GOVERNMENT OF PAKISTAN
UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT
IRRIGATION SYSTEMS MANAGEMENT PROJECT

TECHNICAL CRITERIA FOR REHABILITATION OF CANAL SYSTEMS IN PAKISTAN

prc
PRC Engineering / CHECCHI

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SECTION 1: INTRODUCTION

A. General

These design criteria for rehabilitating canals in Pakistan were developed by PRC/Checchi as part of the Irrigation System Management (ISM) Project co-financed by the United States Agency for International Development (USAID) under the USAID/PRC Contract # 391-0467-66-00-7011-00, dated 03-17-1984. The criteria were prepared with the cooperation of the Provincial Irrigation Departments and are based on the latest technology available and conditions specific to alluvial channels in Pakistan.

Many of the Canal Systems are currently being operated with flows in excess of the original design capacity of the canal; in some cases with a flow of 150% of design capacity. The excessive discharges have caused damaged to banks. Preventive Maintenance of canal banks is not practiced. Maintenance is often deferred until a major problem occurs, after which it is repaired.

Unlined irrigation and drainage channels are subject to both sediment deposition and erosion. The capacity of the channels often diminishes rapidly after construction due to sediment deposition, bank sloughing, weed growth and unplanned obstructions. Furthermore, infiltration losses can be high in unlined canals due to poorly sorted and compacted banks and beds, and seepage can increase dramatically as burrowing animals and insects invade the embankments. Seepage losses can be decreased by proper selection and compaction of the bank and/or bed and by deposition of fine silt and clay particles.

Still there are many advantages to using unlined channels for irrigation projects. Unlined channels have a low initial cost and require a minimum of construction material. The channels are simple to construct and can make maximum utilization of unskilled rural labor. In addition, unlined channels are often favored because of the ease with which modifications can be made as inadequacies are identified. Unlined channels may require considerable annual maintenance to keep them in good operating condition.

When rehabilitating unlined irrigation channels every effort should be made to minimize future maintenance costs through sound design procedures. This includes not only the essential hydraulic design involving discharge and velocity, but also the design of the channel against both erosion and sediment deposition. Water surface profiles must be determined over the range of operating discharges with the future sediment loads expected.

Some constraints were placed in this design criteria due to the USAID contract under which it was prepared. These include adequacy of the original design canal capacities and/or current capacities are not to be evaluated. The design capacities provided by the Provincial Irrigation Department will be used in all designs for rehabilitation. Canal structures are assumed to be adequate with respect to function. Local drainage is not to be considered unless inflows to the canal cannot be avoided. The emphasis is on bringing the canals to the carrying capacity designated by the PID and to minimize sediment accumulations. Hydraulic design criteria are of primary importance. Other non-hydraulic criteria presented herein must also be met by the designer.

These design criteria provide the guidelines to be used by the engineer in preparing designs, construction drawings, and tender documents for the contractor. The design criteria is the basic tool used to arrive at a sound, logical and safe design. Obviously, all engineering information, assumptions, and judgments are not design criteria even though they are used in the final design of a canal or structure.

The design for rehabilitating an irrigation and drainage system is complex enough that it is not possible to anticipate all of the situations that may confront the design engineer. Therefore, it is assumed that the project engineer may be required to issue additional project specific criterion during the course of the design period. The procedures for this are as follows:

1. The proposed criterion addition, change, etc., is prepared in memorandum form by the project design engineer.

2. The memorandum should be circulated through the design staff for review and comments thus ensuring that it is a design criterion and not a design detail and that the staff concurs in its applicability.
3. The addendum criterion is then issued by the project manager.

B. <u>Intent</u>

The rehabilitation of unlined alluvial canals should be cost effective. Therefore, the designer should modify canal sections only where needed to provide required flow and sediment carrying capacity. Through deposition the existing banks have accumulated fine sediments which make them more stable and impervious than the original bank materials. To be cost effective only construction that improves hydraulic and sediment transporting performance should be accomplished; this will usually result in a canal section that does not have the well graded appearance of new canal construction. The following is given as design guidance to preserve the most desireable features of the existing canal prism during rehabilitation:

1. Generally the canal bottom width should not be narrowed because the existing naturally formed water tightness and stability could be impaired. If greatly oversized, "killa-bush" spurs or other passive methods may be used for narrowing.
2. It is preferable to restrict canal widening to only those sections that are undersized. In the case where right-of-way permits, it is more effective to move only one existing bank.
3. Where canal capacities have been reduced due to sedimentation, restoration of freeboard and strengthening of embankments must be accompanied by desilting the canal to restore capacity.

