2.4 t/m^3

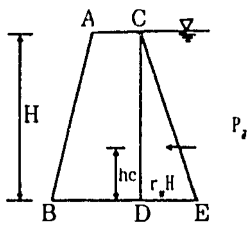
b. Water pressure

The static water pressure acting on the upstream face of a dam is of major concern. As to the water flow pressure, this is only used for determing the top width of the dam.

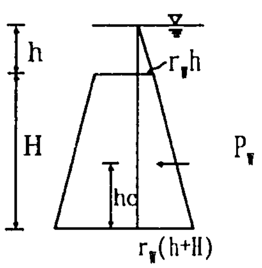
(i) Water pressure on the upstream vertical face with no overflow: The water pressure at point C=0

The water pressure at point D is that $\gamma_w H$ acts on the dam, i.e., $P_w = \frac{1}{2}\gamma_w H^2$

The point of resultant, hc=H/3



(ii) Water pressure on the upstream vertical face with an overflow depth



$$P_w = \frac{1}{2}[\gamma_w h + \gamma_w (h+H)]H$$

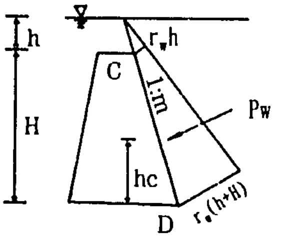
$$= \frac{1}{2}\gamma_w H^2 (1 + \frac{2h}{H})$$

$$hc = \frac{H}{3} \cdot \frac{H+3h}{H+2h}$$

(iii) Water pressure on the upstream sloping face with an overflow depth

$$P_w = \frac{1}{2}[\gamma_w h + \gamma_w(h+H)] \cdot CD$$

$$CD = \sqrt{H^2 + (mH)^2} = H\sqrt{1+m^2}$$



$$\therefore P_w = \frac{1}{2}[\gamma_w H + \gamma_w(h+H)] \cdot H\sqrt{1+m^2}$$

$$= \gamma_w/2 \cdot H \cdot (2h+H)\sqrt{1+m^2}$$

$$hc = \frac{H}{3} \cdot \frac{H+3h}{H+2h}$$

Horizontal component $P_{wH} = \frac{1}{2}\gamma_w H(H+2h)$

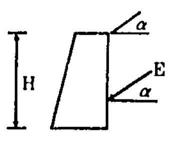
Vertical component $P_{wV} = \frac{1}{2}\gamma_w \cdot m \cdot H(H+2h)$

c. Earth pressure

This is the main pressure of silt and sand acting on the upstream face of a dam. It may be calculated according to the following equations.

(i) Earth pressure on the upstream vertical face with a sedimentation slope of α

$$E = C + \frac{\gamma_s H^2}{2}$$



Where γ_s=unit earth weight (t/m^3)

C=earth pressure coefficient

C is replaced by Ca where earth pressure is active, and C is replaced by Cr in the case of passive earth pressure.

$$\therefore C_a = \cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

$$C_r = \cos\alpha \frac{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}$$

Where ϕ =angle of earth inner friction (usually the angle of repose)

In this case, the direction of the earth pressure is parallel to the ground surface, and the point of the resultant is on the upstream dam face at a height of H/3 from the bottom of the dam.

If the sedimentation surface is level, α =0

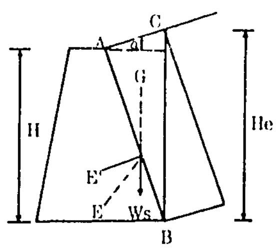
$$C_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \tan^2(45° - \frac{\phi}{2})$$

$$C_r = \frac{1 + \sin\phi}{1 - \sin\phi} = \tan^2(45° - \frac{\phi}{2})$$

If the sedimentation slope equals the angle of repose, i.e., when $\alpha = \phi$, $Ca = Cr = \cos\phi$

(ii) Both the upstream dam face and sedimentation slope are same as α ; the point of the resultant can be obtained by $E' = C\frac{\gamma_s H_c^2}{2}$

The resultant and its direction on the dam surface AB can be obtained from the resultant of E' and the sand and stone weight Ws of △ABC. The amount, direction and acting point of resultant E may be found by the graphical method. However, the result should be checked by deriving the horizontal and vertical components of the resultant.



d. Foundation bearing force

The force acting on the foundation through the dam should be less than the ground bearing force.

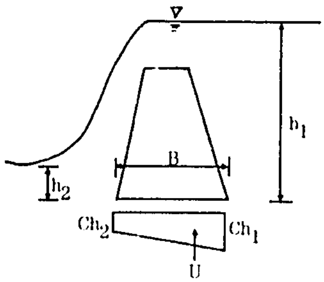
For construction of high dams, the foundation bearing force should be determined through actual field tests.

Table 1-2. General foundation bearing capacities

Properties of foundations	Bearing Capacity (t/m)
Soft clay	10
Common clay	20
Hard clay	40
Soft silt	10
Compact silt	30
Soft coarse sand	30
Soft sand & gravel mix or cobbles	40
Compact sand & gravel nix or cobbles	50
Hard rock	100
Hard shale	100
Granite	450

e. Uplift force

The uplift force is an upward force due to seepage water. It reduces the effective weight of a dam. It may be obtained by the following equation:



$$U = C\frac{h_1 + h_2}{2} B \gamma_w$$

U :Uplift pressure

h_1 :Water depth upstream (m)

h_2 :Water depth downstream (m)

B :Dam base width (m)

C :Uplift coefficient (0.2~0.7)

γ_w:Unit weight of water (t/m^3)

Table 1-3. Foundation uplift coefficients

Properties of foundations	Uplift coefficient
Soft clay	0.6
Common clay	0.5
Hard clay	0.4
Soft sand	0.7
Compact silt	0.6
Soft coarse sand	0.7
Soft sand & gravel mix or cobbles	0.6
Compact sand & gravel mix or cobbles	0.5
Hard rock	0.3
Hard shale	0.25

f. Earthquake

When an earthquake occurs, there are three kinds of effects.

(i) Direct effect to the dam body

$$P_c = m \cdot a = \frac{W}{g} \cdot Kg = Kw$$

P_c: Direct pressure to the dam due to earthquake

m: Unit mass of dam (t/m^3)

a: Earthquake acceleration (m/sec^2)

W: Unit weight of dam (t/m^3)

g: Gravity acceleration (m/sec^2)

$K = a/g \fallingdotseq 0.1\text{-}0.12$

(ii) Increment of static water pressure

$P_{Ew}=K \cdot K_E \cdot C_E \cdot \sqrt{Hh}$

Where P_{Ew}: Increment of water pressure

H: Dam height (m)

h: Height to certain point from water surface

K: Horizontal earthquake coefficient

K_E: Coefficient (depending on the slope of upstream dam face

C_E: Coefficient from Westergard equation

$$C_E = \frac{51}{\sqrt{1 - 0.72\left(\frac{H}{1000tc}\right)^2}}$$

(iii) Earth pressure due to earthquake

From the empirical equation of U.S. T.V.A., earth pressure due to earthquake can be obtained.

$$P = \frac{1}{2}\left(\frac{\cos(\phi - \theta)}{1 + n}\right)^2 \cdot \frac{\cos\delta}{\cos(\delta + \theta)\sqrt{\cos\alpha}} \cdot \gamma_s \cdot H_o^2$$

$$n = \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \delta)}{\cos(\phi + \delta)}}$$

H_o=Height of upstream sedimentation (m) $\delta = \frac{1}{2}\phi$

ϕ =Angle of earth inner friction $\theta = \tan^{-1}K$

Therefore, the additional horizontal earth pressure P_{EH} due to earthquake is the difference of P and the original earth pressure.

g. Expansion and shrinkage due to temperature difference

Computation of these forces can be neglected because temperature differences are not great in Taiwan. Expansion joints are used to solve this problem.

h. Impact of debris flow

The impact force of debris flow should be considered, especially when there is unstable land in the vicinity of a check dam. So far, there is no rational computation method. The impact force is treated as if it were static water pressure, by converting the debris flow to water with a unit weight of over 1.6-1.8 t/m^3. This kind of pressure should be considered not only with regard to the spillway, but also the wing walls.

For a check dam less than 7 meters high, forces are computed according to actual loads and by raising the unit water weight to 1.1-1.2 t/m^3 without considering the items e,f and g. For a check dam over 7 meters in height, or on a large river, all these forces must be checked to ensure the safety of the dam.

i. Dam crosssection

(i) Effective top width

(a) According to dam height

Dam height H< 5m, b≧1.5m(applicable to submerged dam)

5m≦H< 10m, b=1.8~2.0m

10m≦H, b=2.0~3.0m

(b) According to ground conditions

General wild creeks b=1.5m

Creeks with coarse particles b=2.0m

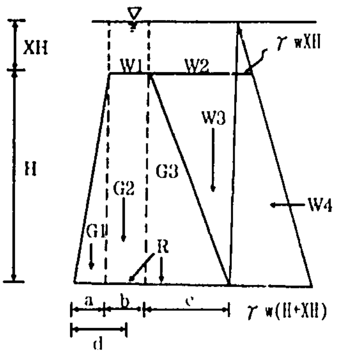
Debris flow or rolling big stones b=2.0~4.0m

(ii) Slope of downstream face

In order to avoid impact of sand and stone on the downstream face of a dam, its slope should be 1:0.2~1:0.3

(iii) Cross section

The crosssection of a check dam is based on the assumption that the resultant of the dam weight and all outside forces pass through the point located at $\frac{1}{3}$ of the dam base width, as measured from the downstream side, i.e., the moment at that point equals zero.



γ_w:Unit weight of water (t/m^3)

γ_m:Unit weight of dam (t/m^3)

H :Effective dam height (m)

XH :Depth of overflow (m)

d=(a+b+c)/3

j. Checking the safety of a gravity dam

A check dam is usually a straight gravity dam, and should satisfy the following conditions:

(i) Overturning

A dam should not overturn, taking its toe as a center. It is desirable that the resultant of the dam weight and outside forces passes through the middle third of the dam base.

(ii) Sliding

No point of the dam should be subject to sliding i.e., the friction resistance force must be greater than the horizontal force. Friction coefficients (μ) in common use are listed in Table 1-4, and the safety factors, FS are as follows:

Effective dam height H=less than 7m FS=1.1

H=7m ~15m FS=1.1~1.5

H=more than 15m FS=1.5

Table 1-4. Coefficients of friction between concrete and foundations

Foundation properties	Friction coefficient (μ)
Hard bedrock	0.7
Cobbles & coarse sand	0.55-0.60
Dry sand	0.45-0.55
Wet silt	0.3-0.40
Sand & clay mix	0.4-0.50
Clay	0.3

(iii) Internal stresses

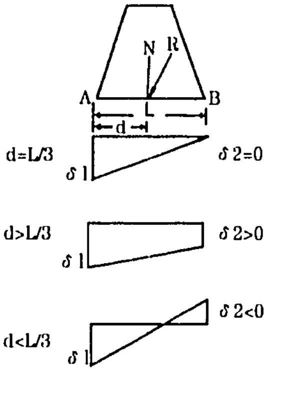
The maximum stress occuring in the dam body should be within the limit of the allowable stress, and should not be a tension stress.

(a) With a hard foundation

When $d=\frac{L}{3}$, it is the most desirable dam section.

When $d>\frac{L}{3}$, it is a safe section.

When $d<\frac{L}{3}$, the section is undesirable, as there will be a tension stress on the upstream face of the dam.



(b) If δ 1 value is greater than the foundation bearing force, the dam base will subside. Therefore, the former should be less than the latter.

(c) Foundation bearing force

The dam foundation bearing capacity must be greater than the maximum stress occuring in the dam body. Safety check of this item should be made assuming conditions of maximum flood and earthquake, and before and after sedimentation.

Chapter 2. Submerged Dams

2.1 Definition

A submerged dam is a structure less than 5 meters in height across a river channel to stabilize the river bed.

2.2 Purpose

(1) To stabilize the river bed by preventing longitudinal and lateral erosion.

(2) To protect the foundations of river banks and other related structures.

2.3 Application

Please refer to the Chapter on Check Dams.

2.4 Design Criteria

(1) Selection of site

a. The dam should be located on a section of the river bed where erosion is in progress or likely to take place.

b. If the area which is subject to erosion is located at a confluence of rivers, the dam should be built dowstream from the confluence.

c. The dam may be located downstream from a structure to protect the foundation of that structure.

d. The dam may be built downstream from the location where collapse or sliding of be barks is taking place .

e. It should not be built on the curve of a river.

f. The dam may also be located downstream from a section where there is serious deposition.

(2) Dam axis direction, cross section, wing wall, water cushion - Refer to the Chapter on Check Dams.

275

Chapter 3. Spur Dikes

3.1 Definition

A spur dike is a structure extending from a river bank towards the center of a river in order to promote sedimentation, shore making and flow adjustment.

3.2 Purposes

(1) To change the direction of water flow so as to protect river-banks.

(2) To maintain a normal river width by regulating the river channel.

(3) To expedite sedimentation in order to establish a new bank.

3.3 Applications

(1) Concrete spur dike: Applicable to a site where the topography does not change much, but the impact of rolling stones is serious.

(2) Wire sausage spur dike: Applicable to a place where the topography changes rapidly due to serious erosion.

3.4 Diagram

(1) Concrete spur dike

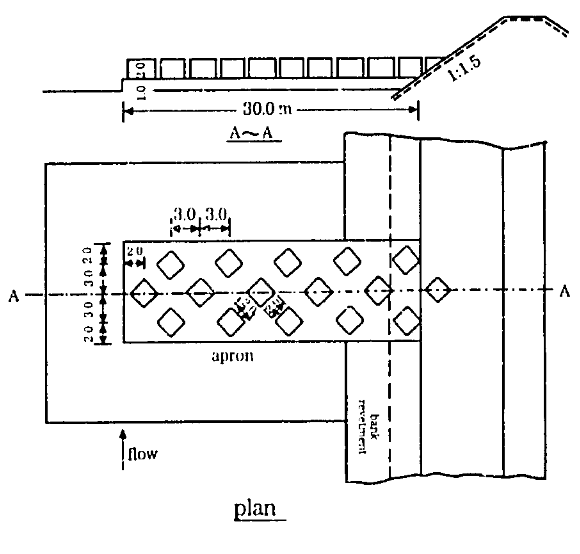


Fig. 3-1. Concrete spur dike 1

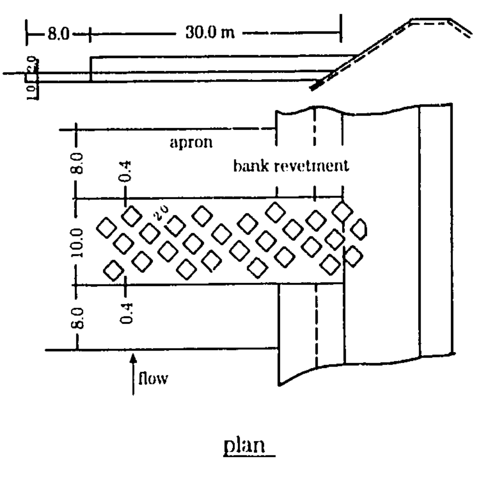


Fig. 3-2. Concrete spur dike 2

(2) Wire sausage spur dike

a. Layout and cross section

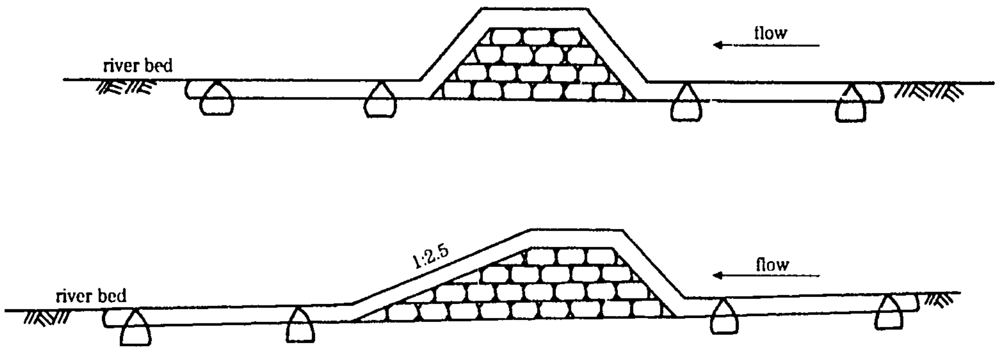


Fig. 3-3.

b. Connection with bank revetment

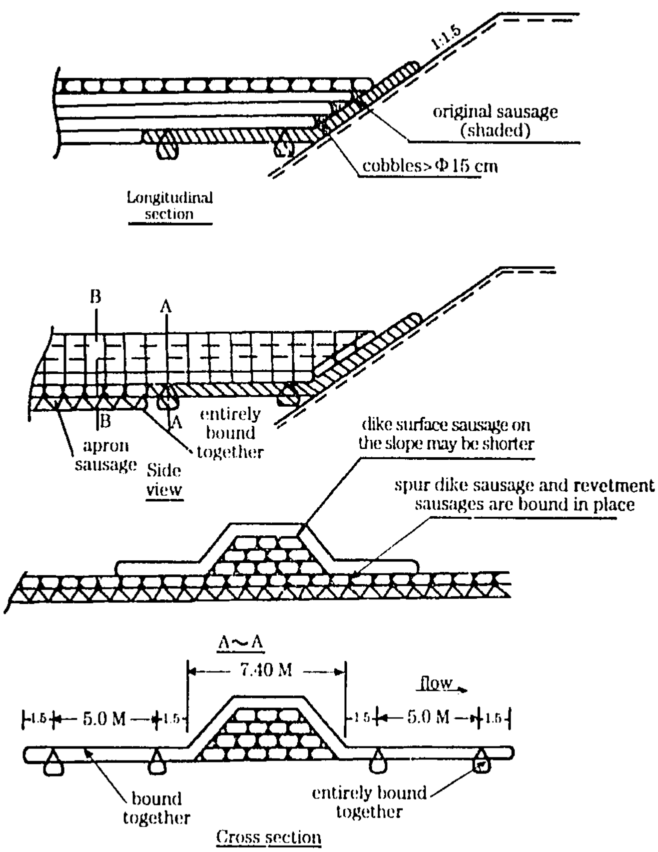


Fig. 3-4.

3.5 Design criteria

(1) Direction

The direction of a spur dike is the angle between the axis of the dike and the water flow of a river. It may be perpendicular to the water flow, toward upstream or downstream. A spur dike pointing upstream may induce water flow towards the center of the river. In this case, since water flows over the dike in a direction nearly perpendicular to the dike, it will cause sedimentation near the downstream bank and scouring at the head of the dike because of the strong resistance to the water flow. The perpendicular spur dike is usually used on a river section with turbulent or unstable flow. The spur dike pointing downstream may increase the possibility of scouring of the downstream bank footing unless a group of spur dikes are placed close togerter. This kind of spur dike may be used, to lead water flows towards a bank to help maintain water depth, if this is needed for some special reason. However, it should not be used without careful consideration.

(2) Interval between dikes

If the interval of spur dikes is D, the dike length is L, and the dike height is H, the interval between spur dikes will be as follows:

In a straight river section:	D/L=2.3
On a concave bank	: D/L=1.5-2
On a convex bank	: D/L=2.5-3.5
	D/H=10-30

(3) Dike length

The length of a spur dike is determined by the purpose of the dike, river width, upstream and downstream conditions, and its effect on the banks, as well as the safety of the structure itself.

(4) Width

The width of a spur dike should be wide enough to resist water impact and erosion. In general, it is 4-6 meters.

(5) Slope

The longitudinal slope of a spur dike from the bank shall be determined according to the cross section of the river and the flood gradient. In general, it is 1/30-1/100.

(6) Height

The height of a spur dike depends on the type of dike, the design, flood water level, and the topographical conditions of the river.

(7) Bank protection

The bank is usually protected a gainst the swirling current at th point where the bank meets the dike. The length of bank protection is usually about 15 meters, and should not be less than 2/3 of the dike length; the height should be above the flood water level.

(8) Dike head

Possible scouring depth should be taken into account when the depth of the footing at the dike head is determined. A gentle slope or a height lower than the flood water level should be adopted, to reduce resistance to water flow at the dike head.

(9) Apron

This is a flexible structure constructed as one unit, made of connected concrete blocks or wire sausages. It should be well connected with a spur dike so that the current will not detach it from the dike.

3.6 Supplementary Note

(1) A concrete spur dike consists of a set of concrete blocks. Its height is less than its width, and the area covered by its base is larger than its cross section. All the blocks are placed with their angles towards the water flow. Each row of concrete blocks is placed in a zigzag line at a gradually reduced height from the bank. The foundation of the dike is usually set at the same level as the river bed. However, it should not have a slope of more than 1/30 toward the river's center line. A cutoff wall is to be provided around the footing of the dike.

(2) Most wire sausage dikes are submerged dams. In order to reduce the impact of water flowing over the dike, the downstream slope is flatter than the upstream one, preferably 1:2.5. Protection of the bank, where the dike meets the bank, must be built separately. In a river section where water flows rapidly with a strong scouring force, the apron at the dike head should be strengthened with longer main sausages and pillow sausages.

279

Chapter 4. Levees

4.1 Definition

A levee is a structure built higher than the ground surface along the water flow of a river or creek to control the water flow and protect the land from inundation.

4.2 Purpose

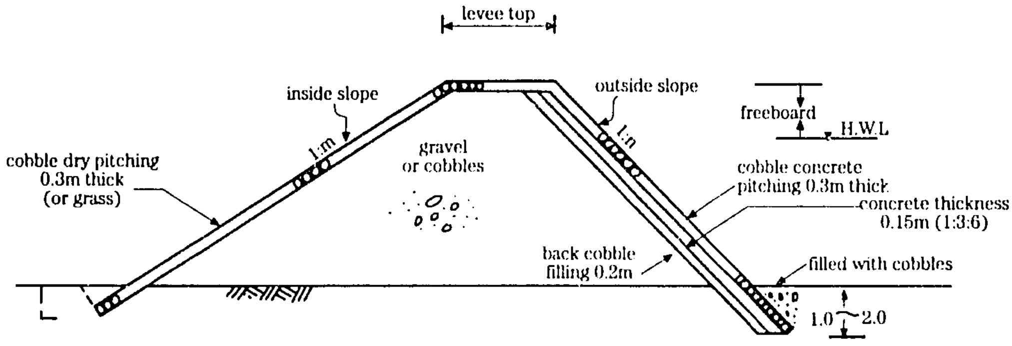
It is to protect river banks and neighboring land, villages and public works against erosion and floods.

4.3 Applications

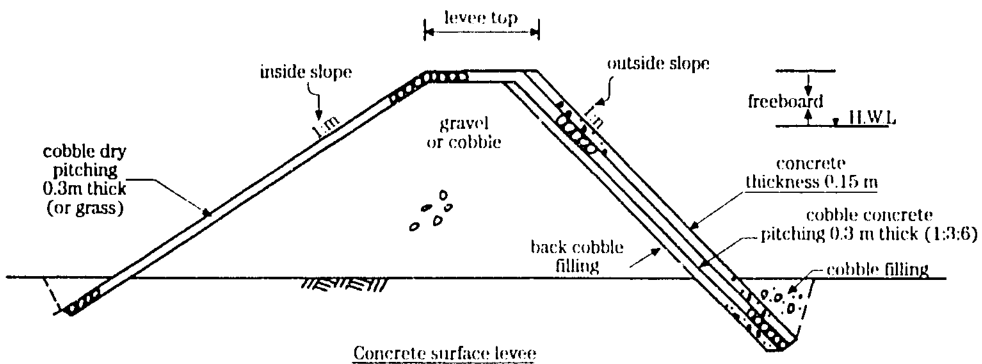
(1) Cobble paved levee: Used in a place where cobbles can be easily obtained.

(2) Concrete surface levee: Used in a place where the surface of a levee is easily damaged.

4.4 Diagram



Cobble pitching surface levee



Concrete surface levee

Fig. 4-1. Cross-sections of levees

4.5 Design Criteria

(1) Freeboard: 0.8-1.2 meters

(2) Top width: 1.5-2.0 meters when the height is less than 2.5 meters; 2.0-2.5 meters when the height is 2.5-5.0 meters; 2.5 meters when the height exceeds 5 meters.

(3) Side slope: As Table 4-1

Table 4-1. Sideslope of levee

Items \ Height	Less than 2.5m		2.5m-5.0m		More than 5m	
	Outside	Inside	Outside	Inside	Outside	Inside
Cobbled Surface	1:0.5	1:1.5	1:0.5~1.1	1:1.5	1:1~1:1.5	1:1.5
Concrete surface	1:1	1:1.5	1:1.25	1:1.5	1:1.5	1:1.5

Remarks: If cobble concrete pitching is applied to the inside slope face, a slope of 1:0.3-1:0.5 is used

(4) Alignment

a. Follow the alignment according to the regulations laid down for rivers.

b. Follow the water flow as smoothly as possible, avoiding abrupt curves.

c. Use a radius of curvature 10-20 times the river channel width for the curved sections of a river.

d. Adopt parallel levee alignments for both banks whenever possible. Avoid abrupt changes in river channel width.

e. Insert a straight transition section of a length more than 6 times the river channel width, between two reverse curves (S curve).

f. Give a super-elevation to the levee on the concave bank of a river. The elevated height (above the design height at the center line of the river bed, Δh in meters is determined by the following equation:

$$\Delta h = 2.3 \frac{V^2}{g} \log \left(\frac{R_2}{R_1} \right)$$

V=water flow velocity (m/sec)

R_1=radius of curvature on the convex bank (m)

R_2=radius of curvature on the concave bank (m)

g=gravity acceleration (m/sec^2)

g. Widening of a curved section:

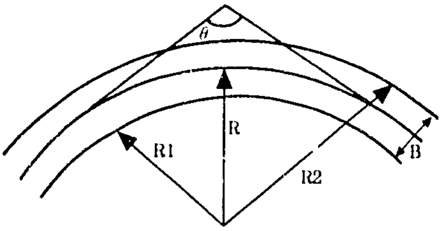
281

Condition	Widening
R/B>10, θ >60°	Widening 10%
R/B>10, θ <60° or R/B<10, θ >60°	Widening 20%
R/B<10, θ <60°	Widening 30%

R=Radius of curvature (m)

B=River width (m)

θ =Included angle of curved channel



4.6 Supplementary Note

(1) Extra-filling of levee: Because of compression or subsidence of the foundation, a levee filled with earth should be heightened according to the following criteria:

Silt, clay: H/10-H/20; sand, gravel: H/20-H/40

Where H is the project height in meters.

(2) Energy dissipating walls may be provided at intervals of 5 meters on the outside face in order to slow down water flow velocity. Protective structures such as concrete blocks, wire sausages or spur dikes may be built to protect the footing from scouring. Especially in a concave section, deepening of footings or strengthening of protective structures is necessary.

(3) Alignment is to be placed on a sound foundation. If the foundation is soft, it should be treated and strengthened.

(4) If a levee cannot have a normal cross section when it passes through densely populated urban areas, flood walls or other special dikes may be built instead, in order to save the expense of securing right-of-ways or pulling down houses.

(5) The intersection angle of a main stream levee and its tributary levee at the confluence point should be less than 60° .

(6) The upstream end of a levee should be located in a place where flood water cannot freely flow into the area behind the levee. If a levee is long enough, openings or culverts may be provided for drainage in order to avoid inundation inside the levee.

(7) If the downstream end of a levee is located on an open plain, it should be protected usually by a semi-circular structure. The radius of this semi-circle should equal the distance between the top and the bottom of the levee at the center of its width. In addition, the footing should also be protected.

Chapter 5. Revetments

5.1 Definition

A revetment is a structure built directly on to a river bank to protect it.

5.2 Purpose

This is to stabilize the bank footing and protect the bank of a river.

5.3 Application

(1) Concrete (or reinforced concrete) revetments: Used in places where banks require protection against rapidly flowing water, or to protect an important area.

(2) Cobble concrete pitching revetment: Used in a places where there are plenty of cobbles.

(3) Flexible or other special structures: Used in a places with special topographical conditions such as land collapse, landslides etc.

5.4 Diagram

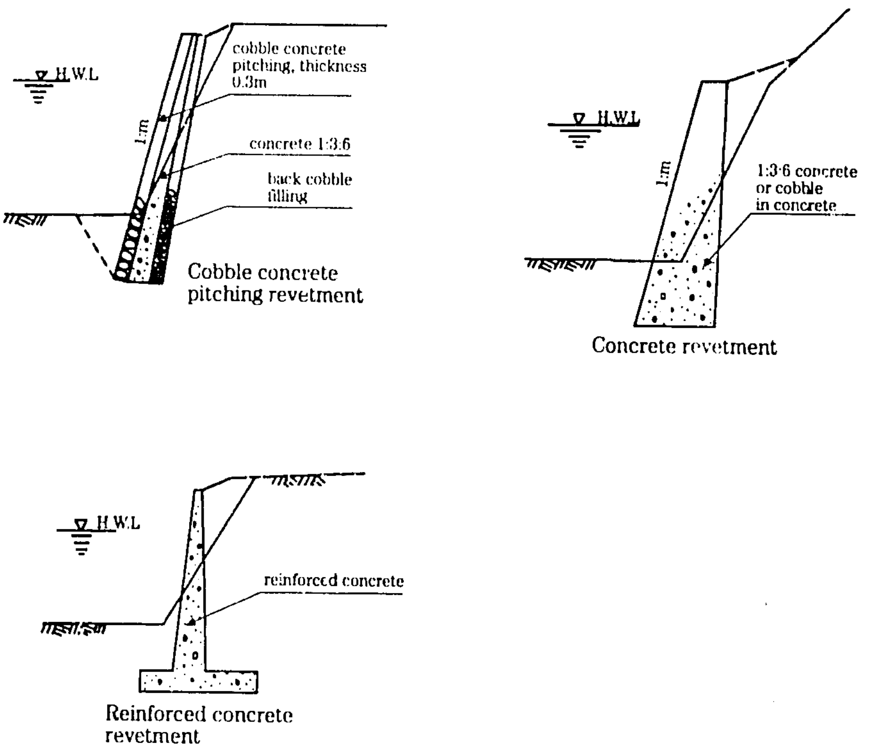


Fig. 5-1. Kinds of revetment

5.5 Design Criteria

(1) Height

The height of a revetment equals the expected floodwater level plus a freeboard of

0.8-1.0 meter. However, it may be the same heitght as the ground surface, if necessary.

(2) Slope

A slope of 1:0.3~1:1 is usually adopted for cobble faced revetments.

(3) Super-elevation

The super-elevation of a levee along the concave bank of a river is determined as follows (refer to the Chapter on Levee):

$$\triangle h=2.3\frac{V^2}{g}\log\left(\frac{R_2}{R_1}\right)$$

where $\triangle h$=super-elevation of a revetment above the design height at the center line of the river bed.

V= water flow velocity (m/sec)

g= gravity acceleration (m/sec^2)

R_1= radius of curvature on the convex bank (m)

R_2= radius of curvature on the concave bank (m)

(4) Foundation depth

The foundation depth of a revetment is usually 1-2 meters below either the design river bed elevation or the existing river bed elevation, whichever is lower.

(5) Alignment

At the beginning of a revetment, there must be a solid bank. If the bank is soft, the revetment must be properly inserted into the bank. The end of the revetment shall be aligned so that water flows smoothly downstream or flows away from the bank. The end of the revetment on the concave bank should extend downstream beyond the end of the curve.

(6) Safety checking includes not only water pressure but also the same factors as those considered for retaining walls.

5.6 Supplementary Note

(1) The footing of a revetment should be protected, using concrete blocks, wire sausages or submerged dams, where the river channel is subject to deep scouring, especially in the section of a concave bank.

(2) When concrete blocks or wire sausages are used to protect the footing, they should not be fixed to the revetment.

(3) Earth filling on the back side of the revetment should be thoroughly compacted and raised a little higher than the revetment in order to avoid ponding, which would increase water pressure on the back of the revetment.

(4) Weep holes should be provided at a certain height and at suitable intervals along an impervious revetment.

Chapter 6. River Regulation

6.1 Definition

River regulation refers to integrated engineering work, including revetments, levees,fixing of river beds, drops, spur dikes, river bed protection etc., aimed at preventing longitudinal and lateral erosion in the deposit and eddy flow sections in a wild creek or river.

6.2 Purpose

(1) To stabilize the river bed in order to prevent longitudinal and lateral erosion in the deposit and eroded section.

(2) To control water flow for the purpose of protecting land, houses and public facilities on both banks.

(3) To protect banks and their footings in unusual geological sections (such as mudstone, or volcanic ash areas) from erosion or collapse.

6.3 Application

River regulation work should be provided in sections where the slope of a creek is over 1/100, or where there is silt/sand damage, silt/sand deposits, serious longitudinal and lateral scouring which produces a large amount of silt and sand; or in silt/sand deposit areas where there are meandering or eddy flows which may cause inundation; or where there are objects to be protected along a creek. The kinds and applications of river regulation work are as follows:

(1) Bed protection

This is to protect the river bed by lining it, and may be combined with lining on both banks. It is applicable to a section with a slope of more than 1/30.

(2) Energy dissipation

Drops, river bed fixing works, submerged dams etc. are used to dissipate water flow energy and to stabilize the river bed. These are used in sections where water flows rapidly.

(3) Spur dikes

Spur dikes are used to control and stabilize water flow. They are used in relatively wide creeks where there are eddy flows.

285

6.4 Diagram

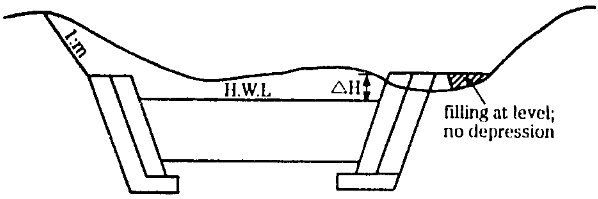


Fig. 6-1. Protection with lining

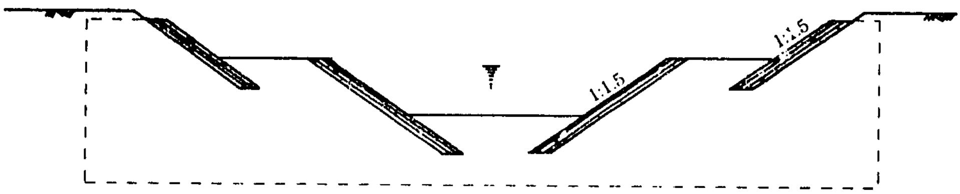
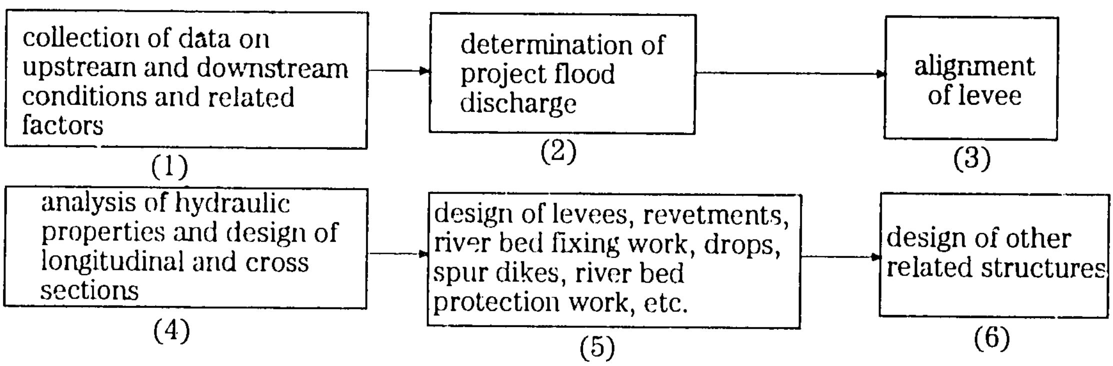


Fig. 6-2. Compound sections

6.5 Design Criteria

In designing work for river regulation, safety economic factors must be taken into account, as well as the function and purpose of the work, so as to enable water to flow safely without affecting the utilization of water resources, groundwater levels, or the natural environment in neighbouring areas, as well as the maintenance and management of the constructed works.

(1) A design flow chart is shown as follows:



(2) Estimation of project flood discharge

a. A rainfall intensity with a frequency of once in 25-50 years is usually adopted for estimation of a project flood discharge, Qo, by applying the rational formula for a small watershed. (see Part I, Appendix 5: Runoff Estimation).

b. The sediments content in water flow, α is usually 5%-10% with a maximum of 50%.

c. Projeced flood discharge:

$$Qp = Qo \times \frac{1}{1-\alpha}$$

d. Project water flow velocity (with sediments), V_p

$$V_p = \frac{\gamma_w}{\gamma_w + \alpha(\gamma_d - \gamma_w)} V_w$$

V_w=clean water flow velocity (by Manning's formula)

γ_w=unit weight of water (1.0 t/m in general)

γ_d=unit weight of sediments (2.3-2.6 t/m in general)

α=content rate (5%-10% in general)

(3) Alignment of levee

a. The alignment indicated in government river regulation plan should be followed.

b. If there is no existing river regulation plan, selection of the alignment should be based on discharge (Q), topgraphical and geological conditions, land use and title, and other related conditions.

c. The cross-sectional area, A of the river regulation work can be estimated as follows:

$Q_p = A \cdot V_p > Q_o$

$$A = \frac{Q_p}{V_p}$$

d. The values of B and h may be obtained by trial and error. The estimated drainage capacity must be at least 5% greater than the projected flood discharge.

$A \alpha Bh$

Where A=cross-sectional area of the regulation works.

B=width of the regulation works

h=height of the regulation works

e. Width between two levees (refer to "Cross section", 6.5(5) of this Chapter)

(4) Longitudial section

a. The gradient of a longitudinal section gradually decreases from the upstream to the downstream at a degree within 50% of variation of friction velocity.

b. The gradient of a longitudinal section is usually between the original creek bed slope and its half slope. For example, if the original creek bed slope is 0.05, the gradient of a longitudinal section for regulation works will be within 0.05-0.025. When water flows at a velocity over the safety limit in a section where the creek bed slope exceeds 1/30 and the channel width is narrow, the creek bed should be protected by lining it.

(5) Cross section

a. Estimation of width B

$B = \beta \cdot Q_p^{\frac{1}{2}}$

B=width of the cross section (m)

Q_P=project flood discharge (m^3/sec)

β =coefficients from Table 6-1

Table 6-1. River width coefficient reference table

Watershed area,A (km^2)	β value
A≦1.0	2-3
1<A≦10	2-4
10<A≦100	3-5
100<A	3-6

The estimate obtained from the above formula is only for reference in planning the design. The actual design width of a cross section is to be determined according to work site condition, land use, right-of-ways and other factors.

b. Super elevation on the concave bank

$$\triangle h=\frac{V^2}{g}\left[2.303\left(\log R_2-\log R_1\right)+\frac{0.0042}{t}\cdot\sqrt{\frac{R_2-R_1}{R_2+R_1}}\right]$$

Where

$\triangle h$=super elevation (m)

V=water flow mean velocity in the curved section (m/sec)

R_1,R_2=radii of curvature of the convex bank and the concave bank

g=gravity acceleration (m/sec^2)

t=water depth (m)

B=width of the cross-section (m)

R=Radius of curvature of the river channel center line

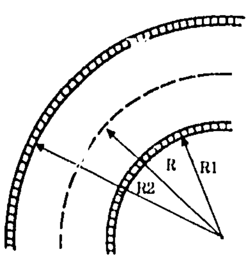


Fig. 6-3

c. The length of transition for a super elevation on the concave bank

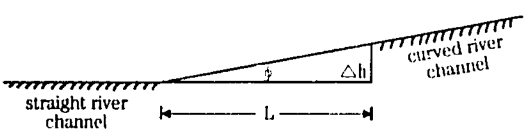


Fig. 6-4

$$\tan\phi=\frac{V^2}{R\cdot g}$$

$$\tan\phi=\frac{\Delta h}{L}$$

$$L=\frac{\Delta h}{\tan\phi}=\frac{\Delta h}{\frac{V^2}{R\cdot g}}=\frac{\Delta h\cdot R\cdot g}{V^2}$$

Remarks:The above equations are not applicable to abruptly reversed curves or S curved river channels. In this situation, it is necessary to adjust the alignment to make a smooth, gentle curve.

〔Calculation example〕

Assume that the curved channel width, β is 10 meters, the radius of curvature of the channel center line, R is 60 meters, water flow mean velocity is 4.9 meters per second and water depth is 1.5 meters.

(i) Super-elevation, $\triangle h$

$$\triangle h = \frac{V^2}{g}\left[2.303\left(\log R_2 - \log R_1\right) + \frac{0.0042}{t} \times \sqrt{\frac{R_2 - R_1}{R_2 + R_1}}\right]$$

$$= \frac{4.9^2}{9.8}\left[2.303(1.813 - 1.740) + \frac{0.0042}{1.5} \times 0.288\right] = 0.412 \text{ m}$$

(ii) Length of transition, L

$$L = \frac{\Delta h \cdot R \cdot g}{V^2} = \frac{0.412 \times 60 \times 9.8}{4.9^2} = 10.09 \text{ m} \fallingdotseq 10\text{ms}$$

d. If the topographical conditions permit, the width of a curved river channel may be increased by 10-20%, and if the included angle of a curve, θ is greater than 60, the preferred ratio of the radius of curvature to the river width is 10~20:1.

e. The cross section below the confluence of a main stream and a tributary.

The river width below the confluence of a main stream and a tributary is to be determined by taking into account the conditions of the two stream flows. In general, the following principles are followed in designing:

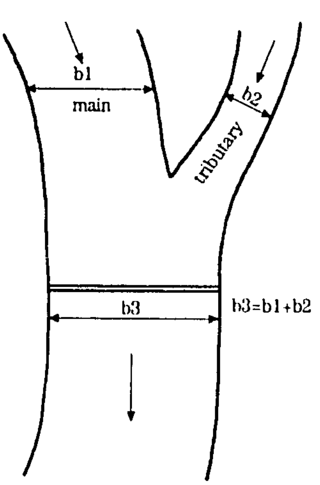


Fig. 6-5.

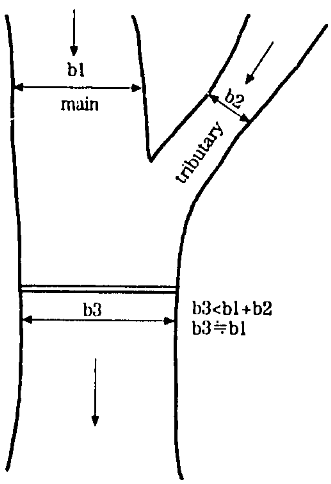


Fig. 6-6.

(i) When the main stream and the tributary have less sediment, and the slopes of their river bed and their projected water levels are similar (i.e. the two streams have the same tractive force), the channel width downstream from the confluence must be the sum of the two (Figure 6-5).

(ii) When the tractive force of the tributary is greater than that of the main stream, the channel width downstrean from the confluence is smaller than the sum of the two, in order to avoid sedimentation at the confluence (Figure 6-6).

(6) Design of levee revetments

Design of levee revetments for river regulation follows the same procedure as that presented in the Chapter on Revetments. However, special attention should be paid to the freeboard.

a. Generally adopted data for the freeboard (Table 6-2)

Table 6-2. Freeboard of Levees and Revetments

Projected Flood Discharge (Q_p) cms	Freeboard (m)
$Q_p \leqq 200$	more than 0.6
$200 < Q_p \leqq 500$	more than 0.8
$Q_p > 500$	more than 1.0

b. Relationship between freeboard and creek bed slope or projected water height, H(Table 6-3)

Table 6-3. Creek bed slope and ratio of freeboard to project water height

Slope(s)	more than 0.1	0.1-0.033	0.02-0.014	0.014-0.01	0.01-0.025
$\triangle H/H$	0.5	0.3	0.25	0.2	0.1

(7) Protection of creek beds

a. Concrete lining: Concrete can be laid over be creek bed with a thickness of 0.2-0.5 meter, usually 0.3 meter. The lining should be thicke in sections where defacement is serious due to movement of large amounts of silt and sand. However, this kind of lining should be avoided as much as possible.

b. Wire sausage: A and B type sausages can be placed on the creek bed. They are used in sections with seepage water.

c. Concrete blocks: Different kinds of concrete blocks are placed on the creek bed. The top surface of each concrete block must be placed at the same level as the project creek bed.

d. Cobble pitching or riprap.

(8) Interval of bed stabilizing concrete sill: To be calculated by the following equation:

$$L = \frac{100}{n - m} h$$

L=interval (m)

h=elevation difference in the section to be protected (m)

n=creek bed slope (%)

20

m=projected creek bed slope(%)

6.6 Supplementary Note

(1) It is desirable to have a check dam or a stable watershed upstream, so that no sediment flows down to the regulation work.

(2) The downstream section of regulation work should have proper protection or safety facilities.

(3) The projected slope of consecutive bed stabilizing concrete sills should in principle be one half of the original creek bed slope. This kind of bed stabilization usually takes the form of a series of low sills or dams.

(4) When a compound section is used, a rainfall intensity with a frequency of once in 5 years should be assumed in estimating the flood discharge in designing the low discharge cross section.

(5) Both banks of such work should be provided with revetments. Dikes that reduce the width of the original creek should be avoided, for fear of major damage if the dike collapses.

(6) The wing walls of the bed stabilizing concrete sills or submerged dams should be deeply inserted into stable banks or bedrock.

(7) The wing wall of a bed stabilizing concrete sill must be smoothly joined to the revetment. It should not protrude.

(8) Both ends of river regulation structures should be built on bed rock or in the stable section of a creek.

(9) The direction of a bed stabilizing concrete sill should be perpendicular to the center line of the downstream water flow.

(10) During investigation and planning, attention should be paid to neighboring drainage and other public facilities in order to maintain their functioning during and after completion of the engineering work.

(11) Concrete floor lining should be provided with weep holes.

(12) Earth filling behind a levee should be higher than the top of the levee.

(13) The footing of a levee or revetment on the concave bank of a creek should be deepened and protected.

291

Chapter 7. Earth Dams

Definition:

An earth dam is a structure made of earth fill, which is built at an appropriate site on a creek to stop and store runoff and sediment.

7.2 Purpose

(1) To store water.

(2) To stop movement of silt, sand or stones.

7.3 Application

An earth dam is used in places where particles of bed materials are small; the creek bed is impervious, and earth for fill is available. An earth dam should not exceed 12 meters in height.