The existing water surface elevations control the discharge to the watercourses and their command areas. The hydraulic design to pass the design flow and sediment may require changes, on the order of 0.5 foot or less, may be acceptable. Changes greater than this may require the remodelling of the outlets.

SECTION 2

HYDRAULIC CRITERIA

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SECTION 2 : HYDRAULIC DESIGN CRITERIA, CANALS

A. General

The hydraulic design criteria (HDC) for rehabilitating alluvial canals with sand beds and sediment loads are contained herein. Three separate conditions are considered:

1. Unlined alluvial canals with sediment transport.
2. Large canals, lined sides with sediment transport.
3. Small lined canals with sediment transport.

The purpose is to design stable alluvial canals or canals with sediment transport. The HDC is based on the latest technology in the field that includes more relevant parameters than Lacey, particularly with regard to sediment transport. The new parameters include sediment grainsize, bed load sediment concentrations, water temperature, bed forms such as dunes and ripples, bank stability as well as the older roughness factors, velocity, and width to depth ratios. The HDC provides a single design for each channel and makes it possible to estimate the average annual desilting required and allows the engineer to select appropriate sites for removal using sediment traps.

A selected part of the equilibrium canal data which WAPDA and later ACCA have collected were used to develope the design criteria. The equilibrium data covered canals with discharge ranging from 30 to 10,000 ft^3/s, slopes ranging from 0.000333 to 0.00005 and sands with median sieve sizes from 75 to 300 micron.

The criteria for non-erodible bank conditions are presented to cover special conditions where right-of-way problems prevent widening and velocities are high. Lining of small channels is often required to reduce seepage losses and maintenance.

Supporting data for HDC and results of comparisons of width, depth-velocity and sediment transport relations are presented in the separate reports: "Study to Establish Hydraulic Design Criteria for Pakistan Irrigation Systems" and "Guidelines for Preliminary Design of Canals in the Rehabilitation Project".

B. Unlined Alluvial Canals with Sediment Transport

1. Water Discharge

General Consideration - The requirement of the canal is to deliver an amount of water equal to the sanctioned discharge to the service area.

Criterion - The determination of the sanctioned discharge is beyond the scope of these criteria. Herein, it is assumed that the design water discharge is known at all locations in the canal. Water will be proportioned to all outlets as equitably as possible throughout the normal range of flows.

2. Incoming Sediment Load

General Consideration - Sediment accompanies the water entering the headgate of the canal. The amount and sizes of this sediment determine how the canal functions and what the equilibrium condition will be.

Criterion - The annual cycle and long-term projections of the amount and sizes of the sediment inflow must be estimated. The annual variation can be obtained by sampling the sediment at the headgate. The long-term variation is estimated by studying the supply and transport of sediment in the rivers which are the water sources for the canal. Upstream dams and operation of the barrages have a major influence on the supply of sediment.

3. Canal Alignment

General Consideration - The alignment of the canal is an important consideration in the initial design. The alignment is chosen to supply a command area at a minimum capital cost.

Criterion - The alignment for the rehabilitated canal is unchanged. Bank protection must be provided on the portions of bends that are eroding.

4. Bed Slope

General Consideration - The canal bed slope is set so that the canal is capable of carrying sediment load through the headgate without significant changes to the bed elevation. For rehabilitated canals the bed slope can be modified within limits from that which the canal had established prior to rehabilitation, by inserting, changing control elevations or removing structures.

Criterion - As a first estimate, the bed slope is taken as that existing in the field immediately prior to the time of rehabilitation.

5. Bed Material

General Consideration - The sediment on the bed of the canal is molded into sand waves by the flow. The sand waves move downstream, being a significant part of the bed material transport. Movement is dependent on particles size and weight.