7.4 Diagram

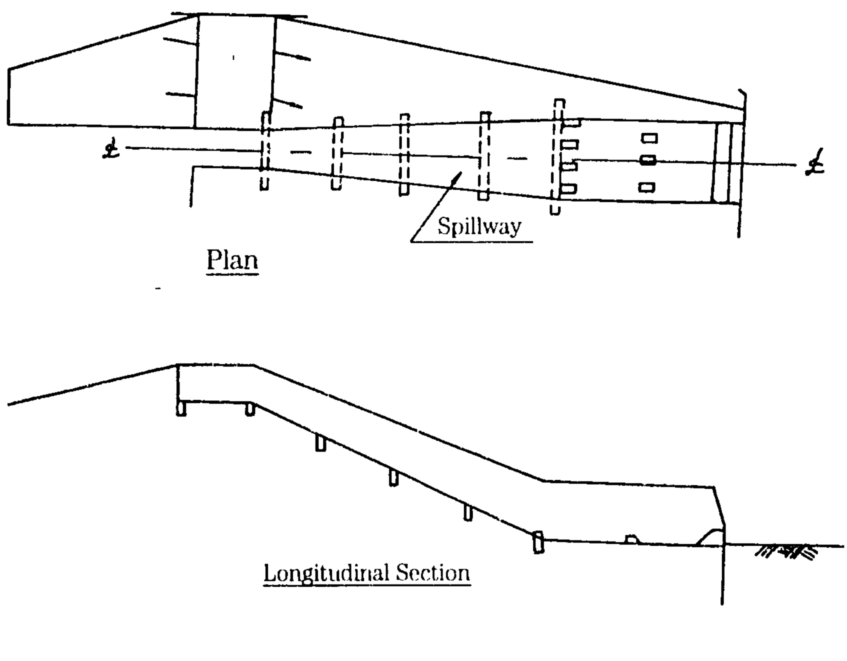


Fig. 7-1. Open channel type spillway

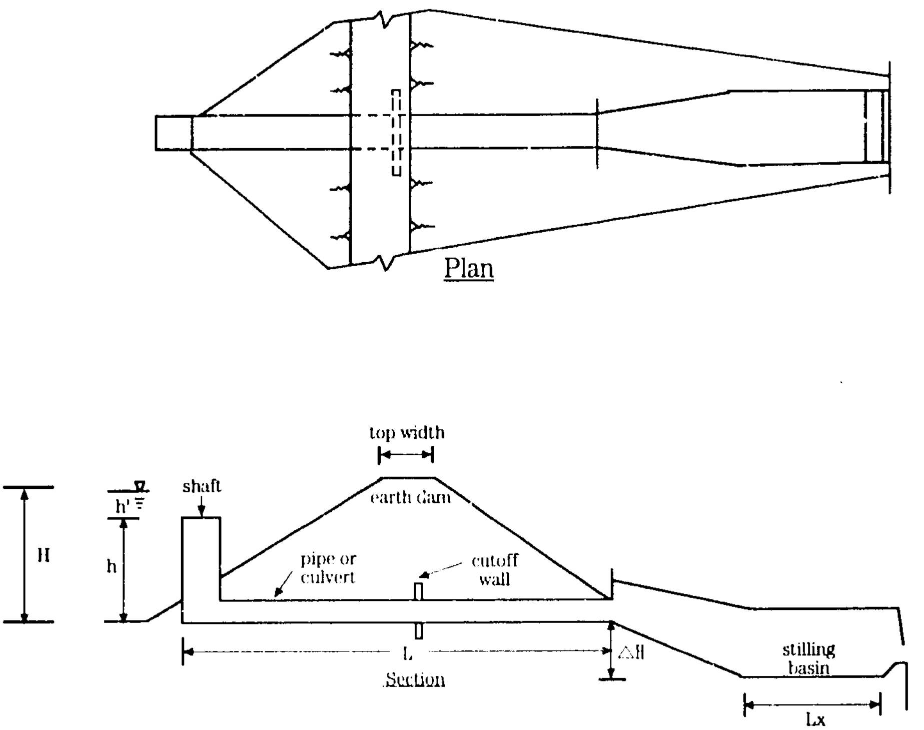


Fig. 7-2. Vertical shaft culvert type spillway

7.5 Design Criteria

(1) Project flood discharge should be estimated according to a frequency of once in 50 years, and emergency spillway capacity according to a frequency of once in 10 years (refer to Part I, Appendix 5. Runoff Estimation)

(2) There are two kinds of spillway, namely main spillways and emergency spillways. There are two types of main spillway, the open channel type and the vertical flow culvert type. A dam which has a vertical flow culvert spillway should be provided with an emergency spillway. A spillway should not be built on a soft foundation. A main spillway is built of reinforced concrete or plain concrete as the basic material.

a. Open channel spillway:

(i) A rectangular cross section should be used.

(ii) Hydraulic computation

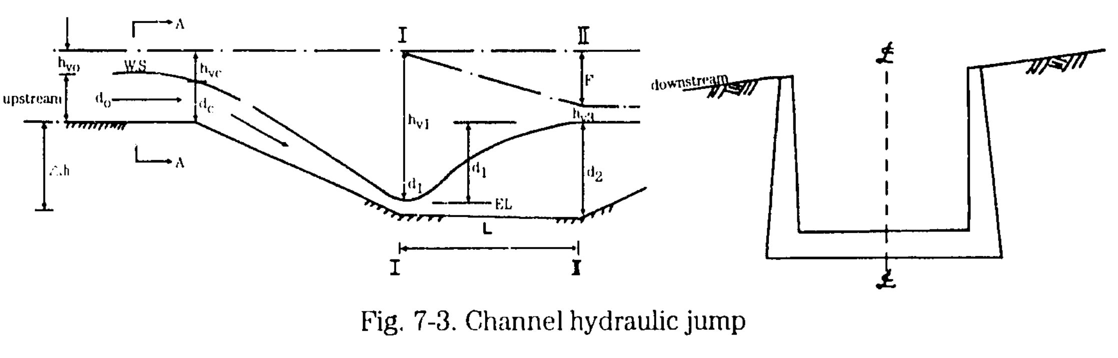


Fig. 7-3. Channel hydraulic jump

293

(a) Inlet section

i. To compute the overflow depth (i.e. upstream water depth), d_o by the broad crest weir flow formula

$$d_o = \left(\frac{Q}{1.84b}\right)^{\frac{2}{3}}$$

Where Q=project flood discharge (m^3/sec)

b=width of inlet section (m)

ii. To compute the upstream energy height, E_o

$$E_o = d_o + \frac{V_o^2}{2g} \qquad (h_{vo} = \frac{V_o^2}{2g})$$

Where V_o=average velocity at the inlet section

h_{vo}=velocity head at the inlet section

iii. To compute the gradient, S_o by Manning's formula

$$S_o = \left(\frac{V_o n}{R^{\frac{2}{3}}}\right)^2$$

where R=Hydraulic radius at the inlet section

n=roughness

(b) Downstream section: To compute its energy height, E_2

$$E_2 = \frac{V_2^2}{2g} + d_2 \qquad (h_{v2} = \frac{V_o^2}{2g})$$

V_2=average velocity at the downstream section

d_2=water depth at the downstream section

h_{v2}=velocity head at the downstream section

(c) To compute upstream and downstream energy height difference, $\triangle E = \triangle H + E - E_2$

$\triangle H$=elevation difference of the upstream and the downstream

(d) To compute the critical depth, d_c (for rectangular cross section)

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}}$$

(e) To determine the height of the control section: In determining the height of the control section for a straight transition with a constant flow discharge, the energy height at the control section is lower than the energy height at the beginning of the transition by 20% of the velocity head difference, that is

$d_o + h_{vo} = d_c + h_{vc} + 0.2(h_{vc} - h_{vo})$

where $h_{vc} = \frac{V_C^2}{2g}$

254

(f) To determine $d_2/d_1=K$ and d_1/d_c values by using
$\triangle E/d_c$ value (from Table 7-1)

(g) To determine d_1 by using d_1/d_c value.

(h) To determine d_2 by using d_2/d_1 value.

(i) Stilling basin

i. When the stilling basin is built in the form of a level apron (without a real basin), there are four types (Figure7-4) of water jump to be determined according to the Froude number. The length of the water jump can be based on the data in Figure 7-5.

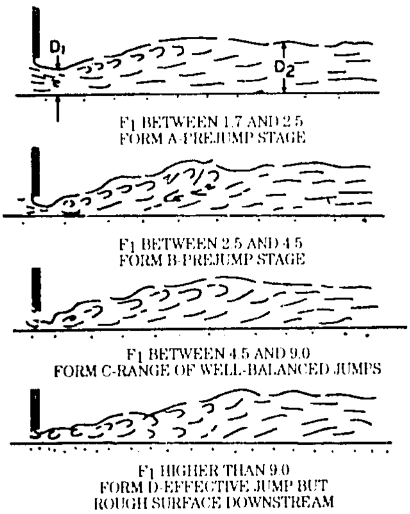


Figure. 7-4. Characteristic forms of hydraulic jump related to the Froude number. (U.S.B.R)

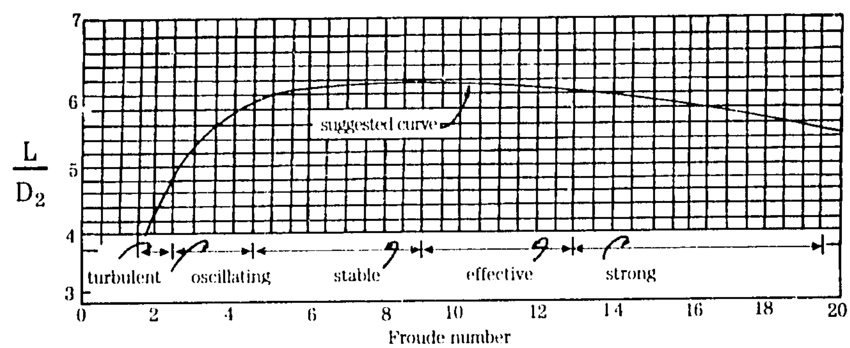


Fig. 7-5. Water jump length and D_2 curve (U.S.B.R.)

To compute the Froude number

$$F_1 = \frac{V}{\sqrt{gd}}$$

In this type of basin (actually an apron without a real basin), the water jump is the pre-jump type (F_1=1.7-2.5); the characteristics of which are shown in figure 7-6, the length of the basin may be derived from Figure 7-7.

Q=total discharge

W=width of basin

q=discharge of unit width

V_1,D_1,E_1=velocity, water depth, energy
height (Section I)

V_2,D_2,E_2=velocity, water depth, energy
height (Section II)

F_1=Froude number

D_z=D_2-D_1=water jump height

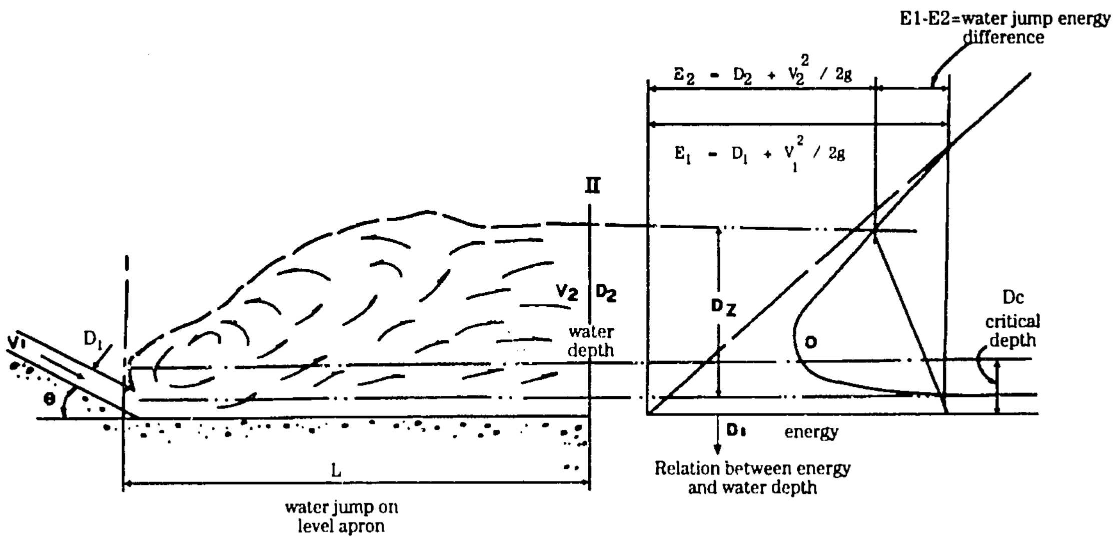


Fig. 7-6. Characteristics of water jump without stilling basin

ii. First type of stilling basin: Jump phenomena, where the incoming flow factors are F_1=2.5-4.5, are designated as the transition flow stage, since a true hydraulic does not fully develop. See Figure 7-8 (from Design of Small Dam,U.S.B.R.).

iii. Second type of stilling basin: Complete water jump(F_1=4.5-9.0) See Figure 7-9.

iv. Third type of stilling basin: Effective water jump ($F_1 \geqq 4.5$, Figure 7-10) may reduce wave action due to incomplete water jump. Because the dissipation is accomplished primarily by hydraulic jump action, the basin length will be greater than that indicated for the type II basin. The basin length may be determined by the following ratio, if model tests are lacking: $\frac{L}{d_2} = 4$

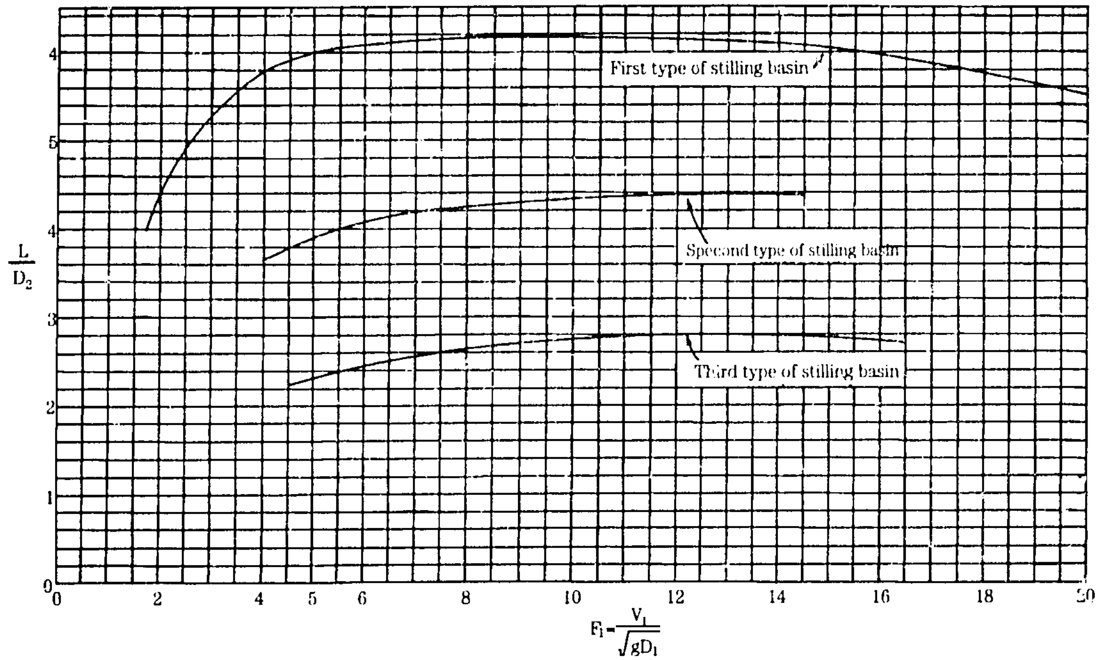


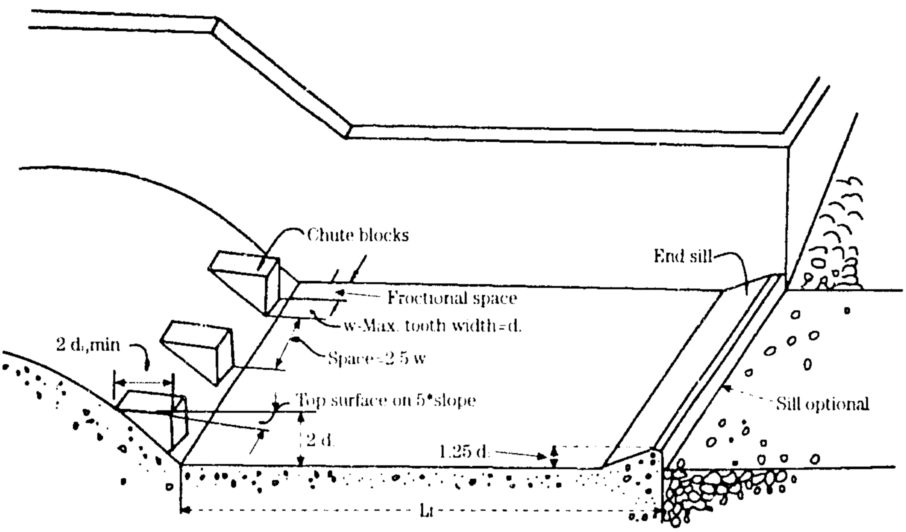
Fig. 7-7. Water jump length on level apron (stilling basin type I, II, III)(U.S.B.R.)

297

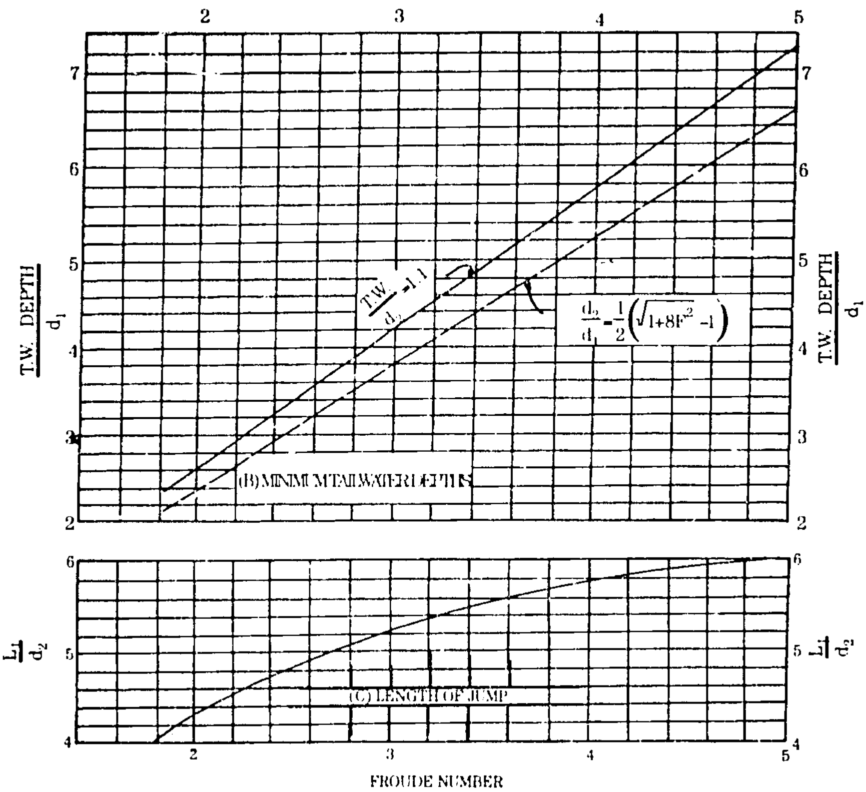
Table 7-1. Water depth d_1 and d_2 in rectangular stilling basin (U.S.B.R.)

$K=d_2/d_1$		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	$\Delta E/d_c$	0	0.0002	0.0015	0.0045	0.0096	0.0169	0.0264	0.0382	0.522	0.0684
	d_1/d_c	1.0	0.951	0.912	0.874	0.842	0.811	0.781	0.758	0.735	0.713
2	$\Delta E/d_c$	0.087	0.107	0.129	0.153	0.179	0.206	0.235	0.266	0.298	0.331
	d_1/d_c	0.693	0.675	0.653	0.641	0.626	0.611	0.597	0.585	0.573	0.561
3	$\Delta E/d_c$	0.367	0.403	0.440	0.479	0.519	0.560	0.602	0.645	0.690	0.736
	d_1/d_c	0.550	0.540	0.530	0.520	0.511	0.502	0.494	0.486	0.479	0.470
4	$\Delta E/d_c$	0.782	0.830	0.878	0.928	0.978	1.029	1.081	1.134	1.188	1.243
	d_1/d_c	0.464	0.457	0.451	0.444	0.438	0.432	0.427	0.421	0.416	0.411
5	$\Delta E/d_c$	1.297	1.35	1.41	1.47	1.52	1.58	1.64	1.70	1.77	1.83
	d_1/d_c	0.405	0.400	0.396	0.391	0.387	0.383	0.378	0.374	0.370	0.366
6	$\Delta E/d_c$	1.89	1.95	2.01	2.08	2.14	2.21	2.27	2.34	2.41	2.47
	d_1/d_c	0.363	0.359	0.355	0.352	0.348	0.345	0.342	0.338	0.335	0.332
7	$\Delta E/d_c$	2.54	2.61	2.68	2.75	2.82	2.89	2.96	3.03	3.10	3.17
	d_1/d_c	0.329	0.326	0.323	0.321	0.318	0.315	0.313	0.310	0.308	0.305
8	$\Delta E/d_c$	3.24	3.32	3.39	3.47	3.54	3.62	3.69	3.77	3.85	3.92
	d_1/d_c	0.303	0.300	0.298	0.296	0.294	0.291	0.289	0.287	0.285	0.283
9	$\Delta E/d_c$	4.00	4.08	4.15	4.23	4.31	4.39	4.47	4.55	4.63	4.71
	d_1/d_c	0.281	0.279	0.277	0.275	0.273	0.272	0.270	0.268	0.266	0.265
10	$\Delta E/d_c$	4.79	4.88	4.96	5.05	5.12	5.21	5.29	5.37	5.46	5.54
	d_1/d_c	0.263	0.261	0.260	0.258	0.257	0.255	0.254	0.252	0.251	0.249
11	$\Delta E/d_c$	5.63	5.71	5.80	5.88	5.97	6.06	6.14	6.23	6.32	6.40
	d_1/d_c	0.248	0.246	0.245	0.243	0.242	0.241	0.239	0.238	0.237	0.235
12	$\Delta E/d_c$	6.49	6.58	6.67	6.76	6.84	6.93	7.02	7.12	7.21	7.30
	d_1/d_c	0.234	0.233	0.232	0.230	0.229	0.228	0.227	0.226	0.225	0.223
13	$\Delta E/d_c$	7.39	7.48	7.57	7.66	7.76	7.85	7.94	8.03	8.13	8.22
	d_1/d_c	0.222	0.221	0.220	0.219	0.218	0.217	0.216	0.215	0.214	0.213
14	$\Delta E/d_c$	8.31	8.41	8.50	8.60	8.69	8.79	8.88	8.98	9.08	9.17
	d_1/d_c	0.212	0.211	0.210	0.209	0.208	0.207	0.206	0.205	0.204	0.203
15	$\Delta E/d_c$	9.27	9.37	9.46	9.56	9.66	9.76	9.86	9.96	10.06	10.16
	d_1/d_c	0.2027	0.2018	0.2010	0.2001	0.1993	0.1985	0.1977	0.1968	0.1960	0.1952
16	$\Delta E/d_c$	10.26	10.36	10.46	10.56	10.66	10.76	10.86	10.96	11.06	11.16
	d_1/d_c	0.1954	0.1937	0.1929	0.1922	0.1914	0.1907	0.1899	0.1892	0.1884	0.1877
17	$\Delta E/d_c$	11.26	11.37	11.47	11.57	11.67	11.78	11.88	11.98	12.09	12.19
	d_1/d_c	0.1870	0.1863	0.1856	0.1849	0.1842	0.1835	0.1828	0.1821	0.1814	0.1808
18	$\Delta E/d_c$	12.29	12.40	12.50	12.61	12.71	12.82	12.92	13.03	13.13	13.24
	d_1/d_c	0.1802	0.1795	0.1789	0.1782	0.1776	0.1770	0.1764	0.1757	0.1751	0.1745
19	$\Delta E/d_c$	13.35	13.46	13.57	13.67	13.78	13.89	14.00	14.10	14.21	14.32
	d_1/d_c	0.1740	0.1734	0.1728	0.1722	0.1716	0.1711	0.1705	0.1699	0.1694	0.1698
20	$\Delta E/d_c$	14.43	14.53	14.64	14.75	14.84	14.97	15.08	15.19	15.30	15.41
	d_1/d_c	0.1683	0.1677	0.1672	0.1666	0.1661	0.156	0.165	0.1545	0.1640	0.1635
21	$\Delta E/d_c$	15.52	15.63	15.74	15.85	15.96	16.08	16.19	16.30	16.41	16.52
	d_1/d_c	0.1630	0.1625	0.1620	0.1615	0.1610	0.1605	0.1600	0.1596	0.1591	0.1586
22	$\Delta E/d_c$	16.64	16.75	16.87	16.98	17.09	17.21	17.32	17.43	17.55	17.66
	d_1/d_c	0.1581	0.1576	0.1572	0.1567	0.1563	0.1558	0.1554	0.1547	0.1545	0.1541
23	$\Delta E/d_c$	17.78	17.89	18.01	18.12	18.24	18.35	18.47	18.59	18.70	18.82
	d_1/d_c	0.1536	0.1532	0.1527	0.1523	0.1519	0.1515	0.1510	0.1506	0.1502	0.1498
24	$\Delta E/d_c$	18.93	19.05	19.17	19.29	19.40	19.52	19.64	19.76	19.88	20.00
	d_1/d_c	0.1494	0.1490	0.1486	0.1482	0.1478	0.1474	0.1074	0.1466	0.1463	0.1459
25	$\Delta E/d_c$	20.11	10.12	20.35	20.47	20.59	20.71	20.83	20.95	21.07	21.19
	d_1/d_c	0.1455	0.1451	0.1447	0.1444	0.1440	0.1437	0.1433	0.1429	0.1425	0.1422
26	$\Delta E/d_c$	21.31	21.43	21.55	21.67	21.79	21.91	22.03	22.15	22.27	22.40
	d_1/d_c	0.1418	0.1414	0.1411	0.1407	0.1404	0.1400	0.1397	0.1393	0.1390	0.1386
27	$\Delta E/d_c$	22.31	22.63	22.75	22.87	22.99	23.12	23.24	23.36	23.48	23.61
	d_1/d_c	0.1383	0.1380	0.1376	0.1373	0.1370	0.1366	0.1363	0.1360	0.1357	0.1353
28	$\Delta E/d_c$	23.73	23.86	23.93	24.10	24.23	24.35	24.48	24.60	24.73	24.85
	d_1/d_c	0.1351	0.1347	0.1344	0.1341	0.1338	0.1335	0.1332	0.1329	0.1326	0.1323
29	$\Delta E/d_c$	24.98	25.10	25.23	25.35	25.48	25.60	25.73	25.86	25.98	26.11
	d_1/d_c	0.1320	0.1317	0.1314	0.1311	0.1308	0.1305	0.1302	0.1299	0.1297	0.1294
30	$\Delta E/d_c$	26.23	26.36	26.49	26.61	26.74	26.87	27.00	27.12	27.25	27.38
	d_1/d_c	0.1291	0.1288	0.1285	0.1283	0.1280	0.1277	0.1274	0.1272	0.1269	0.1266
31	$\Delta E/d_c$	27.51	27.64	27.77	27.90	28.04	28.15	28.28	28.41	28.54	28.68
	d_1/d_c	0.1264	0.1261	0.1258	0.1256	0.1253	0.1250	0.1248	0.1245	0.1243	0.1240
32	$\Delta E/d_c$	28.80	28.93	29.06	29.19	29.32	29.45	29.58	29.71	29.84	29.97
	d_1/d_c	0.1238	0.1235	0.1233	0.1230	0.1228	0.1225	0.1223	0.1220	0.1218	0.1215
33	$\Delta E/d_c$	30.10	30.23	30.37	30.50	30.63	30.76	30.89	31.02	31.15	31.29
	d_1/d_c	0.1231	0.1211	0.1208	0.1206	0.1203	0.1201	0.1199	0.1197	0.1194	0.1192
34	$\Delta E/d_c$	31.42	31.55	31.68	31.82	31.95	32.08	32.21	32.35	32.48	32.61
	d_1/d_c	0.129	0.1187	0.1184	0.1182	0.1180	0.1178	0.1175	0.1173	0.1171	0.1169
35	$\Delta E/d_c$	32.75	32.88	33.01	33.15	33.28	33.42	33.55	33.69	33.82	33.96
	d_1/d_c	0.1167	0.1166	0.1162	0.1160	0.1158	0.1156	0.1154	0.1152	0.1149	0.1147
36	$\Delta E/d_c$	34.09	34.23	34.36	34.50	34.63	34.77	34.96	35.04	35.18	35.31
	d_1/d_c	0.1145	0.1143	0.1141	0.1139	0.1137	0.1135	0.1132	0.1130	0.1128	0.1126
37	$\Delta E/d_c$	35.45	35.59	35.72	35.86	36.00	36.13	36.27	36.41	36.55	26.69
	d_1/d_c	0.1124	0.1122	0.1120	0.1118	0.1116	0.1114	0.1112	0.1110	0.1108	0.1106
38	$\Delta E/d_c$	36.82	36.96	37.10	37.24	37.37	37.51	37.65	37.79	37.93	38.06
	d_1/d_c	0.1105	0.1103	0.1101	0.1099	0.1097	0.109	0.1093	0.1091	0.1089	0.1087
39	$\Delta E/d_c$	38.20	38.34	38.48	38.62	38.76	38.90	39.04	39.18	39.32	39.46
	d_1/d_c	0.1086	0.1984	0.1082	0.1080	0.1978	0.1077	0.1075	0.1073	0.1071	0.1069

298



Chute blocks
End sill
Fractional space
w-Max. tooth width=d.
Space=2.5 w
2 d,min
Top surface on 5°slope
2 d.
1.25 d.
Sill optional
Lt



T.W. DEPTH / d1
T.W. / d2 = 1.1
d2/d1 = 1/2(√(1+8F²) - 1)
(B) MINIMUM TAILWATER DEPTHS
Lt / d2
(C) LENGTH OF JUMP
FROUDE NUMBER

300

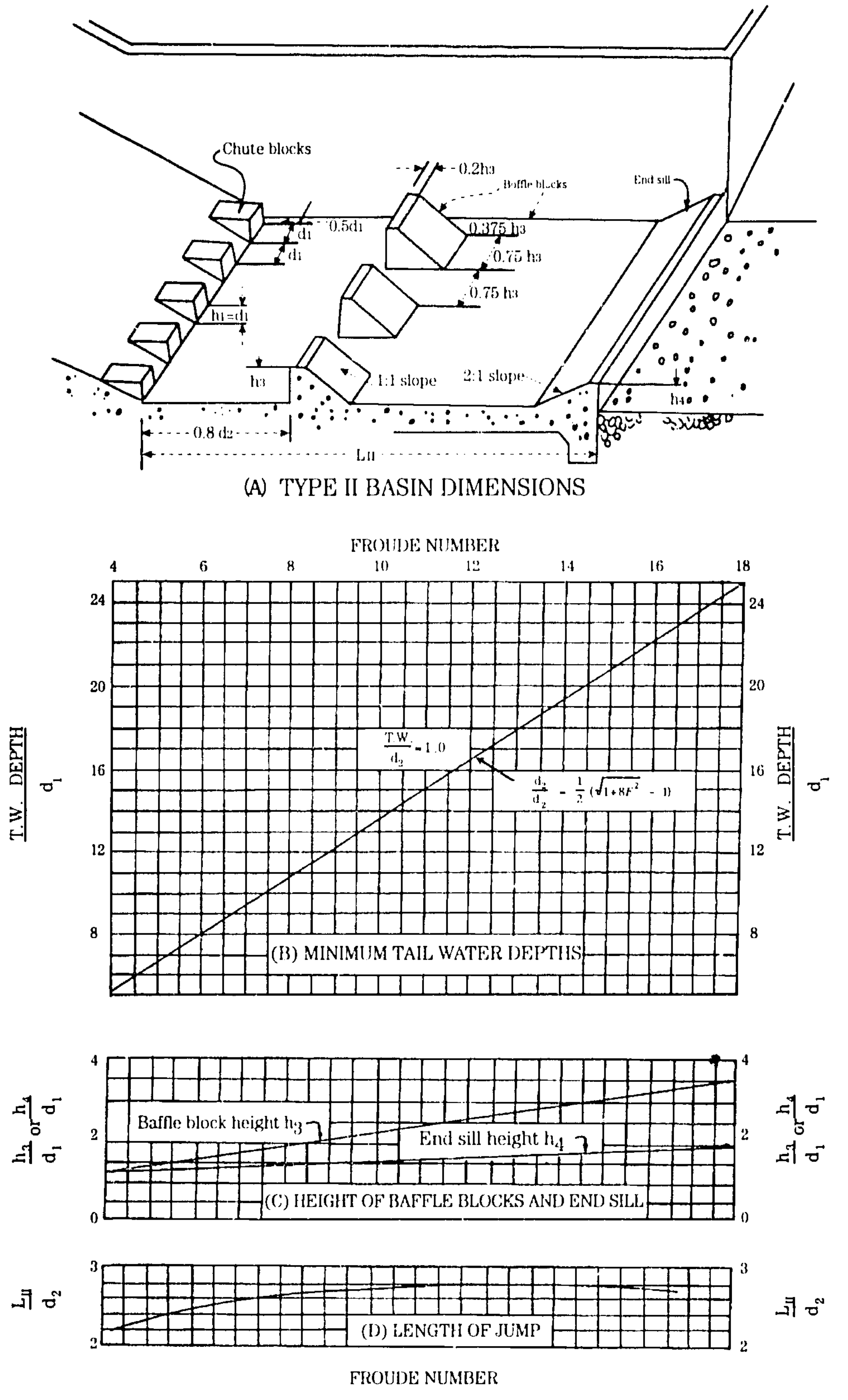


Figure 7-9. Stilling basin characteristics for Froude numbers above 5 where incoming velocity does not exceed 50 feet per second. (U.S.B.R.)

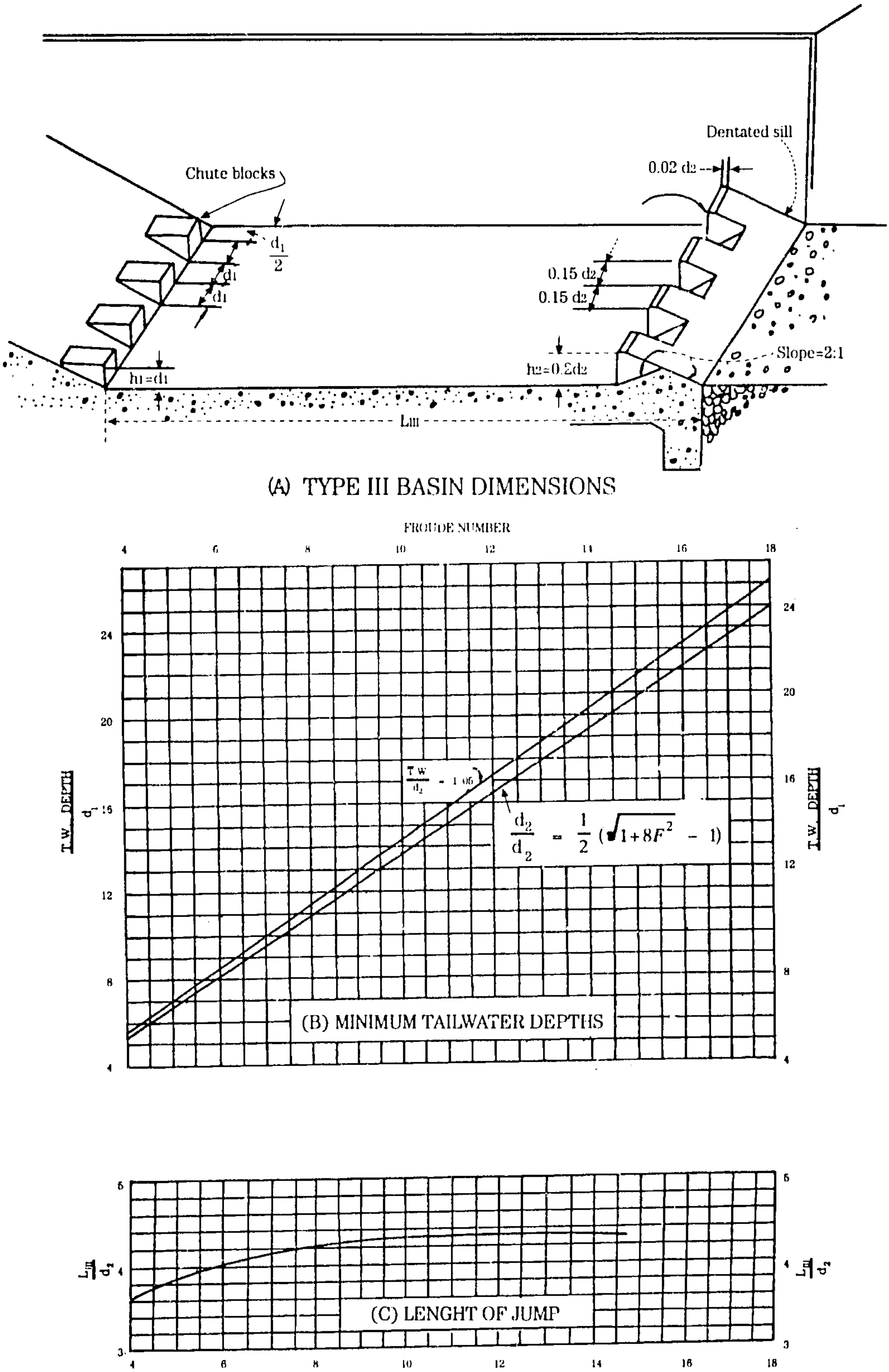


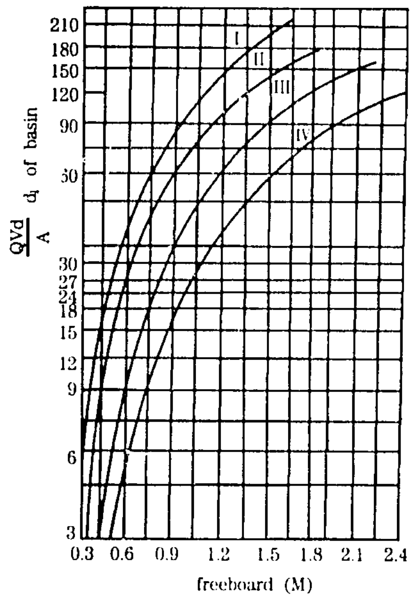
Figure 7-10. Stilling basin characteristics for Froude numbers above 4. 5. (U.S.B.R.)

202

v. Freeboard

Inlet transition: 0.6 meter

Stilling basin: to get the required freeboard by using the value of $\frac{QVd}{A}$ from Figure 7-11



I. rectangular chute
II. trapezoidal chute with side slope 1:1.5
III. rectangular stilling basin
IV. trapezoidal stilling basin with side slope 1:1.25

Fig. 7-11. Freeboard of chute and stilling basin (U.S.B.R.)

vi. Wall height of stilling basin

$H=d_2+h_{v2}+\triangle H$

where $\triangle H$=free board

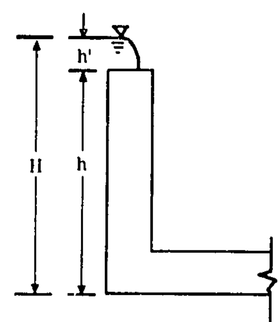


Fig. 7-12. Shaft pipe

b. Vertical shaft culvert type spillway

(i) Hydraulic computation

(a) Vertical pipe

i. Shape: square, rectangle, circle or bell mouth

ii. Height: not more than 8 meters in general.

iii. Diameter of overflow section: from the overflow weir formula,

$Q=C \cdot L \cdot h'^{3/2}$

where Q=inlet discharge=project flood discharge

L=effective overflow circumference

h'=overflow water depth (0.6-2.0 meter)

C=discharge coefficient (refer to Figure 7-13 for a circular shape shaft)

The required diameter: $D = \frac{L}{2\pi}$

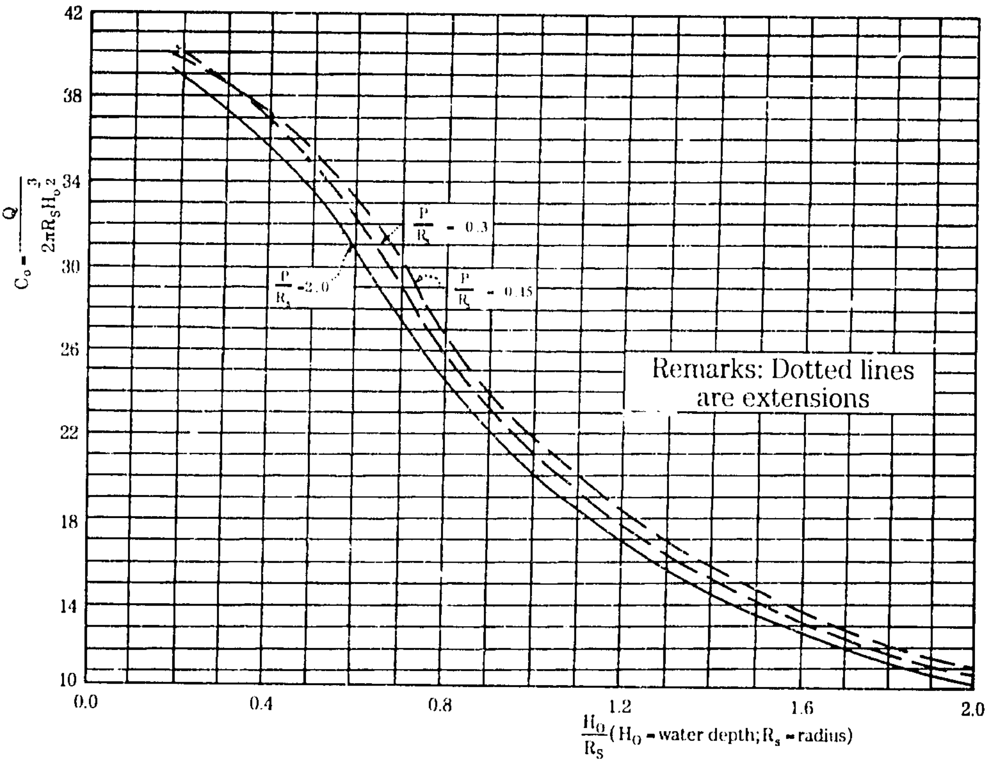


Fig. 7-13. Relationship between coefficient C and $\frac{H_o}{R_s}$ for a different apprcach water depth (with air-vented nap) (U.S.B.R.)

If a bell-mouth shaft spillway is used, refer to "Design of Small Dams(U.S.B.R.)." With rectangular or square spillways, follow the following computation.

(b) Horizontal pipe:

i. Shape: Square, rectangular, circular, or horse-shoe shaped; adopted according to the shape of the vertical pipe.

ii. Length: To be determined according to dam height and field conditions.

iii. Cross section

$$A = \frac{Q}{C\sqrt{2gH}}$$

Where A=cross-sectional area of the pipe (m^2)

H=total water head (vertical pipe height plus overflow water depth) (m)

C=pipe orifice coefficient

The horizontal pipe is designed with 75% of the cross section of the full water flow and with a slope of 1-5%.

iv. Velocity at the outlet

$$H_p = (1 + K_o + f\frac{L}{4R})\cdot\frac{V^2}{2g}$$

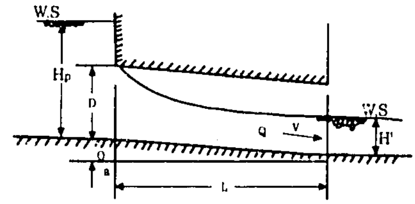


Fig. 7-14. Horizontal pipe

Where H_p=water head for pipe design=2/3H(m)

V=velocity at the outlet (m/sec)

K_o=water head loss at the inlet (m)

f=friction head loss(m)

L=pipe length (m)

R=hydraulic radius(m)=A/P (P:wetted perimeter(m), A:cross section of water)

v. Cutoff wall: Cutoff walls are provided at an interval of 8-10 meters in order to reduce seepage velocity.

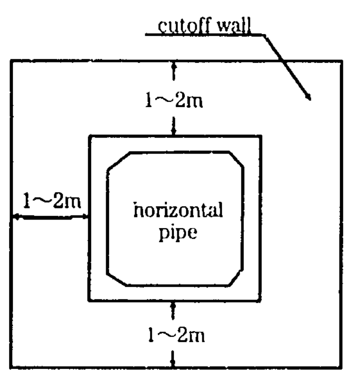


Fig. 7-15. Cuttoff wall of horizontal pipe

vi. Stilling basin:same as the open channel type.

(ii) Mechanics computation

(a) Vertical pipe: Water pressure may be obtained from the following equation:

$$P = \gamma_w(h+h')\ell = \gamma_w H \ell$$

$$q = \frac{P}{\ell} = \gamma_w H$$

where P=total water pressure at the bottom of the pipe (t/m^2)

h=height of the pipe (m)

h'=overflow water depth (m)

γ_w=unit weight of water (t/m³)

ℓ=width of the pipe (m)

q=water pressure of unit width (t/m²)

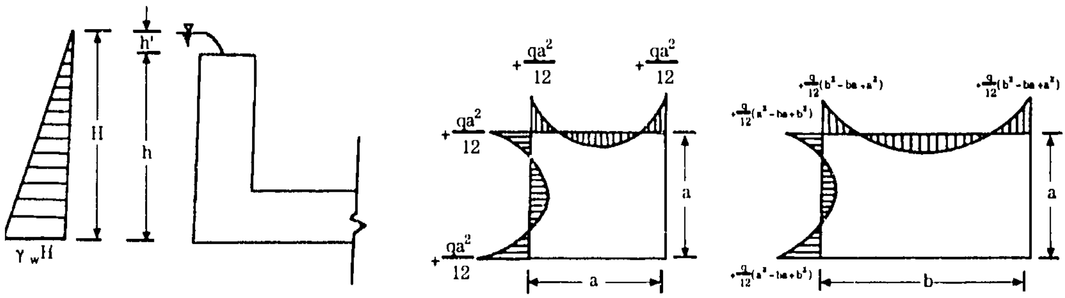


Fig. 7-16.

i. Square:

Moment at the corner: Mmax $\frac{q}{12}a^2$

Shear stress at the center:

Vmax=$\frac{q}{12}a$

ii. Rectangle:

Moment at the corner: Mmax=$\frac{q}{12}(a^2-ab+b^2)$

Shear stress at the center:Vmax= $\frac{q}{2}$ a (Short edge)

Vmax= $\frac{q}{2}$ b (Long edge)

iii. Circle:

Pipe stress f=PR_e / e

where Re=inner diameter

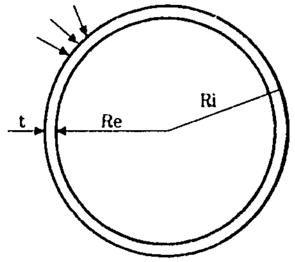


Fig. 7-17.

Ri=outer diameter

t=thickness

(b) Horizontal pipe: The Highway Culvert Standard Drawings may be used to design ordinary types of horizontal pipe. Further computations have to be made for special types.

(3) Dam body

a. Top width of dam: To be more than 2 meters; at least 2.5 meters if the dam is constructed with machinery. The top of the dam may be used as a road, and its width may be increased depending on actual need.

b. Face of dam

(i) Slope: The slope of the upstream face of the dam should be less than 1:3 (vertical:horizontal); and the downstream slope should be less than 1:2

(ii) Protection: The top of a dam should be protected with vegetation except if it is used as a road. The entire downstream face and the upstream face above the highest floodwater level should be protected with vegetation. The upstream face below the highest floodwater level should be protected with riprap, concrete cobble paving, or caustic lime-soil cement lining (with a thickness of more than 30 cm).

(iii) Materials: Materials used for dam construction should have the following properties

(a) The face should not be unstable if it is submerged under water.

(b) Limited water permeability.

(c) Ease of excavation and, transport of matenals, compact.

(d) None of its constituents should be watersoluble.

(e) Inner friction angle is not subject to reduction.

(f) The dam should not crack easily when it dries.

(g) It should not contain grass, wood, roots or other organic materials.

(iv) Freeboard:1-2 meters

(4) Earth fill should be deposited in layers, each 30-50 cm thick and to a compactness of 90-95%.

a. Settlement should be 10% of the filled height.

b. Cutoff trench should be dug at least 30 cm into the impervious layer.

c. The water content of earth fill should be controlled at the optimum level.

7.6 Supplementary Note

(1) It is necessary to investigate in detail important public facilities and inundation areas, in the vicinity of the dam site.

(2) Pits from which earth is borrowed should have a sufficient supply of earth materials, and be convenient for transport. Attention should be paid to soil conservation and public safety along the transport route.

(3) Pits from which soil is borrowed should be treated with soil conservation measures.

(4) Organic soil, roots, grass or weathered soils and debris at the construction site around the dam foundation or on the banks should be cleared.

(5) Excavation of the foundation of the dam and banks should continue until it reaches hard earth or rock. If the bedrock has cracks, it should be treated with grouting.

(6) During excavation of the foundations, any groundwater should be drained away and the entry plugged by grouting or some other method.

307

Chapter 8. Retaining Walls

8.1 Definition

A retaining wall is a structure built to hold banks of natural or filled earth, stones, gravel and similar materials, to prevent them from collapsing.

8.2 Purpose

(1) To maintain the safety of two adjacent ground surfaces at different elevations.

(2) To prevent earth fill or excavated slope faces from collapsing.

(3) To stabilize side slopes and to reduce earth cutting and filling.

8.3 Applications

(1) Sandwich type retaining wall

This wall consists of three layers: the outside layer of cobble concrete pitching, the middle layer of concrete and the inside layer of small cobbles. It can be used on excavated slope faces less than 6 meters in height, and for earth filled slope faces less than 4 meters in height.