Criterion - The size of the bed material is determined by taking samples from the canal and determining their cumulative grainsize distribution in the laboratory. The specific gravity of the sand in canals in Pakistan is 2.65.

6. Water Discharge Over the Sand Bed

General Consideration - The water discharge over the sand bed portion of the wetted portion of the canal boundary is paramount in determining the behavior of the alluvial canal. The water molds the sediment on the bed into bars and smaller sand waves, which are the principal resistance to the flow.

Criterion - The discharge of water over the bottom width of the canal is given by the expression:

$$Q = \left[\left(\frac{z^3}{2(z^2+1)^{\frac{1}{2}}}\right)^{\frac{1}{2}} \frac{h}{b} + 1\right] Q_b \qquad (1)$$

in which Q_b = Water discharge over the bottom width of the canal, ft^3/s.

Q = Design water discharge for the canal, ft^3/s.

z = Side slope (z horizontal to 1 vertical).

b = Bottom width of the canal, ft.

h = Depth of flow, ft.

7. Bottom Width

General Consideration - The bottom (or bed) width of the canal is chosen so that the flow does not cause unwanted erosion or deposition on the banks of the canal. Canals with soil banks with large values of cohesion can be narrower than those with low cohesion.

Criterion - The bottom width is determined from the expression:

$$b = K_s\ (Q_b)^{\frac{1}{2}} \qquad (2)$$

in which K_s is a coefficient determined from field measurements and b and Q_b are as defined previously. No canals shall be narrowed.

Field measurements of width and other factors which affect width shall be made. The following values should be used to make a tentative estimate of bed width for canals with cohesive banks:

	K_s
Sind canals	2.2
Punjab canals	2.6

When the estimated width is no more than 1.1 times the existing width, no widening shall be done. When the estimated width is greater than 1.1 times the existing width, field investigations must be conducted to determine if the soil which will form the bank of the enlarged section is the same as that in the existing banks. When the soil contains significantly more sand but is still cohesive, the value of K_s should be increased to 3.0. Sandy and gravelly soils without cohesion are not stable for canal banks and if encountered, stabilizing of the banks will be required. Alternatively, the canal can be over excavated and banks created with "Killa-bush" spurs or with compacted clay lining.

8. Side Slopes

General Consideration - Flatter canal side slopes are more stable but fine sediment carried in the flow may deposit on the slope forming a berm and in effect, steepening the slope.

Criterion - The side slope of the canal before rehabilitation are measured in the field. When no measurements are available, the side slope is estimated as 0.5 horizontal to 1 vertical.

9. Depth of Flow

General Consideration - The normal depth of flow in the canal is the result of the balancing of the downstream component of the gravity force acting on the fluid and the shear and pressure forces of the canal boundary resisting movement of the field.

Criterion - The average depth of flow over the bottom width of the canal is:

$$h = \left(\frac{f}{8gi}\right)^{1/3} q_b^{2/3} \qquad (3)$$

in which
- h = Average depth of flow, ft.
- f = Darcy's friction factor, no units.
- i = Bed slope of the canal, ft/ft.
- q_b = Water discharge per unit width over the bottom width, q_b/b.
- g = Acceleration due to gravity, 32.2 ft^2/s.

10. Flow Velocity

General Consideration - The average velocity of the water flowing over the bed of the canal is the principal measure of transport, for both water and sediment.

Criterion - The velocity of water flowing over the bed of the canal is:

$$V = \left(\frac{8ghi}{f}\right)^{1/2} \qquad (4)$$

in which V = Average water velocity over the bed, ft/s.

The velocity for the design discharge should not exceed a Froude number of $0.25\ (gh)^{1/2}$ which ensures being in the low flow regime.

11. Darcy's Friction Factor

General Consideration - The friction factor is a roughness coefficient having two components; one is the roughness resulting from the movement of the fluid over the particles of sand on the bed (grain roughness); the other caused by the movement of the water over the sand waves formed on the bed by the flow (form roughness).