(2) Gravity type retaining wall

a. Cobbled concrete retaining wall:This is constructed with concrete mixed with cobbles. It is economical and efficient in protecting slope faces which have been cut and filled and, which are less than 6 meters high.

b. Concrete retaining wall: Constructed with concrete. It is economical and efficient in protecting slope faces less than 6 meters in height which have been cut and filled.

(3) Semi-gravity type retaining wall

This is a concrete retaining wall partially reinforced with steel bars for tensile strength. It is used to protect cut and filled slope faces 3-8 meters in height.

(4) Cantilever type retaining wall

This is made of reinforced concrete and is used to protect filled slope face of 5-8 meters in height.

(5) Buttress type retaining wall

a. Front support: A reinforced concrete retaining wall with buttress supports on the outside of the wall. It is used to protect cut and fill slope faces 5-10 meters in height, where there is enough room for the buttresses.

b. Back support: A reinforced concrete retaining wall with buttresses on the inside of the wall. It is used to protect filled slope faces 5-10 meters in height.

(6) Aggregate type retaining wall

a. Retaining wall of wire sausages: Consists of stacked wire sausages which are filled with cobbles. It is used to protect slope faces from which water is seeping out, and for soft unstable foundations. The height is usually less than 4 meters.

b. Wire box retaining wall:Consisting of box-shaped wire cages filled with cobbles. It is used to protect slope faces with copious seepage, when the height is less than 3 meters.

c. Concrete crib retaining wall: This is built by piling up box-shaped concrete cages filled with cobbles. It is used to protect slope faces with copious seepage. The total height of the structure should not exceed 6 meters, with each layer less than 3 meters high.

d. Structures of strengthened soil: Structures built of soil to which strengthening materials are added.

(7) Sheet-pile type retaining wall

a. Cantilever sheet-pile retaining wall: This is built by driving wooden, steel or concrete sheet piles into the ground. It is used to protect excavated slope faces less than 5 meters in height.

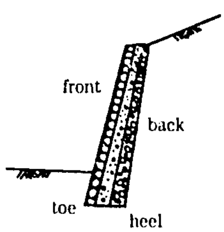
b. Anchored sheet pile retaining wall: The sheet piles are attached to anchor blocks buried in the earth by connecing strips. This is used of protect excavated faces 5-10 meters in height.

(8) Anchorage type retaining wall

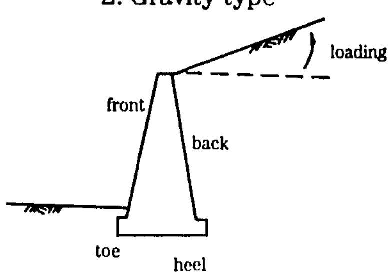
This type of wall consists of reinforced concrete columns or plates connected to anchorages with prestressed wires at proper intervals. It is suitable for fractured rock zones, joint plane, or unstable land prone to sliding.

8.4 Diagrams

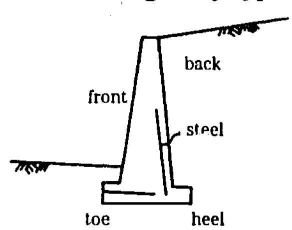
1. Sandwich type



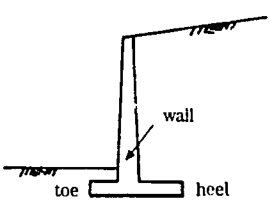
2. Gravity type



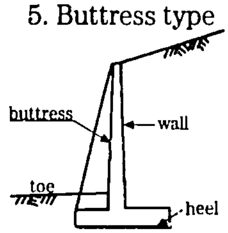
3. Semi-gravity type



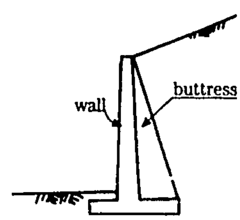
4. Cantilever type



5. Buttress type

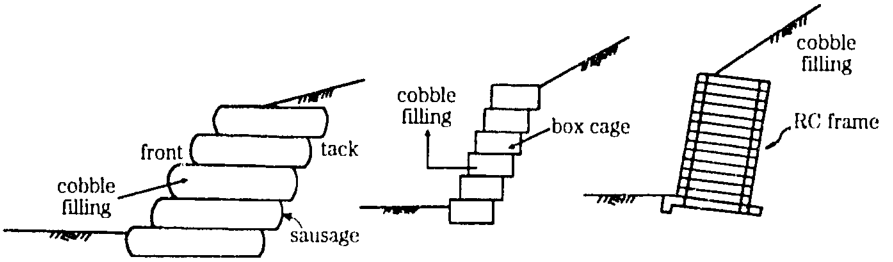


(1) Front support



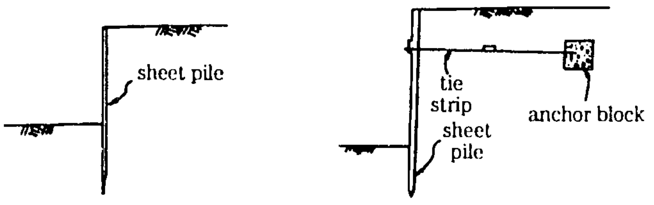
(2) Back support

6. Aggregate type



(1) Built of wire sausages (2) Built of box-tpe wire cages (3) Concrete crib

7. Sheet pile type



(1) Cantilever (2) Anchor & tie

8. Anchorage type

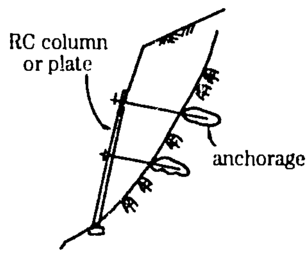


Fig. 8-1. Kinds of retaining walls

8.5 Design Criteria

(1) Retaining walls are designed according to the following criteria

a. Sliding: Safety factor is 1.1-1.5. Friction coefficients for the contact face between concrete foundations and ground are shown in Table 8-1.

Table 8-1. Coefficients of friction between concrete and ground

Materials	Friction coefficients
Hard bedrock	0.70
Cobbles & coarse sand	0.55-0.60
Dry sand	0.45-0.55
Confined wet silt	0.30-0.40
Sand & clay mixture	0.40-0.50
Clay	0.30

b. Overturning: The resistance moment must be greater than the over turning moment. The resultant of all forces shall act on the point as described in c.

c. The eccentric moment arm (e) of the resultant on the foundation should be within the following limits:

(i) Bed rock foundation. The resultant acts in the middle half of the foundation base width, i.e., $e \leqq \frac{1}{4} d$ (where d is the foundation base width).

(ii) Hard earth foundation: The resultant acts in the middle third of the foundation base, i.e., $e \leqq \frac{1}{6} d$.

(iii) Highly compressible earth foundation: The resultant acts at the center or between the center and the heel of the foundation.

(iv) Compressive stresses of Pt and Ph at the toe and the heel of the foundation respectively should be in the allowable limit. The allowable bearing capacities of different ground materials are listed in Table 8-2.

Table 8-2. Allowable bearing capacities of ground materials

Materials	Allowable bearing capacity
Soft clay	10
Common clay	20
Hard clay	40
Soft silt	10
Compacted silt	30
Soft coarse sand	30
Soft gravel & cobble mixture	40
Compacted gravel & cobble mixture	50
Hard rock	100
Hard shale	100

(From Volume "Retaining Wall", U.S. Civil Engineering Hand Book)

(v) All the stresses on the retaining wall should be in the allowable limits of different materials (according to ACI specifications).

(2) Forces on the retaining walls

a. Wall weight (per unit length)

This is the product of the unit weight of construction materials multiplied by the cross-sectional area of the retaining wall. The resultant force passes through the center of gravity.

b. Earth pressure

Coulomb's and Rankine's theories can be used for computation of the earth pressure. For a gravity type or semi-gravity type retaining wall with a flat or nearly flat ground surface behind it. Coulomb's theory is preferable. For a cantilever type or buttress type retaining wall with sloping ground behind it, Rankine's theory may be applied. Both theories have the same assumption that soil is not cohesive. Therefore, sand and gravel are preferable for back filling. Earth pressure may be classified into active earth pressure, static earth pressure and passive earth pressure.

(i) Active earth pressure:

Whenever the retaining wall moves, even very slightly, in the outside direction, earth near the wall face expands and its horizontal pressure decreases. When this horizontal pressure has decreased to a minimum, it is called the active earth pressure, i.e., the earth pressure acting in the direction of the retaining wall.

(a) Coulomb's earth pressure equation

$$P=\frac{1}{2}C_a\,\gamma_s\,H^2 \qquad (1)$$

where C_a=Coulomb's active earth pressure coefficient

$$C_a = \frac{\cos^2(\phi - a)}{\cos^2\alpha\cos(\delta+\alpha)\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\delta+\alpha)\sin(\beta-\alpha)}}\right]^2}$$

where P=active earth pressure (t/m^2)

γ_s=earth unit weight (t/m^3)

H=height of retaining wall (m)

ϕ =earth internal friction angle (degree)

δ =friction angle between the wall back face and earth

α =included angle between the wall back face and vertical line. If the backface is vertical, α =0 (as shown in Figure 8-2 a). If the wall inclines towards outside, α is "-"; if the wall inclines towards inside α is "+" (As Figure 8-2 b and c).

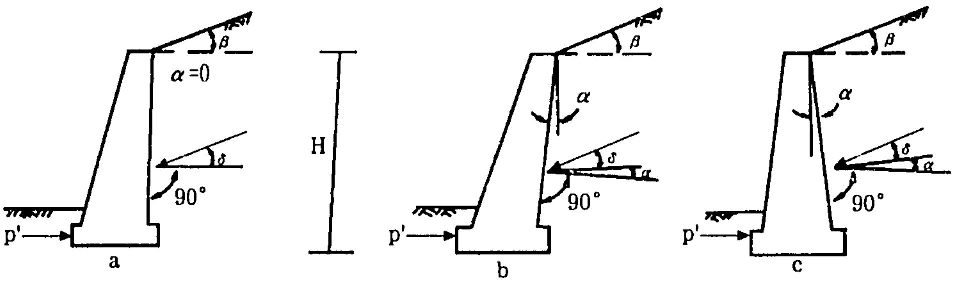


Fig. 8-2.

(b) Rankine's earth pressure equation

$P = \frac{1}{2} C_a \gamma_s H^2$

where C_a=Rankine's active earth pressure coefficient

$$C_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \tan^2(45° + \frac{\phi}{2}) \text{ ------------------------------ (2)}$$

where P, γ_s and H are the same as in Equation 1. When the retaining wall back face is not vertical and the friction angle between the wall and earth, δ is not zero, the above equation is applicable.

(ii) Passive earth pressure

If the retaining wall moves in the inside direction, there will be a shear stress in earth causing earth destruction. This horizontal pressure borne by the wall is called passive earth pressure.

$P' = \frac{1}{2} C_p \gamma_s H^2$

where C_p=passive earth pressure

$$C_p = \frac{1 + \sin\phi}{1 - \sin\phi} = \tan^2(45° + \frac{\phi}{2}) \text{ ---------------------------------- (3)}$$

(iii) Static earth pressure: earth pressure on the retaining wall in a static status.

c. Added load

Added loads on the back of the retaining wall are mainly from buildings and automobile loads. In making a pressure distribution diagram, the added loads shall be converted to the same specific weight of the filled earth with an added height h as shown in Figure 8-3a.

In this case, the earth pressure diagram is a trapezoid (Figure 8-3a) which is composed of a triangle representing earth pressure (Figure 8-3b) and a rectangle (Figrure 8-3c) representing the added load. The top width is P_1(equivalent to the converted pressure at the depth of h), and the bottom width is P_2 (equivalent to the sum of the pressure at H and the converted pressure at h).

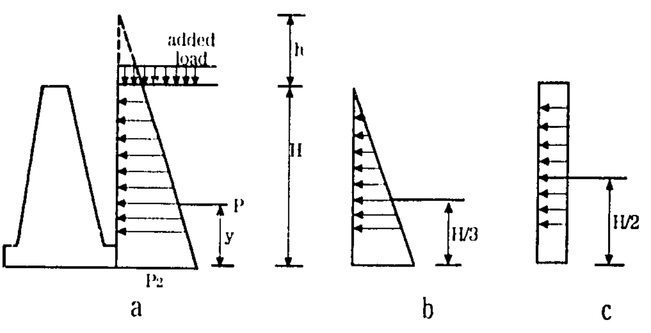


Fig. 8-3.

Total pressure P

$P=(P_1+P_2)H/2$

and $P=\frac{1}{2}C_a\gamma_s H(H+2h)$ -- (4)

Height of the acting point where the resultant, P passes through, y

$$y = \frac{H}{3}\cdot\frac{H+3h}{H+2h} \quad \text{-- (5)}$$

The added load of a building structure on the back fill earth, per square meter,W is to be converted to the same specific load of the back fill earth in order to get the pressure height, h

$$h = \frac{W(t/m^2)}{\gamma_s(t/m^3)}$$

As to an automobile load, it may be considered as a mean load acting on the back of the retaining wall. Its land distribution diagram is shown in Figure 8-4.

From Figure 8-4, it is noted that the weight of H-20 acts on an area of $7\times2.75m^2$. Its weight per unit area will be:

$$\frac{20}{7\times2.75}=1.04\ t/m^2$$

Therefore, the converted earth height will be

$h=1.04/1.8=0.578m\fallingdotseq0.6m$

where $1.8\ t/m^3$ is the unit weight of earth.

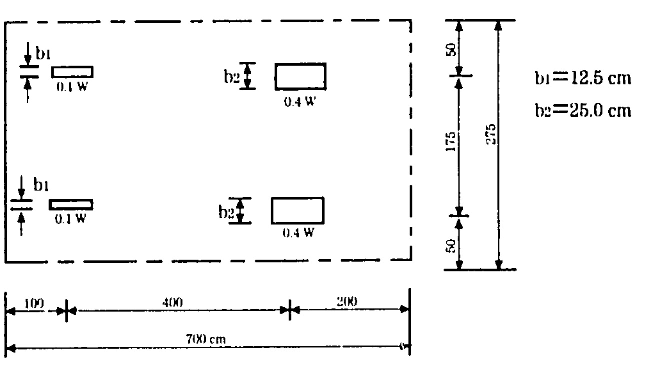


Fig. 8-4.

d. Water pressure

In general, retaining walls have weep holes and are filled with pervious materials such as sand and gravel on their inner side, sothat they are not likely to have to bear much water pressure. However, in an area of abundant seepage or high

317

groundwater, water pressure may exist simultaneously with earth pressure is. In this case, the earth pressure reduce by the buoyancy produced by water pressure. Consequently, these two kinds of pressure are to be computed together.

e. Vertical pressure on the foundations

The earth bearing pressure beneath the foundations of a retaining wall is assumed to be a linear variation, and its shape may be rectangular, triangular or trapezoidal. The resultant of this pressure is expressed as ΣV, as shown in Figure 8-5.

(i) The resultant ΣV acting at the center, the point O, of the foundation is distributed with an equal stress, i.e. $\delta_1 = \delta_2 = \Sigma V/B$ as shown in Figure 8-5.

(ii) The resultant ΣV acting at the point O causes a distribution of unequal stresses, which may be computed as follows:

$$d_1 = \frac{\Sigma V}{B}(1 + \frac{6e}{B}) \quad \text{------------} (6)$$

$$d_2 = \frac{\Sigma V}{B}(1 - \frac{6e}{B}) \quad \text{------------} (7)$$

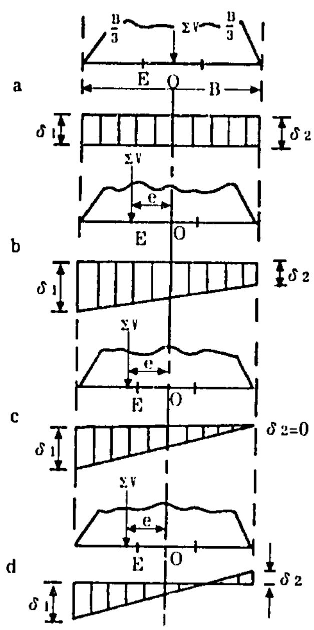


Fig. 8-5.

where e is an eccentric distance.

The stress distribution in the case of the resultant ΣV acting between point O and point E, the end of the middle third, is shown in Figure 8-5 b. In this case δ_1 and δ_2 are all positive.

The stress distribution in the case of ΣV acting at point E is shown in

315

Figure 8-5 c.

In this case, $\delta_1=2\Sigma V/B, \delta_2=0$

The stress distribution in the case of ΣV acting outside the point E is shown in Figure 8-5d. In this case, δ_1 is maximum and δ_2 is negative, i.e., a tension stress.

f. Horizontal resistance pressure on the foundations

The horizontal resistance pressure on the foundations is the product of the vertical pressure multiplied by the friction coefficient between the foundation (concrete)and earth. The total horizontal resistance pressure resultant is $\Sigma \tan\phi$, and the safety factor for resistance against sliding may be computed from the following equation:

$$F_s = \frac{\Sigma V \tan\phi + P'}{\Sigma V} \quad \text{------------} (9)$$

where F_s=sliding safety factor

ϕ =friction angle between the foundation and the earth

P'=passive earth pressure

8.6 Supplementary Note

(1) Except for the aggregate type, retaining walls should have weep holes 5-7.5 cm in diameter. There should be at least one hole for every 4 m^2, and holes should be installed with proper filter facilities. If seepage water is abundant, or in a high groundwater area, special drainage facilities must be provided behind the retaining wall.

(2) If the foundation pressure exceeds the allowable soil bearing capacity, the area of the foundation should be enlarged, or other methods such as piling be employed.

8.7 Precautions in Construction and Maintenance

(1) If it is found during construction that the actual bearing capacity of the foundation is less than the expected allowable bearing capacity, revision of the design must be made immediatlely.

(2) The filling materials behind the retaining wall should be sand and gravels, and fill should be higher than the wall by more than 20 cm.

(3) If the back filling materials subside or are lower than the wall height, refilling is necessary.

(4) If the retaining wall has cracks or damage, investigation should be made to find out the cause of the damage and remedial measures be carried out immediately.

(5) It is necessary to pay attention to the effectiveness of weep hole drainage at any time.

(6) Expansion joints have to be provided at an interval of 20-40 meters.

319

Chapter 9. Earth Dumping Sites

9.1 Definition

A set of facilities built, by taking advantage of the topography, as a site for dumping excess or abandoned earth.

9.2 Purpose

(1) To hold abandoned earth, stones and slag.

(2) To stabilize dumped earth and stones to prevent erosion and downstream damage.

(3) To protect human lives, properties and public facilities.

(4) To protect the environment and natural landscape.

9.3 Applications

(1) Valley dumping ground

This is a flat depression in a valley, with earth retaining structures, drainage, slope protection measures and vegetation cover to facilitate deposition of abandoned earth and stones. In principle, the upstream watershed area of a dumping site should not exceed 20 hectares, otherwise drainage facilities must be strengthened. Inlets of drainage culverts should be well designed to avoid clogging.

(2) River bank dumping ground

This is a wide depression along a river bank, provided with levees, revetments and other facilities for deposition of abandoned earth and stones. It should not affect flood prevention or the safety of flood control facilities for the river.

(3) Hillside dumping ground

This is a flat hillside, equipped with drainage, slope stabilization and other facilities for deposition of earth, stones and slags. Any area which has the possibility of land collapse shich may cause damage to houses and important public facilities in its downstream influence zone should not be selected for this purpose.

(4) Flat land dumping ground

This is a flat area used to deposit abandoned earth and stones. It should not interfere with transportation or drainage.

9.4 Diagrams

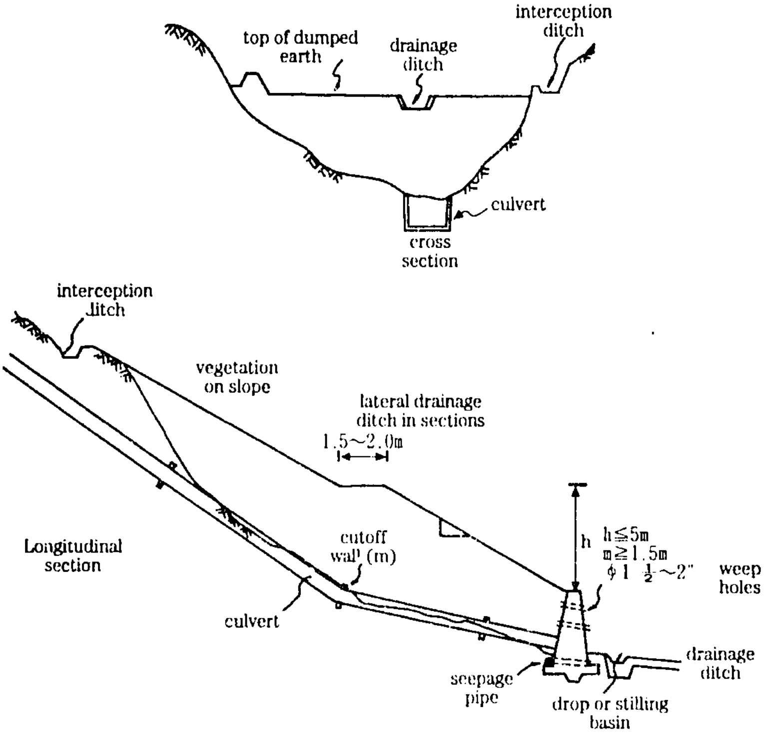


Fig. 9-1. Valley dumping site

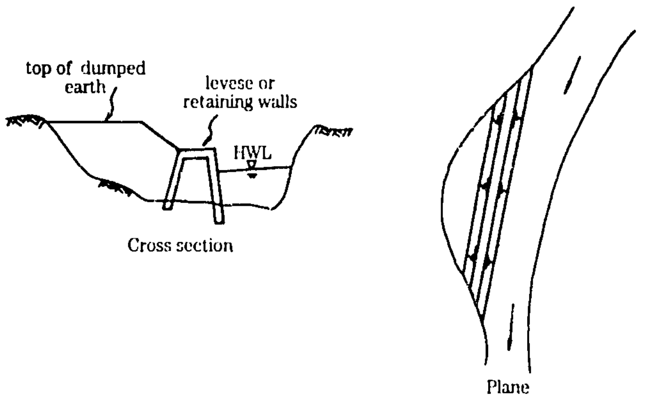
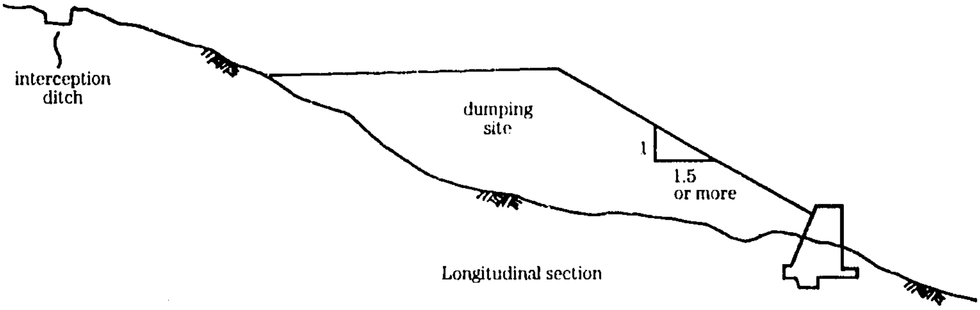


Fig. 9-2. River bank dumping site



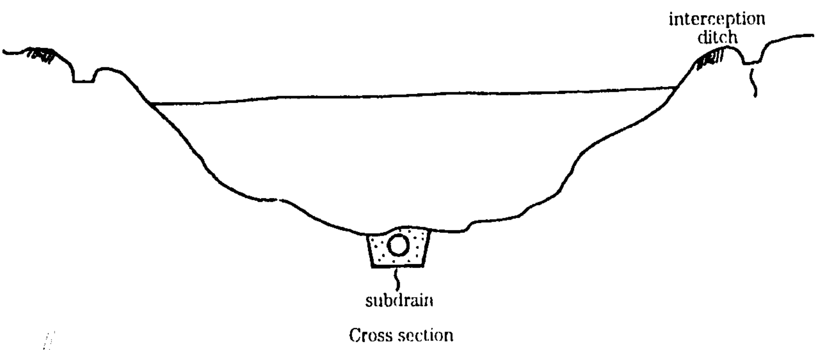


Fig. 9-3. Hillside dumping site

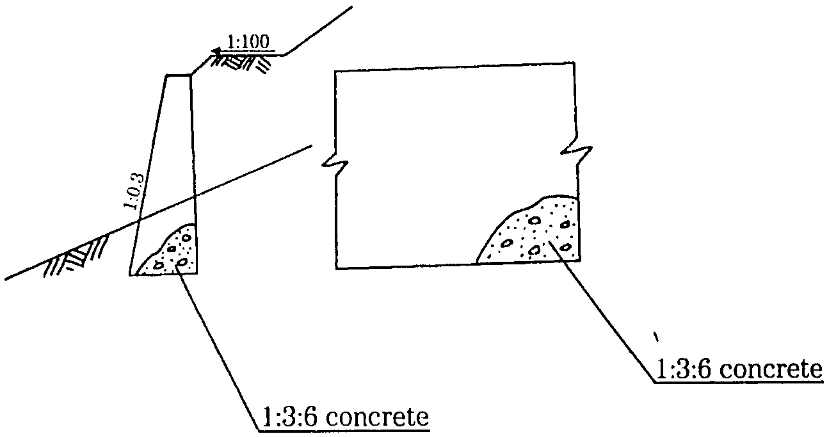


Fig. 9-4. Flat land dumping site

9.5 Design Criteria

(1) Main structures for individual dumping sites

Kinds	Main Structures
Valley dumping site	1. Retaining wall 2. Check dam, 3. Drainage system, 4. Vegetation
River bank dumping site	1. Levee, 2. Revetment, 3. Drainage system. 4. Vegetation
Hillside dumping site	1. Retaining wall, 2. Drainage system, 3. Vegetation
Flat land dumping site	1. Retaining wall, 2. Vegetation

In general, the location of a dumping site should be selected with reference to the kind of materials to be dumped, topographical and geological conditions of the watershed, environment, and water source conditions etc.

(2) Design of individual basic structures may be referred to related chapters. Other criteria are as follows:

a. Subdrainage pipe (subsurface drainage pipe): To drain seepage water from a dumping site, a subsurface drain is provided. It is common to use a seepage pipe of ϕ25-30 cm, to be surrounded by 30-50 cm of well graded gravel.

b. Subdrainage culvert: A valley or hillside dumping site should be provided with a drainage culvert in order to drain out runoff from upstream watershed areas. Its cross section must be sufficient to drain out runoff, debris, silt, sand and drifting materials. Weep holes should be provided on the top of the culvert to drain out seepage water.

c. Diversion ditches should be built on both sides of the highest earth pile in the valley or hillside dumping site.

d. On the slope face of a dumping site, longitudinal drainage ditches should be built at intervals of 50 meters.

e. A drainage ditch is to be built along the downstream side of the retaining wall in order to drain out seepage or spring water.

f. A silting basin is to be provided at the proper location in the upstream section of a subsurface drain.

g. The height of earth piles in a dumping site should not be higher than the neighboring ground surface.

h. A terrace 1.5-2 meters in width should be formed for every 5 meters of earth fill. The slope of the earth pile should not exceed 33% (1:1.5).

i. The surface of the earth pile should be planted with grasses for greening, except the area which is under water flow, which should have special protective work.

j. Plants used for greening should in principle be native ones.

9.6 Supplementary Note

(1) If a dumping site is used to deposit large rocks, a small earth dike or trench should be built on the upstream side of a dam or retaining wall, as a buffer to keep rocks from falling down from above.

(2) Trash containing organic matter from urban areas should not be allowed in the dumping site.

(3) Vegetative cover shall be removed from the dumping site to prevent landslides or excessive subsidence.

9.7 Management and Maintenance

(1) The inlet and silting basin of a drainage culvert in a valley dumping site should be occasionally cleaned in order to avoid clogging and flooding.

(2) The surrounding facilities such as diversion ditches, drains, and weep holes of the retaining wall should be maintained in good functioning condition.

(3) Attention should be paid to vegetation on slope faces at all times.

Chapter 10. Drainage Facilities

10.1 Definition

Drainage facilities are structures built to divert runoff or excess water to a safe place.

10.2 Purpose

(1) To intercept upstream runoff to prevent damage to farmland, houses and public facilities.

(2) To regulate the flow of runoff to prevent erosion.

10.3 Application

(1) Drainage ditches

a. Classified by function

(i) Diversion ditch: The ditch is built along a contour line and above the land or objects to be protected, in order to divert runoff to a safe place. This is used wherever it is necessary to intercept runoff in order to avoid erosion and damage.

(ii) Longitudinal ditch: The ditch is built along a slope to drain runoff. It is used on steep slopes with fast runoff velocity; if the velocity is within the allowable velocity limit of lining materials.

b. Classified by lining materials

(i) Grass ditch: An earth ditch the surface of which is covered by grass for the purpose of preventiog erosion. It is suitable for periodical draining of runoff from farmland, It should have a slope of less than 30%, a velocity no more than 15 m/sec and a length of less than 30 meters.

(ii) Cobble paved ditch: This is an earth ditch lined with cobbles. If is suitable for farmland drainage systems, farm pond spillways, roadside ditches and slopeland community drainage systems, where the water flow velocity is relatively high and soil is less resistant to erosion.

(iii) Brick lined ditch: This is an earth ditch with a brick lining. This ditch may be used in a farmland drainage system with complicated topography, marked changes in longitudinal slope, and when the supply of cobbles or stones are scarce.

(iv) Concrete ditch: This is a ditch lined with concrete. It is used for farm pond spillways, road side ditches, and slopeland community drainage systems where the water flow velocity is high and soils are easily eroded (refer to Drainage Ditch Chapter, Part I).

(v) Precast concrete ditch: This is built by assembling precast concrete sections of a ditch. This ditch is used in farmland drainage systems, or in places where water or labor is scarce for construction, or when transportation is difficult.

(vi) Earth ditch: This is dug into the soil and not lined. It is used in places on a moderate slope where soil properties allow.

(2) Drop

a. A type drop (with a straight inlet and an apron): To be built from bricks or concrete.

b. B type drop (with a straight inlet and stilling basin): To be built from reinforced concrete or with brick.

c. C type drop (with a box inlet and a stilling basin): To be built from reinforced concrete or bricks.

d. D type drop (with a curved inlet and a stilling basin): To be built from reinforced concrete or bricks.

e. E type drop (with a straight inlet and a stilling basin): To be built from concrete blocks.

(3) Culverts

a. Ordinary concrete pipes: These are reinforced concrete pipes which are usually 60 cm in length and 20-120 cm in diameter. The pipes are used in farmland drainage systems with a maximum road load of H-20.

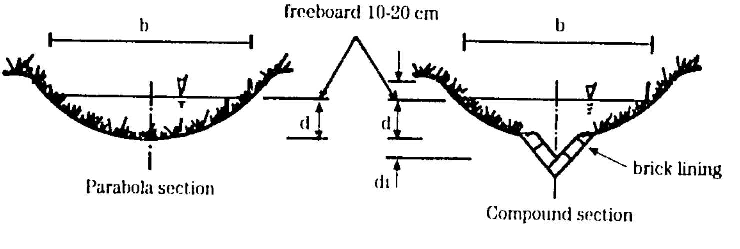
b. Centrifugal concrete pipes: These are a reinforced concrete product manufactured by the centrifugal method. They are used in different kinds of drainage systems with a maximum road load of H-20. As general specifications, a pipe 20-120 cm in diameter has an effective length of 2.5 meters, and a pipe 135-300cm has an effective length of 2.43 meters. The outside pressure strength ranges from 780 kg/m^2 for small pipes to 11,730 kg/m^2 for large pipes.

c. Box culverts: These are reinforced concrete structures used in a number of different drainage systems. According to the Taiwan Highway Bureau Standard, the culvert may be square or rectangular, with different sizes of 1 m × 1 m - 3 m × 3 m, and is classified into classes of 50 cm difference. The culvert has a maximum road load of H-20. The earth cover on a culvert may be 0-7 meters deep.

10.4 Diagram

(1) Drainage ditch

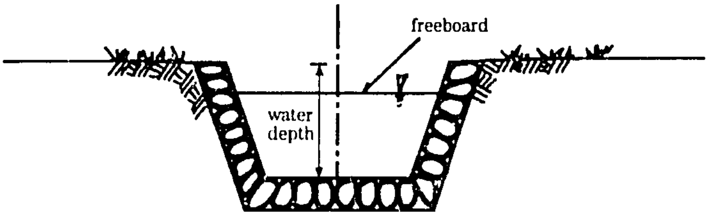
a. Grass ditch



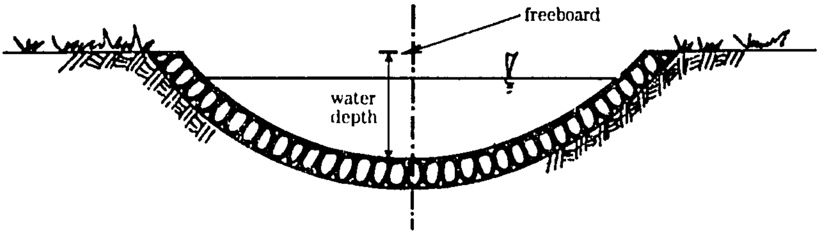
723

b. Cobbled ditch

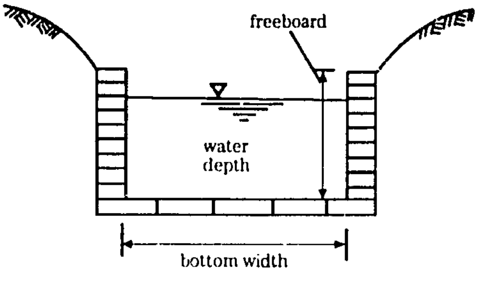
(i) Trapezoidal section



(ii) Parabola section

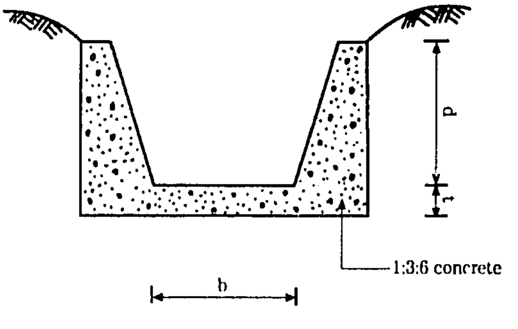


c. Brick ditch



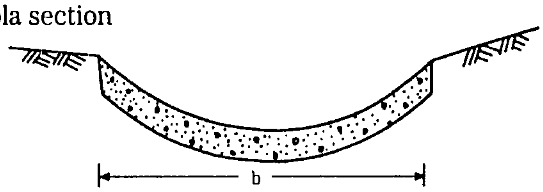
d. Concrete ditch

(i) Trapezoidal section



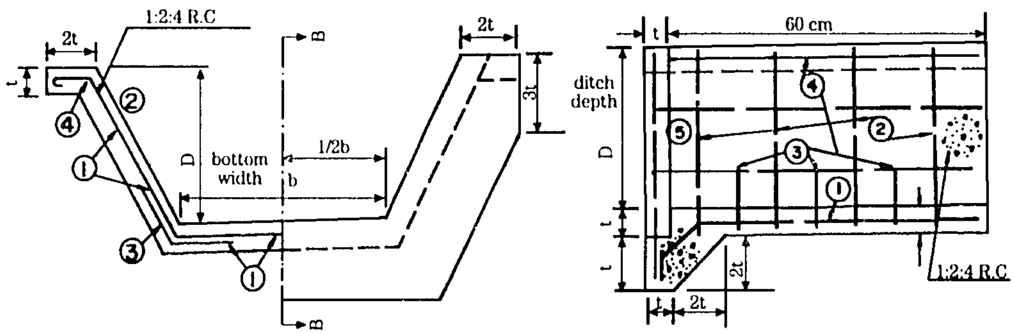
324

(ii) Parabola section



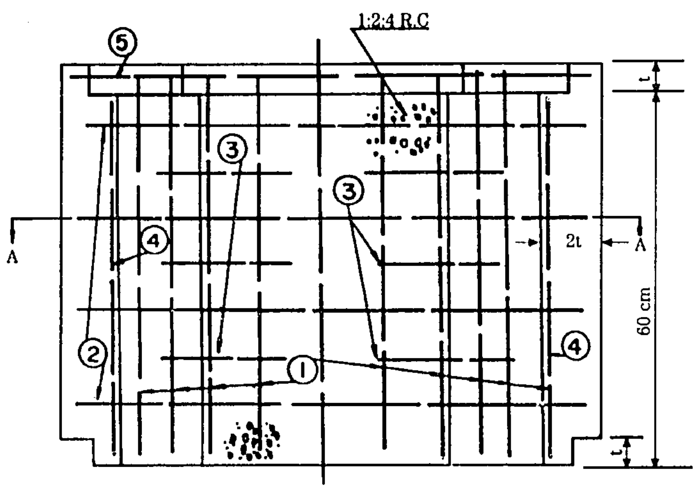
e. Precast concrete ditch

(i) Trapezoidal section



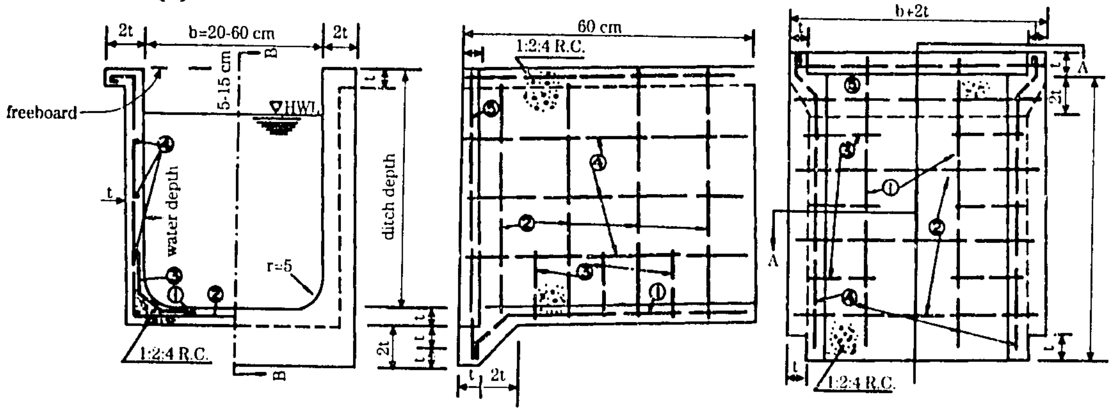
Section A-A

Section B-B



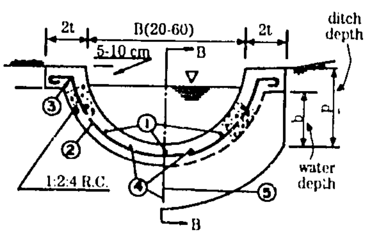
325

(ii) U section

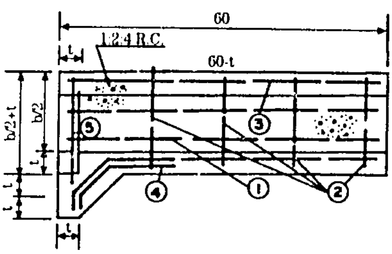


Section A-A Section B-B

(iii) Semi-circular section



Section A-A



Section B-B

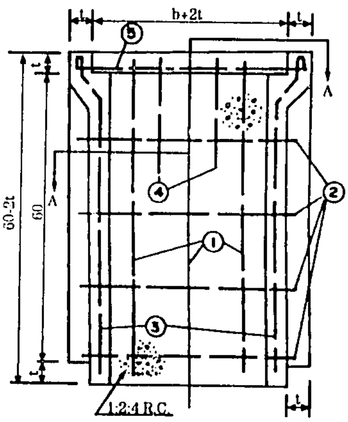
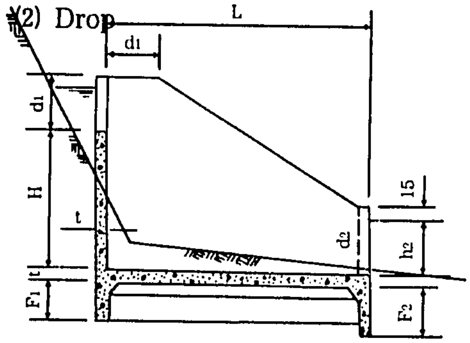
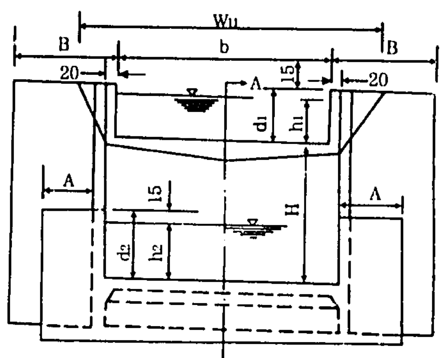


Fig. 10-1. Drainage ditch

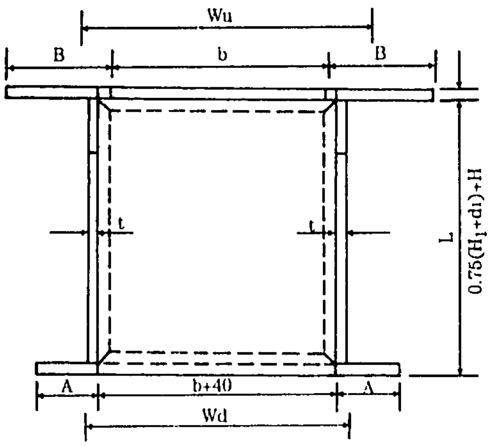
(2) Drop



A-A section



Front view



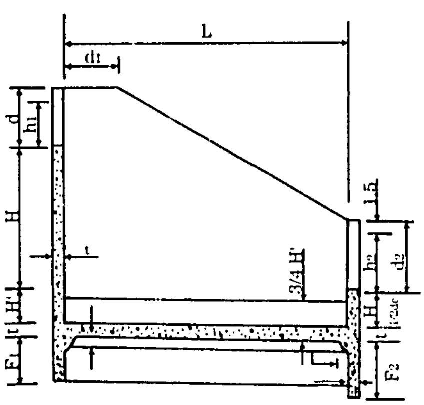
Plan

Remarks:

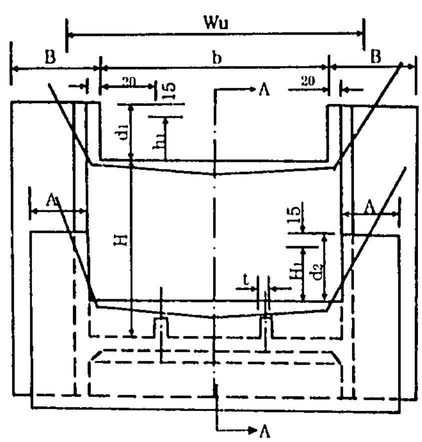
1. A and B shall be adjusted according to the widths of the upstream and downstream ditches, and actual conditions. In principle, they should extend at least 1 meter into the bank.

2. F_1 and F_2 are determined according to soil properties of the bottom $F_1 \geqq 80$ cm $F_2 \geqq 100$ cm.

Fig. 10-2. A type drop

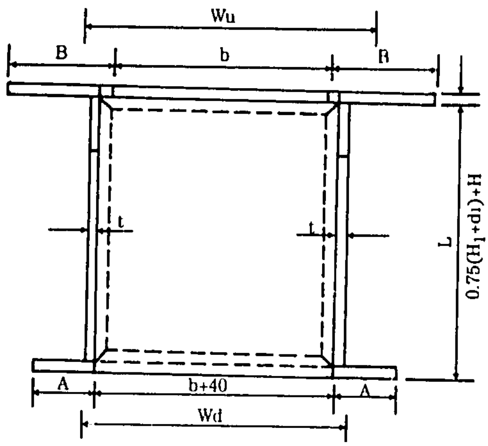


A-A section



Front view

327

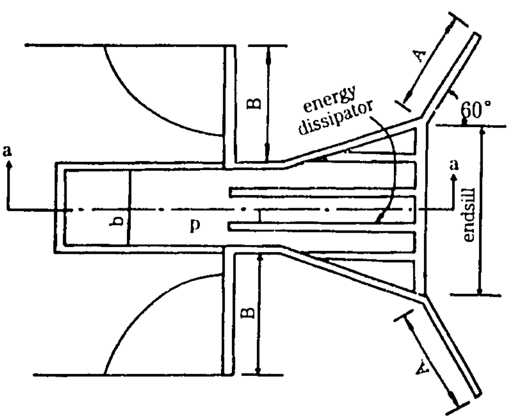


Plan

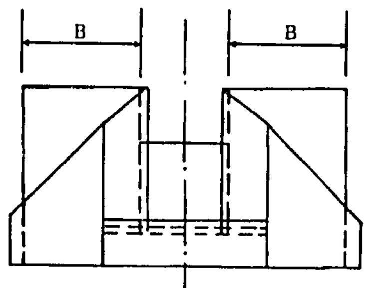
Remarks:

1. A and B are determined by the width of the ditch, and should extend at least 1 m into the bank.
2. F_1 and F_2 are determined by the soil properties of the bottom; F_1 80 cm, F_2 100cm.

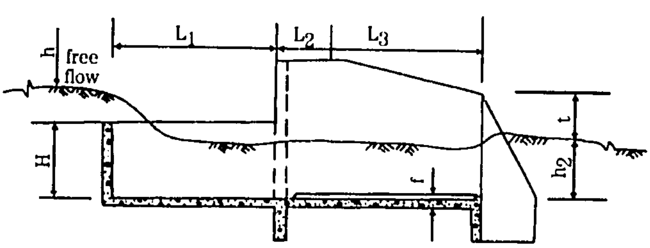
Fig. 10-3. B type drop



Plan



Front view



Section A-A

Fig. 10-4. C type drop

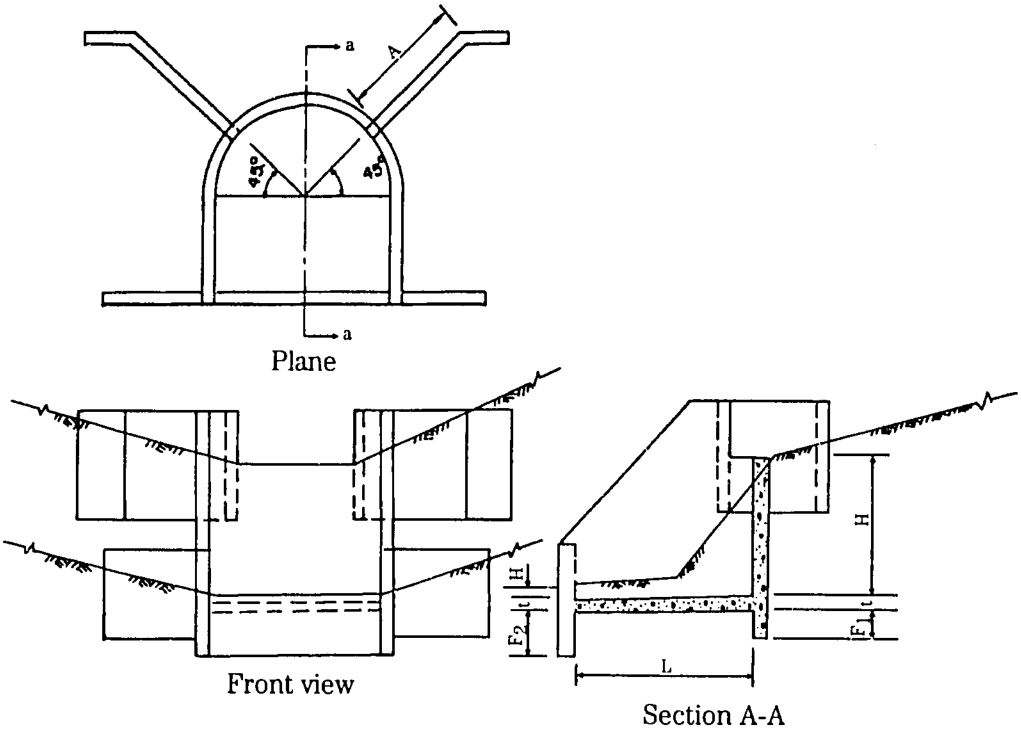


Fig. 10-5. D type drop

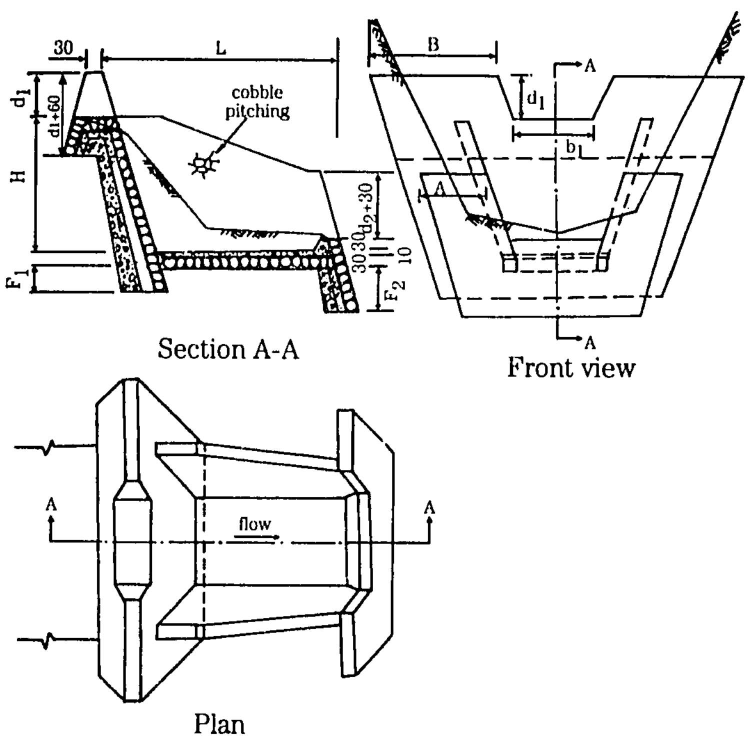
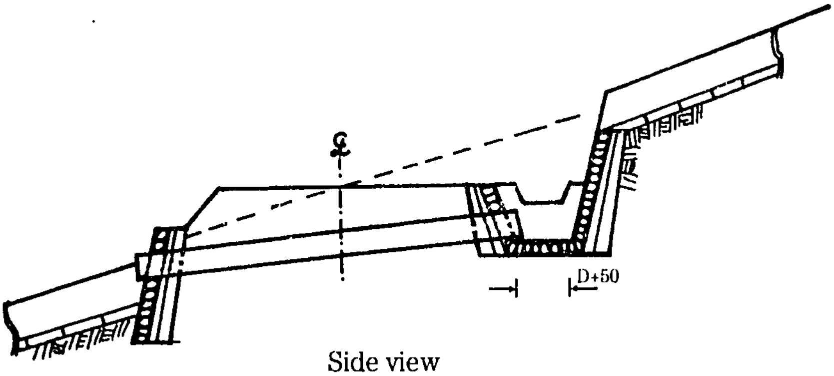
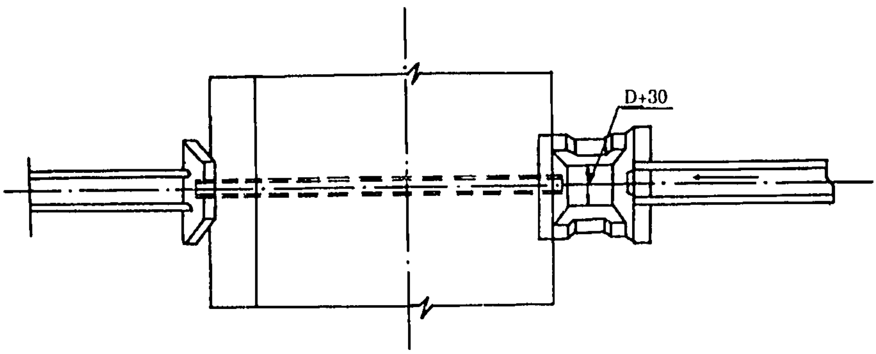


Fig. 10-6. E type drop

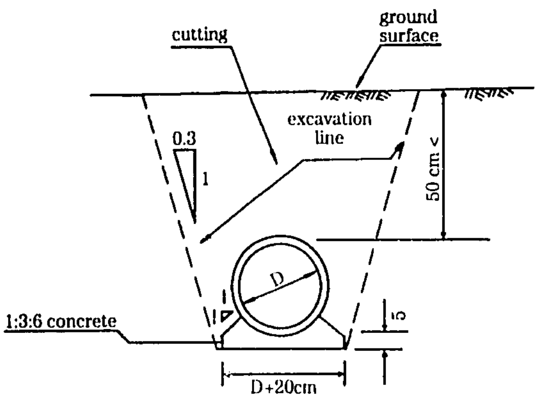
(3) Culvert



Side view



Plan



cross section

Fig. 10-7. Culvert

10.5 Design Criteria

(1) Drainage ditch

a. Runoff discharge, Q: To be determined according to the rainfall intensity of the area (see Appendix 1, Hydrological Analysis), importance of the project etc.

b. Slope, S: To adopt the least possible slope along the longitudinal section as the design slope.

c. Type: To be determined according to topographical, geological and economical conditions, importance of the project, available materials in the vicinity, construction equipment available etc. A range of cross sections are available, e.g. rectangular, trapezoidal, U-shaped, semicircular, parabola etc.

d. Size of cross section: To be determined according to runoff discharge, slope, lining material, roughness of ditch lining etc. The size of the cross section here means the width and depth's of a ditch's cross section.

e. Roughness, n: Depending on the smoothness of the materials which form the ditch surface. Manning's values for different materials and situations are listed in Table 10-1.

Table 10-1. Roughness 'n' of Manning's formula

Material on surface of ditch		Range of n values	Mean	Material on surface of ditch		Range of n values	Mean
Without lining	Clay (smooth)	0.016-0.022	0.020	With lining	Brick mortar pitching	0.012-0.017	0.014
	Sandy loam, clay loam (smooth)	-	0.020		Cobble mortar pitching	0.017-0.030	0.020
	Loosely grassed	0.035-0.045	0.040		Cobble dry pitching	0.025-0.035	0.033
	Densely grassed	0.040-0.060	0.050		Smooth earth bottom with cobble pitching on both sides	-	0.025
	Mixed with ϕ 1-3 cm gravel	-	0.022		Irregular earth bottom with cobble pitching on both sides	0.023-0.035	0.030
	Mixed with ϕ 2-6 cm gravel	-	0.025		Smooth mortar lining	0.010-0.014	0.012
	Smooth and homogeneous rock	0.030-0.035	0.033				
	Rough surface rock	0.035-0.045	0.040				

f. Hydraulic radius, R:

$R = A/P$ (m)

where A= cross section of water flow (m^2)

P= wetted perimeter, i.e. the circumference of the cross section of that part of a ditch, which is filld by water (m).

g. Mean velocity V: from Manning's formula

$$V=\frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}} \text{ (m/sec)}$$

n=roughness (in decimal)

R=hydraulic radius (m)

S=water surface slope may be represented by the slope of the bottom of the ditch in a normal water flow.

The computed V should be less than the maximum safe velocity for flow without inducing erosion. The maximum safe velocities under different conditions are listed in Table 10-2.

Table 10-2. Maximum safe velocity (m/s)

Soil	Maximum safe velocity	Soil	Maximum safe velocity
Pure silt	0.23-0.30	Ordinary gravel	11.23-1.52
Soft silt	0.30-0.46	Dense grass	1.50-2.50
Coarse stone and fine gravel	0.46-0.61	Coarse gravel & sand	1.52-1.83
Ordinary sand	0.61-0.76	Gravelly rock, hard earth layer, soft aqueous rock	1.83-2.44
Sandy loam	0.76-0.84	Hard rock	3.05-4.57
Hard loam & clay loam	0.91-1.14	Concrete	4.57-6.10

h. Flood discharge capacity, Q_0: This is the product of the cross sectional area (A) multiplied by the mean velocity (V) as follows:

$Q_0 = A \cdot V$

Q_0 = flood discharge capacity (m^3/sec)

A = cross sectional area (m^2)

V = mean velocity (m/sec)

i. Comparison and selection: To compare Q_0 and Q, $1.05\,Q > Q_0 > Q$

Larger Q_0 may be selected in a special case. Considering sediments and drifting matters, $1.3\,Q > Q_0 > Q$.

j. Freeboard: A freeboard of 0.15-0.5 meter is to be added to the cross section designed according to the above procedures.

(2) Drop

a. Runoff discharge, Q: To estimate Q, see Appendix 1, Hydrological analysis.

b. Type of drop: The type of a drop is determined on the basis of the ditch width, slope, elevation difference, runoff discharge and construction materials.

c. Inlet dimensions: To determine h_1 and b or b_0 by the following equations:

(i) Straight inlet

(a) Rectangular inlet: $Q = 1.767bh_1^{3/2}$ (preferably $h_1/b \geqq 0.2$)

(b) Trapezoidal inlet: $Q = (1.77b_0+1.42h_1)h_1^{3/2}$

(side slope 1:1)

$$Q = (1.77b_0+0.71h_1)h_1^{3/2}$$

(side slope 1:0.5)

$$Q = (1.77b_0+0.425h_1)h_1^{3/2}$$

(side slope 1:0.3)

(ii) Box inlet: $Q=1.767\ (b+2L_1)h_1^{3/2}$

(iii) Arch inlet: $Q=1.76\ L_0h^{3/2}$

Where Q=discharge (m^3/sec)

h_1=upstream water depth (m)

b =rectangular inlet width (m)

b_0=trapezoidal inlet bottom width (m)

L_1=box inlet length (m)

L_0=arch inlet length (m)

[Example] Assume discharge at a frequency of once in 10 years, Q=0.2 m^3/sec, ditch width=1.2 m; compute the dimension of a rectangular inlet

[Solution]

Try: $h_1=0.2$, b=0.8, $Q=1.767\times0.8\times(0.2)^{3/2}$

$=0.126\ m^3/sec$ (too small)

Try again: $h_1=0.25$, b=1.0, $Q=1.767\times1.0\times(0.25)^{3/2}$

$=0.22\ m^3/sec$ (too large)

Try again: $h_1=0.24$, b=1.0, $Q=1.767\times1.0\times(0.24)^{3/2}$

$=0.208\ m^3/sec$ (O.K.)

d. Length of apron or stilling basin

(i) A type drop:

The length of an apron may be determined by the following formula:

$$L=0.75(H+d_1)+H$$

Where L=length of apron (m)

H=elevation difference of drop (m)

$d_1=h_1$+freeboard (m)

(ii) B,D, and E type drops:

The length of a stilling basin may be determined according to the following procedures:

(a) To get the critical depth (d_c) at the inlet

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}} \text{(m)}$$

g=9.8 m/sec^2

(b) To get the lenght of a stilling basin, L

$$L = \sqrt{Hd_c}\left[2.5 + 1.1\frac{d_c}{H} + 0.7(\frac{d_c}{H})^3\right]$$

[Example] Assume the elevation difference=2m, water depth = 0.24 m, discharge = 0.2 m^3/sec, rectangular inlet width = 1.0 m, compute the length of a stilling basin.

[Solution]

(a) To get d_c

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}} = \sqrt[3]{\frac{(0.2)^2}{(1.0)^2 \times 9.8}} = 0.16\text{m}$$

(b) To get L

$$L = \sqrt{2 \times 0.16} \times \left[2.5 + 1.1 \times \frac{0.16}{2.0} + 0.7\left(\frac{0.16}{2.0}\right)^3\right]$$

$$= 0.566 \times 2.5916 = 1.46 \text{ m}$$

(iii) C type drop:

The length of a stilling basin is determined according to the following procedures:

(a) Critical depth at the straight inlet, d_c

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}}$$

(b) Critical depth at the outlet of the basin, d_{ce}

337

$$d_{ce} = \sqrt[3]{\frac{Q^2}{b_e^2 g}} \text{ where } b_e = 0.8\, W_d$$

(c) To get the least $L_2 = d_c\ (0.2b/L_1) + 0.3$

(d) To get the least $L_3 = \dfrac{b + 2L_1}{2L_1 / b} \geq 0.25$

[Example] Assume a box inlet b=0.5 m,

L_1= 0.25 m, discharge=0.2 m³/sec, upstream water depth = 0.24m, downstream ditch width = 1.2m, compute the length of a stilling basin.

[Solution]

i. $$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}} = \sqrt[3]{\frac{(0.2)^2}{(0.5)^2 \times 9.8}} = 0.254$$

ii. $b_e = 0.8W_d = 0.8 \times 1.2 = 0.96$, say 1.0 m

$$\therefore d_c = \sqrt[3]{\frac{Q^2}{b_2^2 g}} = \sqrt[3]{\frac{(0.2)^2}{(1.0)^2 \times 9.8}} = 0.16 \text{ (m)}$$

iii. $$L_2 = d_c\left(\frac{0.2b}{L_1}\right) + 0.3 = 0.254\left(\frac{0.2 \times 0.5}{0.25}\right) + 0.3 = 0.4 \text{ (m)}$$

iv. $$L_3 = \frac{b + 2L_1}{2\dfrac{L_1}{b}} = \frac{0.5 + 2 \times 0.25}{2 \times \dfrac{0.25}{0.5}} = 1 \text{ (m)}$$

(e) Dimensions of apron or stilling basin

(i) Upstream expanding cutoff length, B

$B = \frac{1}{2}(W_a - b) + h + 0.2 > 1.0$m (applicable to all types of drop)

(ii) Wing wall length, A

$A = \frac{1}{2}(W_d - b - 0.4) + h + 0.2 > 1.0$ m

(applicable A, B, D, and E type drops)

$A = \frac{1}{2}(W_d - b_e)h_2$ (applicable to C type drop)

where W_a=upstream ditch width (water surface width) (m)

W_d=downstream ditch width (water surface width) (m)

(iii) Energy dissipation sill

(a) B, D and E type drops

$$H' = \frac{1}{2} d_c$$

$X = C_x b + 0.45$

Where C_x may be obtained from Table 10-3.

Table 10-3. Cx values for drops

Wd/b	1.0	1.05	1.1	1.15	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2.0
C_x	0	0.075	0.125	0.15	0.17	0.19	0.21	0.23	0.24	0.25	0.26	0.27

(b) C type drop

at least $h_2 = 1.6 d_{ce}$

at least $t = \frac{1}{3} h_2$

$b_c < 11.5\ d_{ce}$

$f = \frac{1}{6} h_2$

$p = \frac{1}{5} b\ (\frac{1}{4} b \sim \frac{1}{6} b)$

(3) Culvert

a. Maximum design load limit: H-10 for ordinary concrete pipes, H-20 for centrifugal concrete pipes and H-20 for box culverts.

b. A culvert is designed for partial water flow. The optimal water depth is 0.8 D or 0.8 H in order to avoid clogging by sediments or drifting matter.

c. The slope of a culvert should be more than 3% and less than 26% in principle. If a culvert has a slope greater than 26%, it should be provided with stopping wedges or cutoffs to prevent sliding.

d. Burying depth: more than 50 cm for ordinary concrete pipes, more than 20 cm for centrifugal concrete pipes, and generally less than 6 meters; 0-7 meters for box culverts.

e. Manning's formula is used for computing the diameter or water depth of a culvert, assuming a steady flow.

f. The length of a stilling basin at the culvert inlet should not be less than 50 cm. The stilling basin width is D+30 cm and the bottom is at least 20 cm lower than the bottom of the culvert.

g. The bottom of the culvert outlet is to be on the same level as, or higher than the water level of the downstream ditch.

10.6 Supplementary Note

(1) Drainage ditch

a. A grass ditch should have a compound section when there is a continuous water flow. It is even better if the bottom part is lined.

b. It is not desirable to use a grass ditch if there is not enough sunshine for grass growth, or if the bed is covered by too much gravel or stones which are not suitable for vegetation.

c. A cobble lined ditch on a farm may have a parabola cross section over which it is easy for farm machinery to pass.

d. A drainage ditch should have a stilling basin or drop at proper intervals, and at the end of the ditch.

e. A wide, shallow ditch with a brick lining may be used as a path. If its slope is steep, steps may be provided.

f. Side pressure must be taken into consideration when a precast concrete ditch is used as a road-side ditch.

g. A precast concrete ditch should be built in a straight line. It should be coupled with a drop when it has to make a turn because of topographical conditions.

(2) Drop

a. This is installed in a steep section of a ditch where there is a sharp fall in elevation.

b. The height of a drop is preferably less than 3 meters, otherwise a special design should be made.

c. The height of a drop built with brick pitching should not exceed 2 meters. When a wall is higher than 1 meter, it should be built with bricks laid in 1 B form.

d. The A type drop should not be used in to a place where the elevation difference and discharge are great.

e. The A type drop may be constructed in series wherever needed as circumstances require.

f. Where a large water discharge passes through a narrow place with a low head the C or D type is more favorable.

g. A reinforced concrete drop with a height, H, of less than 2 meters should have a wall thickness of 12 cm and 3/8" diameter steel bars at an interval of less than 25 cm; one with a height at more than 2 meters should have a wall thickness of 15cm and 3/8" diameter steel bars at an interval of less than 20 cm.

f. If a stilling basin can not be built according to the criteria because of topographical limits, it may be made shorter, but not less than 80% of the design.

(3) Culvert

a. Building a culvert on filled earth should be avoided.

b. A stilling basin which connects a culvert and a roadside ditch must be provided with an appropriate opening.

c. A trashrack is to be provided at the front of a culvert.

d. A stilling basin may be built with precast concrete plates.

e. Rubber connection joints, flat type joints or insert-type joints may be used for connection of centrifugal concrete pipes.

f. The outlet of a culvert shall be provided with an energy dissipator or be connected with a ditch.

10.7 Precautions

(1) Drainage ditches

a. Earth fill of an earth drainage ditch should be heightened (assuming subsidence of 10%) and grass be planted on the earth surface for stabilization.

b. A grass ditch should be kept free of livestock, and be irrigated in case of drought.

c. The top of a ditch must be lower than the original ground surface on both banks, in order to facilitate drainage from both sides.

d. Installation of precast concrete pieces for construction of a ditch shall be made with concave joints facing upwards. The pieces should be laid well connected, one by one from the downstream to the upstream.

(2) Drops

a. The site of a drop structure should be investigated in detail, with an emphasis on the relative positions of its various parts, in accordance with topographical conditions. The inlet and outlet on a sharp curve should be aligned with the upstream and downstream direction of flow.

b. Attention should be paid to field setting, to ensure that the apron or stilling basin is a little lower than the downstream ground surface.

c. Excavated earth should not be placed in the ditch, but piled up on the banks.

d. Back fill earth should be thoroughly compacted. It must be higher than the wing wall by 20 cm, and slope downwards to the drop.

e. If the subsoil beneath the foundation at the designed depth is too soft, the design should be revised and the depth increased.

f. Weep holes shall be made on the panel wall and wing walls. In general, one hole 3-5 cm in diameter is provided per 1 m^2.

(3) Culverts

a. The foundation of a culvert shoul be made flat and stable. In places where the foundation is not strong enough, it should be strengthened with 1:3:6 concrete.

b. Culvert joints shoul be filled with 1:3 mortar.

c. Back fill earth should not contain stones, and is to be laid and compacted in layers.

Table 10-4. Size and materials of semi-circular precast concrete ditches

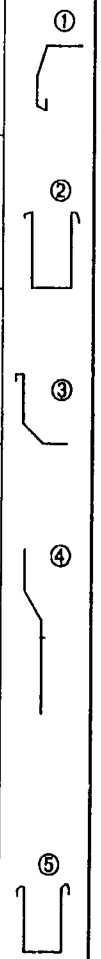
Piece/60cm

Ditch width b (cm)	Ditch depth d (cm)	Thick-ness t (cm)	Concrete (m³)	Cement (bag)	8# wire (0.1064kg/m) No.	m/piece	No. piece	Total length (m)	Total weight (kg.)	Total weight of all wires	Remarks
20	10	4	0.014	0.09	①	0.75	1	0.75	0.08	0.61	
					②	0.56	4	2.24	0.24		
					③	0.7	2	1.40	0.15		
					④	0.36	2	0.72	0.08		
					⑤	0.6	1	0.60	0.06		
25	12.5	4	0.017	0.11	①	0.76	2	1.50	0.16	0.76	
					②	0.64	4	2.56	0.27		
					③	0.7	2	1.40	0.15		
					④	0.36	3	1.08	0.11		
					⑤	0.68	1	0.68	0.07		
30	15	4	0.019	0.12	①	0.75	2	1.50	0.16	0.80	
					②	0.71	4	2.84	0.30		
					③	0.7	2	1.40	0.15		
					④	0.36	3	1.08	0.11		
					⑤	0.76	1	0.76	0.08		
35	17.5	5	0.030	0.19	①	0.75	2	1.5	0.16	0.86	
					②	0.83	4	3.32	0.35		
					③	0.7	2	1.40	0.15		
					④	0.36	3	1.08	0.11		
					⑤	0.89	1	0.89	0.09		
40	20	5	0.033	0.21	①	0.75	3	2.25	0.24	0.93	
					②	0.91	4	3.64	0.39		
					③	0.7	2	1.40	0.15		
					④	0.36	4	1.44	0.15		
					⑤	0.96	1	1.96	0.10		
45	22.5	5	0.036	0.23	①	0.75	4	3.00	0.32	1.19	
					②	0.99	4	3.96	0.42		
					③	0.7	2	1.40	0.15		
					④	0.36	5	1.80	0.19		
					⑤	1.04	1	1.04	0.11		
50	25	6	0.051	0.33	①	0.75	4	3.00	0.32	1.25	
					②	1.10	4	4.40	0.47		
					③	0.7	2	1.40	0.15		
					④	0.36	5	1.80	0.19		
					⑤	1.17	1	1.17	0.12		
55	27.5	6	0.055	0.35	①	0.75	5	3.75	0.40	1.41	
					②	1.18	4	4.72	0.50		
					③	0.7	2	1.40	0.15		
					④	0.36	6	2.16	0.23		
					⑤	1.25	1	1.25	0.13		
60	30	6	0.059	0.38	①	0.75	5	3.75	0.40	1.49	
					②	1.26	4	5.04	0.54		
					③	0.7	2	1.40	0.15		
					④	0.36	6	2.40	0.26		
					⑤	1.33	1	1.33	0.14		

335

Table 10-5. Size and materials of U-shaped precast concrete ditches

Piece/60cm

Ditch width b (cm)	Ditch depth d (cm)	Thick-ness t (cm)	Concrete (m³)	Cement (bag)	8# wire (0.1064kg/m) No.	m/piece	No./ piece	Total length (m)	Total weight (kg.)	Total Weight of all wires	Remarks
20	25	4	0.025	0.16	①	0.75	2	1.50	0.16	1.15	
					②	0.92	4	3.48	0.39		
					③	0.30	6	1.80	0.19		
					④	0.70	4	2.80	0.30		
					⑤	1.08	1	1.08	0.11		
25	30	4	0.029	0.19	①	0.75	2	1.50	0.16	1.25	
					②	1.07	4	4.28	0.46		
					③	0.32	6	1.92	0.20		
					④	0.70	4	2.80	0.30		
					⑤	1.23	1	1.23	0.13		
30	40	4	0.036	0.23	①	0.75	3	1.50	0.24	1.65	
					②	1.32	4	5.28	0.56		
					③	0.37	6	2.22	0.24		
					④	0.7	6	4.20	0.45		
					⑤	1.48	1	1.48	0.16		
35	45	5	0.054	0.35	①	0.75	3	2.25	0.24	1.77	
					②	1.50	4	6.00	0.64		
					③	0.40	6	2.40	0.26		
					④	0.70	6	4.20	0.45		
					⑤	1.70	1	1.70	0.18		
40	50	5	0.059	0.38	①	0.75	4	3.00	0.32	1.94	
					②	1.65	4	6.60	0.7		
					③	0.42	6	2.52	0.27		
					④	0.70	6	4.20	0.45		
					⑤	1.85	1	1.85	0.20		
45	55	5	0.065	0.42	①	0.75	4	3.00	0.32	2.19	
					②	1.80	4	7.20	0.77		
					③	0.45	6	2.70	0.29		
					④	0.70	8	5.60	0.60		
					⑤	2.00	1	2.00	0.21		
50	60	6	0.089	0.58	①	0.75	4	3.00	0.32	2.30	
					②	1.98	4	7.92	0.84		
					③	0.47	6	2.82	0.30		
					④	0.70	8	5.60	0.60		
					⑤	2.22	1	2.22	0.24		
55	65	6	0.096	0.62	①	0.75	5	3.75	0.40	2.48	
					②	2.13	4	8.52	0.91		
					③	0.50	6	3.00	0.32		
					④	0.70	8	5.60	0.60		
					⑤	2.37	1	2.37	0.25		
60	70	6	0.103	0.67	①	0.75	5	3.76	0.40	2.71	
					②	2.28	4	9.12	0.97		
					③	0.52	6	3.12	0.33		
					④	0.7	10	7.00	0.74		
					⑤	2.52	1	2.52	0.27		

340

Table 10-6. Size and materials of trapezoidal-shape precast concrete ditches

Piece/60cm

Ditch width b (cm)	Ditch depth d (cm)	Thick-ness t (cm)	Concrete (m³)	Cement (bag)	8# wire (0.1064kg/m)						
					No.	m/piece	No./ piece	Total length (m)	Total weight (kg.)	Total Wieght of all wires	Remarks
20	15	4	0.0216	0.140	①	0.75	2	1.50	0.16	0.93	
					②	0.76	4	3.04	0.32		
					③	0.40	6	2.20	0.26		
					④	0.70	2	1.40	0.15		
					⑤	0.68	1	0.68	0.44		
25	17.5	4	0.0250	0.163	①	0.75	3	2.25	0.24	1.11	
					②	0.86	4	3.44	0.37		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	0.82	1	0.82	0.09		
30	20	4	0.0253	0.184	①	0.75	4	3.00	0.32	1.24	
					②	0.97	4	3.88	0.41		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	0.93	1	0.93	0.10		
35	25	50.0	0.0458	0.298	①	0.75	5	3.75	0.40	1.41	
					②	1.16	4	4.64	0.49		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.06	1	1.06	0.11		
40	30	5	0.0524	0.341	①	0.76	6	4.50	0.48	1.59	
					②	1.32	4	5.23	0.56		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.27	1	1.27	0.14		
45	32.5	5	0.0569	0.370	①	0.75	7	5.25	0.56	1.73	
					②	1.43	4	5.72	0.61		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.38	1	1.38	0.15		
50	35	6	0.0796	0.517	①	0.75	7	5.25	0.56	1.79	
					②	1.56	4	6.24	0.66		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.50	1	1.60	0.16		
55	37.5	6	0.0852	0.554	①	0.75	8	6.00	0.64	1.93	
					②	1.67	4	6.63	0.71		
					③	0.40	6	2.40	0.26		
					④	0.70	2	1.40	0.15		
					⑤	1.61	1	1.61	0.17		
60	40	6	0.0916	0.595	①	0.75	8	6.00	0.64	1.98	
					②	1.77	4	7.08	0.75		
					③	0.40	6	2.40	0.26		
					④	0.7	2	1.40	0.15		
					⑤	1.71	1	1.71	0.18		

Chapter 11. Silting Basins

11.1 Definition

A silting basin is a structure to intercept flowing water and promote the deposition of the suspended bed loads.

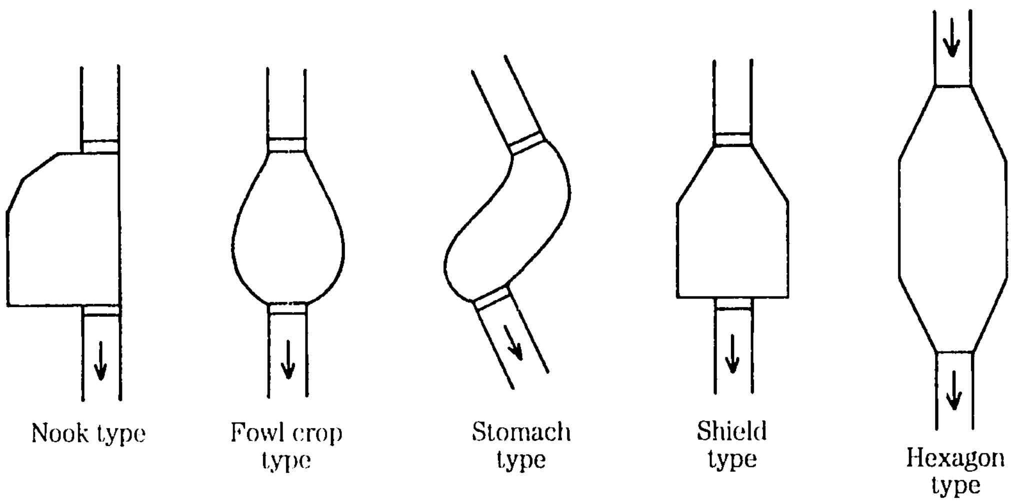
11.2 Purpose

To reduce the amount of silt, sand and debris flowing to downstream areas, so as to protect land, houses and public facilities.

11.3 Applications

The type and size of a silting basin are to be determined according to water flow discharge, the suspended and bed loads, configuration of the tasin, river slope at the intake, sedimentation and topographical conditions. The usual types of silting basins include the nook type, the fowl crop type, the stomach type, the shield type, the hexagon type and the long ellipse type etc. The sides of the basin are protected by concrete, cobble pitching or earth dams.

11.4 Diagram



11.5 Design Criteria

(1) Determination of capacity

a. Estimation of soil erosion is based on three factors.

(i) The rainfall, area, degree of development, and topographical, geological and vegetation conditions in the upstream watershed.

(ii) Past erosion data indicate that the amount of silt and sand flowing out of an excavation work area may be estimated at 500 m^3 of soil per hectare per year.

(iii) According to the Universal Soil Loss Equation, Am=Rm.Km.L.S.C.P

Where

Am=soil loss(t/ha/yr)

Rm=rainfall erosion index (j/ha)

Km=soil erosion index(t/j)

L=slope length factor (in decimal)

S=slope gradient factor (in decimal)

C=crop management factor (in decimal)

P=erosion control practice factor (in decimal)

(iv) Following the Japanese system of soil loss estimation.

The upstream watershed area is divided into forest land, grassland and exposed land. Soil loss in these three lands are calculated separately as follows:

Forest land: $Ef=A\times[0.1+(0.07\times0.75)]$

Grass land: $Eb=A\times[10+(7\times0.750)]$

Exposed land: $Ed=A\times[100+(60\times0.750)]$

where A is eroded area (sloping land) in hectares.

Total soil loss, $V=Ef+Eb+Ed$ (m^3/yr)

b. Cleaning of the basin

In general, a silting basin should be cleaned 1-2 times a year. If clearing takes place a year, then

$Va=V/2$

Va=silting basin capacity (m^3)

V=soil erosion loss upstream (m^3/yr)

(2) Structure

a. At the inlet and outlet of a silting basin, the bottom should be protected by bed stabilization works and the banks by revetments.

b. The bed stabilization and revetments at the inlet are designed in the same way as in river regulation. The design for stabilizating the bed at the outlet should follow that of a weir.

c. Silting basin length

$L=KQ/BVg$

Where

L=basin length (m)

K=safety factor, 1.5-2.0

Q=project flood discharge (m^3/sec)

B=basin width (m)

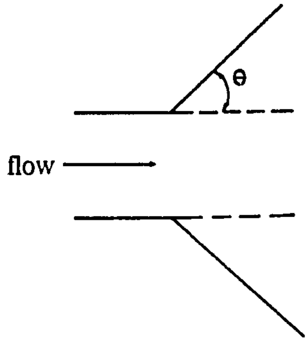
Vg=sedimentation velocity of the smallest particle (m/sec)

d. The width of a silting basin is 3-5 times the original river width.

e. The depth to be excavated depends on the capacity of the basin. In general, this should be less than 3 meters for convenience in cleaning. The longitudinal slope of the basin should be greater than 0.5%.

f. The inlet divergency angle depends on water flow condition and location of the work site.

In general, θ =30° - 60°



g. If a road is to be built specifically to facilitate the cleaning of deposits in a silting basin, it should be designed to give easy access to machinery used in cleaning and transport. Flood water should be prevented from flowing over the road.

11.6 Supplementary Note

(1) Drainage pipes should be provided at the outlet of a silting basin in order to drain out water quickly, to reduce the number of mosquitos .

(2) A silting basin should be surrounded by some type of fencing to protect the safety of human beings and livestock.

(3) Silting basins may be built at several sites midstream and downstream as part of river regulation work, according to the amount of sediment and topographical conditions.

(4) Colgging of the inlet of a silting basin will cause overflow, therefore should be prevented.

3<

Chapter 12. Runoff Detention Dams

12.1 Definition

A runoff detention dam is a structure built across a river to reduce the flood peak, to control the flow direction and to regulate the outflow of silt and sand.

12.2 Purpose

To retard and control flood peak discharges and to function as a check dam.

12.3 Application

A runoff detention dam is different from a check dam, in that a runoff detention dam has a rectangular opening at the spillway or a circular opening at the bottom of the dam (as shown in Figure 12-1).

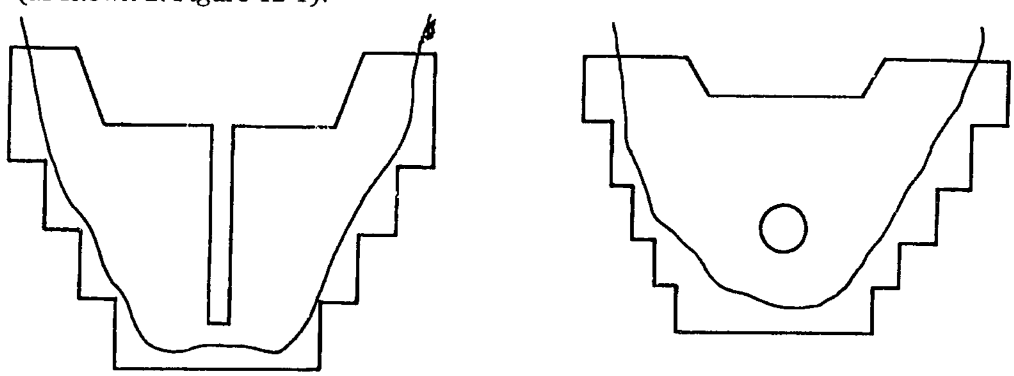


Fig. 12-1. Schematic front view of flood detention dams

(1) According to the construction materials used, flood detention dams may be classified into earth dams, concrete dams and reinforced concrete dams.

(2) Applications:

a. Earth dams: Used when runoff discharge is small, and when the geological conditions of the dam site are poor.

b. Concrete dam Applicable to the midstream and downstream sections of a river where a larger structure is needed.

c. Reinforced concrete dams: Used for larger runoff discharge in midstream and downstream, where a large, permanent structure is needed.

12.4 Design Criteria

(1) For selection of the site, direction, cross section, water cushion, etc. of a detention dam, refer to the Chapters on Check and Earth Dams.

(2) The opening width of a runoff detention dam should be 2.4-2.8 times that of the largest particles of river bed materials upstream, in order to avoid clogging. However, the effect of runoff detention may decrease if the opening is enlarged. Therefore, a check dam or comb dam may be built upstream from the runoff detention dam in order to

intercept particles of larger sizes. The opening is then designed according to the following design procedures.

(3) The opening of a runoff detention dam should be a deep narrow rectangle. Its structure must be strong enough to resist the current, and the friction produced by rolling sand and stones. It may be designed with two buttress walls on both sides of the opening to give extra strength.

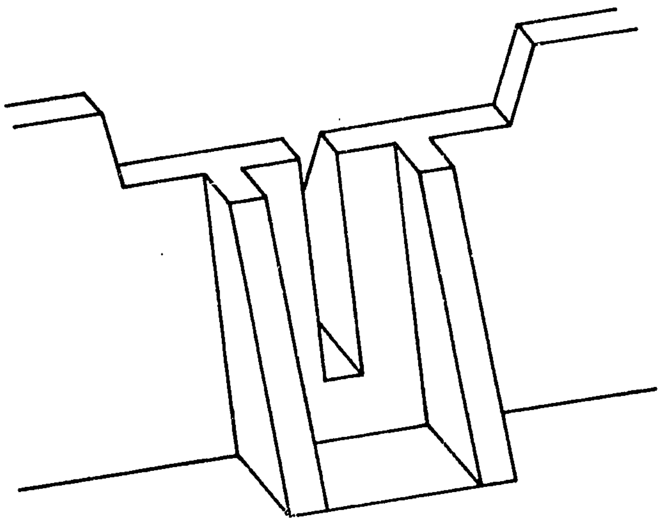


Fig. 12-2. Schematic diagram of buttress wall downstream from a runoff detention dam

(4) The discharge of an opening in relation to its water head may be determined by the following equation verified by laboratory experiments.

$Q=2.942bH^{1.7297}$

Q=discharge(cms)

b=opening width(m)

H=water head

This equation is applicable when

$0<h/Hd/<4$

$0.061<b/D<0.318$

Downstream face: 1:0.3

Upstream face: 1:0.5

h=water head at the trapezoidal spillway

Hd=vertical distance from the opening to bottom of the dam

D=base width of the dam

12.5 Supplementary Note

(1) The main purpose of a runoff detention dam is to reduce a flood peak from Q_1 to Q_2 (as

shown in Figure 12-3) so as to fit the capacity of the existing drainage system.

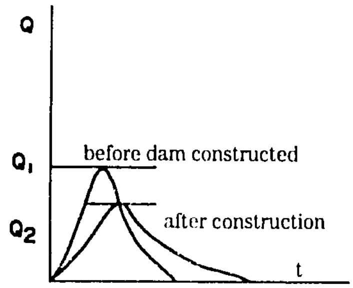


Fig. 12-3. Hydrograph before and after construction of a detention dam

(2) In addition to reducing the flood peak, a runoff detention dam is also used to trap sand and stones. This is illustrated in the schematic diagram in Figure 12-4. A wedge-shaped channel runs from the opening facing the upstream, with its deeper end located at the opening. The angle of the sideslope approximates the angle of repose of the sediments, and its width is wider than the opening. The amount of intercepted sediment may be estimated from Figure 12-5.

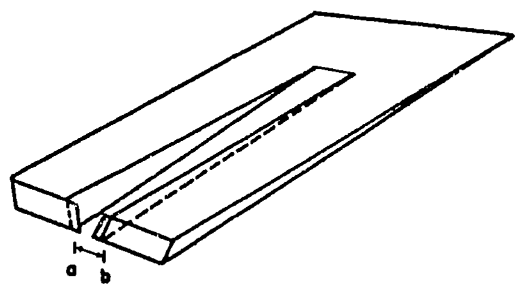
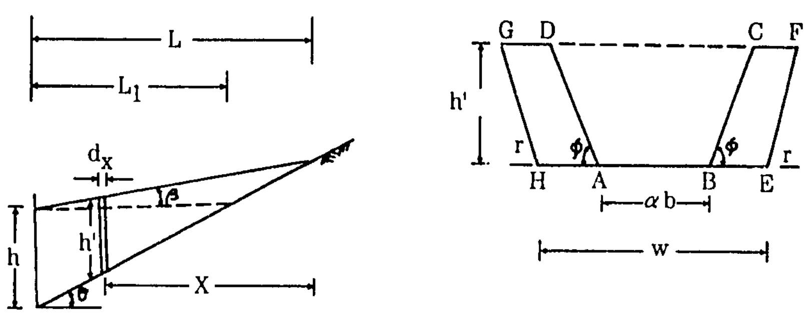


Fig. 12-4. Schematic diagram of sediment interception trench of a runoff detention dam



Side view

Front view

Fig. 12-5. Front and side views of interception trench upstream from a runoff detention dam

$$L = \frac{h}{(\tan\theta - \tan\beta)} = \frac{h}{(S_1 - S_2)}$$

$$h' = xh / L = x(S_1 - S_2)$$

$$\text{Trapezoid EFGH} = [W + (W + 2h'\cot\gamma)] \times h' / 2$$

$$= W(S_1 - S_2)x + \cot(S_1 - S_2)^2 x^2$$

To integrate from 0 to L, then

$$V_s = \int_0^L [W(S_1 - S_2)x + \cot(S_1 - S_2)^2 x^2]dx$$

$$= \frac{Wh^2}{2(S_1 - S_2)} + \frac{h^3\cot\gamma}{3(S_1 - S_2)}$$

Where

S_1: critical creek bed slope, $S_1 = \tan\theta$

S_2: longitudinal sediment slope, $S_2 = \tan\beta$

W: width of creek bed

V_S: estimated volume of sediment without opening

α : ratio of the width of channel to that of opening b, α =2.45-8.32

ϕ : side slope angle of trench = angle of repose ≒ 35°

γ : angle of repose of original side (bank) slope

The volume of sediment flowing down from the runoff detention dam, V_1 is shown by A,B,C,D.

$$V_1 = \frac{\alpha bh^2}{2(S_1 - S_2)} + \frac{h^3\cot\phi}{3(S_1 - S_2)}$$

Therefore, the volume of sediment intercepted by the runoff detention dam, V_{so} is

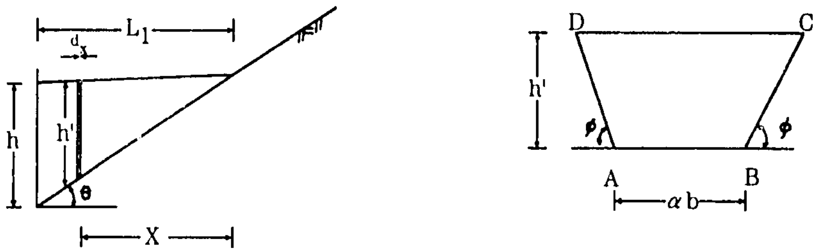
$$V_{so} = V_s - V_1$$

$$= \frac{(W - \alpha b)h^2}{2(S_1 - S_2)} + \frac{h^3(\cot\gamma - \cot\phi)}{3(S_1 - S_2)}$$

(3) Sediments should be removed when the upstream channel of the runoff detention dam is full. In order to facilitate the removal work, a boundary must be clearly marked, according to specific standards, by building revetments on both banks of the creek. The exact volume of sediments to be removed may then be calculated with the help of Figure 12.5.

(4) The cross-sectional design of a spillway for a runoff detention dam is the same as that for a check dam, according to the amount of flood discharge. Computation for this may be referred to the Appendix "Hydrological Analysis". The water storage volume in the upstream channel of a runoff detention dam may be roughly estimated on the basis of the actual river bed slope, the slopes of the two banks and the width of the river bed, according to the storage capacity equation. A schematic diagram for esti-

mating water storage capacity is shown in Figure 12-6.



Longitudinal section

Cross section

Fig. 12-6. Storage capacity of runoff detention dam

$\because \tan\theta = S_1$

$L_1 = h/\tan\theta = h/S_1$

$h_1 = xh/L_1 = xS_1$

Trapezoid ABCD=$[\alpha b + (\alpha b + 2h_1 \cot\gamma)] \times h_1/2$

$= \alpha bS_1 x + \cot\phi\, S_1^2 x^2$

To integrate from O to L, then

$V = \int_0^{L_1} (\alpha\, bS_1\, x + \cot\phi\, S_1^2\, x^2)dx$

$= \alpha bh^2/(2S_1) + (h^3 \cot\phi)/(3S_1)$

Where V is an approximate water storage volume in the upstream channel of a runoff detention dam. After removal of sediments, the water storage volume is larger, i.e. the volume V' espressed by EFGH, which can be obtained by integrating an equation frcm 0 to L_1.

$V' = Wh^2/(2S_1) + (h^3 \cot\gamma)/(3S_1)$

Design Procedures:

a. The maximum flood peak discharge should be determined by hydrological analysis. The design of the opening should be based on a flood frequency of once in 25 years.

b. The dam height and river bed slope should be determined.

c. To determine the ϕ value, 35° is usually adopted.

d. The α value is then determined. From experiments, α falls in the range of 2.45-8.32. The larger the discharge, the higher the value of α.

e. Inflow hydrograph analysis

(i) An outflow hydrograph before construction of the runoff detention dam is used as the inflow hydrograph after construction of the dam. The Puls method is used to obtain the outflow hydrograph after construction of the dam.

(ii) From the Rational Formula.

$Qp=1/360\ CIA$

Where

Qp=flood peak discharge (m^3/sec)

C=runoff coefficent, in decimal

I=rainfall intensity (mm/hr)

A=watershed area (ha)

(iii) Inflow triangle hydrograph

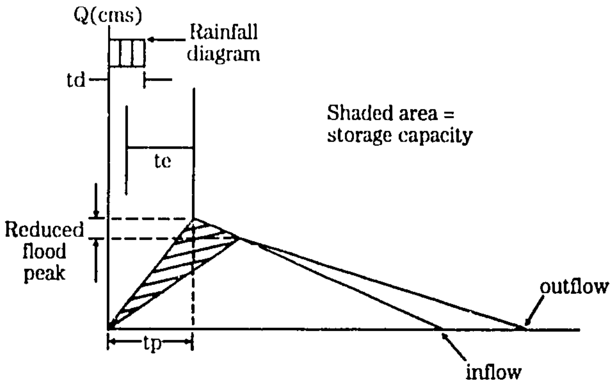


Fig. 12-7.

$t_c=te/0.6$

$\therefore t_p=t_d/2+t_e$

$t_d/2+0.6\ t_c$

$t_c=L/V,\ V=72(H/L)^{0.6}$……Revised Rziha equation

$$\therefore t_p = \frac{t_d}{2} + \frac{0.6L}{72(\frac{H}{L})^{0.6}}$$

where t_d=duration of rainfall

t_e=duration from the center of rainfall diagram to the flood peak

t_p=time of flood peak

t_c=time of concentration

V=flood flow velocity

H=elevation difference between the upstream point and the dam site

L=horizontal distance between the upstream point and the dam site.

(6) From the hydrological fundamental equation, $I - 0=\triangle V/\triangle t$, the area between the inflow hydrograph and the outflow hydrograph is

$(I_1+I_2)/2-(O_1+O_2)/2= (V_2-V_1)/\triangle t$ ------------------------------(1)

350

Where

I=inflow

O=outflow

V=storage

$\triangle t$=time interval

Equation(1) may be transformed by partially changing sides as

$(I_1+I_2)\triangle t/2+(V_1-O_1\triangle t/2)=V_2+O_2\triangle t/2$ ---------------------------- (2)

Equation(2) is of the Puls' method.

Computation procedures of the Puls' method:

a. To compute $(I_1+I_2)/2$

b. From Puls' river characteristic curves O and $V-O\triangle t/2$, to get $V_1-O_1\triangle t+/2$ to get $V_1-O_1\triangle t+/2$ corresponding to O_1.

c. To compute $V_2+O_2\triangle t/2=(I_1+I_2)\triangle t/2+(V_1-O_1\triangle t/2)$

d. From Puls' river characteristic curves O and $V+O\triangle t/2$, to get $V_2+O_2\triangle t/2$ corresponding O_2.

e. To repeat the procedures from (1) to (4).

(7) The volume of water storage may be found by the trial and error method, i.e. assuming the b value (with a rectangular opening). The outflow discharge may then be obtained from the storage volume. If this outflow discharge is smaller than the maximum outflow discharge of the rectangular opening, this is the figure to be used. If the computed outflow discharge is larger than the maximum discharge of the opening, computation shall be repeated by changing the b value. If changing the b value still leaves too high an outflow discharge, the dam height, H, should be revised following step 2 of the Design Procedure. If H can not be increased, a series of runoff detention dams may be designed rather than a single one.