Criterion - Darcy's friction factor is estimated from field measurements of h, q_b and i for flow within 10% of the design discharge prior to rehabilitation. Equation (3) is employed. When no measurements are available the function is estimated from the expression:

$$f = 8\left[5.75 \log \left(\frac{12h}{3D_{90} + \kappa}\right)\right]^{-2} \qquad (5)$$

in which log = Logarithm to the base 10.

D_{90} = Equivalent sieve size of the bed material for which 90% is finer by weight, ft.

κ = Roughness parameter for sand waves on the bed, ft.

The roughness parameter κ is defined as:

$$\kappa = \kappa_{ripple} + \kappa_{dune}$$

The ripple roughness (κ_r) is directly related to the velocity:

κ	=	0.3	for $V < 1.3$ (ft/s)
κ	=	0.3[(2.5-V)/1.2]	for $1.3 \leq V < 2.5$ (ft/s)
κ	=	0	for $V > 2.5$ (ft/s)

The dune roughness (κ_d) is defined as:

$$\kappa_d = 1.1\ \Delta\ [1-\exp(-25\ \frac{\Delta}{\lambda})] \tag{6}$$

in which Δ = Average height of the sand dunes on the bed, ft.

λ = Average wave length of the sand dunes on the bed, ft.

λ = 7.3 h.

The component of the friction factor which is due to sand grain roughness alone is:

$$f' = 8[5.75\ \log\ (\frac{12h}{3D_{90}})]^{-2} \tag{7}$$

12. Sand-Wave Height

General Consideration - The sand dunes which form on the canal bed create a retarding pressure force on the flow. The magnitude of this force is proportional to the height of the sand dunes.

Criterion - The average height of the sand dunes is determined from echo soundings of the canal bed during periods of high flow. When no measurements are available, the average dune height is estimated from the expression:

$$\Delta = 0.11h(\frac{D_{50}}{h})^{0.3}\ [1-\exp(-0.5\ T_s)]\ (25-T_s) \tag{8}$$

in which D_{50} = Equivalent sieve size of the bed material for which 50% is finer by weight, ft.

T_s = Dimensionless shear parameter defined as:

$$T_s = \frac{\Theta'}{\Theta_c} - 1 \tag{9}$$

in which Θ' = Shields parameter for the flow over the sand grains.

Θ_c = Critical Shields parameter.

The Shields parameter for the flow over sand grains is:

$$\Theta' = \frac{f'\ V^2}{8gD_{50}(S_s-1)} \tag{10}$$

The specific gravity (S_s) is 2.65 for the sand in Pakistan canals.

The value of critical Shields parameter are obtained from the following:

Particle Parameter Range	Critical Shields Parameter
$D_* \leq 4$	$\Theta_c = 0.24\ D_*^{-1}$
$4 \leq D_* \leq 10$	$\Theta_c = 0.14\ D_*^{-0.64}$
$10 < D_* \leq 20$	$\Theta_c = 0.04\ D_*^{-0.1}$
$20 < D_* \leq 150$	$\Theta_c = 0.013\ D_*^{0.29}$
$D_* > 150$	$\Theta_c = 0.055$

The particle parameter (D_*) is:

$$D_* = D_{50}\left[\frac{(S_s-1)g}{\nu^2}\right]^{1/3}$$

in which ν = Kinematic viscosity of water, ft^2/sec and the variables are as previously defined.

The kinematic viscosity of water is a function of its temperature and is estimated from the expression:

$$\nu = [1.23 - 0.333(t-15) + 0.00073\ (t-15)^2]\ \times\ 10^{-5} \qquad (12)$$

in which T = Water temperature, ° Celsius.

The water temperature in the canal varies from 15° to 35° Celsius throughout the year. The temperature for design should be selected from that period in which the canal is running at peak discharge. If there are no temperature data available, a value of 25° Celsius is suitable for all of Pakistan.

13. Sediment Transport Capacity

General Consideration - The water flowing in the canal carries some of its sediment load as particles in suspension (suspended load) and the rest as particles rolling, sliding or bounding along the bed (bed load). That part of the suspended load consisting of sizes smaller than those found in appreciable quantities on the bed is known as wash load. The sum of the remainder of the suspended load and the bed load is called the bed material load.