[Example of the Puls method]

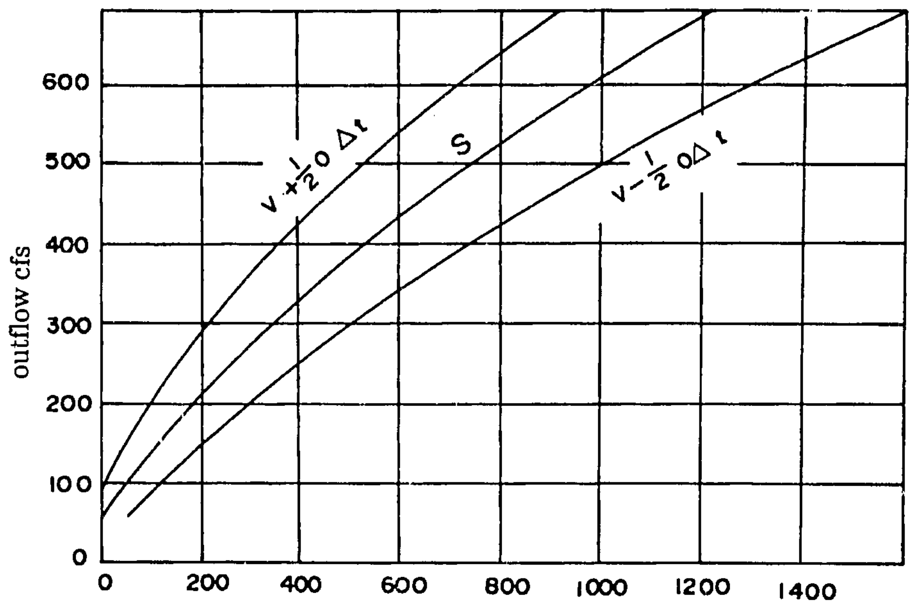
a. Assume that there is a known inflow hydrograph, and O_1= 85 cfs, $\triangle t$=1 hr.

b. From the characteristic curve, $V_1-O_1\triangle t/2=O$ when O_1=85 cfs

c. $V_1-O_1\triangle t/2=115+0=115$ sfd

d. From the characteristic curves, O and $V+\triangle t/2$, it is found O_2=103 cfs when$V_2+O_2\triangle t/2=115$ sfd.

e. To repeat the procedures from (1) to (4).



$S - \frac{1}{2} O \Delta t, S + \frac{1}{2} O \Delta t$ and S(sfd)

Fig. 12-8. Puls' characteristic curves (S=Volume V)

(1) Time interval hr	(2) Inflow cfs	(3) Mean inflow $(I_1+I_2)/2$ cfs	(4) Outflow O cfs	(5) S-O△t/2 sfd	(6) S+O△t/2 sfd
1	93		85		
		115		0	115
2	137		103		
		172		12	184
3	208		143		
		264		41	305
4	320		206		
		381		99	480
5	442		288		
		494		192	686
6	546		373		
		588		313	901
7	630		456		
		654		445	1099
8	678		527		
		684		572	1256
9	691		582		
		692		674	1366
10	692		621		
		688		745	1433
11	684		644		
		678		789	1467
12	671		656		

sfd: ft^3/sec-day

352

III Engineering Construction and Maintenance

1. Foreword

Construction and maintenance have a close relationship with the quality, utility life and economic benefits of engineering work. Needless to say, engineering construction methods must fulfill the requirements that they are dependable, rapidly completed, economical and safe. Engineering work should be completed within a proper time limit, without waste or skimping of labor and materials, with an emphasis on reliability, responsibility and attention to safety of the work and the environment, in order to achieve a superior quality of work.

In selecting construction methods, thorough evaluation must be made of the scale of the work, construction period, construction season, social environment, etc., in order that the most effective and economical methods can be found.

Proper management and maintenance of engineering works will reduce or prevent damage or disaster, ensure the success of the project and prolong the life of the work.

2. Earthworks

Earthwork includes cutting, borrowing, conveying, filling and, dumping soil, shaping of slopes, and related disaster prevention work.

The following precautions should be taken during construction:

(1) Earth excavation and embankments must be done in accordance with design drawings and layout in the field.

(2) Site from which earth is borrowed must be in a safe area or a specially designated area that will not cause damage to existing structures, except in exceptional cases.

(3) Earth dumping areas must be provided for disposal of excess earth.

(4) When explosives are to be used, it is necessary to follow the "Safety Rules for Use of Explosives" and to have proper safety measures.

(5) Any surface on which earth filling is to be deposited, or any surface on which a structural foundation is to be laid, should be cleared of weeds and debris. The surface should be cut into small steps or roughened.

(6) Earth fill should not contain tree roots, weeds, or debris.

(7) Earth filling (including back filling) should be done according to the construction specifications and related rules, and with an extra height to allow subsidence. For the extra height refer to Table III-1.

(8) Earth fill and cut slopes should immediately be planted with grasses.

(9) Earth fill should be deposited on both sides of a structure at the same time. Layers on each side should be of approximately the same thickness.

Table III-1. Extra earth fill to allow Subsidence

Height of Earth fill	Additional height as %
1 meter	12%
1-2 meters	10%
Above 2 meters	8%

(10) Earth fill should be deposited carefully without any damage to a structure. If water accumulates during filling or cutting, it must be drained out. Earth fill should not be deposited on loose sediments or into water.

3. Masonry work

(1) Masonry materials must be hard, and their size should be selected according to the design, with a flexibility of 20%.

(2) Where no cemert, mortar is used, joints should be smoothly and firmly made so as to maximize the contact surface.

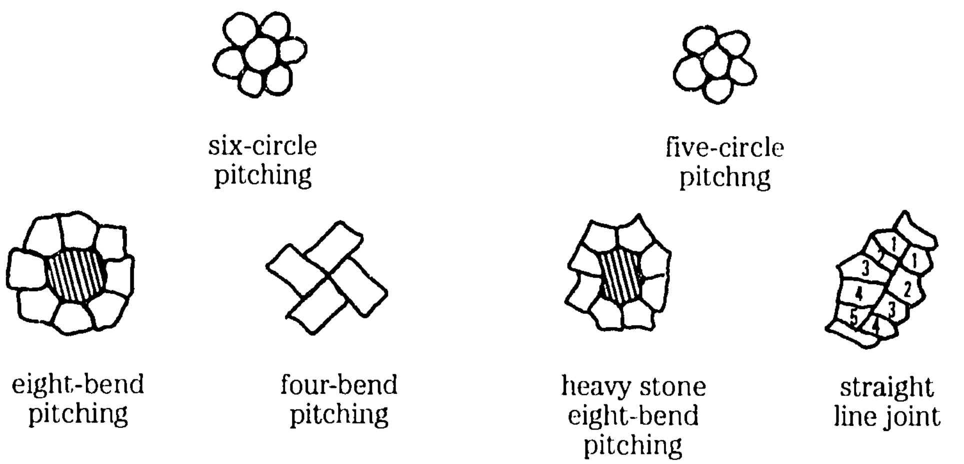


Fig. III-1. Proper pitching of stones

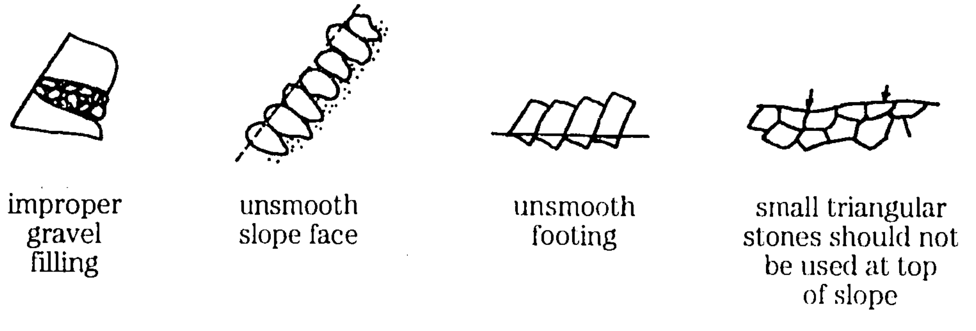


Fig. III-2. Improper pitching of stones

The six circle method is most commonly used for dry pitching of cobble stones. Lateral, four bind and eight-bind pitching should not be used, because their joints are not firm. The joints of stones should not form a straight line.

(3) Stones used for wet pitching should be washed and placed firmly on to level concrete or mortar. After completion, the, surface should be covered with a straw mat or a sponge sheet, and kept damp with water sprayed several times a day. The surface should be protected from any impact for at least three days.

(4) Cement mortar which has been left unused for more than 40 minutes after preparation and begun to set, should not be used.

(5) The height of each section of pitching work should not exceed 1.5 meter for dry pitching; and 2 meters for cement or concrete pitching. Step joints sould be provided if the work is to be continued the next day.

(6) The foundation of pitching work should be solid and sound. If concrete is used in the foundations, stones should be pressed into the concrete.

(7) Both ends of a stretch of cobble pitching work should be inserted into the original ground according to actual field conditions, except when specified otherwise in the design drawing.

(8) Cement mortar used as a surface finish for cobble concrete pitching should not exceed 3.5 cm in thickness above the surface of the cobbles.

(9) Gravel used to fill in the back of pitching work should be neither too large nor too small. The size should be decided by field supervisors in keeping with actual field conditions, or in accordance with specifications in the design drawing.

(10) When a new stretch of cobble pitching work is to be connected with an existing one which has a different slope, the slope of the new section should be adjusted for a suitable length in order to make the connection smooth.

(11) Earth piled up in front of the footing of a masonry dike should be removed to a suitable place.

(12) If the top of a masonry dike is to be filled with earth, the fill should be shaped into a hump of a height equivalent to 1/30 of the width of the top, and covered with paving stones along the center line.

4. Wire sausages

(1) A wire sausage is made of 36 or 24 longitudinal lines of 4.191mm or 4.000mm galvanized wires, with hexagonal meshes 20cm or 15 cm in diameter. Its cross section is elliptical, 60cm or 40cm in short diameter, and 100cm or 67cm in long diameter. Every 150cm, the wire sausage is partitioned with a wire net.

(2) The sausage should be fully filled with cobbles 25-35 cm in long diameter. To make the sausage completely full, crevices should be filled with cobbles 10-22 cm in diameter according to the instruction of field supervisors. The grades of cobbles to be used are: 80% ϕ25-35cm; 15% ϕ15-25cm and 5% ϕ10-15cm.

(3) Wire sausages should be connected with each other with wire at 60 cm intervals, and the ends of all the sausages should be firmly connected with two wires. Connections in

important places should be strengthened according the instruction of supervisors.

(4) The length of a wire sausage fully filled with stones is measured by the length of its center line.

(5) The residual length of wire at the end of a completed wire sausage cage should not exceed 20 cm.

(6) If wire sausages are woven by machine, their specifications should be printed and attached to the sausage by the manufacturer for inspection.

5. Concrete

(1) Basic requirements of concrete

a. Sufficient strength

b. Good workability

c. Durable

d. Stable volume

e. Economical

f. Other factors such as impermeable, waterproof etc.

(2) Factors affecting concrete strength

a. Material quality(Cement, aggregate, water and compound materials)

b. Mixing ratio (Cement-water ratio, aggregate particle size, proportion of cement and aggregate).

c. Construction methods (mixing, conveying, casting or placing, vibration and curing).

d. Age of concrete.

e. Test conditions (sample shapes, sizes and test methods)

(3) Important properties of concrete

a. Workability:

The workability of concrete is the degree of ease with which a given set of materials can be mixed into concrete and subsequently handled, transported, deposited, compacted and finished with minimum loss of homogeneity against segregation. Poor workability affects the quality of concrete. However exceptionally easy workability may sacrifice the quality of the concrete or increase its cost.

Consistency or viscosity is an important factor in the workability of concrete. The commonly used method of measuring the consistency of concrete is the slump test.

For a slump test, an open ended mold in the shope of a frustum cone 10 cm in diameter at the top, 20 cm in diameter at the bottom and 30 cm in height, is placed on a flat plate, and filled with concrete which is rammed in layer by layer. The mold is then carefully lifted. The height by which the concrete subsides below the top of the mold is measured and is defined as the slump, which is usually measured in cm.

The test should be repeated three times with three equal amounts of concrete. According to the specifications of the American Concrete Institute (ACI), slumps of concrete for different structures are shown in Table III-2.

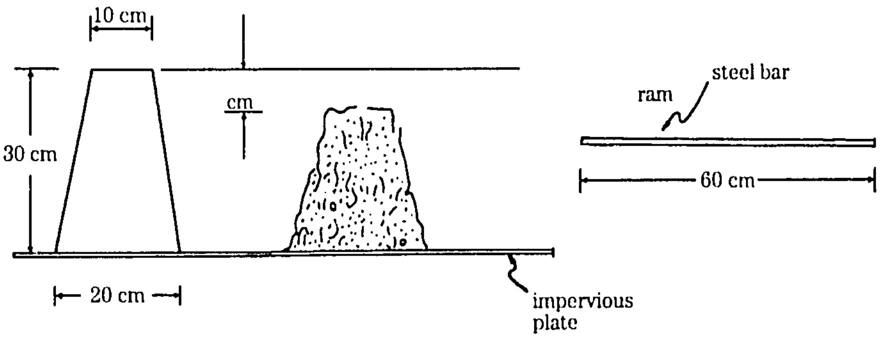


Fig. III-2. Slump test

Table III-2. Slumps of concrete

Kind of structure	Slump (cm)	
	Maximum	Minimum
R.C. footing, wall beam	7.6	2.5
Concrete footing, caison wall	7.6	2.5
Slab, beam, R.C. concrete wall	10.0	2.5
Columumn of house	10.0	2.5
Pavement	7.6	2.0
Large volume structure	7.6	2.5

b. Water-cement ratio and concrete strength

Among the factors affecting the strength of concrete, the water-cement ratio is the most important. In genseral, the water-cement ratio is selected with consideration of the requirements of durability and strength. Concerning the water-cement ratio of concrete, it may be summarized as follows: Among the various component materials in concrete, voids between pebbles in the aggregate must be filled thoroughly with cement mixing, so that voids will be reduced to a minimum. (Theoretically in perfect concrete the voids should be nil.) Therefore, the strength of concrete is actually determined by the strength of cement mortar between pebbles etc. in the aggregate after hardening. In other words, the strength of concrete depends on the density of cement mortar, i.e., the ratio of water to cement affects the strength of concrete. Based on this fact, it is confirmed that the strength of concrete is inversely proportionate to the amount of water used in mixing concrete with a constant amount of cement.

354

This may be expressed by the following equation:

$S=A/B^x$

where S=strength of concrete (kg/cm^2)

x=water-cement ratio (w/c in weight)

A=constant in relation to aggregate

B=constant depending on quality of cement and aggregate, age of con crete, curing condition

Figure III-4 gives the result of an experiment which shows that variation in concrete strength is closely related to the amount of water added (i.e., the value of water-cement ratio) to the same amounts of cement and aggregate.

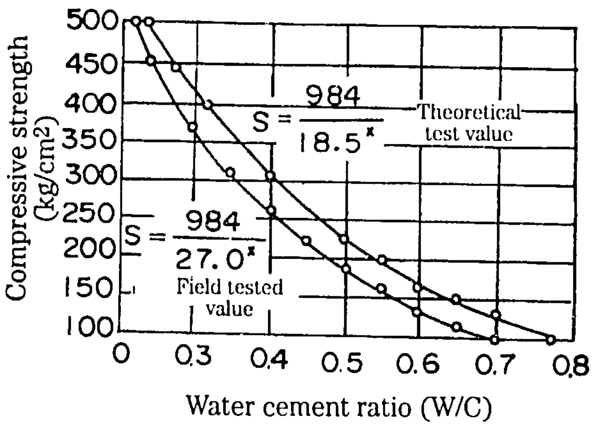


Fig. III-4. Water-cement ratio and concrete strength

Table III-3. Concrete strength and water-cement ratio

Water-cement ratio in weight	Compressive strength after 28 days	
	Common concrete	Air entrained concrete
0.35	420	340
0.44	350	280
0.53	280	225
0.62	225	180
0.71	175	140
0.80	140	110

(4) Volume change in concrete

a. Volume variation in concrete before setting

(i) Methods of preventing water bleeding and setting shrinkage:

358

(a) Use saturated aggregate

(b) Reduce the amount of water used in mixing

(c) Ensure proper proportioning of materials

(d) Use watertight forms which do not absorb water

(e) Avoid casting too thick a layer of concrete at anyone time.

(ii) Plastic shrinkage

Concrete shrinks when it is in a plastic status, and cracks will occur on the surface (plastic cracks).

Method of prevention: Immediately after concrete is poured, proper curing should begin to reduce evaporation from the surface of the concrete.

b. Volume change in concrete during hardening

(i) Hydration of cement

Method of prevention: Use cement made of fine particles and reduce the amount of cement used.

(ii) Control of temperature

During hydration, concrete produces heat and its volume continues to expand. As the hydration heat is lost and the temperature goes down, the surface of the concrete shrinks while the inside body is still expanding. Consequently, the surface of concrete which bears tension stresses cracks.

Method of prevention:

(a) To provide tunnels into the inside of the concrete

(b) To place concrete in layers (the first layer 75 cm thick, and the remainder each 150cm thick)

(c) To use low-heat cement

(d) To bury pipes in concrete for cooling or precooling

(iii) Dry shrinkage

(iv) Carbonization

(5) Improving the impermeability

a. Concrete should be mixed, poured and thoroughly compacted, To avoid segregation of materials and to release trapped air bubbles.

b. Sufficient curing: To reduce cracks and hydrate thoroughly, to eliminate trapped air.

(6) Concrete mixing

a. Concrete mixing should be done by machine, except under special conditions.

b. During machine mixing, specifications or instructions of the supervisor concerning batch quantity of the mixer, mixing time and revolving velocity should be observed, in order to produce concrete that will fully meet engineering requirements.

c. As to the revolving velocity of the drum mixer, one meter of the circumference per second velocity is usually used. In general, the revolutions per minute shall not be less than 14 revolutions and not more than 20. The time of mixing shall be adjusted according to the result of experiments. If no experimental data are available, Table III-4 may be followed.

Table III-4. Reference concrete mixing times

Drum capacity of mixer	Minimum mixing time		Remarks
	Natural gravel	Crushed gravel	
2.25 m^3	2.0 min.	2.5 min.	Maximum mixing time should not
1.50 m^3	1.5 min.	2.0 min.	exceed 3 times the minimum. If over
0.75 m^3	1.2min.	1.5 min.	this limit, stop the mixer.

d. Manual mixing uses an iron plate. The procedure is as follows: Four men with shovels (or two with shovels and two with harrows) are paired into two teams standing in opposite positions, with the first team at the right side of the plate. The first team turns cement and fine aggregate on the plate from right to left and the second team follows the first team and turns the mix from left to right. After turning three times coarse aggregates are added. Three more turnings follow the same pattern as before to complete the dry mixing. Finally, the required amount of water is evenly added to the dry materials.

The wet mixing is then completed by four turnings as before. Attention should be paid to ensure that the required amount of water should be evenly added the first three times of wet mixing, and that the water should be thoroughly mixed with the dry materials without draining away off the plate.

e. Ready-mixed concrete

(i) For good quality and high strength, every batch of concrete materials must have the same slump, proportioning and homogeneity.

(ii) If concrete is mixed in a stationary mixer in a factory and then hauled in a truck agitator to the site of the works, the time of mixing at the factory should be 30 seconds less than the normally specified mixing time, and the time from hauling in the truck at the factory to the completion of placing at the site of the works should not exceed one hour and 30 minutes.

(iii) Concrete unloaded from the truck should be directly poured into the forms. There should not be any delay. Intervals between batches should not exceed 20 minutes. If concrele appears to be beginning to set, it should not be used.

f. Transport and pouring of concrete

(i) Concrete is conveyed from the mixer to the forms using equipment such as wheelbarrows, chutes, dump buckets, endless-belt conveyors, pressure pipes, trucks, etc. If wheel barrows are used, the road should be flat to prevent the concrete from segregating. Chutes usually have a slopes of between 1:3-1:2, and should be equipped with a vertical down pipe of more than 60cm in length so that concrete is poured in the right place.

(ii) Concrete conveyance equipment should be cleaned before use. There should not be any foreign matter, and it is necessary to make sure that there is no leak in the equipment.

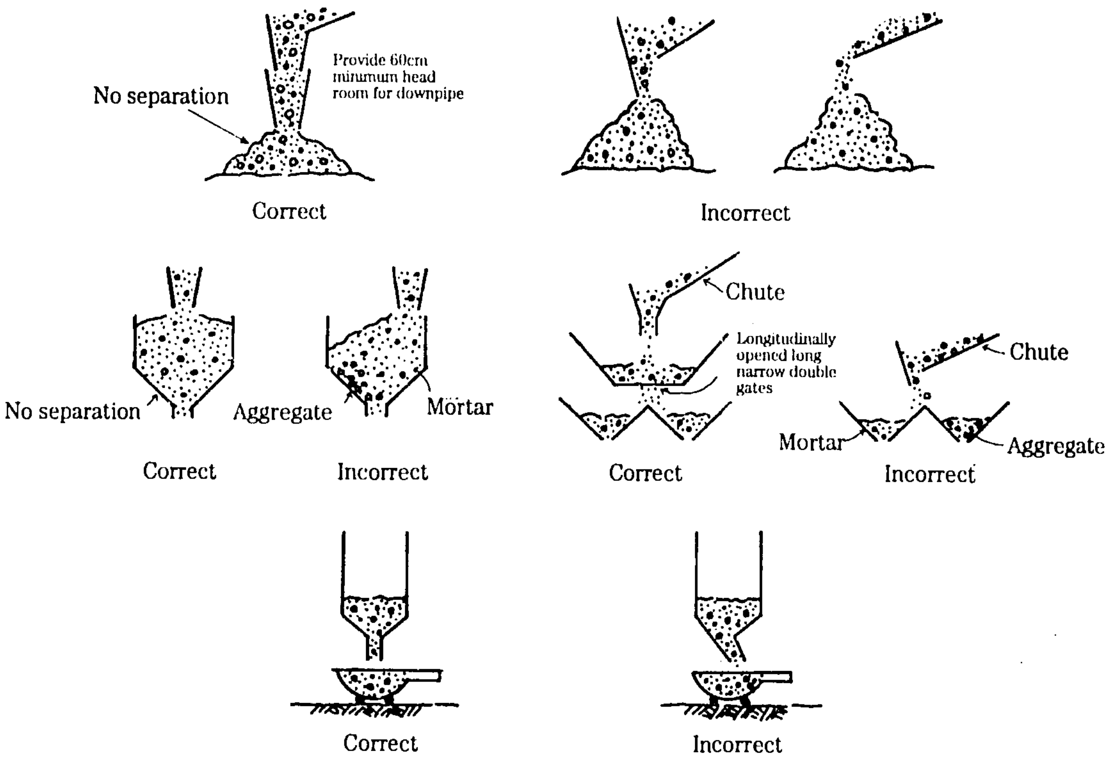


Fig. III-5. Schematic diagram for concrete packing (Concrete Manual, U.S.B.R.)

(iii) If concrete is to be placed on an existing concrete or rock face, the latter should be chopped to form a rough face, thoroughly cleaned, moistened with water, and plastered with the originally specified mortar 24 hours before placing in order to ensure a firm joint.

(iv) In the transport and pouring of concrete, attention should be paid to the consistency and homogeneity of concrete. Segregation and loss of concrete should be prevented. Reinforcing steel bars should not be loosened.

(v) Concrete should be poured as near as possible to the outlet of the delivery equipment. The vertical discharging height shall not exceed 1.5 meter.

(vi) Concrete should be poured layer by layer. Each layer should be less than 30 cm thick in the case of plain concrete; less than 15 cm for reinforced concrete; and less than 50 cm for large volume concrete. Poured concrete should be compacted thoroughly without leaving cold joints.

(vii) Concrete pouring should proceed continuously, until a specific section is completed. If there must be a pause during pouring, it should follow the instruction of supervisors, and construction joints should be arranged.

(viii) Concrete should not have water bleeding.

(ix) Proper lighting facilities are required for concrete placing at night.

(x) After completion of concrete pouring, the forms and reinforcing steel bars must not be vibrated or pressed.

g. Concrete compaction

(i) Concrete must be compacted with special care into every corner of the forms and into all spaces between steel bars. However, the forms and steel bars should not be vibrated or moved after pouring is completed. Attention should be paid to avoiding too much or too little compaction with vibration.

(ii) Steel bars, bamboo rods or iron shovels may be used for compaction. They may be inserted into concrete to a depth of 15-30 cm. Compaction is completed when a thin film of mortar is brought to the surface.

(iii) Compaction is usually made using specially designed vibrators. The vibration frequency of the vibrator should be more than 4500 times per minute.

(iv) The vibrator is to be inserted into or withdrawn from concrete slowly in a vertical direction in order to avoid trapping air insie the concrete. The vibrator should be inserted at fairly close intervals, not exceeding twice the vibration radius. Operation of the vibrator should continue until the work in a section is completed. When necessary, it may be repeated in part of the concrete.

(v) The inserting depth of a vibrator depends on the depth of a concrete layer, which should not exceed 30 cm, with an additional depth of 10 cm into the lower layer in order to make the upper and lower layers combine together into one unit. Manual compacting may be used to help achieve thoroughness of compaction.

(vi) For thin walls, pipes, tunnel linings and similar structures, form vibrators may be used, following the instruction of field supervisors.

h. Joints

(i) All the joints shall be provided precisely according to the position and structure shown in the design drawings.

(ii) Construction joints should be provided in places where the bearing and shear forces are minimum without affecting the appearance. For structures such as foundations and dams, the joints shall be provided in a direction perpendicular to the compressive stress; for cobbles set in concrete, half of each cobble should be kept outside the concrete as wedges for construction joints.

(iii) On the surface of concrete, small grooves are provided at an interval of 5-10 meters. The depth of a groove is 1/3-1/4 of the concrete depth.

(iv) Concrete structures should be provided with expansion joints to prevent cracks.

362

(v) There are two kinds of expansion joints, namely open joints and filled joints. The open joint is made by putting a wooden or metal strip into fresh concrete at the right place, and pulling it out after proper time without damage to the concrete edges. The filled joints are made of polystyrene plates or other materials according to the instruction of supervisors. After concrete is placed on one side, a polystyrene plate will be placed in the right place. After the form is removed, concrete is placed on the other side of the polystyrene plate.

(vi) Water stops are provided following the dimension and quality specified in the design drawing.

i. Adjustment and finish

(i) After placing concrete, extra concrete on the surface shall be immediately removed so as to fit the required height and shape. If a smooth surface is needed, the surface should be finished with a smoothing iron.

(ii) After the forms are removed, all protuberances should be cut away to leave a flat surface.

All the holes, honeycombs, wooden plates, bracing rod holes and broken concrete etc. should be thoroughly brushed, cleaned and moistened with water for three hours, and then plastered and compacted with the same grade and relatively dry cement mortar, and afterwards cured properly according to the specifications.

(iii) After the forms are removed, the remaining ends of the wires used for bracing the forms should be cut and coated with cement mortar, which should have the same color as the concrete.

j. Curing

After placing and before hardening, concrete must be properly cured at appropriate moisture and temperature, to promote hydration.

(i) Curing methods

(a) Moist curing: In order to prevent evaporation of concrete moisture, the exposed concrete surface is covered and properly treated to keep it moist for a certain period of time. There are several methods such as covering the concrete with wet sand (more than 2.5 cm thick), covering it with gunny or straw bags and sprinkling water on them, or ponding water by building small earth dikes so that water remains lying on the concrete. Usually the curing takes more than one week. If fly-ash cement is used, the curing period should be more than two weeks.

(b) Liquid-film curing: Curing compounds shall be used according to specifications. The best time for spraying liquid-film compounds is 1.5-2 hours after concrete is poured. Before application, the compound should be agitated thoroughly. The amount of compound to be sprayed is 20 m^2 per gallon.

(c) Steam curing: This kind of curing begins 2-4 hours after pouring of concrete. It has the effect of shortening the curing period so that forms can be removed early.

(ii) Precautions

(a) After concrete is poured, proper measures should be taken immediately, following the directions of supervisor, to deal with any problems of low temperatures, drying, loading and impacting which would be unfavorable to concrete quality. All necessary equipment and materials shall be prepared before concrete is poured.

(b) Covering materials and water to be used should be clean, without any dirt, mud, or other substances that might discolor the structure.

(c) During curing, the surface temperature of concrete should be kept above 5℃.

(d) Usage of liquid-film compounds should follow regulations, with special attention to environmental protection and safety.

k. Construction works under water

(i) The cement content of concrete per cubic meter must be at least 8 bags.

(ii) The proportion of fine aggregate must be higher than normal.

It should be 45-50% of the total weight of all aggregates (with a constant amount of coarse aggregate)

(iii) The largest particle size of coarse aggregate should be less than 5 cm (2 inches) in diameter.

(iv) Slump tests must be done before pouring.

(v) Methods of concrete pouring include the dump bucket method, the filling hopper method, the sinking bag method, and the concrete pipe method.

(vi) The flow velocity of water should not exceed 3 meters per minute during construction.

(vii) Water should be kept static until be concrete hardens and sets.

(viii) Concrete shall be placed evenly in order to avoid segregation.

(ix) The deposited surface of concrete shall be kept flat.

(x) Concrete shall not be poured when the water is muddy or contains unwanted materials.

(xi) The water temperature should not be less than 2℃, and the temperature of the concrete must be between 16℃ − 49℃.

(xii) Pouring concrete in water should continue, until the top of the concrete is rising above the water to a certain height.

(xiii)Construction joints must be thoroughly treated to remove floating foam.

(xiv)No method of compaction should be used when concrete is powed under water.

l. Cobbled concrete

(i) The diameter of cobbles to be used depends on the design, and cobbles should be washed and moistened in advance.

(ii) After concrete is poured, cobbles should be uniformly placed in the concrete. After placing the next layer of concrete on the cobbles, the space surrounding each cobble should be thoroughly compacted so that no air remains.

(iii) Clearance between cobbles should not be less than 15 cm; that between the cobble and the surface of the structure should be at least 30 cm; and that between the cobbles and the bottom surface should be at least 15 cm.

6. Forms

(1) In order to ensure the quality and scheduled progress of construction, it is necessary to prepare sufficient forms of proper dimensions, adequate strength, water resistance and minimum deformation. The strength and deformation of important forms should be calculated for safety.

(2) Forms shall be installed by proper methods, precisely and firmly according to the size, shape and position specified in the design drawing, for easy removal in the future. The structure of forms should not be affected by load, moisture or vibration.

(3) Forms should be of good quality and planed inside. In general, the thickness of a form after being planed shouldt be not less than 1.5 cm, unless otherwise specified.

(4) Special attention should be paid to the braces and props which support the forms, so that they are placed on a firm footing without any subsidence or deformation. The setting and framing of form works should be properly carried out with approval of supervisors.

(5) The angles or corners of the forms should be provided with fillet materials to reduce sharp edges.

(6) Forms of a thin wall or a column of more than 1.5 meters in height are likely to make it difficult to carry out interior cleaning, oil painting, inspection, concrete pouring, vibration and compaction. Manholes or windows may be provided to facilitate these works.

(7) Scaffoldings should be firmly assembled under supervision, and no part of the scaffolding should be in contact with the forms.

(8) After they are inspected and approved by supervisors, the forms should be painted with oil before plain concrete is poured into them. For reinforced concrete, the forms should be painted with oil before the steel rods are installed.

(9) Kinds and characteristics of forms:

Table III-5. Comparison of materals commonly used for forms

Material		Characteristics	Strength	Economy
Wooden forms		Inexpensive, easy to process and frame, heavier than plywood	Relatively weak.	Can be re-used 3-5 times, inexpensive
Plywood forms		Form plane larger,easy to process, not heavy, fewer joints	Poor tolerance of moisture, which affects its strength	Re-use not easy, more expensive than wooden forms
Metal forms	Steel forms	High accuracy, good water-tightness, smooth concrete surface	Very strong	Re-usable, economical
	Alminum forms	Light (half weight of the steel), high accuracy, good watertightness	Very strong	Re-usable, price twice as much as that of steel forms
Strengthened plastic forms		Light (1/4 of the steel), accuracy, good watertight-ness, resistant to corrosion, easy to detouch	Strength affected by temperature	Re-usable, expensive

(10) Forms shall not be removed until concrete strength increases to the extent that the concrete can bear its own load and other loads. When the forms are removed, concrete shall not be vibrated, impacted or damaged.

(a) Removal date and method shall be decided by supervisors according to the results of tests, or with reference to Table III-6

Table III-6. Time for removal of forms after concrete is poured

Item	Wall beam	Column	Foundation	Slab	Support frame of arch and beam
Time	More than 30 days	3-7 days	1-2 days	7-14 days	14-21 days

Table III-7. Minimum concrete strenght of structures for removal of forms
(Summarized from Concrete Manual, U.S.B.R.)

Explanation	Structures for example	Minimum concrete strength PSI	kg /cm²
Concrete without obvious bending stress or direct stress. Its weight does not rely on the vertical supports of forms, and it will not be damaged because of removal of forms or other construction activities.	1. Vertical or nearly vertical surface of structure with thick cross section. 2. Outside surface of a structure with cylindrical cross section. 3. Side wall of tunnel lining which resists rock. 4. Top of side slope	500	35
Concrete with considerable bending stress and direct stress. Its weight relies partly on the vertical supports of forms (1) Only to bear static load	1. Vertical or nearly vertical surface of a structure with thin cross section. 2. Inside surface of a structure with cylindrical cross section 3. Arch section of tunnel lining which resists rock 4. Lower part of slope face (1:1 or steeper)	750	53
(2) To bear static or live loads	1. Interior of galleries and other openings of dams. 2. Outside wall of tunnel	1500	105
Concrete with high bending stress partially or totally relies on the vertical supports of forms	Roof, slabs, beams, lower part of slope (flatter than 1:1), bridge slabs, girders, path ways, balconys	1000	140

7. Steel bars

(1) Steel bars should be precisely processed by a proper method to the dimensions and shapes as specified by the design drawings. Processed steel bars are to be consistent with the drawings and should not change in quality. Steel bars are bent with out heating except if there are special directions in the drawings or permission is given by supervisors. All lengths and sizes of the straight and curved bars, as well as the lengths of hook and plain connections, are to be the same as shown in the drawings.

(2) Before the framing of steel bars, any swelling rust, oil, paint and other matters which

reduces the bond stress should be thoroughly removed.

(3) When steel bars are bound and framed, supplementary steel bars may be used to fix them. Steel bars shall be firmly framed according to specified sizes and at the intervals shown in the design drawings. They should be tightly bound with #20 wires where they cross other wires. If interval between wires are less than 20 cm, then every other intersection should be bound. Clearance between steel bars of two layers, and between steel bars and forms, should be set with precast concrete blocks but not cobbles, bricks, iron pipes or pieces of wood.

(4) Steel bars shall be connected according to the design drawing. They should not be connected in any other places, and especially not in positions where moment is greatest. Except for special specifications, the overlap length of steel bars at a connection is 30 times of the steel bar diameter, and the steel bars shall be put closely together and bound tightly with #20 wire. The minimum clearance of connected steel bars and the thickness of concrete covering shall follow the design standards.

(5) Steel wires used for prestressed concrete should be separately specified.

8. Arrangement of working site

(1) The environment of the working site shall be kept clean. Waste such as cement paper bags, wooden plates and pieces and discarded forms should be removed.

(2) Temporary construction offices or warehouses should be cleared and the ground restored to its original status, after the of construction work is completed.

(3) Temporary paths and drainage facilities should be removed after completion of constructions works.

(4) Abandoned earth should be properly disposed of, and supervisors should ensure that it is taken to the designated dumping site.

(5) Earthworks above structures should be leveled off accordingly.

(6) If there is any damage to public facilities or waterways inside or outside the work area during construction, it should be repaired immediately.

(7) Earth and stones falling down onto the bottom of structures, e.g. canals, stilling basins, apron etc. from the top of a levee or bank during the progress of clearing, should be removed completely.

9. Maintenance

(1) All engineering work should be periodically inspected, and properly maintained at the appropriate time, especially after natural disasters e.g. typhoons, rainstorms or earthquakes. If there is any damage, it should be repaired immediately so that the work is able to continue functioning well.

(2) Attention should be paid to ensure that normal water flow is not affected by road foundation repairs, filling of damaged openings, clearing of collapsed earth or excavating of ditches.

(3) Attention shouls be paid to bridge piers, abutments, wing walls, approach retaining walls and revetments. If any holes have been scoured, they should be filled and strengthened.

(4) Flowing water should be kept clear of sediment and debris.

(5) Care should be taken to maintain the piers and expansion joints of bridges in good condition. Drains in bridges should be kept from clogging.

(6) Before an upstream check dam becomes full of sediment, the downstream river bed usually suffers serious erosion. Attention should be paid to its maintenance all times.

(7) Safety measures should be taken for those relatively dangerous facilities such as storage ponds, check dams, stilling basins, aprons, etc., and warning signs should be provided at the sites.

20
m

IV. Appendices

1. Hydrological Analysis

1.1 Foreword

Water flow on the surface of the ground which originates in rainfall is called runoff. Excessive runoff due to rainstorms is called a flood.

The accuracy of analysis of data related to runoff in a watershed area has great importance in the structural design and cost estimation for watershed management, river regulation and soil conservation. Since most soil conservation structures are located in the midstream and upstream of a river, in remote areas where long-term water level and discharge data are not available, rational formula or empirical equations are usually used to estimate flood discharge. However, it is necessary to use more accurate methods to estimate flood discharge for important engineering planning and design.

1.2 Rational formula method

In engineering work for soil conservation such as control of wild creeks, check dams, road culverts, farmland drainage systems, etc. which are located on relatively small creeks in watershed areas, the rational formula may be applied without difficulty in order to estimate flood discharges. Flood discharge can be calculated on the basis of watershed area, rainfall intensity, the time of concentration, runoff coefficient, and other closely related factors, such as soil, vegetation cover, ground surface features and topographical conditions. This method is suitable for a watershed area of less than 100 hectares, but not suitable for one large than 10 km^2.

$$Q_p = \frac{1}{360} \cdot C \cdot I \cdot A \text{ -- } (1)$$

Where Q_p= peak discharge (cms)

C= runoff coefficient(in decimal)

I= mean rainfall intensity (mm/hr)

A= watershed area (ha)

(1) Runoff coefficient

The runoff coefficient is the ratio of the amount of runoff to the amount of rainfall. Its value depends on such factors as the watershed area, ground surface features, topographical and geological conditions, soil properties, land use, vegetation cover, amount, intensity and duration of rainfall etc. The runoff coefficient may be classified into the following three categories:

a. Flood peak runoff coefficient: The ratio of the flood peak discharge to the uniform rate of rainfall during the time of concentration which produces the flood peak.

b. Single rain storm runoff coefficient: This is the ratio of the total amount of runoff to the rainfall of a single storm.

c. Long terms runoff coefficient: This is the ratio of the total amount of runoff to that of rainfall within a specified period of time which may be a year, a season or a month.

The flood peak runoff coefficient is used for the structural design of soil conservation work, to ensure the safety of the structures. Table 1-1 may help to determine the runoff coefficients.

Table 1-1. Reference values of runoff coefficients

Watershed area situation	Steep mountain area	Mountain area	Hilly land & forest area	Flat plain & farmland	Irrigated paddy field	River in mountainous area	Small rivers in flat plain	Large river in mostly flat plain
Runoff coefficient	0.75 – 0.9	0.70 – 0.80	0.5 – 0.75	0.45 – 0.60	0.70 – 0.80	0.75 – 0.85	0.45 – 0.75	0.5 – 0.75

Source: Japan Agricultural Civil Engineering Handbook, 1957

Since soil conservation work is mainly located in mountainous areas or on slopeland, especially in small watershed areas, the runoff coefficient is generally higher than that of other area. If there are no dependable actually measured data available for estimating flood peaks, it is suggested that the flood peak runoff coefficient be set in the range of 0.7-0.9 for soil conservation works in mountainous or slopeland areas, and 0.9-1.0 for community development work on slope-lands.

(2) Rainfall intensity

a. Rainfall intensity may be computed by using one of the rainfall intensity equations which fits the project area or the area in the vicinity, in terms of weather conditions and rainfall frequency as well as requirements of the engineering work. Table 1-3 shows the rainfall intensity equations with different frequencies and Table 1-4 shows the sites of observation stations in different localities in Taiwan.

b. To compute hourly rainfall intensity, Monobe's equation can be used, based on the daily rainfall of an adequate frequency in the project area or nearby:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{k} \quad \text{--} (2)$$

where I=rainfall intensity (mm/hr)

R_{24}=daily rainfall of an adequate frequency (mm/day)

t=time(hr)

k=coefficient

The coefficient k varies with the conditions of rainfall characteristics and different frequencies in the project area. The values of k falls in the range 0.6-0.67. This is obtained by characteristics-coefficient analysis, using the maximum daily and hourly rainfall recorded by observation stations in Taiwan.

(3) Time of concentration

This is the time required for the runoff to flow from the farthest point to the work site in a watershed area, including the time if takes runoff to flow over the ground surface from the farthest boundary to a river and the time it takes to flow down the river from upstream to the work site dowstream. The time of concentration varies with factors such as watershed size, shape, slope, physical characteristics of rivers, rainfall intensity etc., and shortens as the rainfall intensity increases. Therefore, it is not easy to calculate. Consequently, the accuracy of the estimate of average rainfall intensity to be used in the rational formula is also affected. Methods for estimating the time of concentration are as follows:

a. Kadoya and Tomitori empirical equation

$T_p=C_1 \cdot R_e^{-0.35} \cdot A^{0.22}$ .... (3)

Where T_p=time of concentration (min)

C_1=coefficient; constant varying with the surface conditions of the watershed, as shown in Table 1-2.

R_e=effective rainfall intensity (mm/hr),

$R_e=I \cdot C$ I=rainfall intensity,

C =flood peak runoff coefficient

A=watershed area (km^2)

Table 1-2. C_1 Values of Kadoya's equation

Surface classification	C_1 value	Surface classification	C_1 value
Hilly land and Forest land	290	Golf course	130-150
Pasture	190-120		
Urban area	60-90	Farmland (with plenty waterways)	90-110

b. Estimation by Sections

The time of concentration, $t_c=t_o+t_s$

Where t_o=the time required for the runoff to flow from the boundary of the watershed to the river (the time of the ground surface runoff)

t_s=the time required for the collected ground surface runoff to flow through the river channel from an upstream location to the downstream outlet (the time of river runoff)

The velocity of the ground surface runoff (V) is usually in the range 0.3-0.6 m/sec, so that the time of ground surface runoff can be obtained by dividing the slope length, L, by V. As to the velocity of the runoff flowing down the river channel, it can be calculated by the Manning formula according to the cross section, slope, and roughness of various cross sections of the creek. Once the velocity and lengths of individual river sections have been estimated, the total time (t_s) can be finally calculated.

c. Rziha formula

$$t_c=\frac{L}{V} \text{ where } V_1=20(\frac{H}{L})^{0.6}(\text{m/sec})$$

$$V_2=72(\frac{H}{L})^{0.6}(\text{km/hr})$$

t_c=time of concentration (sec or hr)

L=horizontal distance from the farthest upstream point to the downstream outlet (m or km)

H=elevation difference between the farthest upstream point to the downstream outlet (m or km)

V_1,V_2=flow velocities

(4) Methods of estimating the flood peak

The flood peak discharge has a close relation to such factors as the runoff coeficient, time of concentration, rainfall intensity and watershed area. Of these, time of concentration, rainfall intensity and watershed area are especially closely related. Therefore, estimation of flood peak discharge using the rational formula includes the interacting relations among these factors. From equation (3),

$$T_p=C_1 \cdot R_e^{-0.35} \cdot A^{0.22}$$

which can be rewritten as

$$T_p=C_1 \cdot (I \cdot C)^{-0.35} \cdot A^{0.22} \quad \text{------------ (4)}$$

From Table 1-3,

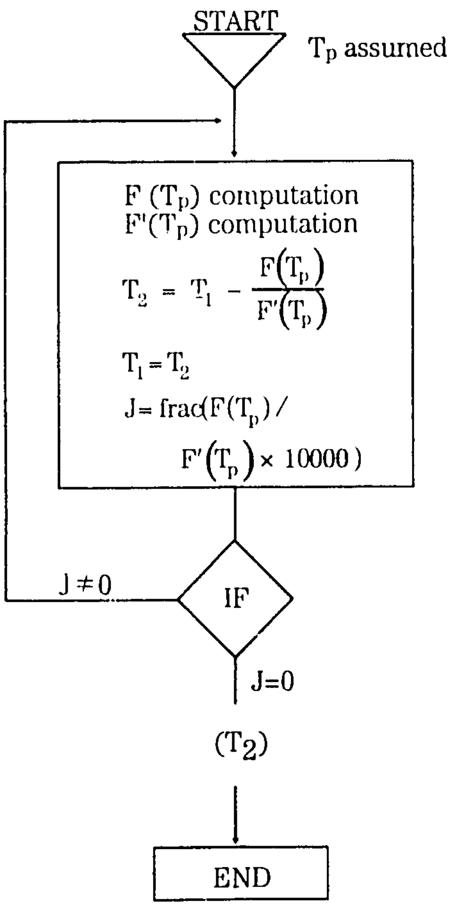
$$I=\frac{a}{(t+b)^n} \quad \text{------------ (5)}$$

To get the rainfall intensity for the time of concentration, T_p, subsitute T_p for t, and $R_e=I \cdot C$ or $I=R_e/C$ in equation (5), therefore

$$R_e=\frac{C \cdot a}{(T_p+b)^n} \quad \text{------------ (6)}$$

From equation (4) and equation (6), We can get the solution of R_e and T_p. The

Newton method can first be applied to get T_p. Then fit it into equation (5) to compute the rainfall intensity I. Finally, the flood peak discharge can be computed using the rational formula. A personal computer (PC) program for computation of a flood peak runoff discharge by applying the Newton method is shown as follows:




```
10 REM "KADOYA-GOURI"
20 INPUT "A(KM2)=",AO
30 INPUT "C1=",C1
40 INPUT "C=",C
50 INPUT "I(a)=",A
60 INPUT "I(b)=",B
70 INPUT 'I(m)=",M
80 INPUT 'I(n)=",N
90 X=C1^2.857*AO^0.62357
100 Y=A*C:TP=10
110 F1=X/TP^2.857
120 F1=F1-Y/(TP M+B)^N
130 F2=M*N*Y/(TP^M+B)^(N+1)*TP^(M-1)
140 F2=F2-2.857*X/TP^3.857
150 P=F1/F2:TP=TP-P
160 IF ABS(P)>1/10^4 THEN 110
170 R1=A/(TP^M+B)^N
180 R2=C*R1
190 Q=AO*R2/3.6
200 PRINT "TP=";TP
210 PRINT "I=";R1
220 PRINT "Q=";Q
230 END
```

Input: I(a)=a

I(b)=b — coefficients of rainfall intensity eqiuation

I(m)=m

I(n)=n

A(KM2)=AO watershed area

C_1=coefficient of Kadoya and Tomitori equation

C=flood peak runoff coefficient

Output: T_p=time of concentration (min)

I=rainfall intensity (mm/hr)

a=flood peak runoff discharge (cms)

For exampie, in the Chitou watershed area of National Taiwan University Forestry Experimental Station, the watershed area=0.618 km^2. Since there is no rainfall intensity equation available in that area, the rainfall intensity equation for the nearby Tsaoling area is applied as follows:

$$I = \frac{388.4}{(t+7)^{0.32897}} \text{(with a frequency of 25 yr)}$$

where the input data are

A=0.618 km^2

C_1=290

C=0.75

I(a)=388.4

I(b)=7

I(m)=1

I(n)=0.32897

As the results of computation by the PC program, the outputs are:

T_p=57.9 min······the time of concentration

I=98.4 mm/hr······rainfall intensity

Q=12.7 cms······flood peak discharge

The above results may be compared with the actually measured data of September 2,1989 below:

T_p=55 min······the time of concentration

I=88.0 mm/hr······rainfall intensity

Q=12.7 cms······flood peak discharge

Since the actually measured hydraulic data and the applied rainfall intensity equation come from different localities, the above computation results are of referential value only.

378

Table 1-3. Results of Horner equation at ten observation stations, Central Weather Bureau, R.O.C.

Station \ Frequency	5 years	10 years
Keelung	$I=(1054.3)/(t+18)^{0.63521}$	$I=(1304.7)/(t+22)^{0.64592}$
Taichung	$I=(1165.1)/(t+20)^{0.63096}$	$I=(1226.3)/(t+23)^{0.60598}$
Tainan	$I=(1199.7)/(t+17)^{0.62310}$	$I=(1720.3)/(t+25)^{0.65239}$
Taitung	$I=(603.7)/(t+5)^{0.53884}$	$I=(673.8)/(t+4)^{0.53630}$
Kaohsiung	$I=(992.1)/(t+22)^{0.58917}$	$I=(1985.0)/(t+50)^{0.65699}$
Taipei	$I=(1891.3)/(t+25)^{0.73365}$	$I=(2067.3)/(t+27)^{0.72115}$
Hsinchu	$I=(1431.5)/(t+32)^{0.66672}$	$I=(1806.7)/(t+37)^{0.67791}$
Hengchun	$I=(1065.5)/(t+20)^{0.60212}$	$I=(1376.8)/(t+26)^{0.61925}$
I-lan	$I=(815.8)/(t+18)^{0.56006}$	$I=(954.5)/(t+23)^{0.55218}$
Hualien	$I=(839.1)/(t+20)^{0.57040}$	$I=(926.5)/(t+21)^{0.56381}$

Table 1-3. Results of Horner equation at ten observation stations, Central Weather Bureau, R.O.C.

Station \ Frequency	20 years	25 years
Keelung	$I=(1653.8)/(t+28)^{0.66329}$	$I=(1776.0)/(t+30)^{0.66854}$
Taichung	$I=(1291.1)/(t+27)^{0.58511}$	$I=(1298.3)/(t+28)^{0.57733}$
Tainan	$I=(2566.2)/(t+35)^{0.69246}$	$I=(2969.4)/(t+39)^{0.70857}$
Taitung	$I=(742.1)/(t+3)^{0.53571}$	$I=(733.8)/(t+3)^{0.53781}$
Kaohsiung	$I=(6453.2)/(t+113)^{0.79529}$	$I=(11236.1)/(t+147)^{0.86342}$
Taipei	$I=(2116.7)/(t+28)^{0.70325}$	$I=(2104.1)/(t+28)^{0.69609}$
Hsinchu	$I=(2293.8)/(t+43)^{0.69514}$	$I=(2529.1)/(t+46)^{0.70444}$
Hengchun	$I=(1746.2)/(t+32)^{0.63850}$	$I=(1883.5)/(t+34)^{0.64529}$
I-lan	$I=(1077.2)/(t+28)^{0.54251}$	$I=(1121.6)/(t+30)^{0.54014}$
Hualien	$I=(1012.1)/(t+22)^{0.56012}$	$I=(1031.5)/(t+22)^{0.55820}$

Table 1-3. Results of Horner equation at ten observation stations, Central Weather Bureau, R.O.C

Station \ Frequency	50 years	100 years
Keelung	$I=(2229.3)/(t+37)^{0.68663}$	$I=(2931.7)/(t+47)^{0.71249}$
Taichung	$I=(1422.4)/(t+35)^{0.56563}$	$I=(1627.7)/(t+46)^{0.56169}$
Tainan	$I=(4688.2)/(t+52)^{0.76040}$	$I=(7873.2)/(t+68)^{0.82268}$
Taitung	$I=(842.0)/(t+2)^{0.53836}$	$I=(907.2)/(t+1)^{0.53880}$
Kaohsiung	$I=(163227.0)/(t+333)^{1.19602}$	$I=(2579820)/(t+540)^{1.52818}$
Taipei	$I=(2043.3)/(t+28)^{0.67373}$	$I=(2013.0)/(t+29)^{0.65525}$
Hsinchu	$I=(3156.7)/(t+52)^{0.72303}$	$I=(3993.9)/(t+59)^{0.74548}$
Hengchun	$I=(2404.7)/(t+41)^{0.66921}$	$I=(2977.3)/(t+47)^{0.69038}$
I-lan	$I=(1272.5)/(t+37)^{0.53406}$	$I=(1455.9)/(t+46)^{0.53051}$
Hualien	$I=(1089.0)/(t+22)^{0.55288}$	$I=(1172.1)/(t+23)^{0.55226}$

Table 1-4. Addresses of observation stations, Central Weather Bureau, R.O.C.

Station	Address	Elevation	Years of record
Keelung	Ju-chuan Li, Chungchen District, Keelung	3.00	86
Taipei	Yungwen Li, Chengchung District, Taipei	8.00	90
Hsinchu	133 Kungyuan Road, Hsinchu	33.00	49
Taichung	Chingwu Road, North District, Taichung	83.80	90
Tainan	Chaomei Li, Central District, Tainan	13.00	90
Kaohsiung	Haifeng Li, Kushan District, Kaohsiung	2.40	56
Hengchun	Tienwen Road, Hengchun	22.00	90
I-lan	Lihsing Street, I-lan	7.00	52
Hualien	Hwakang Street, Minchu Li, Hualien	18.00	86
Taitung	Tatung Road, Taitung	9.00	86

2. Concrete Design and Construction Specifications

2.1 General description

(1) Concrete is the main construction material for modern structures. Its quality and strength entirely depend on whether the construction is precisely implemented in compliance with the design drawings and specifications.

(2) The strength, durability and watertightness of concrete should meet design requirements. No effort should be spared to achieve concrete homogeneity.

(3) Concrete work, from mixing to pouring and finishing, should be overseen by supervisors.

(4) During construction, all matters related to the work such as work situation, curing method, weather, temperature, and construction tests, as well as the quantities and delivery dates of cement and other materials, should be recorded for future reference.

(5) For effective management, all tests and inspections should be strictly carried out.

(6) During construction, work involving concrete should be coordinated with work on forms, steel bars, pipe lines etc.

2.2 Materials

(1) Cement: Its quality should meet the requirements of the National Standards for Portland cement.

(2) Water: water used for concerete mixing should be clear and colorless. As to the content of harmful substances in water, such as oil, acid, salts, organic matters etc., except otherwise specified, water samples should be taken and tested and compared with water of good quality. If there is a significant difference in sedimentation time, or the strength of cement mortar produced is 10% below standard, such water should not be used for concrete mixing.

2.3 Fine aggregates

(1) The grade, fineness modulus, harmful substance content, bulk specific weight, and hardness of fine aggregate should meet the following specifications, unless otherwise specified in design. Fine aggregate which does not meet the specifications should not be delivered to the work site.

(2) The grades of fine aggregate should meet the requirements of the standards shown in Table 2-1.

Table 2-1. Standard grades of fine aggregate

Sieve No.	No.4	No.8	No.16	No.30	No.50	No.100	Bottom plate
Percentage of accumulated weight remaining	0-5	10-20	20-40	40-70	70-88	92-98	100

(3) The fineness modulus (F.M.) of fine aggregate shall be within 22-32.

(4) The harmful substance contents of fine aggregate should not exceed the limits listed in Table 2-2.

Table 2-2. Maximum permitted content of harmful substances in fine aggregate

Type of harmful substances		Maximum allowable limit (% of weight)
Mud clod		1.0
Coal and brown coal		1.0
Passing No.200 sieve	Easily defaced concrete	3.0
	Other concrete	5.0

(5) The organic matter content of fine aggregate is acceptable if its liquid color is lighter than the color test standard.

(6) The bulk specific weight of surface dryed fine aggregate should not be less than 2.55.

(7) The soundness of fine aggregate is acceptable, if its loss of weight is less than 10% when it is subjected five times to sodium sulfate liquid circulation test.

2.4 Coarse aggregate

(1) The grade, maximum particle size, harmful substance content, defaced percentage, bulk specific weight, and hardness shall fulfill the following specifications, except when otherwise prescribed.

Coarse aggregate which does not meet the specifications should not be sent to the work site.

(2) The grade of coarse aggregate should meet the requirements of the standards shown in Table 2-3.

Table 2-3. Standard grades of coarse aggregate

Standard mesh / Particle diameter	Percentage of weight passing through the sieve										
	3 1/2"	3"	2 1/2"	2"	1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8
3"-NO.4	100	96-100			45-75		20-40		5-15	0-5	
2"-NO.4			100	95-100		35-70		10-30		0-5	
1 1/2"-NO.4				100	95-100		35-70		10-30	0-5	
1"-NO.4					100	96-100		25-60		0-10	0-5
1/4"-NO.4						100	96-100		20-55	0-10	0-5
1/2"-NO.4							100	90-100	40-70	0-15	0-5
3"-1 1/2"	100	90-100	45-75		0-15		0-15				
2"-1"			100	90-100	35-70	0-15		0-5			
1 1/2"-3/4"				100	90-100	20-55	0-15	0-5			

(3) The maximum particle diameter of coarse aggregate should not be greater than $\frac{1}{5}$ of the narrowest space in forms, or $\frac{3}{4}$ of the smallest clearance of steel bars.

(4) The content of harmful substances in coarse aggregate should not exceed the limits listed in Table 2-4.

Table 2-4. Maximum permitted content of harmful substances in coarse aggregate

Harmful substance	Maximum allowable limit (% by weight)
Concrete lumps	0.25
Coal or brown coal	1.00
Particles passing through a No. 200 sieve	1.00
Soft fragments (including shale)	5.00
Slender particles (length is greater than 5 times the average thickness)	15.00

(5) The defacement rate after the Los Angeles test should not exceed 10% by weight at 100 r.p.m., and 40% at 500 r.p.m.

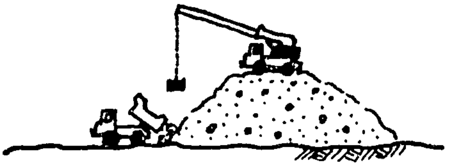
(6) The soundness of coarse aggregates is acceptable, if its loss weight is less than 12% when it is subjected five times to sodium sulfate liquid circulation tests.

2.5 Storage

(1) Cement must be stored with proper damp-preventing facilities. It should be placed on a platform elevated more than 30 cm above the ground in a warehouse which is properly installed and located with the approval of the supervisor. If the construction work is small in scale, cement may be stored in the open field with permission of the supervisor, but it should be covered with waterproof sheets. Cement should be stored and used in order of the time of its delivery. Each pile of cement should not exceed 13 bags, and proper paths should be provided between piles for transport and inspection. Cement stored more than three months or suspected of humidification should not be used, except with the permission of the supervisor. If cement is damaged during storage and conveyance due to negligence on the part of the contractor, compensation should be made by the contractor.

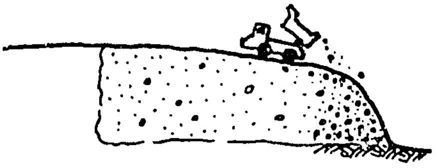
(2) The sites of stock pilies of aggregate should be designated by the supervisor. Fine and coarse aggregates should be piled separately. Coarse aggregate with a maximum particle diameter of more than three inches should be separated to two or more sizes for stock piling, according to the direction of the supervisor. Mixing of separately piled aggregate of different sizes should be avoided. During transport and storage of aggregate, attention shall be paid to avoid segregation of particles or inclusion of dirty water, dust or other debris. Improper storage of aggregate will cause segregation and breakdown.

a. After aggregate is unloaded from a truck, it is piled up by a crane as shown in the figure. Sliding of aggregate should be prevented.



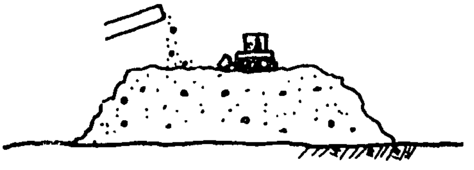
Preferable

b. The method shown below causes the aggregate to slide and segregate. It also induces breakdown of aggregate when trucks travell to and fro on top of the pile.



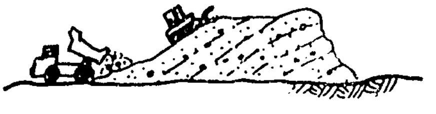
Objectionable

c. Aggregate is brought in by belt conveyers, and bulldozers are used to pile it up layer by layer. Piling ladders should also be used if possible.



Permissible but
not preferable

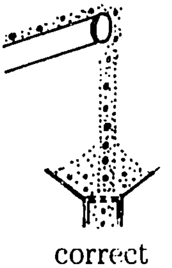
d. Bulldozers are used to pile up aggregate in inclined layers on slopes greater than 3:1. This method may causes less breakdown of aggregate, but is not preferable.



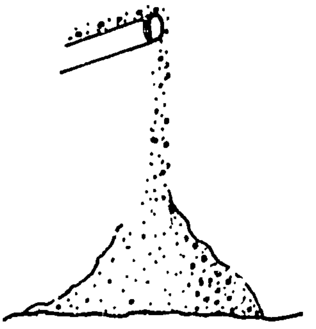
Permissible but
not preferable

(If aggregate is to be finally sieved at the batches plant, how it is piled up is not so important).

e. Aggregate falling from a belt conveyer should be protected by a chimney like cylinder, in order to prevent fine materials from being blown away be the wind. Such a device may be adjusted to a suitable height.

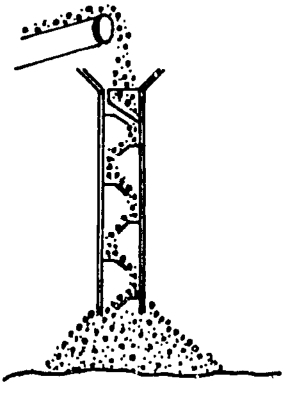


correct



incorrect

f. Ladders are used to pile up untreated or fine aggregates (dry) and large sized aggregates, in order to reduce breakage of the materials



finished
aggregate
storage

Figures of correct and incorrect methds of stocking aggregates (Concrete Manual, U.S.B.R.)

2.6 Cobbles

Hard cobbles without cracks are selected for making cobble concrete. In general, cobble size should be 15-45 cm in diameter. In cobble concrete, cobbles are placed at intervals according to the design (Refer to III. Engineering Construction and Maintenance, Part II)

2.7 Construction safety

It is the current concept that safety is of the first priority in engineering construction. Negligence in operating procedures when equipment is being used will not only endanger working personnel, waste materials and increase construction costs, but will also affect the morale of working personnel, thus causing delay or even failure of the work. Therefore, in any construction work, great attention should be paid to safety.

437

A. General safety rules

(1) Construction barracks should not be built in places subject to flood scouring, falling stones, possible land collapse, or under high voltage power lines.

(2) The construction road should be provided with signals in dangerous places and with necessary safety facilities.

(3) The construction area should be provided with suitable traffic and warning signs.

(4) Everyone who enters the construction area should be wearing a safety helmet and be safety conscious. In particular, people must be careful not to walk into or pass through areas threatened by falling stones or land collapse. Areas where machinely is in action should also be avoided.

(5) Those who ride a material conveyance vehicle should not stand but sit in the vehicle, so that they do not fall out if the vehicle is suddenly braked.

(6) Before construction , special attention should be paid to overhead wires, underground wires, gas pipes, water pipes etc. Hazard prevention measures should be taken if necessary.

(7) Temporary electric wires used in the construction area should be suspended overhead. They should not be laid across an inundated depression or wet ground in order to avoid any danger to human beings or animals, if there is leakage of electricity.

(8) When cranes or excavation machines move into the construction area, attention shall be paid to the height of the overhead wires.

(9) Electric switches installed in the open field should be provided with switch boxes.

(10) Tall batcher plants and asphalt or concrete mixers which may attract lightning must be provided with lightning rods.

(11) No one should be allowed to ride n heavy machinery except its operator, during operations.

(12) Since the noise of an operating machine is usually too loud for the operator to hear other people, anyone who approaches the machine should not stand before or behind the machine, or inside its operation radius.

(13) No-one should stand or pass under a load being hoisted by a crane.

(14) It is vital to drain out rainwater or groundwater which may cause earth collapse or falling stones.

(15) During the process of excavation, the cut bank should not be allowed to protrude over the working machine, for fear that it might collapse and bury the machine and operator.

(16) Forms or supports and other wooden materials with nails in them should not be placed in any path, to avoid hurting pedestrians.

(17) Structures such as trenches, tunnels, wells, manholes, openings etc., which cannot be covered for the time being should be provided with fences or barricades, and

safety warning signals should be installed. These should be red flags in the day time and red lamps in the night time.

(18) Personnel working up high should pay attention to the safety of workers below them.

(19) During construction at night, the work site should be provided with sufficient lighting, and dangerous places should have red warning lights.

(20) No one should follow closely behind a moving machine, to avoid injury if the machine suddenly stops or backs.

(21) If there are winds stronger than the fifth grade over the construction area, the high framing work should be temporarily stopped.

(22) Personnel working in high places on framing, rock drilling, removal of walls etc., should be provided with safety belts or nets according to need.

(23) Areas with falling rocks, machinery should be provided with a strong canopy over the operator's seat to protect him.

(24) During construction in a tunnel or pit where gas might be released, smoking must be prohibited, and motors and lights must be equipped with safety devices in order to avoid gas explosion.

(25) When concrete is being poured on the floor of a building or as bridge slabs, construction equipment and materials should not be concentrated at any one place on the forms, in order to avoid load collapse due to unbalanced loading or overloading.

(26) Even when work is urgent, machinery should be given regular checkups and maintenance, in order to keep the it in a safe and efficient condition.

(27) No-one but authorized personnel should touch the switches of electric devices or machines, in order to avoid accidents.

(28) Earth collapse should be prevented in areas where excavation is being carried out or explosives used, to avoid accidents.

(29) During work on scaffolding, necessary measures should be taken to prevent tools and materials from falling down and hurting people.

(30) Electric wires should not be hung through places where water is dripping, or on wet or iron supports in tunnels, in order to avoid electricity leakage.

(31) Usage and strorage of explosives must follow the "Regulations on Mining Explosives and Explosions" "Taiwan Provincial Government Regulations Governing Industrial Explosives" and "Taiwan Provincial Government Rules on the Control of Matters Dangerous to the Public"

B. Safety rules for reinforced concrete construction

(1) Personnel working with steel bars should use gloves.

(2) No-one is allowed to work directly over exposed steel bars.

(3) Sitting on the concrete bucket is prohibited.

(4) No-one should stand under a concrete bucket being hoisted by a crane or cable.

(5) When a mixer truck is working on sloping ground, it should be braked, and wooden wedges should be placed under the tires to prevent it from sliding.

(6) During hoisting or installing of steel bars or forms in a high place, all personnel below must be evacuated from the site.

(7) For safety, removal of forms shall be done under the supervision of experienced personnel.

(8) Removed forms shall be arranged and stacked in an orderly way without delay. If the removed forms are kept at a place near the working area or along a passage way, all exposed iron on the forms that might hurt people must be removed.

(9) When concrete finishing, repairing, curing and other works are performed on high places such as the top of a column or a wall, or on an inclined surface, scaffolding, safety belts or ropes must be used.

(10) When steel bars are conveyed by crane or cable, they must be firmly bound together to prevent them from falling down.

(11) Steel bars shall not be loosely placed on a work stand.

Table 2-5. Concrete Specifications of U.S. ACI Code 318-53 (for buildings)

Description		Allowable unit stresses						
		For any strength of concrete in accordance with section 302 n=30,000/f_c'	Maximum value, psi	For strength of concrete shown below				
				f_c' = 2000 psi n=15	f_c'= 2500 psi n=12	f_c'= 3000 psi n=10	f_c'= 3750 psi n=8	f_c'= 5000 psi n=6
Flexure: f_c								
Extreme fiber stress in compression ---	f_c	0.45 f_c'		900	1125	1350	1688	2250
Extreme fiber stress in tension in plain concrete footings ---------------	f_c	0.03 f_c'		60	75	90	113	150
Shear: v (as a measure of diagonal tension)								
Beams with no web reinforcement -----	v_c	0.03 f_c'	90	60	75	90	90	90
Beams with longitudinal bars and with either stirrups or properly located bent bars --------------------------------	v	0.08 f_c'	240	160	200	240	240	240
Beams with longitudinal bars and a combination of stirrups and bent bars (the latter bent up suitably to carry at least 0.04 f_c' ----------------	v	0.12 f_c'	360	240	300	360	360	360
Footings * ------------------------------------	v_c	0.03 f_c'	75	60	75	75	75	75
(For flat slabs, see Chapter 10)								
Bond: u								
Deformed bars (as defined in Section 104)								
Top bars † ------------------ -	u	0.07 f_c'	245	140	175	210	245	245
In two-way footings (except top bars)	u	0.08 f_c'	280	160	200	240	280	280
All others --------------------------------	u	0.10 f_c'	350	200	250	300	350	350
Plain bars (as defined in Section 104) (must be hooked)								
Top bars --------------------------------	u	0.03 f_c'	105	60	75	90	105	105
In two-way footings (except top bars)	u	0.036 f_c'	126	72	90	108	126	126
All others --------------------------------	u	0.045 f_c'	158	90	113	135	158	158
Bearing: f_c								
On full area ---------------------------------	f_c	0.25 f_c'		500	625	750	938	1250
On one-third area or less ‡ ---------	f_c	0.375 f_c'		750	938	1125	1405	1875

* See Sections 905 and 809.

† Top bars, in reference to bond, are horizontal bars so placed that more than 12 in of concrete is cast in the member below the bar.

‡ This increase shall be permitted only when the least distance between the edges of the loaded and unloaded areas is a minimum of one-fourth of the parallel side dimension of the loaded area. The allowable bearing stress on a reasonably concentric area greater than one third but less than the full area shall be interpolated between the values given.

Table 2-6. Concrete Specifications of U.S.ACI Code 318-63 (for buildings)

Description		Allowable stresses					
		For any strength of concrete	For strength of concrete shown below				
			f_c'= 2500 psi	f_c'= 3000 psi	f_c'= 3750 psi	f_c'= 4000 psi	f_c'= 5000 psi
Modulus of elasticity ratio:n							
For concrete weighing 145 lb per cu ft ..	n	$\frac{29,000,000}{W^{1.5}33\sqrt{f_c'}}$	10	9	8.25	8	7
Flexure: f_c							
Extreme fiber stress in compression..........	f_c	$0.45\ f_c'$	1125	1350	1688	1800	2250
Extreme fiber stress in tension in plain concrete footings and walls	f_c	$1.6\sqrt{f_c'}$	80	88	98	102	113
Shear: ν (as a measure of diagonal tension at a distance d from the face of the support)							
Beams with no web reinforcement*	ν_c	$1.1\sqrt{f_c'}$	55*	60*	67*	70*	78*
Joists with no web reinforcement...........	ν_c	$1.2\sqrt{f_c'}$	61	66	73	77	86
Members with vertical or inclined web reinforcement of properly combined bent bars and vertical stirrups	ν	$5\sqrt{f_c'}$	250	274	306	316	354
Slabs and footings (peripheral shear, Section 1207, ACI 318-63)*	ν_c	$2\sqrt{f_c'}$	100*	110*	122*	126*	141*
Bearing: f_c							
On full area		$0.25\ f_c'$	625	750	937	1000	1250
On one-third area or less †		$0.375\ f_c'$	938	1125	1406	1500	1875

*For shear values of lightweight aggregate concrete see Section 1208, ACI 318-63.

† This increase shall be permitted only when the least distance between the edges of the loaded and unloaded areas is a minimum of one-fourth of the parallel side dimension of the loaded area. The allowable bearing stress on reasonably concentric area greater than one-third but less than the full area shall be interpolated between the values given.

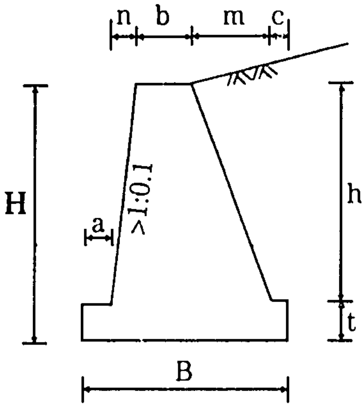
3. Design of Retaining Walls

3.1 Design of gravity-type retaining wall

(1) Design procedures

a. To assume the cross section:

The cross section and its dimensions are assumed from the data given below, with some actual examples.



$$a = \frac{1}{2}t \sim t$$

$$b = \frac{1}{12}H \text{(at least 30cm)}$$

$$t = \frac{1}{6} \sim \frac{1}{8}H$$

$$B = \frac{1}{2} \sim \frac{2}{3}H$$

b. To compute the wall weight, position of the center of gravity, moment and its arm. In general, the unit weight of materials is as follows:

Back filled earth: 1.8 t/m^3

Foundation earth: 1.9 t/m^3

Concrete: 2.3-2.4 t/m^3, (2.35 t/m^3 is commonly used.).

c. To compute the earth pressure, size of additional loads, moment and its arm.

d. To check whether the resultant fits the safety conditions of the wall or not. If the result of checking shows that the wall is unsafe or uneconomical, the cross section and its dimensions should be revised to meet requirements.

(2) Design example

A gravity-type retaining wall with a height of 6 meters is to be designed.

a. The ground surface slope on the back of the wall is 15° upward. The known data are as follows:

Back filling earth weight=1.8 t/m^3, friction angle=30°

Foundation earth weight=1.9 t/m^3, friction angle=35°

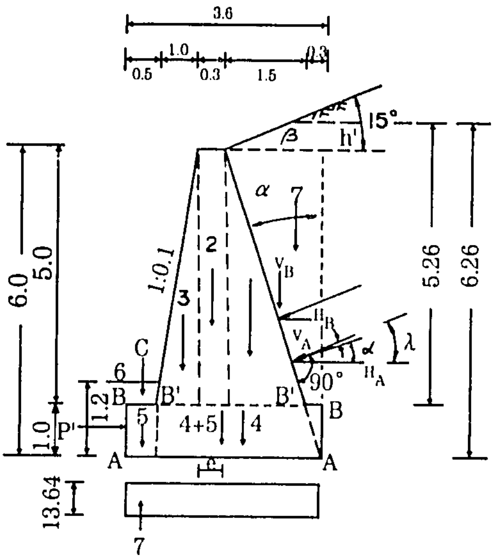
Foundation allowable bearing capacity=25 t/m^2

Concrete strength, $f'c = 140\ kg/cm^2$

Concrete unit weight $= 2.35\ t/m^3$

Friction angle between the foundation soil and concrete $= 35°$

From the figure, $\tan\alpha = \dfrac{1.8}{6.0} = 0.3$



$\therefore \alpha = 16.7°$

$\lambda = \alpha + \delta$

$\beta = 15°$

Assume the friction angle between concrete and soil is:

$\delta = \dfrac{2}{3}\phi = 20°$

$\therefore \lambda = 20° + 16.7° = 36.7°$

$\sin\lambda = 0.598$

$\cos\lambda = 0.802$

$h' = \sin 15° = 0.26$

b. The weight of the wall, earth pressure and other forces are computed as listed in the following table:

Table of computed forces acting on gravity type retaining wall

Item	1	2	3	4	5	6	7	8
	Cross section	Load	Computation	Unit weight t/m^2	Force t	Arm m	Moment t-m	Mechanics computation
1	A-A	1	1/2×1.5×5.0=3.75	2.35	8.81	1.3	11.46	
2	B-B	2	0.3×5.0=1.5	2.35	3.525	1.95	6.87	$Z_A = \frac{\sum M_A}{\sum V_A} = \frac{88.45}{49.09} = 1.80$
3		3	1/2×1.0×5.0=2.50	2.35	5.875	2.43	14.28	
4		Σ	7.75m²		18.21		32.61	$e_A = 1.8 - 1.80 = 0.0 \le \frac{3.6}{6} = 0.6$ O.K.
5	A-A	4+5	1.0×3.6=3.6	2.35	8.46	1.80	15.23	δ_1 and $\delta_2 = \frac{\sum V_A}{AA} \cdot (1 \pm \frac{6e_A}{AA}) = \frac{49.09}{3.6}(1 \pm \frac{6 \times 0}{3.6})$
6		6	0.2×0.5=0.10	1.8	0.18	3.35	0.60	
7		7	6.26×1.8/2=5.63	1.8	10.14	0.6	6.08	δ_1 & δ_2 13.64 & 13.64
8		V_A	18.60×0.598		12.10	0	0	$Z_B = \frac{\sum M_B}{\sum V_B} = \frac{60.01}{33.87} = 1.77$
9		H_A	18.60×0.802		← 16.24	2.09	33.94	
10	V_A	Σ	Items 4&5 A=11.35m²	$\sum V_A$	49.09	$\sum M_A$	88.45	$e_B = 1.77 - 0.3 - \frac{2.8}{2} = 0.07 < \frac{2.8}{4} = 0.7$ OK
11	B-B	V_B	14.29×0.598		8.55	0.3	2.57	δ_1 and $\delta_2 = \frac{\sum V_B}{BB'} \cdot (1 \pm \frac{6e_B}{BB'}) = \frac{33.87}{2.8}(1 \pm \frac{6 \times 0.07}{3.6})$
12		H_B	14.29×0.802		← 11.46	1.67	19.14	
		7	5.26×1.5/2=3.95	1.8	7.11	0.8	5.69	= 13.91 & 10.28 O.K.
13		Σ		$\sum V_B$	33.87	$\sum M_B$	60.01	$f = \frac{6 \times 1.37}{1 \times 1.0^2} = 8.22 t/m^2$
	H_B							
14	C-C	6	0.2×0.5=0.1	1.8	0.18	0.25	0.05	$= 0.82 kg/cm^2 < 0.03 fc' \fallingdotseq 4.2$ O.K.
15		5	1.0×0.5=0.5	2.35	1.18	0.25	0.29	Remark : $f = \frac{My}{I} = \frac{M \times \frac{d}{2}}{\frac{bd^3}{12}} = \frac{6M}{bd^2}$
16		7	0.5×13.64		6.82	0.25	-1.71	
17		Σ			-5.46		-1.37	

Coulomb's earth pressure coefficient:

$$C_a = \frac{\cos^2(30^\circ - 16.7^\circ)}{\cos^2 16.7^\circ \times \cos(20^\circ + 16.7^\circ)\left[1 + \sqrt{\dfrac{\sin(30^\circ + 20^\circ)\sin(30^\circ - 15^\circ)}{\cos(20^\circ + 16.7^\circ)\cos(15^\circ - 16.7^\circ)}}\right]^2}$$

$$= \frac{\cos^2 13.3^\circ}{\cos^2 16.7^\circ \times \cos 36.7^\circ\left[1 + \sqrt{\dfrac{\sin 50^\circ \times \sin 15^\circ}{\cos(36.7^\circ)\cos(-1.7^\circ)}}\right]^2}$$

$$= \frac{0.9471}{0.9174 \times 0.8018 \times \left[1 + \sqrt{\dfrac{0.7660 \times 0.2588}{0.8018 \times 1}}\right]^2}$$

$$= \frac{0.9471}{0.9174 \times 0.8018 \times 2.242} = 0.574$$

$P_A = \frac{1}{2} C_a \gamma_s H_A^2$

$= \frac{1}{2} \times 0.574 \times 1.8 \times 6.26^2 = 20.24$ t/m

$V_A = 20.24 \times 0.598 = 12.10$ t/m

$H_A = 20.24 \times 0.802 = 16.23$ t/m

$P_B = \frac{1}{2} C_a \gamma_s H_B^2$

$= \frac{1}{2} \times 0.574 \times 1.8 \times 5.26^2 = 14.29$ t/m

$V_B = 14.29 \times 0.598 = 8.55$ t/m

$H_B = 14.29 \times 0.802 = 11.46$ t/m

c. Check

(i) A-A section

(a) Sliding safety factor

$$F_s = \frac{\sum V_A \tan\phi + P'}{\sum H_A}$$

$$\therefore P' = \frac{1}{2}\gamma_s h^2 \frac{1+\sin\phi}{1-\sin\phi} = \frac{1}{2} \times 1.9 \times 1.2^2 \times \frac{1+\sin 35^\circ}{1-\sin 35^\circ}$$

$$= \frac{1}{2} \times 1.9 \times 1.44 \times \frac{1+0.5736}{1-0.5736} = 5.05 \text{ t/m}$$

$$\therefore F_s = \frac{49.09 \times \tan 35^\circ + 5.05}{16.24} = 2.43 > 1.5 \quad \text{O.K.}$$

$$\text{Neglecting } P', \text{then } F_s = \frac{49.09 \times \tan 35^\circ}{16.24} = 2.12 > 1.5 \quad \text{O.K.}$$

(b) Overturning safety factor and foundation pressure

$$Z_A = \frac{\Delta M_A}{\Delta V_A} = \frac{88.45}{49.09} = 1.8$$

Eccentric distance :

$$e_A = 1.8 - \frac{3.6}{2} = 0 < \frac{3.6}{6} = 0.6 \ \text{O.K}$$

Foundation pressure :

$$\delta_1 \text{ and } \delta_2 = \frac{\sum V_A}{AA}\left(1 \pm \frac{6e_A}{AA}\right) = \frac{49.09}{3.6}\left(1 \pm \frac{6 \times 0}{3.6}\right)$$

$$\delta_1 \ \& \ \delta_2 = 13.64 \ \& \ 13.64 < 25 \ t/m^2$$

(ii) B-B section

$$Z_B = \frac{\sum M_B}{\sum V_B} = \frac{60.01}{33.87} = 1.77$$

Eccentric distance :

$$e_B = 1.77 - 0.3 - \frac{2.8}{2} = 0.07 < \frac{2.8}{4} = 0.7 \ \text{O.K.}$$

(iii) C-C section

$$\text{Maximum stress} : f = \frac{6M_c}{1 \times h^2} = \frac{6 \times 1.37}{1 \times 1.0^2} = 8.22 \ t/m^2$$

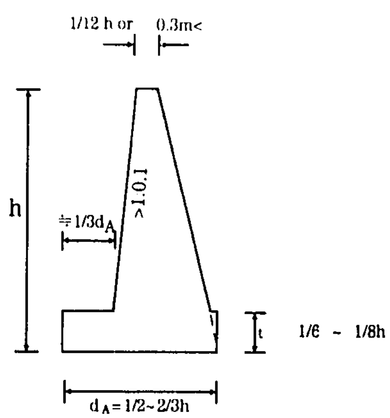
$$= 0.82 \ kg/cm^2 < 4.2 \ kg/cm^2 \ \text{O.K.}$$

ACI Code: $0.03fc' = 0.03 \times 140 = 4.2 \ kg/cm^2$

3.2 Design of semi-gravity type retaining wall

(1) Design procedures

a. To assume the cross section: In principle, the volume of a semi-gravity type retaining wall is smaller than that of a gravity type one. In some parts of the former, tensile stresses may occur. This stress shall be taken by steel bars, if it exceeds the allowable limit. A cross section is shown below for reference.



393

b. To compute the wall weight, position of the center of gravity, moment and its arm: Same as the gravity type.

c. To compute the earth pressure, foreign forces, moments and arms: Same as the gravity type.

d. To check the resultant on the foundation to see whether it meets the safety conditions of the wall: Same as the gravity type.

e. To compute the size of steel bars which take tensile stresses.

(2) Design example

To design a semi-gravity type retaining wall 8 meters high. The ground surface slope on the back of the wall is 15° upward. The known conditions are:

Back filling earth unit weight=18 t/m^3, ϕ =30°

Foundation earth unit weight=1.9 t/m^3, ϕ =35°

Concrete unit weight= 2.35 t/m^3, fc'=140 kg/cm^2

Steel bar allowable stress, f_S=1400 kg/cm^2

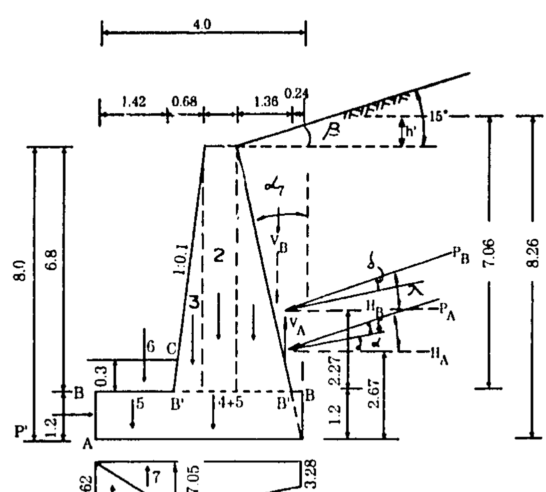
Friction angle between foundation soil and concrete=35°

[solution]

a. Assume the cross section as follows:

cos λ =0.8545

h' =sin 15°=0.26



In the figure $\tan\alpha = 1.6/8.0 = 0.2$

$\alpha = 11.3°$

$\therefore \lambda = \alpha + \delta$

$\beta = 15°$

Assume the friction angle between concrete and soil is:

$\delta = 2/3\,\phi = 20°$

$\therefore \lambda = 11.3° + 20° = 31.3°$

$\sin\lambda = 0.5195$

$\cos\lambda = 0.8545$

$h' = \sin 15° = 0.26$

b. The retaining wall weight, earth pressure and other foreign forces are computed as listed in the following table:

Coulomb's earth pressure coefficient:

$$C_a = \frac{\cos^2(30^\circ - 11.3^\circ)}{\cos 11.3^\circ \cos(20^\circ + 11.3^\circ) \times \left[1 + \sqrt{\dfrac{\sin(30^\circ + 20^\circ)\sin(30^\circ - 15^\circ)}{\cos(20^\circ + 11.3^\circ)\cos(15^\circ - 11.3^\circ)}}\right]^2}$$

$$= \frac{\cos^2 18.7^\circ}{\cos^2 11.3^\circ \times \cos 31.3^\circ \left[1 + \sqrt{\dfrac{\sin 50^\circ \times \sin 15^\circ}{\cos 31.3^\circ \times \cos 3.7^\circ}}\right]^2}$$

$$= \frac{0.8972}{0.9806 \times 0.8545 \times \left[1 + \sqrt{\dfrac{0.7660 \times 0.2588}{0.8545 \times 0.998}}\right]^2}$$

$$= \frac{0.8972}{0.9806 \times 0.8545 \times 2.1972} = 0.487$$

$P_A = \frac{1}{2} C_a \gamma_s H_A^2$

$= \frac{1}{2} \times 0.487 \times 1.8 \times 8.26^2 = 29.90$ t/m

$V_A = 29.90 \times 0.5195 = 15.53$ t/m

$H_A = 29.90 \times 0.8545 = 25.55$ t/m

$P_B = \frac{1}{2} C_a \gamma_s H_B^2$

$= \frac{1}{2} \times 0.487 \times 1.8 \times 7.06^2 = 21.85$ t/m

$V_B = 21.85 \times 0.5195 = 11.35$ t/m

$H_B = 21.85 \times 0.8545 = 18.67$ t/m

c. Check

(i) A-A cross section

(a) Sliding safety factor

$$F_s = \frac{\sum V_A \tan\phi + P'}{\sum H_A}$$

$$\therefore P' = \frac{1}{2} W_2 h^2 \frac{1 + \sin\phi}{1 - \sin\phi} = \frac{1}{2} \times 1.9 \times 1.5^2 \times \frac{1 + \sin 35^\circ}{1 - \sin 35^\circ}$$

$$= \frac{1}{2} \times 1.9 \times 2.25 \times \frac{1 + 0.5736}{1 - 0.5736} = 7.89 \text{ t/m}$$

$$\therefore F_s = \frac{52.03 \times \tan 35^\circ + 7.89}{23.97} = 1.85 > 1.5 \quad \text{O.K}$$

If P' is neglected,

$$F_s = \frac{52.03 \times \tan 35^\circ}{23.97} = 1.52 > 1.5 \quad \text{O.K}$$

(b) Overturning safety factor and foundation pressure

$$Z_A = \frac{\sum M_A}{\sum V_A} = \frac{139.14}{60.91} = 2.28$$

Eccentric distance:

$$e_A = 2.28 - 2.0 = 0.28 < \frac{4.0}{6} = 0.67 \quad \text{O.K.}$$

Foundation pressure:

$$\delta_1 \ \& \ \delta_2 = \frac{60.91}{4.0}(1 \pm \frac{6 \times 0.28}{4.0})$$

$$= 21.62 \ \& \ 8.83 \ t/m^2 < 25 \ t/m^2 \quad \text{O.K.}$$

(ii) B-B cross section

$$Z_B = \frac{\sum M_B}{\sum V_B} = \frac{84.99}{41.07} = 2.07$$

$\therefore$ Eccentric distance $e_B = 2.07 - 1.17 = 0.9 > \frac{d_B}{4} = 0.685$ O.K.

To be reinforced, since the resultant passes beyond the 1/4 point. The required cross sectional area of steel bar is:

$$A_s = \frac{M_{HB}}{f_s jd} = \frac{43.87}{1.4 \times 0.87 \times 2.24} = 16.08 \ cm^2$$

$\because d = 2.34 - 0.1$ (Clearance) $= 2.24$

Use #8 steel bar @30cm $A_s = 17.00 \ cm^2$

(iii) C-C cross section

Concrete bending tensile stress:

$$f = \frac{6M}{1 \times h^2} = \frac{6 \times 16.88}{1 \times 1.2^2} = 70.32 \ t/m^2 = 7.03 \ kg/cm^2$$

$0.03 \ fc' = 4.2 kg/cm^2$

(ACI Code : $f < 0.03 f'c$)

Therefore, reinforcing steel bars are needed.

The required cross-sectional area of steel bar is:

$$A_s = \frac{M}{f_s jd} = \frac{16.88}{1.4 \times 0.87 \times 1.1} = 12.60 \ cm^2$$

$$\sum O = \frac{V}{ujd} = \frac{22.69}{140.0 \times 0.87 \times 1.1} = 0.169 \ m = 16.9 \ cm$$

$(u = 0.1 \ fc' = 14.0 \ kg/cm^2 = 140 \ t/m^2)$

$\because$ Use #8 steel bar @30cm $A_s = 17.0 cm^2$

$\sum O = 16.9 cm > 23.33 cm$ O.K.

Table of computed forces acting on semi-gravity type retaining wall

Item	1 Cross section	2 Load	3 Computation	4 Unit weight t/m^3	5 Force t	6 Arm m	7 Moment t-m	8 Mechanics computation
1	A-A	1	1/2×6.8×1.36=4.62	2.35	10.86	1.15	12.49	
2		2	0.3×6.8=2.04	2.35	4.79	1.75	8.38	
3	B-B	3	1/2×6.8×0.68=2.312	2.35	5.43	2.13	11.57	
4		Σ	$10.332m^2$		21.08		32.44	
5		7	1/2×7.06×1.36=4.8	1.8	8.64	0.69	5.96	Z_B=84.99/41.07=2.07
6	B-B	V_B	21.85×0.5195		11.35	0.24	2.72	e_B=2.07-1.17=0.9>d_B/4=0.685
7		H_B	21.85×0.8545		← 18.67	2.35	43.87	To be reinforced, if the resultant passes
8		Σ		ΣV_B	41.07	ΣM_B	84.99	beyond the 1/4 point.
9	A-A	4+5	1.2×4.4=5.28	2.35	12.41	2.20	27.30	Z_A=139.14/60.91=2.28
10		6	1.42×0.3=0.43	1.8	0.77	3.69	2.84	$e_A = 2.28 - 2.0 = 0.28 > \frac{4.0}{6} = 0.67$ O.K
		7	1/2×8.26×1.6=6.61	1.8	11.89	0.53	6.30	δ_1 and $\delta_2 = \frac{60.91}{4.0}(1 \pm \frac{6 \times 0.28}{4.0})$
11		V_A	29.90×0.5195		15.53	0.00	0.00	
12		H_B	29.90×0.8545		← 25.55	2.75	70.26	$= 21.62 \& 8.83\ t/m^2 < 25\ t/m^2$ O.K.
13		Σ		ΣV_A	60.91	ΣM_A	139.14	$f = \frac{6M_o}{1 \times h^2} = \frac{6 \times 16.88}{1 \times 1.2^2}$
14	C-C	5	1.42×1.2	2.35	4.00	0.71	2.84	
15		6	1/2×1.2=0.43	1.8	0.77	0.71	0.55	$= 70.33\ t/m^2$
16		7	1/2×17.05×1.42		-12.11	0.47	-5.69	$= 7.03\ kg/cm^2 > 0.03fc' = 4.2 kg/cm^2$
17		8	1/2×21.62×1.42		-15.35	0.95	-14.53	To be reinforced
18		Σ		ΣV_c	-22.69	ΣM_c	-16.88	

397

4. Design of Check Dams

4.1 Basic data

(1) Unit weight of water=1.0 t/m^3, mud water=1.1 t/m^3

(2) Unit weight of concrete=2.3 t/m^3

(3) Unit weight of sand (porosity=35%) =2.6×(1-0.35)=1.69 t/m^3

(4) Unit weight of gravel in water(porosity=35%)=1.69-(1-0.35)×1 =1.04 t/m^3

(5) Unit weight of saturated gravel=1.69+0.35×1=2.04 t/m^3

(6) Unit weight of cobble concrete (5:7)=0.3×2.6+0.7×2.3=2.39 t/m^3

(7) Dam base friction coefficient (between concrete and deposit layer) =0.55, floating coefficient=0.5

(8) Internal friction angle of deposits (sands and gravels), θ =30°

(9) Horizontal earthquake acceleration=0.12 g.

4.2 Hydraulic computation

(1) From the topographical map of 1/25,000, watershed area,

A=110.62 ha

flow length, L=1500 m

elevation difference, H=605-185=420 m

(2) Slope length = 150 m,surface flow velocity, V=0.5 m/s

$$t_1 = \frac{150}{0.5} = 300 \text{ sec} = 5 \text{ min}$$

$$t_2 = \frac{L}{72(\frac{H}{L})^{0.6}} = \frac{1.5}{72(\frac{0.42}{1.5})^{0.6}} = 0.045 \text{ hr}$$

$$= 2.68 \text{ min.}$$

The time of concentration, $t=t_1+t_2=5+2.68=7.68$ min.

(3) Adopting a frequency of once in 50 years, the rainfall intensity in Hualien is

$$I = \frac{1123}{(t+20)^{0.5591}} = \frac{1123}{(7.68+20)^{0.5591}}$$

$$= 175.47 \text{ mm/hr}$$

(4) Use the rational formula to compute the flood discharge, Q

Q=C · I · A where C=runoff coefficient=0.85

Q=1/360×0.85×175.47×110.62=45.83 cms

(5) Overflow section

A trapezoidal section with a side slope of 1:0.5 is used.

Form the broad crest weir formula,

$$Q' = \frac{2}{15} Ch\sqrt{2gh}(3B_o + 2B_u)$$

Where C=discharge coefficient=0.6

h=overflow water depth (m)

B_u=top width of the section (m)

B_o=bottom width of the section (m)

Therefore, when the side slope is 1:0.5

$Q'=(1.77\ B_o+0.71h)h^{2/3}$

Let B_o= 20m, h=1.2 m

$\therefore Q'=1.77\times20+0.71\times1.2)\times1.2^{2/3}=47.65$ cms>45.83 cms

Subsitute Q=45.83 cms into the above formula,

we get h=1.16 m

Finally B_o=20 m

d=h+freeboard=1.5 m

(6) Critical depth, d_c

The critical depth of a trapezoidal section is computed by using the following equation:

$$\frac{Q^2}{g} = \frac{(B_u + B_o)^3}{8B_u} \cdot d_c^3$$

where Q=Project flood discharge=45.83 cms

g=gravity acceleration=9.8 m/sec^2

B_u=width of water surface at the section

=B_o+d_c, when side slope=1:0.5

B_o=bottom width of the section=20 m

Subsitute the known data into the above equation,

$$\frac{(45.83)^3}{9.8} = \frac{[(20 + d_c) + 20]^3}{8(20 + d_c)} \cdot d_c^3$$

By the trial method, we get

d_c=0.81 m

From W. Rand's empirical equation,

$d_o=0.715\ d_c=0.715\times0.81=0.58$ m

(7) From the end sill empirical equation,

$h'=\frac{1}{6}(H+h)$

399

where h'=height of end sill (m)

H=effective height of dam=7.4 m

h=overflow water depth of dam=1.16 m

$\therefore h'=\frac{1}{6}(7.4+1.16)=1.42$ m, use 1.4 m

(8) Length of stilling basin

use Yano's equation (Japan)

$$L=k(H+h)-nH$$

where k=coefficient, 1.5-2.0, 1.5 in general

h=overflow water depth=1.16 m

H=effective height of dam=7.4 m

n=downstream face slope of dam=0.3

$\therefore L=1.5(7.4+1.16)-0.3\times7.4=10.62$ m, use 10.6 m

(9) Water jump depth (before and after)

From W. Rand's empirical formula

$$\frac{d_1}{H}=0.54\left(\frac{d_c}{H}\right)^{1.275}$$

where H=effective height of dam=7.4 m

d_1=water depth before jump

$$\therefore \frac{d_1}{7.4}=0.54\left(\frac{0.81}{7.4}\right)^{1.275}$$

$$\therefore d_1=0.24\text{m}$$

and $\frac{d_2}{d_1}=\frac{3.07}{\left(\frac{d_c}{H}\right)^{0.465}}$ $\qquad$ d_2 = water jump (m)

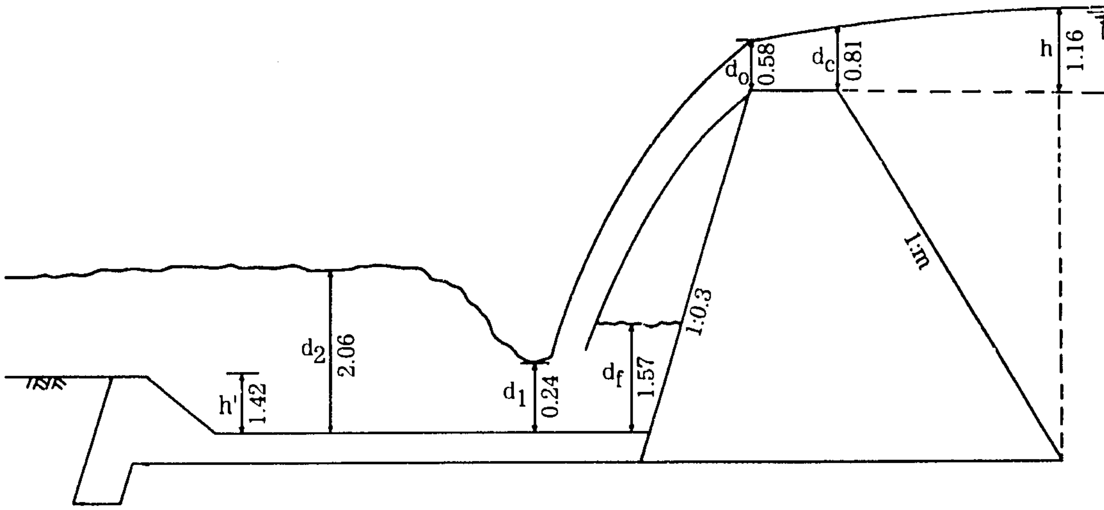
$$\therefore d_2=\frac{3.07\times0.24}{\left(\frac{0.81}{7.4}\right)^{0.465}}=2.06\text{ m}$$

(10) Back water depth, d_f

From Meore formula,

$$d_f=d_c\left[\left(\frac{d_1}{d_2}\right)^2+2\left(\frac{d_c}{d_1}\right)-3\right]^{\frac{1}{2}}$$

$$=0.81\left[\left(\frac{0.24}{2.06}\right)^2+2\left(\frac{0.81}{0.24}\right)-3\right]^{\frac{1}{2}}=1.57\text{ m}$$



4.3 Stability of dam

The design of a check dam shall meet stability requirements in the four stituations listed below.