The flowing water has the capacity to carry a certain amount of sediment. When more sediment is added to the flow than the canal is capable of carrying, deposition occurs. Conversely, when the canal is capable of carrying more sediment than is being supplied at the headworks, the flow picks up sediment from the bed and erosion occurs.

Criterion - All material finer than 0.0625 mm is considered wash load which can be transported at all concentrations without deposition on the bed.

The capacity of the canal to transport bed materials is determined by measurements in the field. When there are no measurements, the bed material load is estimated from the expression:

$$S_t = \frac{0.4b\ (h \times i)^{2.5}\ g^{0.5}}{(S_s - 1)^2\ D_{50}\ f} \qquad (13)$$

in which S_t = Bed material transport rate, ft^3/s.

14. Sediment Balance

General Consideration - When the inflow of bed material sediment is not equal to the transport capacity of the canal, the canal bed aggrades or degrades. In equilibrium canals, the bed aggrades and at other times it degrades during the year. When these variations of the bed level are within acceptable limits over a long period of time and the canal banks are stable, the canal is said to be "in-regime".

Criterion - The "in-regime" condition for the canal bed is obtained by achieving a balance between sediment inflow and transport capacity. The balance everywhere along the canal is :

$$\int_0^{t_1} (S_s - S_t)\,dt = 0 \qquad (14)$$

in which

S_i = Inflow of bed material load, ft^3/s.

S_t = Transport capacity of the canal, ft^3/s.

t = Time

t_1 = A long period of time. As a minimum $t_i \geq$ 1-year.

C. Large Canals, Lined Sides With Sediment Transport

The lining of canal banks is costly. There are three main reasons for which lining would be required in a rehabilitated canal: 1) reduce seepage losses, 2) reduce right-of-way requirements of a canal flowing through a village or populated area, and 3) reduce the maintenance problems due to animal and people trespass. Without detailed studies and economic analysis it is seldom appropriate to line the channel bottom of large canals. The sides are lined to prevent bank erosion. The decision to line the banks is based on economics. The following only concerns the hydraulic criteria required for such a design.

1. Water Discharge

General Consideration - The requirement of the canal is to deliver an amount of water equal to the sanctioned discharge to the service area.

Criterion - The determination of the sanctioned discharge is beyond the scope of these criteria. Herein, it is assumed that the design water discharge is known at all locations in the canal. Water will be proportioned to all outlets as equitably as possible throughout the normal range of flows.

2. Incoming Sediment Load

General Consideration - Sediment accompanies the water entering the headgate of the canal. The amount and sizes of this sediment determine how the canal functions and what the equilibrium condition will be.

Criterion - The annual cycle and long-term projections of the amount and sizes of the sediment inflow must be estimated. The annual variation can be obtained by sampling the sediment at the headgate. The long-term variation is estimated by studying the supply and transport of sediment in the rivers which are the water sources for the canal. Upstream dams and operation of the barrages have a major influence on the supply of sediment.

3. Canal Alignment

General Consideration - The alignment of the canal is an important consideration in the initial design. The alignment is chosen to supply a command area at a minimum capital cost.

Criterion - The alignment for the rehabilitated canal is unchanged.

4. Bed Slope

General Consideration - The canal bed slope is set so that the canal is capable of carrying sediment load through the headgate without significant changes to the bed elevation. For rehabilitated canals the bed slope can be modified within limits from that which the canal had established prior to rehabilitation, by inserting, changing control elevations or removing structures.

Criterion - As a first estimate, the bed slope is taken as that existing in the field immediately prior to the time of rehabilitation.

5. Bed Material

General Consideration - The sediment on the bed of the canal is molded into sand waves by the flow. The sand waves move downstream, being a significant part of the bed material transport. Movement is dependent on particles size and weight.

Criterion - The size of the bed material is determined by taking samples from the canal and determining their cumulative grainsize distribution in the laboratory. The specific gravity of the sand in canals in Pakistan is 2.65.

6. Water Discharge Over the Sand Bed

General Consideration - The water discharge over the sand bed portion of the wetted portion of the canal boundary is paramount in determining the behavior of the alluvial canal. The water molds the sediment on the bed into bars and smaller sand waves, which are the principal resistance to the flow.