(1) Stability requirements

a. Overturning safety checking: The resultant of all forces acting on the dam base should be within the middle third, i.e. there should be no tensile stress on the base.

b. Sliding safety factor: 1.1-1.2.

c. Vertical stress on the dam base: $\leqq 45$ t/m^2 (the allowable bearing capacity of gravely earth).

d. Internal stress: Not to exceed the allowable compressive stress, and to fit requirement (1).

(2) Four situations in which stability must be maintained

a. When the maximum water discharge occurs before any deposition.

b. When the maximum discharge occurs after sediments are fully desposited.

c. When normal discharge occurs together with an earthquake occurs before sediments are deposited.

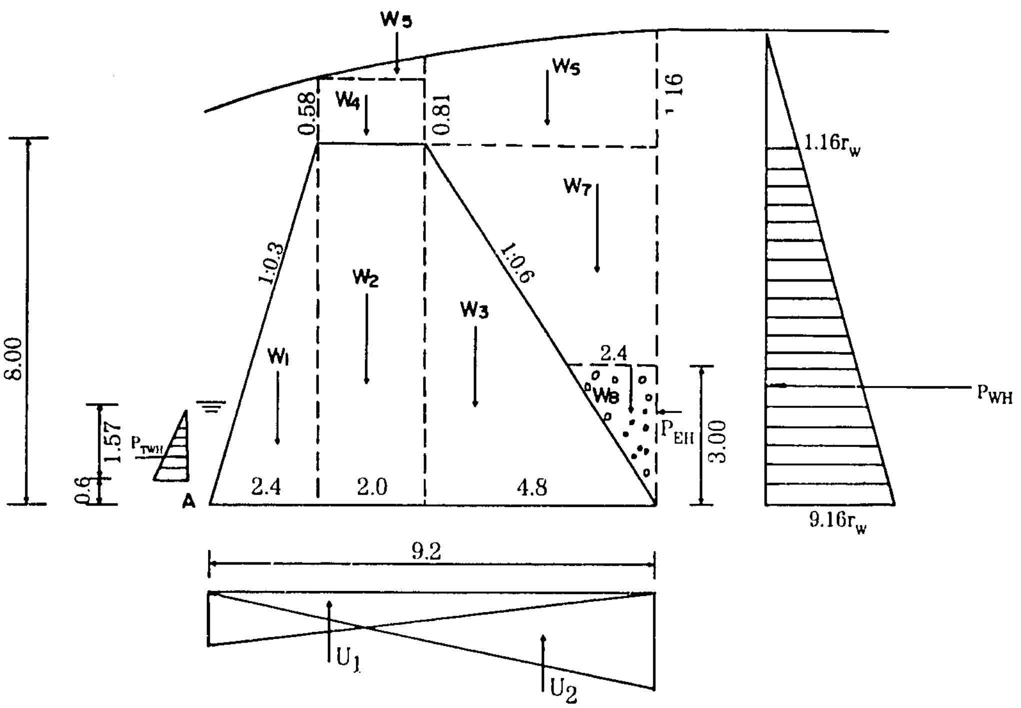
d. When a normal discharge together with earthquake occur after sediments are fully deposited.

4.4 Check for dam stability

(1) When the maximum discharge occurs before deposition

$$P_{EH} = \frac{1}{2} C_S \gamma_S H^2$$

$$C_S = \frac{1+\sin\theta}{1-\sin\theta} \quad (\theta = 20°, \text{Usually more than } 30°)$$



Acting force					Moment at A	
Force	Computation	Vertical force	Horizontal force	Arm	+	-
W_1	1/2×8×2.4×2.39	22.94		1.60	36.70	
W_2	2.0×8×2.39	38.24		3.40	130.02	
W_3	1/2×4.8×8×2.39	45.89		6.00	275.33	
W_4	0.58×2.0×1.1	1.28		3.40	4.34	
W_5	1/2×2.0×0.23×1.1	0.25		3.74	0.95	
W_6	1/2(0.81+1.16)×4.8×1.1	5.20		6.80	35.37	
W_7	4.8×8×1.1×1/2	21.12		7.60	160.51	
W_8	1/2×3×2.4×1.04	3.74		8.40	31.42	
P_{TWH}	1/2×1.57²×1.1		→ 1.36	1.12	1.52	
P_{WH}	(1.16+9.16)×8/2×1.1		← 45.41	2.67		120.79
P_{EH}	1/2×0.49×1.04×3²		← 2.29	2.00		4.58
U_1	1/2×9.2×2.17×0.5×1	4.99 ↑		3.07		15.32
U_2	1/2×9.2×9.16×0.5×1	21.07 ↑		6.14		129.36
Σ		112.60	46.34		676.16	270.05

402

a. Check for overturning

Let the distance from the acting point of the resultant to point A be X then 112.6X=676.16-270.05

X=3.61 m $\because$ 2/3×9.2>3.61>1/3×9.2 O.K.

The overturning safety factor, $n=\frac{676.16}{270.05}=2.50$

b. Check for sliding

Friction resistance on the base, F

F=112.6×0.55=61.93

then sliding safety factor, $F_s=\frac{61.93}{46.34}=1.34>1.1$ O.K.

c. Check for vertical stress on the base of the dam

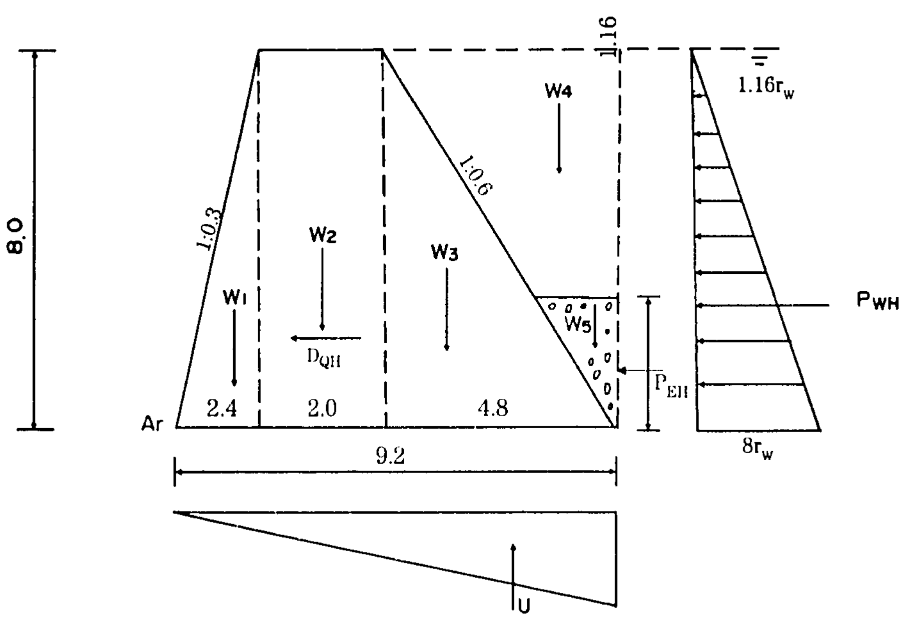
Eccentric distance, $e=\frac{9.2}{2}-3.61=0.99$. Let the vertical stress at the toe of the dam be δ_2, and that at the heel be δ_1, then

$$\delta_1 \text{ and } \delta_1 = \frac{\sum V}{B}(1 \pm \frac{6e}{B})$$

$$= \frac{112.6}{9.2}(1 \pm \frac{6 \times 0.99}{9.2})$$

$$= 20.14 \text{ and } 4.33\ t/m^2 < 45\ t/m^2 \text{ O.K.}$$

(2) When a normal discharge together with an earthquake occurs before depositing.



a. Horizonal inertia force of the dam due to earthquake

$D_{QH}=\alpha \sum W=0.12(W_1+W_2+W_3)$

=0.12(22.94+38.24+45.89)=12.85

b. Additional water pressure due to earthquake

Check dams are usually provided with drainage holes, so that there will be no water on the upstream side of the dam during normal flow. Therefore, additional water pressure due to earthquake may be neglected.

Acting force					Moment at A	
Force	Computation	Vertical force	Horizontal force	Arm	+	-
W_1	1/2×8×2.4×2.39	22.94		1.60	36.70	
W_2	2.0×8×2.39	38.24		3.40	130.02	
W_3	1/2×4.8×8×2.39	45.89		6.00	275.33	
W_4	1/2×4.8×8×1.0	19.20		7.60	145.92	
W_5	1/2×3×2.4×1.04	3.74		8.40	31.42	
P_{WH}	8×8×1/2×1.0		← 32.0	2.67		85.44
P_{EH}	1/2×0.49×1.04×3²		← 2.29	2.00		4.58
U_1	1/2×9.2×8×0.5×1	18.4 ↑		6.14		112.98
D_{QH}			← 12.85	2.83		36.37
Σ		111.61	47.14		619.39	239.37

c. Check for overturning

Let the distance from the acting point of the resultant to point A be X

then 111.61 X=619.39-239.37

X=3.40m ∵2/3×9.2>3.40>1/3×9.2 O.K.

The overturning safety factor, $n=\dfrac{676.16}{270.05}=2.59$

d. Check for sliding

Friction resistance on the base, F

F=111.61×0.55=61.39

then, sliding safety factor, $F_s=\dfrac{61.39}{47.14}=1.30$

e. Check for vertical stress on the base of the dam

Eccentric distance, $e=\dfrac{9.2}{2}-3.40=1.20$

Let the vertical stress at the toe of the dam be δ_2, and that at the heel be δ_1, then

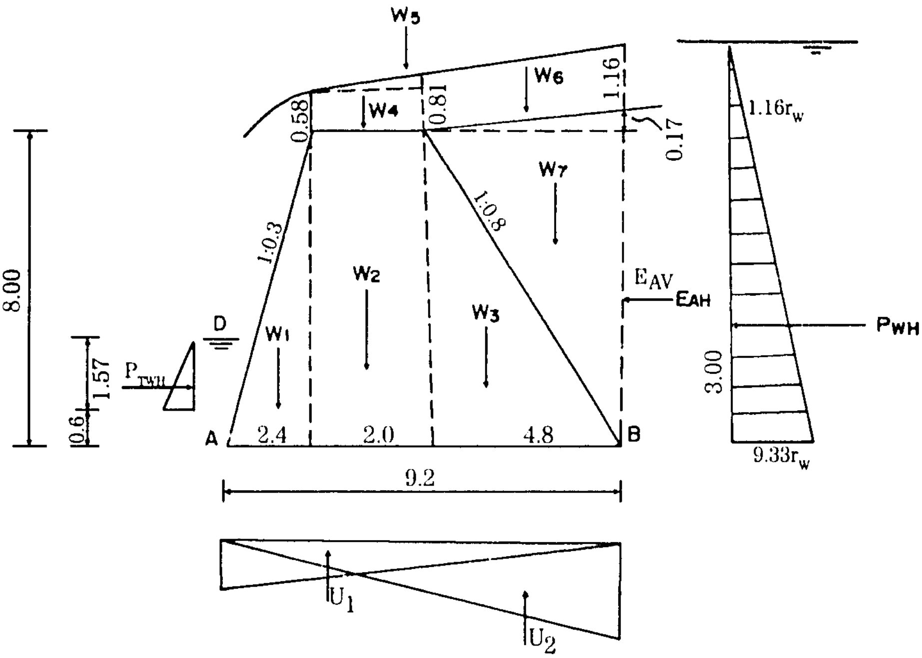
$$\delta_1 \text{ and } \delta_2 = \frac{\Sigma V}{B}(1 \pm \frac{6e}{B})$$

$$= \frac{111.6}{9.2}(1 \pm \frac{6 \times 1.20}{9.2})$$

$$= 21.63\ t/m^2 \text{ and } 2.64\ t/m^2 < 45\ t/m^2 \text{ O.K.}$$

406

(3) When the maximum discharge occurs after deposition



Rankine's formula is used to determine the coefficient needed for computing the earth pressure of the deposit at the back of the dam.

$$K_A = \cos\beta \times \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

Where β =sloping angle of the deposits

≑2° (depending on the river bed slope)

ϕ =internal friction angle of the deposits on the back of the dam=20° (usually more than 30°)

$$\therefore K_A = \cos 2^\circ \times \frac{\cos 2^\circ - \sqrt{\cos^2 2^\circ - \cos^2 20^\circ}}{\cos 2^\circ + \sqrt{\cos^2 2^\circ - \cos^2 20^\circ}} = 0.492$$

$$\therefore E_A = \frac{1}{2} K_A \gamma H_e^2 = \frac{1}{2} \times 0.492 \times 1.04 \times (8 + 4.8 \tan 2^\circ)^2 = 17.08\ \text{T}$$

$$E_{AH} = E_A \cdot \cos\beta = 17.08 \times \cos 2^\circ \fallingdotseq 17.07\ \text{T}$$

$$E_{AV} = E_A \cdot \sin\beta = 17.08 \times \sin 2^\circ \fallingdotseq 0.60\ \text{T}$$

405

Acting force					Moment at A	
Force	Computation	Vertical force	Horizontal force	Arm	+	-
W_1	1/2×8×2.4×2.39	22.94		1.60	36.70	
W_2	2.0×8×2.39	38.24		3.40	130.02	
W_3	1/2×4.8×8×2.39	45.89		6.00	275.33	
W_4	0.58×2.0×1.1	1.28		3.40	4.34	
W_5	1/2×2.0×0.23×1.1	0.25		3.74	0.95	
W_6	1/2(0.81+1.16)×4.8×1.1	5.20		6.80	35.37	
W_7	1/2×4.8×8.17×2.04	40.00		7.60	304.00	
E_{AV}		0.60		9.20	5.52	
E_{AH}			← 17.07	2.72		46.43
P_{TWH}	1/2×1.57²×1.1		→ 1.36	1.12	1.52	
P_{WH}	(1.16+9.33)×8.17/2×1		← 42.85	2.67		114.41
U_1	1/2×9.2×2.17×0.5×1	4.99 ↑		3.07		15.32
U_2	1/2×9.2×9.33×0.5×1	21.46 ↑		6.14		131.76
Σ		127.95	58.56		793.75	307.92

a. Check for overturning

Let the distance from the acting point of the resultant to point A be X
then 127.95 X=793.75-307.92
X=3.8 m ∵2/3×9.2>3.80>1/3×9.2

Overturning safety factor, $n=\frac{793.75}{307.92}=2.58$

b. Check for sliding

Friction resistance on the base, F

F=127.95×0.55=70.37

then sliding safety factor, $Fs=\frac{70.37}{58.56}=1.20>1.1$ O.K.

c. Check for vertical stress on the base

Eccentric distance, $e=\frac{9.2}{2}-3.80=0.80$

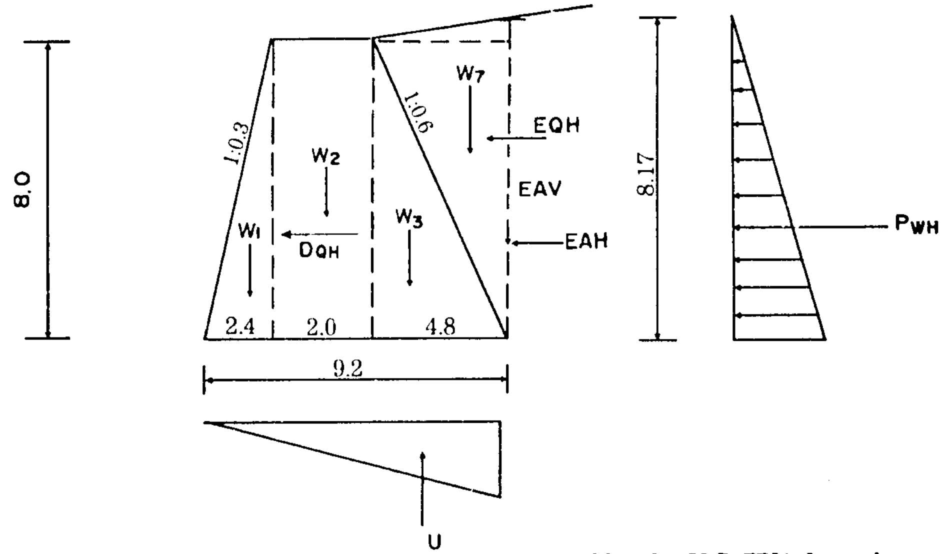
Let the vertical stress at the toe of the dam be δ_2, and that at the heel be δ_1, then

$$\delta_1 \text{ and } \delta_2 = \frac{\sum V}{B}(1 \pm \frac{6 \times e}{B})$$

$$= \frac{127.95}{9.2}(1 \pm \frac{6 \times 0.80}{9.2})$$

$$= 21.16\, t/m^2 \;\&\; 6.65\, t/m^2 < 45\, t/m^2 \text{ O.K.}$$

(4) When a normal discharge occurs together with an earthquake occur after deposition.



a. Earth pressure due to earthquake is computed by the U.S. TVA formula

$$P_{EH} = \frac{1}{2}[\frac{\cos(\phi - \theta)}{1+n}]^2 \cdot \frac{\cos\delta}{\cos(\delta + \theta)\cos\theta} \cdot \gamma_s H^2$$

$$\text{Where } n = \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta)}{\cos(\phi + \theta)}}$$

$$= \sqrt{\frac{\sin(20^\circ + 10^\circ)\sin(20^\circ + 6^\circ 50')}{\cos(20^\circ + 6^\circ 50')}} = 0.357$$

ϕ =Internal friction angle of gravel = 20°

(Usually more than 30°)

$$\delta = \frac{1}{2}\phi = 10^\circ$$

$$\theta = \tan^{-1}\frac{0.12\,g}{g} = \tan^{-1}0.12 = 6^\circ 50'$$

H = height of deposits on the back of the dam = 8.17m

$$\therefore P_{EH} = \frac{1}{2}[\frac{\cos(20^\circ - 6^\circ 50')}{1+0.357}]^2 \cdot \frac{\cos 10^\circ}{\cos(10^\circ + 6^\circ 50')\cos 6^\circ 50'} \times 1.04 \times 8.17^2$$

= 18.52 T

The additional horizontal pressure due to earthquake, E_{QH} is18.52-17.07=1.45 T

Acting force					Moment at A	
Force	Computation	Vertical force	Horizontal force	Arm	+	-
W_1	1/2×8×2.4×2.39	22.94		1.60	36.70	
W_2	2.0×8×2.39	38.24		3.40	130.02	
W_3	1/2×4.8×8×2.39	45.89		6.00	275.33	
W_7	1/2×4.8×8.17×2.04	40.00		7.60	304.00	
P_{WH}	1/2×1.0×8×8		← 32.00	2.67		85.44
E_{AV}		0.60		9.20	5.52	
E_{AH}			← 17.07	2.72		46.43
E_{QH}			← 1.45	2.72		3.94
D_{QH}			← 12.85	2.83		36.37
U	1/2×9.2×8×0.5×1.0	18.4 ↑		6.14		112.98
Σ		129.27	← 63.37		751.57	285.16

b. Horizontal inertia force of the dam due to earthquake $D_{QH}=\alpha \Sigma W$=12.85 t/m (same as 2.)

(i) Check for overturning

Let the distance from the acting point of the resultant to point A be X

Then 129.27 X=751.57-285.16

X=3.61 m ∵2/3×9.2>3.61>1/3×9.2 O.K.

Overturning safety factor, $n=\frac{751.57}{285.16}=2.64$

(ii) Check for sliding

Friction resistance, F=129.27×0.55=71.10

Sliding safety factor, $Fs=\frac{71.10}{63.37}=1.12>1.1$ O.K.

c. Check for vertical stress on the base of the dam

Eccentric distance, $e=\frac{9.2}{2}-3.61=0.99$

Let the vertical stress at the toe of the dam be δ_2, and that at the heel be δ_1.

$$\delta_2 \text{ and } \delta_1 = \frac{\Sigma V}{B}(1 \pm \frac{6e}{B})$$

$$= \frac{129.27}{9.2}(1 \pm \frac{6 \times 0.99}{9.2})$$

$$= 23.12 \ \& \ 8.00 \text{ t/m}^2 < 45 \text{ t/m}^2 \text{ O.K.}$$

SOIL CONSERVATION HANDBOOK

Part III

Vegetative Measures

1995

CONTENT

410

SOIL CONSERVATION HANDBOOK

Part III. Vegetative Measures

Chapter 1. Introduction

1.1 Scope

The contents of this section include selection of plant materials for revegetation, site preparation, application methods, revegetation in problem areas and maintenance. Often, engineering structures are installed in combination with vegetative measures.

In general, these measures are for field sites where heavy storms, frequent earthquakes, high groundwater levels and unfavorable geological conditions occur and on mine tailings, quarrying wastes, bare rock and unstable slopes along rural roads and in residential areas.

1.2 Definition and functions of vegetation

Vegetation is defined as all of the plants growing in a given area, especially such plants as grasses, shrubs and trees which cover the surface of the land.

The functions of vegetation can be listed as follows:

(1) store and supply water

(2) prevent surface erosion

(3) prevent shallow landslides (slips)

(4) mitigate flood damage

(5) improve air quality

(6) provide recreation resources for people and a habitat for wildlife

(7) green and beautify the scenery

1.3 Design principles

1.3.1 Site condition and revegetation

(1) Slope

The steepness of the slope is an important factor affecting slope stability and vegetation growth. On steep slopes, plant roots usually reach only a shallow depth. Natural setting of plants may occur on slopes less than 35°, but it will be very difficult for plant to grow naturally on slopes steeper than 35°. Yamatera (1982) summarized plant growth conditions under various slope classes, and recommended appropriate engineering structures. (Table 1-1).

Table 1-1. Plant growth conditions at different slope gradients, and supportive engineering work required.

Slope Ratio	Plant Growth	Supportive Engineering
< 30° (1:1.7)*	1. Good plant growth 2. Natural setting 3. Possible recovery of a plant community in which tall trees are dominant	Drainage
30°~35° (1:1.7~1:1.4)	1. 35° is the upper limit for natural recovery of plants 2. Grasses well established, little erosion	Wattling, netting and trenching
35°~45° (1:1.4~1:1.0)	1. Shrubs and herbs dominant in vegetation 2. Planting tall trees may be hazardous or increase slope instability	Retaining walls, wattling, frames, gabions for slope stabilization
45°~60° (1:1.0~1:0.6)	1. Shrubs and herbs dominant in vegetation 2. 45°~60° are the slope limit for tall trees to become forests	Frames and retaining walls
60° (1:0.6)	Not suitable for planting or natural setting	Retaining walls or frames

* vertical : horizontal

(2) Soil hardness

The growth of plant roots is impeded when soil hardness measured by the Yamanaka type soil hardness meter is above 25mm. At sites where measured soil hardness is greater than 25mm, soil improvement is needed for plant growth. Plant growth conditions under different soil hardness and respective engineering structures required are listed in Table 1-2 (Yamatera 1982).

(3) Climate

Climate affects plant growth. Revegetation should be carried out during the wet season. If revegetation is necessary during a dry period, choose plants resistant to drought, and water them when needed. At windy sites, shelter-belts or windbreaks for protection of new plantings are to be established.

1.3.2 Selection of application methods

Direct seeding and planting are the two major revegetation methods. Usually seeding is preferred, and planting is used as an auxiliary. Seeding can be divided into dibbling, strip sowing and broadcast seeding. Based on the different materials used, seeding can also be divided into direct seeding, vegetation belt pitch work, hydro seeding, and revegetation with seeds in carrying soils. Planting uses plant stems or leaves, sprigs or seedlings. The plants employed include trees, grasses and vines. Methods of planting include direct planting, hole planting and ridge planting, according to site conditions.

Table 1-2. Plant growth conditions under different soil hardness and sustaining measures.

Soil Hardness*	Plant Growth	Sustaining Measures
< 10mm (1.5 kg/cm²)	Poor growth due to water deficit	1. Rice straw mulching 2. Frames with borrowed soils 3. Hydroseeding and then rice straw mulching
10~25 mm (1.5~15 kg/cm²)	1. Good extension of root systems 2. Seed germination and good growth	Native plants are preferred. Vegetation methods include hydroseeding, vegetation bags, soil bags, netting covered by borrowed soils and then hydroseeding
25~30 mm (15~45 kg/cm²)	1. Impeded root growth 2. Poor plant growth	1. Drilling or trenching 2. Avoid using planting, broadcasting or layering methods 3. Use hydroseeding, vegetation belts layered on thick borrowed soils, or frames with borrowed soils. 4. Hole-planting
> 30mm (> 45 kg/cm²)		Hydroseeding after drilling and adding borrowed soils, or gabion with borrowed soils and L- or U-shaped ditch with borrowed soils

* Measured by Yamanaka type soil hardness meter

1.3.3 Selection of plant materials

The factors determining the kinds of plant materials are: objective of the project and functions after vegetation establishment, feasibility of implementation, and adoption of plants to site conditions. Therefore, soil conservation plants are characterized by their wide adaptability, fast growth, easy propagation, effective soil improvement and slope protection. These plants may be introduced or native species. If the supply of seeds or seedlings is dependable, native species should be chosen. In addition, grasses grow faster, and thus are suitable for initial cover of bare ground. Vines are suitable for rocky slopes or masonry side walls, and shrubs and trees are suitable for windbreaks, green belts and protection zones on gentle slopes.

1.3.4 Common plant species for soil conservation in Taiwan

See Table 1-3. List of common plant species for soil conservation in Taiwan.

1.3.5 Amount of seed needed for sowing

The amount of seed needed for sowing depends on seed quality, soil properties, and site conditions. The recommended amount of seeds used in sowing is listed in Table 1-4.

Because the germination and survival rates of plant materials varies under different site conditions, adjustment of the amount of seeds for seeding in line with site conditions is proposed in Table 1-5.

For hydroseeding, the amount of seeds required in seeding should be increased in proportion to the depth of hydroseeded bed of which 1 cm deep is most favorable for seed germination. Therefore, the amount of seeds for seeding should be tripled if the hydroseeded bed is 3 cm in depth.

Table 1-3. Common plant species for soil conservation in Taiwan

Common & Scientific names	Elevation	Habit	Propagation	Seeds per gram	Soil conservation uses
Bahia grass Paspalum notatum	< 1500m	0.3-0.5m Perennial tiller	Division, sowing	350	Grass barrier, grass waterway, bench riser planting, slope protection
Bahia grass Paspalum notatum	< 800m	0.3-0.5m Perennial tiller	Division, sowing	350	Grass barrier, grass waterway, bench riser planting, orchard cover crop
Carpet grass (Broad leaf) Axonopus affinis	< 2000m	0.05-0.35m Perennial creeper	Division, sowing	2500	Slope stabilization, orchard cover crop
Carpet grass Axonopus compressus	<200m	0.1-0.3m Perennial stolon	Cutting	3000	Underwood or orchard cover crop
Love grass Chrysopogon aciculatus	< 700m	0.05-0.1m Perennial creeper	Division, cutting	12030	Grassing of farm roads, formation of grassland
Centipede grass Eremochloa opiuroides	< 1800m	0.05-0.15m Perennial creeper	Division, sowing	1600	Grassing of farm roads, slope protection
Sour grass Paspalum conjugatum	< 2000m	0.05-0.3m Perennial stolon	Cutting	4600	Natural cover for orchard
Bermuda grass Cynodon dactylon	< 600m	0.05-0.4m Perennial Persistent stolon root	Cutting, sowing	3800	Grassing of farm roads, riparian zone or buffer strips, slope protection
St. Augustine grass Stenotaphrum secundatum	Low altitude	0.1-0.3m Perennial creeper	Cutting	—	Revegetation in coastal or mudstone areas
Japanese silver grass Miscanthus floridulus	< 2500m	2-4m Perennial clump	Sowing, division	1250	Revegetation on harsh sites and side slopes
Guinea grass Panicum maximum	< 1000m	1.2-1.6m Perennial clump	Division sowing	1500	Grass barrier, slope protection
Rescue grass Bromus catharticus	1400-2500m	0.1-1.0m Annual clump	Broadcast, self-sowing	68	Cover crop for orchard
Orchard grass Dactylis glomerata	1500-2500m	0.4-0.8m Seasonal clump	Divison, sowing	820	Cover crop for orchard
Perennial ryegrass Lolium Perenne	1500-2500m	0.2-0.4m Seasonal clump	Sowing	460	Slope protection, cover crop for orchard
Kentucky 31 fescue Festuca arundinacea	< 3000m	0.5-0.8m Perennial deep root clump	Sowing	400	Slope protection
Dallis grass Paspalum dilatatum	< 2000	0.5-1.0m Perennial clump	Division, sowing	460	Slope protection, cover crop for orchard
Kikuyu grass Pennisetum clandestinum	500-2000m	Perennial tiller	Cutting	429	Slope protection, formation of alpine grassland
Wild sugarcane Saccharum spontaneum	Coastal plain	1-3m Perennial clump, erect	Division, cutting	—	Windbreak, sand fixation
Littoral spinegrass Spinifex littoreus	Coastal plain	0.3-1.0m Perennial persistent root, creeper	Division, cutting	—	Windbreak, sand fixation
Rhodes grass Chloris gayana	Coastal plain	Perennial clump creeper	Sowing	4250	Pasture, revegetation on saline soils
White clover Trifolium repens	< 3000m	0.2-0.5m Creeper	Sowing	1200	Cover crop for orchard, slope protection

415

Common & Scientific names	Elevation	Habit	Propagation	Seeds per gram	Soil conservation uses
Intortum clover Desmodium intortum	< 1000m	0.2-0.3, Seasonal single vine	Sowing	700	Slope protection, revegetation of mining areas
Railroad-Vine Ipomoea pes-caprae	Coastal plain	Creeping linana	Sowing, cutting	15	Windbreak and sand fixation, revegetation on saline soils
Chinese lespedeza Lespedeza cuncata	Low altitude	0.6-0.1m Perennial herb, erect	Sowing	720	Revegetation on harsh site, soil improvement
Yellow crotalaria Crotalaria pallida	Low altitude	0.5-0.7m	Sowing	191	Landscaping
Taiwan acacia Acacia confusa	< 1600m	5m Evergree tree	Sowing	42	Slope protection, revegetation on harsh site
Roxburgh sumac Rhus semialata var roxburghii	< 1900m	4m Semi-deciduous tree	Sowing	95	Slope protection, revegetation on harsh site
Purple woodnettle Boehmeria densiflora	< 1300m	2m Evergreen shrub	Sowing	11000	Slope protection
Subcostate crape-myrtle Lagerstoremia subcotata	< 1400m	10m Semi-deciduous tree	Cutting	670	Live stake
Linden hibiscus Hibiscus tiliaceus	< 600m	5m Evergreen tree	Cutting	73	Live stake
Formosan alder Alnus formosana	< 3000m	10m Evergreen tree	Sowing	1250	Slope protection, landslide treatment

Table 1-4. The seeding rates of soil conservation plants.

Plants	Pure live seeds (g/cm^2)
Grasses	
Bahia grass A33	10
Bahia grass A44	12
Bermuda grass	6
Ryegrass	10
Red fescue	10
Orchard grass	12
Kentucky 31 fescue (K31F)	12
Japanese silver grass	3
Artemisia Kawakamii	0.1
Woody plants	
Purple woodnettle	0.02
Roxburgh sumac	15-20
Guava tree	15-20
Subcostate crape myrtle	8
Vines	
White clover	12
Siratro	15
Intortum clover	15

Table 1-5. Percentage of adjustment in amounts of seeds for seeding at different sites.

Site conditions	Percentage of adjustment(%)
Gravel, rocks	+20
Very hard soil	+10
High soil fertility	–20
Very infertile soil	+20
Dry	+10
Very dry	+20
Very wet	+10
Very acid soil	+20
Very gently sloping	–10
Very steep	+20

Source: Yamatera, 1982

Chapter 2. Site Preparation

2.1 Purpose

Site preparation refers to implementation of procedures, needed to provide a suitable growth and propagation environment for the plant materials applied on slopes.

2.2 Site improvement

2.2.1 Topsoil and spoil treatment

Topsoil on hillslopes to be excavated should be taken away and stockpiled on a flat piece of ground, and then legume seeds broadcast on top, or the topsoil should be covered with PE sheets to protect it from erosion. Spoil should be dumped in a safe place to mitigate environmental damage.

2.2.2 Grading

Grading is needed on bare slopes. Plant roots are usually unable to stabilize slopes steeper than 45°-50°. To prevent slips or shallow slides, engineering work may be done (Table 1-1). Different forms of unevenness of the slope surface caused by different methods of site preparation may affect plant growth in different ways. In order to ensure that mulching with straw mats or geotextiles is effective, slope surfaces should be smooth. For broadcast seeding, gently rolling slope surfaces help planting materials to adhere and begin rooting. On rocky slopes, rough slope surfaces can benefit revegetation.

2.2.3 Terracing

For longer slopes (>10 m) terraces are necessary. Planting on terraces is also practiced for slope protection and soil stabilization.

(1) Purposes of terracing

a. To shorten long slopes and dispose of runoff.

b. To provide a foundation for other operations.

c. To serve as access roads for operations.

d. To establish vegetation, especially on steep slopes.

(2) Design and procedures of terracing

a. Terracing may cause the following problems. Efforts should be made to prevent any unwanted effect.

(i) Increased infiltration, and consequently reduced slope stability.

(ii) Occurrence of gully erosion in terraces with erodible soils.

(iii) Increase in slope steepness if usable land is limited.

b. Spacing of terraces is usually 5-7m.

c. The width of terraces is 1 m in principle.

418

d. Inward sloping (5-10%) type terraces are preferred.

e. Drainage facilities with a gradient of 1-2% are necessary.

f. Caution should be taken when planting trees on terraces, to be sure that the slope will not collapse.

g. If trees are not to be planted on terraces, drainage ditches with an impervious bottom are needed.

h. When U-shaped prefabricated concrete ditches are installed in the upper part of terraces, make sure that the top edge is below the soil surface and the connection points are fixed.

2.2.4 Soil improvement

Soil improvement should be carried out on poor or infertile soils.

Table 2-1 shows the methods of improving soils on hillslopes.

Table 2-2 lists the application rate of lime for acid soils

If the lime requirements of a specific soil are more that 3 t/ha, the amount should be divided and applied in several years

The application rate of organic fertilizers depends on the nature of the fertilizers: concerned. A rough guide is 1~1.5 kg/m^2 for readily decomposed materals, and 1-4 kg/m^2 for materials which do not readily decompose.

2.3 Drainage facilities

Please refer to Part II, Engineering Work, in this Handbook.

2.4 Hillside foundation work

Engineering structures which are combined with vegetative measures are as follows:

2.4.1 Retaining structures

Retaining work is built at the foot of a slope or on hillsides to reduce slope steepness, support the hillslope and facilitate planting work. The structures are simple, about 1 m high, 20-30 cm thick and usually made of stones, concrete, concrete plates or used railway ties. Sketches of three different foundation structures are shown in Figure 2-1 (a), (b), (c). For details of design and installation, please refer to Part II of this Handbook.

At sites where gravel or rocks are not available, 1:3:6 concrete should be used. For concrete retaining walls, drain holes should be installed a proper distance apart. At moist sites, gabion retaining walls with stakes, or steel or concrete poles, are used for slope stabilization.

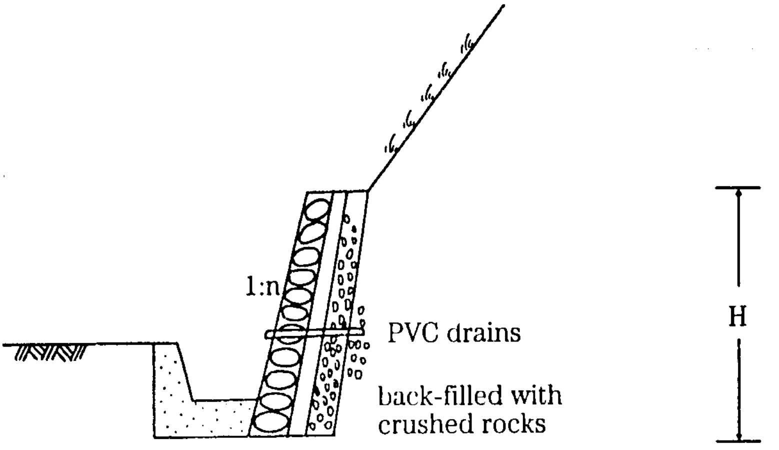
Table 2-1. Methods for improving of different soils.

Soils	Improvement method	Target
Acid soil	Apply lime, basic slag, dolomite powder, oyster shell powder every 2-3 years with organic fertilizers.	Adjust pH values to 5.5~6.0.
Alkaline soil	Apply sulfur powder, peat and organic fertilizers	Adjust pH values to <7.9
Low soil organic matter content	Apply organic fertilizers; plant green manure crops; increase water retention capacity of soil; improve soil structure; apply peat and tree bark compost.	Improve soil properties and microorganism
Shallow soil or gravel	Add borrowed soils; trap silt; remove gravel; apply organic fertilizers	Increase effective soil depth (>10 cm)

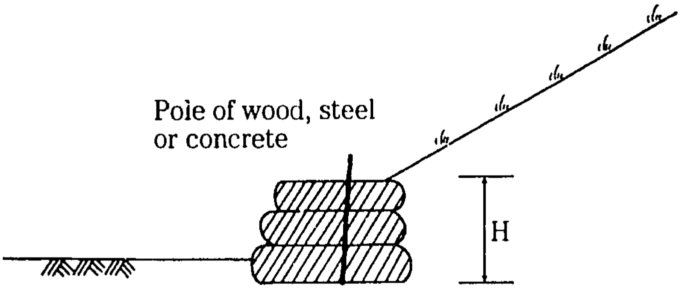
Table 2-2. Application rate of lime for acid soils of different textures and pH values.

Unit: kg/0.1ha

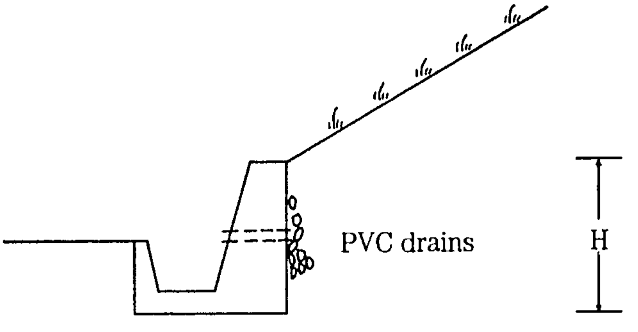
Soil texture	pH values					
	3.5	4.0	4.5	5.0	5.5	6.0
Sandy loam	140~170	100~140	70~100	40~70	0~40	0~20
Loam	240~280	170~200	100~150	50~100	0~40	0~20
Clay loam	290~350	200~250	130~200	60~120	0~60	0~20



(a) Sandwich masonry retaining wall



(b) Gabion retaining wall

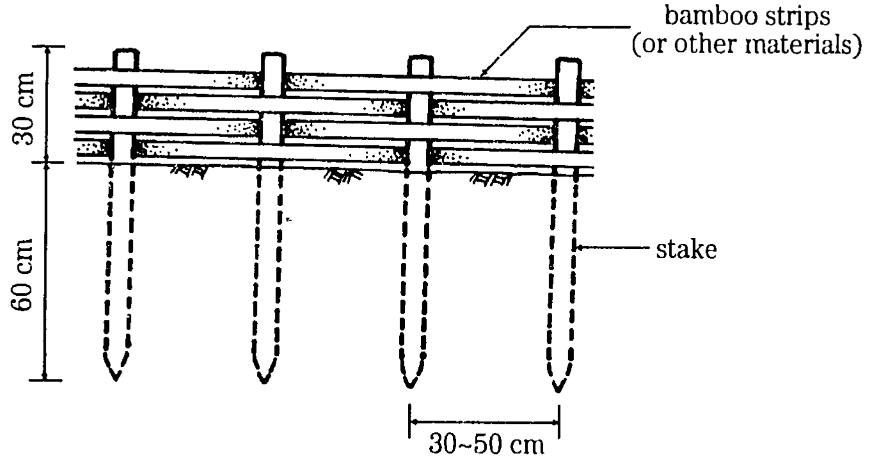


(c) Concrete retaining wall

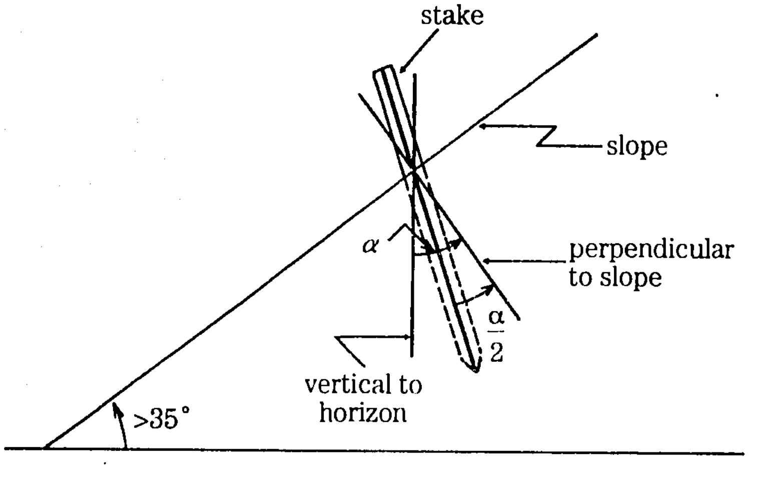
Fig. 2-1. Sketches of three different types of retaining walls

2.4.2 Staking and wattling

Either sprouting or nonsprouting cuttings of bamboo or tree stems are hammered into the ground at appropriate distance apart. Bamboo strips, PE nets or wires are then woven between into fences to trap sediments, so as to reduce slope steepness for vegetation establishment. This method is performed on slopes less than 45°, cut slopes, unstable soil deposits or shallow landslide scars. A sketch is shown in Figure 2-2 (a), (b).



(a) Front view



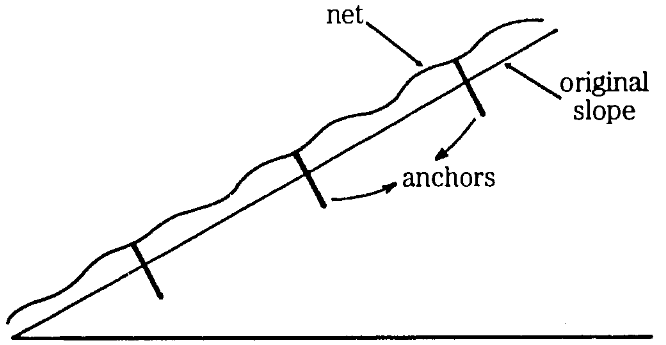
(b) Cross section

Fig. 2-2. Sketches of wattling

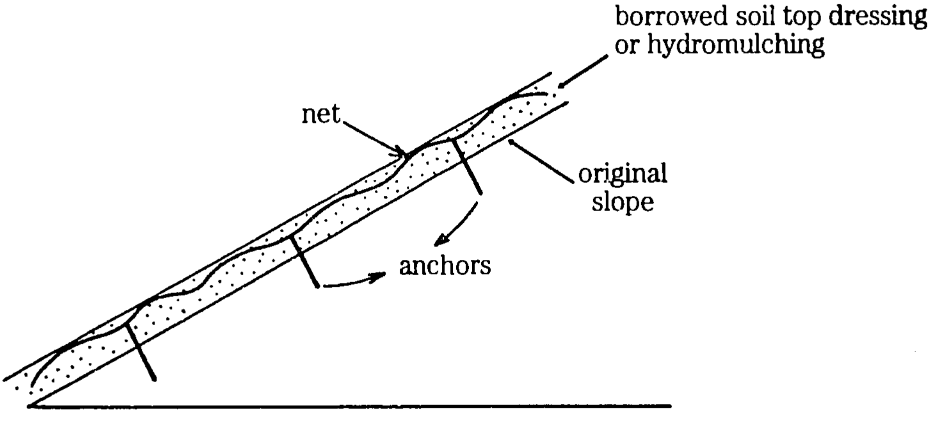
The spacing of stakes depends on slope steepness and geological features. In general, There should be 1-3 m between rows, with 2-3 m between rows of live stakes and 1 m between rows of steel ones. The interval between stakes should be 30-50 cm. For live stakes, the diameter at the sharp end should be 5-8 cm, and the stake length 0.9-1.2 m. For steel stakes, the diameter should be 13 mm, with a length of 0.45-0.75 m. Stakes should be driven into soil for at least two thirds of their length. If tree cuttings are used, more than 25% of the stakes should be live ones (mainly subcostate crape myrtle, Linden hibiscus or ficus spp.) . After staking and wattling work is finished, topdressing or land shaping with borrowed soil should be carried out for other revegetation practices.

2.4.3 Netting

Iron wire woven nets with a rhomboid mesh are laid over slopes to prevent soil or rock slips and to help plants grow. Nets laid on the surface are used on slopes with gravel, rock fragments, and rock with cracks which is susceptible to sliding, or on cemented slopes for vines to climb. Buried nets are used on steep, rocky slopes. A sketch of each type is shown in Figure 2-3 (a), (b).



(a) Surface cover net



(b) Buried net

Fig. 2-3. Sketches of netting

The wire of the most commonly used rhomb-mesh iron net is #14 or ϕ 2.3mm. Anchoring is needed to fix the nets, with a rate of at least 1 anchor/m^2. In general, 30 large anchors (ϕ 9mm, ℓ=350 mm) are needed for 100 m^2.

Buried nets are used for hydroseeding or topdressing with borrowed soil. Nets at the top end of the slope should be extended 1 m or more and then fixed. Adjacent nets should overlap by 10 cm or more.

2.4.4 Drilling and trenching

On slopes with poor soils or special rock formations, drilling or trenching is performed so that borrowed soil can be brougth in to support vegetation. These methods are used on slopes where soil hardness is greater than 25mm as measured by the Yamanaka type soil hardness meter, or where the ground consists of mudstone, or shale, or on rocky cliffs. A sketch is shown in Figure 2-4 (a), (b).

Before this operation, the slope should be cleared. Trenches should be 0-15 cm wide and 10-20 cm deep, with 50 cm between trenches. For drilling, 6-9 drills per m^2 is needed. Drills should be 15-20 cm deep and 7-10 cm in diameter. Borrowed soils and organic fertilizers or slow-release fertilizers are put into the trenches or drills, with 100 kg compost per 1 m^3 borrowed soils. Netting may be incorporated into the drills or trenches. Drilling or trenching is most effective for soils with a soil hardness value of 25-30 mm (Yamanaka meter).

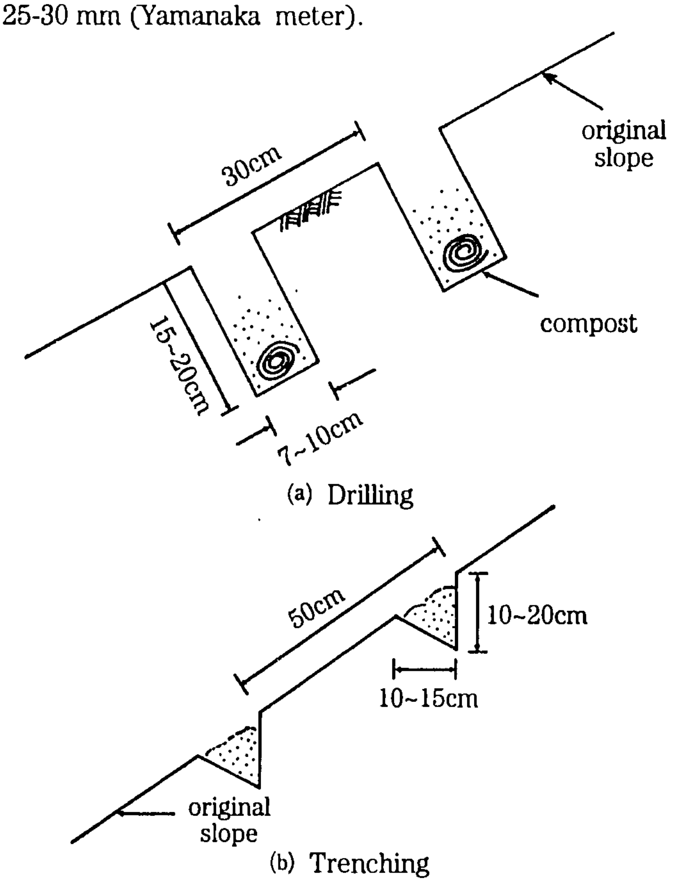


Fig. 2-4. Sketches of drilling and trenching

2.4.5 Frames

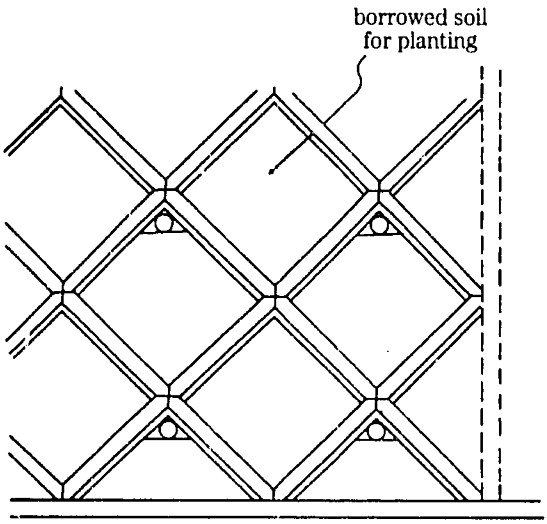
Frames are either prefabricated or constructed on site. They can be made of several kinds of materials, and are used on slopes to hold borrowed soils in which plants can grow. Frames, either prefabricated or made on site are used on slopes with a weak geological structure or on sites prone to landslides. The surface of both kinds at slope should be even. Free frames are used on slopes with a rough, uneven surface, or on slopes under active weathering or erosion, and on steep slopes of 45° to 65°. A sketch is shown in Figure 2-5 (a), (b), (c).

For the installation of prefabricated concrete frames, the slope surface should be shaped. Each member of the frame should be 100 cm long and 10 cm wide and high. The frames are connected by wires (#12) and then fixed by anchors. Borrowed soils are piled into frames to a deepth of 10 cm, and compacted for grass planting.

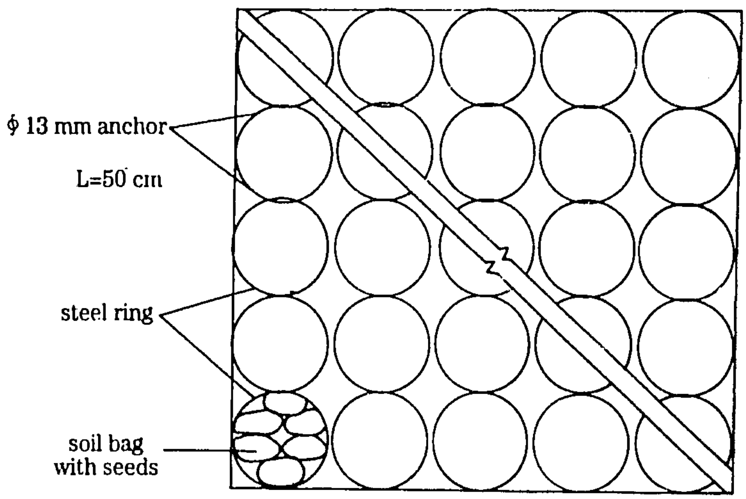
Iron rings, ϕ 1 m and 10 cm high, are installed on shaped slopes. For slopes less than 45°, borrowed sandy loam soils should be used, while for slopes greater than 45°, borrowed clay loam soils are required.

In the installation of free frames, anchors should be 1.2m apart and 50 cm deep.

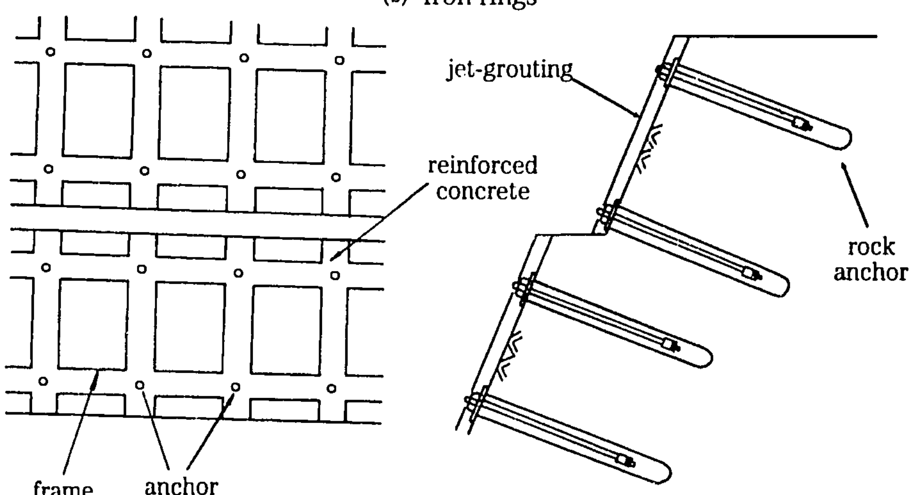
425



(a) Prefabricated concrete frames



(b) Iron rings



(c) Free frames

Fig. 2.5. Sketches of frames of different materials

2.4.6 Planting troughs

Planting troughs 60 cm wide and 60 cm high can be built on slopes at an appropriate spacing to store borrowed soils for planting. They are used on slopes where there are large amounts of gravel, cut slopes with fractured rocks, or cemented sideslopes. A sketch is shown in Figure 2-6. Netting is needed for vines.

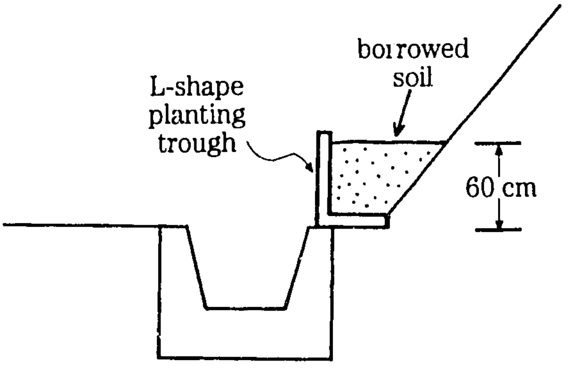


Fig. 2-6. Sketch of L-shape planting trough

Chapter 3. Application Methods

3.1 Direct seeding

Plant seeds can be directly sown onto the slope to control erosion and for greening. This method is employed on natural landslides, or on gentle cut or filled slopes in clay loam or loam soils. The design and procedures of application are:

(1) Clear the land surface.

(2) Apply compost at a rate of 1-1.5 kg/m^2 and Taiwan Fertilizer Corporation (TFC) compound fertilizer No. 43* at a rate of 0.05 kg/m for ordinary soils. A 20% adjustment is recommended for better or poorer soils.

(3) Broadcast seeds uniformly over the slope. The seeding rates for soil conservation plants are listed in Table 1-4.

(4) Apply loose topsoil as a mulch on the seeded slope.

(5) Mulch with rice straw mats (350~500 g/m^2), if necessary.

(6) Plant tree saplings at the same time, if necessary.

3.2 Hydroseeding

Seeds, fertilizers, organic fertilizers (or soils), and adhesive agents are mixed with water and sprayed on slopes with a pump. The thickness of the later on the slope surface depends on the hardness of the soil and the kind of materials on the slope. A shallow layer of hydroseeding (0.1-3 cm) is used on soils with a soil hardness less than 25 mm or on a hard slope surface with a hardness greater than 25 mm. An intermediate-thin hydroseeding (3-6 cm) is used on soft rock slopes. Thick-layer hydroseeding (>6 cm) using cement adhesive is used on hard rock slopes. A sketch is shown in Figure 3-1 (a), (b), (c).

The design and procedures of application of hydroseeding are:

(1) For shallow-layer hydroseeding.

a. Use asphalt emulsion, resin, gelatin or gum as adhesives.

b. Apply seed at a rate of 15 g/m^2, mixed with adhesives (at 0.2 kg/m^2), chemical fertilizers and dyes, with a hydroseeder. Then mulch with rice straw mats or other mulching materials, if necessary.

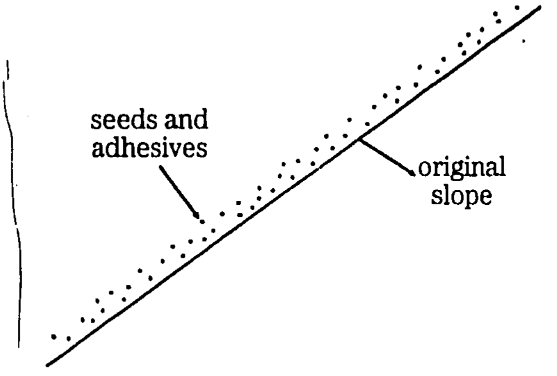
(2) For intermediate-thin hydroseeding

a. Use cement (at 3~10 kg/m^3), resin or asphalt emulsion as adhesive.

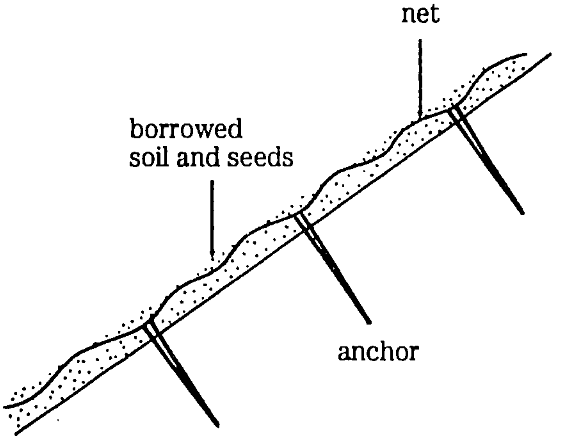
b. Apply seed bed material: One cubic meter seed bed material consists of 2/3m^3 sandy loam, 60 kg bark compost, 20 kg peat moss, 2 kg TFC Compound Fertilizer No. 43*, 3-10 kg cement and 0.5~1 kg calcium superphosphate.

---

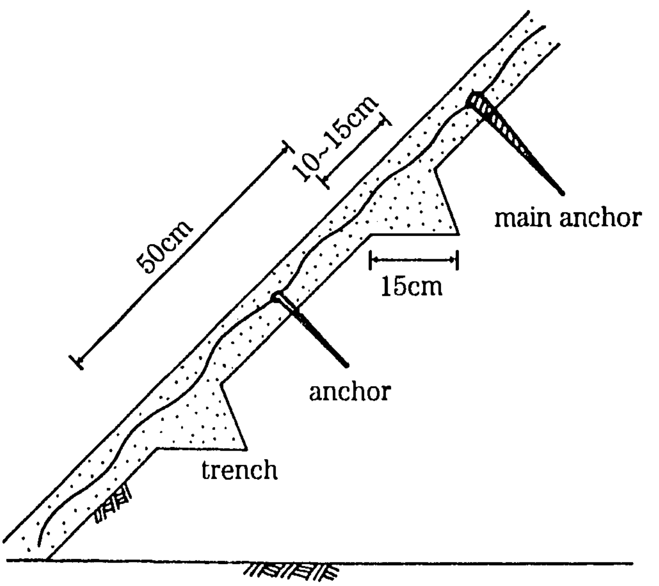
* TFC compound fertilizer No. 43: N 15%, P_2O_5 15%, K_2O 15%, MgO 4%



(a) Shallow-layer (0.1-3 cm) hydroseeding



(b) Intermediate-thin (3-6 cm) hydroseeding



(c) Thick-layer (> 6 cm) hydroseeding

Fig. 3-1. Sketches of three kinds of hydroseeding

c. There are two methods of application: In one, hydroseeding is done only once, with seed rates increased (on the basis of the rate for shallow-layer) in proportion to the increased thickness of the hydroseeded layer. The other method is to hydroseed twice; the seed rate is the same as shallow-layer hydroseeding. Apply seeds with a mixture of adhesives on slopes treated with netting, at a rate of 1 m^3 seed bed materials for 16-30 m^2.

(3) For thick-layer hydroseeding

a. Use cement at 30-50 kg/m^3 as adhesive.

b. Apply seed bed materials

(i) for hard soils, same as intermediate-thin hydroseeding except use cement at 30-50 kg/m^3.

(ii) for rocky slopes, each cubic meter seed bed material should have 150-240 kg bark compost, 30-40 kg peat moss, 1/3 m^3 sandy loam, 1-2 kg calcium superphosphate and 30-50 kg cement.

(iii) application same as intermediate-thin hydroseeding.

For slopes with weathered rocks, holes 1-2 cm in diameter and 15-20 cm deep, should be drilled at a spacing of 20-25 cm to help plant root growth. In thick-layer hydroseeding operation, a mixture of plant seeds for 1 m^3 seed bed material consists of

Bahia grass seed	1.0 kg
Bermuda grass seed	0.5 kg
Purple woodnettle	0.01 kg
Guava tree	1.0 kg
Roxburgh sumac	1.0 kg

3.3 Vegetation belt pavement

Vegetation belts made of fiber and rice straw, with plant seeds inside, are paved on hillside to cover bare slopes quickly. This method is used on soil slopes less than 45° and a soil hardness less than 25 mm. The sketch is shown in Figure 3-2.

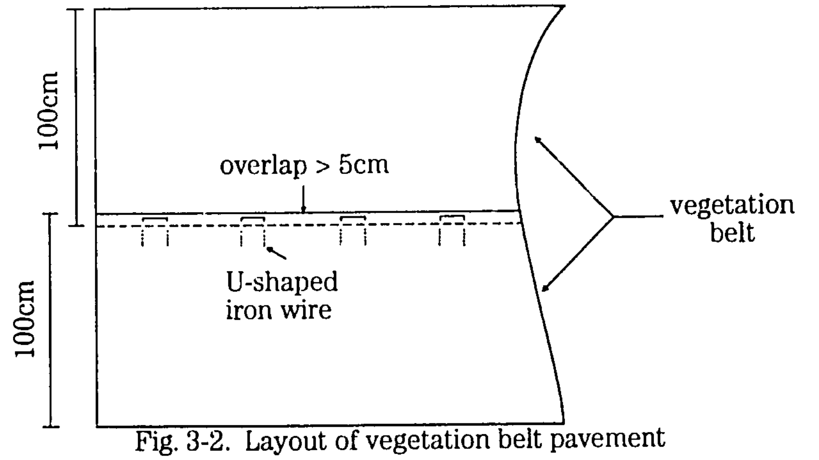


Fig. 3-2. Layout of vegetation belt pavement

432

The design and procedures of application are:

(1) Shape and till the slope surface, apply compost at 1-15 kg/m^2 and TFC compound fertilizer No. 43 at 0.05 kg/m^2 onto the soil. Higher application rates are needed for cut slopes.

(2) The vegetation belt is 1 m wide, an overlap of 5 cm is required when paved.

(3) One U-shaped iron wire at 1 m space is used to hold down the edge of the vegetation belt.

(4) For slopes longer than 3 m, vegetation belts are paved up and down; slopes shorter than 3 m, are paved horizontally.

(5) Rice straw mats can be used to mulch an unwoven vegetation belt.

(6) For slopes of 35°-45° or severely eroded areas, iron nets are used to fix vegetation belts.

3.4 Revegetation with seeds in borrowed-soil bags

Bags filled with borrowed soil and plant seeds are put onto problem soils or gravel slopes or into frames to improve the site conditions. Dirt sacks are used for hole planting while soil bags are used in frames, pavement, retaining walls and grassed waterways. The design and procedures of application are:

(1) Unwoven cloth is used for making rectangular dirt sacks. These sacks are filled with seeds, vermiculite, perlite, and chemical and organic fertilizers.

(2) PE sheet with 70% shade is used for making 60 × 40 cm soil bags. The size will be 30 × 10 × 50 cm after the bag has been filled with organic soils.

(3) Fill the soil bags with seed and bed materials (soil : compost : chemical fertilizer=1 m^3 : 50 kg : 5 kg)

(4) Fix the soil bags on slopes, with iron wires.

(5) Plant cuttings or sprigs on soil bags if necessary.

3.5 Grass sprig planting

Grass sprigs are planted at intervals on slopes for erosion control. This method is used for soil slopes less than 35°, when the grass sprigs are available. The sketch is shown in Figure 3-3 (a), (b).

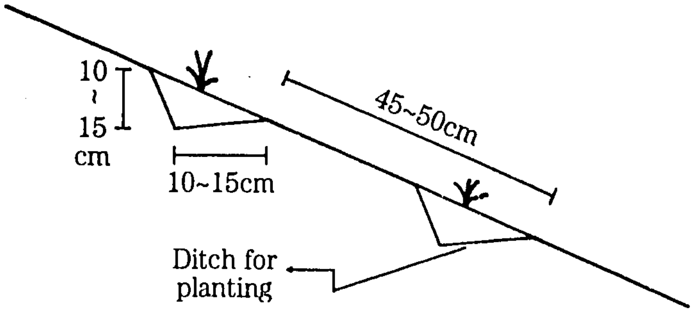
The design and procedures of application are :

(1) Stepping out slopes for grass sprig planting

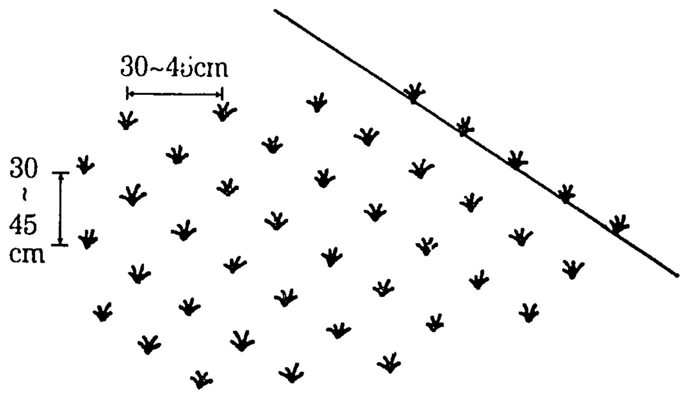
a. Cut steps along contour 45-50 cm apart. The ditch for planting is about 10-15 cm deep and wide and should slope inwards.

b. Apply compost at 2 kg/m^2 and TFC Compound Fertilizer No. 43 at 0.05 kg/m^2, mixed into the original soil.

c. Plant grass sprigs, 10-15 cm long with three or more nodes, then compact and water



(a) Cutting slope into steps for planting of grass sprigs



(b) Hole planting of grass sprigs

Fig. 3-3. Sketches of grass sprig planting

the soil.

(2) Hole planting of grass sprigs

a. Along contours plant the grass sprigs, which should be 10-15 cm long with three or more nodes, then compact and water the soil. The sprigs should be planted in grids of 30-45 cm^2 grids of 30-45 cm^2.

b. The fertilizer application rate is the same as the one used for planting grass sprigs on slopes cut in steps..

c. The planting holes are laid out in a triangular pattern.

For cut slopes of newly constructed roads or small pieces of lands, if the length of the slope is no more than 7 m, grass sprig planting can be employed on slopes up to 45°.

3.6 Sodding

Grasses cultivated in containers or in seed beds are taken complete with stems, roots and soil to planting sites, to be established within a short time for erosion control. This method is used on cut clay slopes of less than 45°, or filled slopes which need rapid cover, or grassed waterways and road surface. A sketch is shown in Figure 3-4.

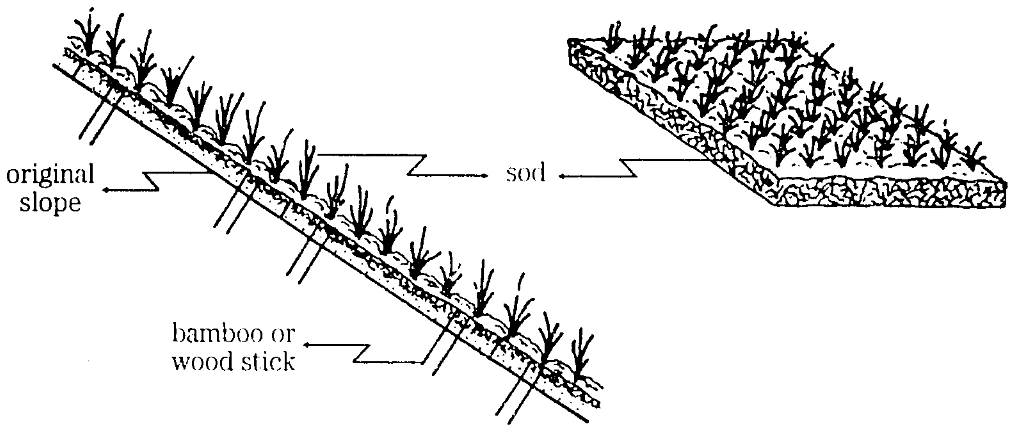


Fig. 3-4. Sketch of sodding

The design and procedures of application are:

(1) Remove roots of weeds and grave from the topsoil; then till and level the surface. Ensure that the land is adequately drained.

(2) If a soil tray is used as a grass nursery, fill the soil tray with organic soils, compound fertilizer and grass seeds. After 1-2 months the sod in the soil tray is ready for sodding. The alternative is to lay unwoven cloth on flat ground and topdress it with a mixture of sieved soil and organic fertilizer, and then sow the seed. After 1-2 months, the sod is ready for sodding.

(3) Sodding is carried out in planting ditches, 20 cm wide and deep, along the contours at a spacing of 40-60 cm. Around 1-2 kg/m^2 compost and 0.05 kg/m^2 TFC compound fertilizer No. 43 should be applied to the planting ditches.

(4) Adequate watering is needed.

(5) Grasses commonly used in sodding include bahia grass, Bermuda grass, and carpet grass.

(6) To establish grass cover rapidly, overall sodding may be used.

3.7 Planting with container-grown seedlings

Seedlings cultivated in containers such as plastic bags, nursery plates and PE tubes are transplanted on sites to be revegetated. Plastic bags are suitable for plants required for reforestation or in a large quantity and uniform specifications. Nursery plates are suitable for herbs or flowers or cuttings to be transplanted to sites where direct planting has a low survival rate. PE tubes are used for tree or vine seedlings. This method is employed on sites characterized by shallow soils, large amounts of gravel, severe erosion; or dumped spoil; or where trenching is not feasible; or where fast covering or replanting is needed.

The procedures are as follows:

(1) For plastic bags, the medium is composed of soil, peat moss and fine sand (6:3:1) or soil

and rice hull (4:1). For nursery plates or PE tubes, the medium is composed of soil, peat moss and perlite (1:1:1). The medium for flowers is peat moss, vermiculite and perlite (1:1:1).

(2) Dig planting holes along the contours. The size of planting holes depends on the type of plant . Lay out the planting holes in a triangular pattern.

(3) Remove seedlings from the containers carefully.

(4) Dibbling or broadcast seeding is used in combination with hole planting for fast rehabilitation.

Chapter 4. Revegetation in Problem Areas

In Taiwan, revegetation is very difficult in some problem areas, including tablelands with red soils, sand dunes on coasts, mudstone areas, and mining wastes.

4.1 Revegetation on tablelands with red soils

Tablelands with red soils are common in hilly areas near coasts or on river terraces in west Taiwan. To protect and stabilize the slopes in these areas, appropriate treatments in combination with vegetation measures need to be designed and performed.

(1) Site preparation

a. Soil improvement: the pH value of red soils ranges from 5.4 to 4.2, therefore application of organic fertilizer at 2-4 kg/m^2 is needed.

b. Drainage: for disposal of runoff from slopes, longitudinal drainage ditches at a spacing of 30-50 m and horizontal ones at a spacing of 5-7 m should be dug.

c. Slope ratio: in principle 1:1.5; but adjustments can be made according to the application method employed.

(2) Application methods

For tablelands with red topsoils, grass sprig planting, hydroseeding, vegetation belts or hole planting can be employed. For those with gravel deposits, grass sprig planting, hydroseeding, hole planting or soil bags can be used.

4.2 Revegetation in mudstone areas

Mudstone areas have soils with high salinity and a high clay content. The soil becomes very hard when dry and very susceptible to erosion when wet. Therefore revegetation is urgently needed in mudstone areas, which are mainly located in southeastern Taiwan. After vegetation is established, surface erosion is reduced, weathering layers are anchored by plant roots and the landscape will become green and more pleasant to the eye. The method is applied on artificial slopes. The design and work procedures are described as follows:

(1) Site preparation

a. Shaping: the slope ratio is 1:1.5.

b. Drainage: for rapid disposal of runoff from slopes, longitudinal drainage ditches at a spacing of 30-50 m and horizontal drainage ditches at a spacing of 5-7 m are dug.

c. Retaining structures: retaining walls are required to stabilize the toe of slopes, and space should be made available for trapping of sediments.

(2) Application methods

a. Vegetation belts and hydroseeding are applicable in mudstone areas. Higher fertilizer application rates at 1.5-2 kg/m^2 organic fertilizers or 0.05-0.1 kg/m^2 TFC Compound Fertilizer No. 43 are needed.

b. A mixture of suitable grasses and woody plants is to be selected, such as bahia grass, Bermuda grass, peacock plume grass, Crotaria palladia, purple woodnettle, Roxburgh sumac, guava tree and subcostate crap myrtle.

4.3 Revegetation of mine spoil areas and mining pits

Revegetation is carried out in mine spoil areas or on scarps in opencast mining pits in order to improve the landscape. Revegetation can provide ground cover in a shorter time, stabilize surface layers on slopes and improve the living environment for nearby inhabitants. The design and work procedures are as follows:

(1) For mine spoil

a. Site preparation

(i) Shaping: see Chapter 2 "Site Preparation".

(ii) Topdressing of surface soil on excavated slopes.

(iii) Adequate drainage at the toe of slopes and in hollows is necessary.

(iv) Retaining structures and staking and wattling: see Chapter 2.

b. Application methods

Dibbling, broadcast seeding, grass sprig planting, planting of container-grown seedlings and soil bags are applicable. For specifications, see Chapter 3.

c. Plant materials

(i) Live stakes: subcostate crape myrtle, Linden hibiscus, water willow, redfruit fig-tree.

(ii) Woody plants: Taiwan acacia, Roxburgh sumac, purple woodnettle, guava tree.

(iii) Vines: palmate-leaved morning glory, Chinese wedelia siratro, intortum clover.

(iv) Grasses: bahia grass, Bermuda grass, Japanese silver grass, Kentucky 31 fescue.

(2) For scarps in mining pits

a. Site preparation

(i) Dig trenches 15 cm deep and 10-15 cm wide, at a spacing of 50 cm.

(ii) Netting with #14 wires in rhomboid mesh and fixed by anchors (ϕ 1.2 cm, 35-45 cm long).

b. Application methods

(i) Hydroseeding on rock surface

One cubic meter of seed bed materials consists of 60-90 kg bark compost, 3-5 kg calcium superphosphate, 30 kg peat moss, 60-80 kg cement, and 0.8 m^3 sandy loam. One cubic meter of hydroseeding materials is enough to hydroseed 16 m^2 to a depth of 5 cm.

(ii) Hole planting on a rocky surface

(a) Dig six holes for every square meter, each hole 20-30 cm deep and 7-10 cm in diameter. Put media (a mixture of 1/3 bark compost, 2/3 topsoils and some TFC Compound Fertilizer No. 43) into the hole.

(b) Fill in the unwoven cloth soil bag (12 cm × 6 cm) with a mixture of 1/3 vermiculite, 1/3 perlite, 1/3 bark compost, and a little compound fertilizer and seed. Where this mixture is not likely to be washed away, a soil bag is not necessary; materials can be placed directly into the holes. A mixture of seeds of bahia grass, Burmuda grass, purple woodnettle and Artemisia kawakamii is recommended.

(iii) Re-fill the toe of slopes and sow the seeds (Fig. 4-1)

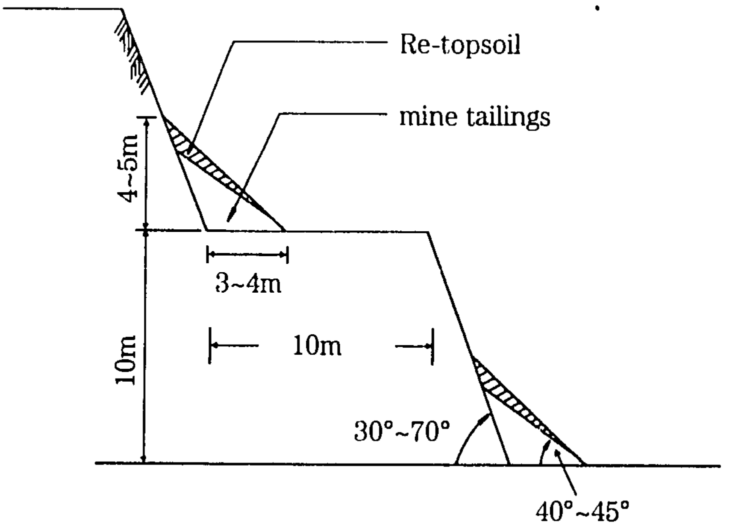


Fig. 4-1. Re-filling of the toe of slopes and direct seeding

(a) Re-topsoil the tailings and then apply fertilizers at 1-2 kg/m^2 (compost) and 200 kg/m^2 (compound fertilizer).

(b) A mixture of the seeds of bahia grass, Bermuda grass, Roxburgh sumac, guava tree and Taiwan acacia is sown, and then a mulch of rice straw mats fixed by hook-shaped nails is applied. Vegetation belts with the above-mentioned plant seeds may also be used.

Revegetation of mine spoil areas should be carried out during the wet season. Native plants should be given priority in the selection of species. Topsoil and good mine wastes should be saved for top-dressing.

4.4 Revegetation of coastal areas

Windbreaks or shelterbelts are established in coastal areas of Taiwan to reduce crop damage caused by strong winds and salt spray, and to improve the living quality of local people. Revegetation can reduce wind and salt damage and fix sand, thus protecting cropland. The procedures are as follows:

(1) Sand fixation structures

433

a. Fence barrier for sand stabilization

Fences are installed in wind erosion areas. Wild sugarcane, railroad vine or littoval spine grass are planted to stabilize sand dunes. Fences are usually made of bamboo strips or bamboo tops. One stake should be set every 4 m, and each stake should stand 1 m above the ground and 50 cm below the surface (Figure 4-2).

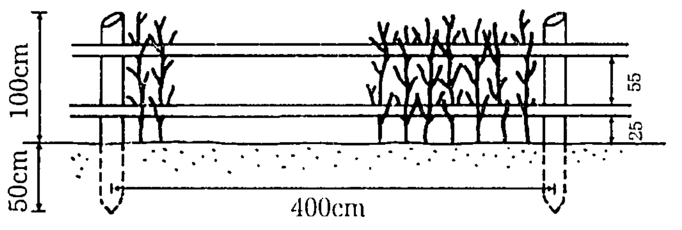


Fig. 4-2. Fence barrier for sand stabilization

The angle between the fence barrier and wind direction should be between 60° and 90°. The spacing of fences is usually 12 times the height of the fences, which is usually 1 m. The optimum density of fence barrier is 25%.

b. Rice stubble can be used as an obstruction to the wind in sand dunes.

c. Suitable plants for sand fixation are sea-purslane, railroad-vine, wild sugarcane, littoral spine grass and chaste-tree.

(2) Windbreaks along coasts

a. Suitable plants

Casuarina, Linden hibiscus, Indiapoon beauty-leaf, Odollam cerberus-tree and scaevola.

b. Width of windbreaks

>80 m

c. Plant seedlings (take casuarina for example) at 1 m × 1 m spacing; dig hole (30 cm deep and wide) if necessary; apply fertilizer and borrowed soils before planting.

d. Planting at inhospitable sites

(i) mud or saline area

Ridges, 1 m wide and 1 m high, should be constructed by bulldozers to facilitate salt leaching. Suitable plants are planted on ridges, with a windbreak nets on the windward side.

(ii) windy areas, or areas affected by salt spray

Ditches 0.3-0.5 m deep and 1-1.5 m wide, and ridges 0.3-0.5 m high are built. Saplings of wind-resistant trees are then planted in the ditches, with wind-resistant or salt-tolerant shrubs on the ridges.

(3) Windbreaks on farmland

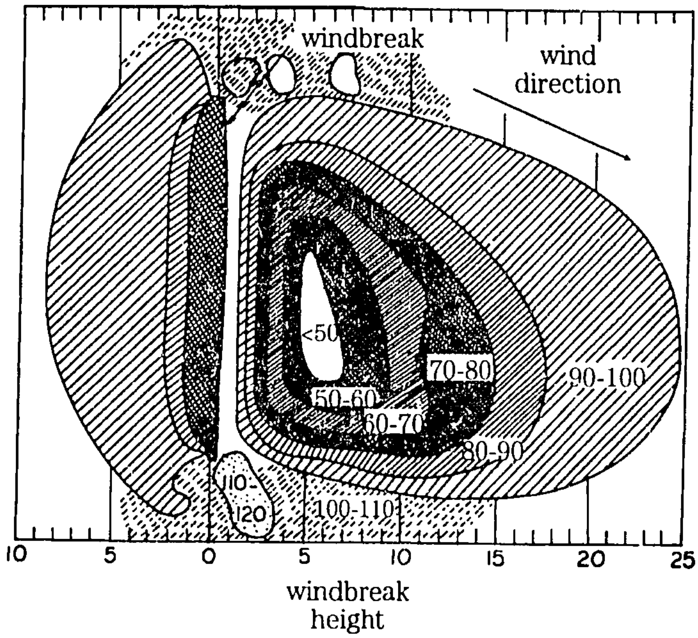
a. Suitable plants

232

Casuarina, long-shoot bamboo, Chinese hibiscus, hedge bamboo, Linden hibiscus, sweet-scented oleander, wild sugarcane, screw-pine.

b. Specification

(i) Height: The effectiveness of a windbreak depends on its height (Figure 4-3).



This chart shows the percentage of normal wind velocity near a windbreak with an average density of 50% (Redrawn from Bates, 1944)

Fig. 4-3. Correlation between windbreak height and windbreak effect

(ii) Density: A higher density of plants is more effective in reducing wind velocity, when the windbreak has only a single row of plants. For casuarina windbreaks, a density of 60-80% is optimum.

(iii) Direction of windbreak: For a wind speed of less than 15 m/s, it is normal to keep a 90° angle to the prevailing winds; for a wind speed greater than 15 m/s, the angle between the windbreak and prevailing wind direction should be 65°~75°.

Chapter 5. Maintenance and Management

Maintenance and management should be undertaken after planting to ensure good survival rates and growth. In general, this work includes fertilization, watering, replanting and pest and disease control.

5.1 Watering

Plants tolerant to drought should be chosen for dry sites where the water supply is limited. Planting should be carried out in the wet season. During a very dry spell, watering may be undertaken to help plants survive.

5.2 Fertilization

(1) Fertilizers.

a. Chemical fertilizers.

Fertilizer is usually applied at or after planting. On low-fertility or sub-soil sites, several maintenance applications of fertilizer may be required.

For revegetation work in Taiwan, the typical application rate is 500 kg/ha of TFC compound fertilizer No. 43 (15% N, 15% P_2O_5. 15% K_2O, 4% MgO).

b. Organic fertilizers

Organic fertilizers include those which do not readily decompose, such as peat moss, bark compost, and those which decomposed rapidly such as manure and garbage compost. Most sites to be revegetated are low-fertility, so that an initial application of organic fertilizers at planting sites is required.

(2) Application rates and periods

a. Ground cover plants (including grasses): Initial application rate: 2 kg/m^2 organic fertilizer and 0.05 kg/m^2 TFC Compound Fertilizer No. 43. Maintenance application rate: 0.05 kg/m^2 TFC Compound Fertilizer No. 43, or other equivalent chemical fertilizers.

b. Shrubs

Initial application rate: 2 kg compost per seedling. An additional application is carried out 60 days after planting, if necessary, at 2 kg compost or 0.05 kg TFC Compound Fertilizer No. 43 per seedling.

c. Trees

Initial application rate: 4 kg compost per tree. An additional application is carried out 60 days after planting, if necessary, at same application rate or 0.05kg TFC Compound Fertilizer No. 43.

For ground cover plants, fertilizer should be applied evenly over the area. Watering is performed right after fertilizer application. If fertilizer is placed in the planting hole, a layer of borrowed soils, 5-10 cm, should be put in to ensure that the fertilizer will not damage the roots.

5.3 Replanting

After the seeds of soil conservation plants are sown, resowing may be needed to compensate low germination rates, wilting, poor initial growth, and losses when seeds are washed away or from pests and diseases. After grass or seedlings are planted, attention should be paid to the growth conditions, vigor and symptoms of diseases or pests. Replanting should be carried out for those plants affected by improper planting or poor management or suffering from pests or diseases.

5.4 Pest and disease control

To prevent pests and diseases, the following measures should be taken:

(1) Choose plants that are adapted to the local environment.

(2) Sow mixtures of different plant seeds.

(3) Choose healthy seedlings

(4) Provide hospitable sites with such features as good drainage, air circulation, and timely application of fertilizers.

When symptoms of pests or diseases are noticed on soil conservation plants, diagnosis should be made and then control measures taken. Diseases of common soil conservation plants of Taiwan are listed in Table 5-3.

Table 5-1. Major nutrient content of common chemical fertilizers

Fertilizers	Nutrients (%)			
	N	P_2O_5	K_2O	MgO
Ammonium sulfate	21			
Calcium ammonium nitrate	20			
Urea	46			
Calcium superphosphate		18		
Potassium sulfate			50	
Potassium chloride			60	
Taiwan Fertilizer Company compound fertilizer No. 1	20	5	10	
Taiwan Fertilizer Company compound fertilizer No. 5	16	8	12	
Taiwan Fertilizer Company compound fertilizer No.43	15	15	15	4

Table 5-2. NPK content of common organic fertilizers

Organic fertilizer	NPK content (%)		
	N	P_2O_5	K_2O
Taiwan Fertilizer Company organic fertilizer No. 1	1.5	4.0	3.0
Bark compost	1.14	0.77	0.36
Peat moss	0.5 - 1.0	0.1 - 0.3	0.4 - 1.0
Peat soil	0.8 - 1.8	0.1 - 0.5	0.6 - 1.5
Plant ash	—	1 - 2	4-10
Soybean meal	7.52	1.77	2.77
Fish meal	7-10	7 - 10	—

Table 5-3. Common diseases of plants used in erosion control

Host plant	Pathogen
Wild sugarcane Saccharum spontaneum	Cercospora longipes
	Mycovellosiella vaginae
	Mycoplasma like organism
	Pucciia melano-cephala
	Ustilago scitaminea
	Virus
White clover Trifolium repens	Pellicularia rolfsii
Railroad vine Ipomoea pescaprae	Cercosporai pomoeae
Chinese lespedeza Lespedeza cuneata	Uromyces lespedezael-procumbenti
Taiwan acacia Acacia confusa	Cephaleuros virescens
	Corticium salmonicolor
	Daldinia concentrica
	Fomes robustus
	Ganoderma applomatum
	Ganoderma lucidum
	Ganoderma rugosum
	Ganoderma tropicum
	Meloidogyne incognita
	Meliola koae
	Phaeosaccardimula javanica
	Phomopsis acaciae
	Poliotelium hyalosporus
	(=Uromyces hyalosporus)
	Pseudocercospora acaciconfusae
	Pseudocercospora hyaloconiddiophora
	Septobasidium acaciae
Roxburgh sumac Rhus semialata var. roxburghii	Exosporella rhois-javanicae
	Meliola brachuyodonta
	Mycosphaerella rhois

Host plant	Pathogen
Roxburgh sumac Rhus semialata var. roxburghii	Pileolaria klughistiana
	(=Uromyces klughistianus)
	Tuberculeria phyllophila
	Uromyces toxicodendri
	Venturia rhois
Subcostate crape myrtle Lagerstoremia subcostata	Uncinula austualiana
	Pseudocercospora lythracearun
Linden hibiscus Hibiscus tiliaceus	Gloeosporium hibisci-tiliacei
	Gnomomella hibisci
	Phragmodothis hibisci
	Phyllachora minuta
Formosan alder Alnus formosana	Hypocapnodium setosum
	Ovulariopsis alni-formosanea
	Phyllactinia corylea
	Sphaceloma alni
	Phizoctonia solani
Bermuda grass Cynodon dactylon	Cerebella cynodontis
	Curvularia sp.
	Bipolaris sp.
	Fusarium equiseti
	Fusarium sporotrichoides
	Marasmiuns sp.
	Lycoperdon sp.
	Clitocybe sp.
	Hyphoderma cynodontis
	Mycoplasma like organism
	Nigrospora sp.
	Phyllachora cynodontis
	Pythium aphanidermatum
	Puccinia cynodontis

444

Host plant	Pathogen
Bernyda grass Cynodon dactylon	Rhizoctonia cerealis
	Rhizoctonia solani
	Ustilago cynodontis
Perennial ryegrass Lolium perenne	Pellicularia rolfsii

Table 5-4. Principal pests of plants used in erosion control

Host plant	Pests
Bermuda grass Cynodon dactylon	Spodopera litura (Fabricius)
	Agrotis ypsilon Rottenberg
	Gryllotalpa africana Palsot Beauvois
	Brachytrupes portentosus Lichtenstein
	Catantops humils Serville
	Catantops pinguis Stal
	Ceracris migricornis Laeta
	Oxya velox (Fabricius) Bolivar
	Scotinophara Scotti Horvath
	Cicadas
	Aphids
Taiwan acacia Acacia confusa	Erehesina fullo Thunberg
	Planococcus citri (Risso)
	Zeuzera coffeae Nietner
	Clania pryeri Leech
	Lymantria xylene Swinhoe
	Notolophus australis-posticus Walker
	Trabada ishnou Lefebure
	Scarabs
	Stromatium longicorne Newman
Roxburgh sumac Rhus semialata var. roxburghii	Schlechtendalia chinensis (Bell)
	Homona menciana
	Philosamia cynthia Pryei (Butler)
Subcostate crape myrtle Lagerstoremia subcotata	Aulacaspis crawii (Cockerell)
	Notolophus australis-posticus Walker
Linden hibiscus Hibiscue tiliaceus	Aulacaspis mangiferae Newstead
Formosan alder Alnus formosana	Notolophus australis-posticus Walker
	Aeolesthes induta Newman
	Linaeidea formosana (Bates)
Purple woodnettle Boehmeria deniflora	Sylepta pernitescens Swinhoe

447

Chapter 6. Survey and Analysis of Vegetation

6.1 Measurement of vegetative population

In an ecological survey and analysis of vegetation, the following measuring systems are used:

(1) Density (or abundance): the number of plants of a species in one quadrat.

(2) Frequency: the number of quadrats in which a species appears.

(3) Coverage: The area of canopy, or the area of ground occupied by floor stratum plants.

In addition, biomass and leaf-area index are also often used. Biomass is usually expressed by the fresh weight in a quadrat. Leaf-area index means the ratio of the total area of leaves of a plant population against the total ground area in a quadrat.

6.2 Size of quadrat

The following quadrat sizes are recommended by Cain and Castro (1959) for sampling of various vegetative strata:

Stratum of moss and lichens	0.01-0.1 m^2
Herbaceous stratum	1-2 m^2
Stratum of low shrubs and tall grass	4 m^2
Stratum of tall shrubs	16 m^2
Tree stratum	100 m^2

6.3 Integration of population measurements

When the above-mentioned three measurements are appraised individually, each may reflect a specific feature of a population. For instance, coverage (or dominance) may express the degree of dominance of a species; density may show the size of a population, and frequency may illustrate the extent of distribution of a species. However, as the size of species varies widely, with a single measure it is impossible to tell the mutual relationship and resource allocation among different species. Therefore, for ecological study of vegetative populations, analysis rarely depends on only one measure, and usually depends on a combination of several measures.

6.4 Importance Value Index (IVI)

This index is the result of integrating the above-mentioned three measures. Since the values of density, frequency and coverage are expressed in different units, they can be integrated only on the basis of their relative values. Under the IVI system, the maximum value of the index is fixed at 300.

IVI = Relative density + Relative frequency + Relative dominance

$$\text{Relative density} = \frac{\text{Number of plants of a species}}{\text{Total number of plants of all species}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}}$$

$$\text{Relative dominance} = \frac{\text{Coverage of a species}}{\text{Coverage of all species}}$$

6.5 Determination of species diversity

The more species a vegetative community includes, the less it will be subject to interference by external influences. Therefore, the degree of complexity of a community is correlated with the stability of the same community. The complexity of a vegetative community may be expressed as follows:

(1) Species richness

$R = S / N$

S: Total number of species in a community

N: Total number of plants in a community

(2) Simpson's index of diversity

$D_{si} = 1 - \sum(ni / N)^2 = 1 - \sum(P_i)^2$

ni: Number of plants of species i

N: Total number of plants in the community

P_i: ni / N

(3) Shannon's index of diversity

$D_{sh} = -\sum(ni / N) \times \log(ni / N)$

$= -\sum(P_i) \times \log P_i$

The minimum value will be 0, when species number (S) equals 1, and ni equals N; that is

$D_{sh} = -(1) \times \log 1 = 0$

The maximum value will be log S, that is, when all P_i values equals 1/S.

6.6 Seed germination rate

A survey of seed germination rate should be performed with random sampling. In principle, quadrats of 1 m × 1 m are desirable. However, when only herbaceous plants are involved, the quadrat may be reduced to 20 cm × 20cm; but the values obtained thereby should be converted to fit the 1 m × 1 m quadrat. One quadrat should be set for every 1000 m^2 of work area. When a slope face is completely seeded with grass seeds, by either broadcasting or hydroseeding, the average germination rate after one month should be over

1000 plants/m^2. When seeds of wood plants are mixed with herbaceous plant seeds, the germination rate of wood plant should be no less than 3 plants per square meter.

6.7 Coverage

Vegetative cover is calculated on the basis of the area of shade projected by a plant vertically onto a slope surface. On an improved earth slope, or on a slope evenly covered by a thick layer of borrowed soil, four months after the seeding of grass, if adequate maintenance has been provided during this period, a 90% coverage should be attained. On a slope which is partly covered by borrowed soil, or on a slope where mining has taken place, the average coverage should reach 80%. On a slope face consisting of rubble or exposed bed rock, it will be difficult for plants to grow, although seeds still may germinate in the crevices among rocks. In this situation, the expected coverage after four months is 30%. The rational equation for computation of design coverage (R) is as follows:

CR=100 [(0.8 × ratio of earth slope face) + (0.3 × ratio of rocky slope face)] %

When a slope face is extremely rocky, it should be treated with borrowed soil or other improvement measures to provide a better environment for vegetation. If this is done, a coverage of 50% should be attained four months after seeding. On a very rocky slope where grasses or low shrubs exist, if it is difficult to carry out sampling in quadrats, a survey may be carried out by the line intercept method. By this method the percentage of coverage may be obtained, but not the number and density of plants of a species.

445