Criterion - The discharge of water over the bottom width of the canal is given by the expression:

$$Q = \left[\left(\frac{z^3}{2(z^2+1)^{\frac{1}{2}}}\right)^{\frac{1}{2}} \frac{h}{b} + 1\right] Q_b \qquad (1)$$

in which Q_b = Water discharge over the bottom width of the canal, ft^3/s.

Q = Design water discharge for the canal, ft^3/s.

z = Side slope (z horizontal to 1 vertical).

b = Bottom width of the canal, ft.

h = Depth of flow, ft.

7. Bottom Width

General Consideration - The bottom (or bed) width of the canal is chosen in combination with the bed slope so that the flow does not cause (net) sedimentation or erosion on the bed of the canal.

Criterion - Determination of the bed width is based on designing an equilibrium canal with respect to sediment transport. Canal bottom widths are set to even feet except widths less than five feet in which case half foot intervals are allowed.

8. Side Slopes

General Consideration - Hydraulic flow conditions are not a factor in determining side slopes of lined banks. Factors that govern selection are:

- bank material(s)
- height of bank
- drainage conditions at toe of bank (potential hydrostatic conditions)
- Operation of the canal
- weight of lining material; resistance of hydrostatic loading conditions.

Choice of side slopes should be based on both bank and lining stability.

Criterion - Bank stability is defined in Section 3.

9. Depth of Flow

General Consideration - The normal depth of flow in the canal is the result of the balancing of the downstream component of the gravity force acting on the fluid and the shear and pressure forces of the canal boundary resisting movement of the field.

Criterion - The average depth of flow over the bottom width of the canal is:

$$h = \left(\frac{f}{8gi}\right)^{1/3} q_b^{2/3} \tag{3}$$

in which
- h = Average depth of flow, ft.
- f = Darcy's friction factor, no units.
- i = Bed slope of the canal, ft/ft.
- g = Acceleration due to gravity, 32.2 ft^2/s.
- q_b = Water discharge per unit width over the bottom width, Q_b/b.

10. Flow Velocity

General Consideration - The average velocity of the water flowing over the bed of the canal is the principal measure of transport, for both water and sediment.

Criterion - The velocity of water flowing over the bed of the canal is:

$$V = \left(\frac{8ghi}{f}\right)^{\frac{1}{2}} \tag{4}$$

in which V = Average water velocity over the bed, ft/s.

The velocity for the design discharge should not exceed a Froude number of 0.25 $(gh)^{\frac{1}{2}}$ which ensures being in the low flow regime.

11. Darcy's Friction Factor

General Consideration - The friction factor is a roughness coefficient having two components; one is the roughness resulting from the movement of the fluid over the particles of sand on the bed (grain roughness); the other caused by the movement of the water over the sand waves formed on the bed by the flow (form roughness).

Criterion - Darcy's friction factor is estimated from field measurements of h, q_b and i for flow within 10% of the design discharge prior to rehabilitation. Equation (3) is employed. When no measurements are available the function is estimated from the expression:

$$f = 8[5.75 \log (\frac{12h}{3D_{90} + \kappa})]^{-2} \qquad (5)$$

in which log = Logarithm to the base 10.

D_{90} = Equivalent sieve size of the bed material for which 90% is finer by weight, ft.

κ = Roughness parameter for sand waves on the bed, ft.

The roughness parameter is defined as:

$$\kappa = \kappa_{ripple} + \kappa_{dune}$$

The ripple roughness (κ_r) is directly related to the velocity:

κ	=	0.3	for $V < 1.3$ (ft/s)
κ	=	0.3[(2.5-V)/1.2]	for $1.3 < V \leq 2.5$ (ft/s)
κ	=	0	for $V > 2.5$ (ft/s)

The dune roughness ( ) is defined as:

$$\kappa_d = 1.1\ \Delta\ [1-\exp(-25\ \frac{\Delta}{\lambda})] \qquad (6)$$

in which Δ = Average height of the sand dunes on the bed, ft.

λ = Average wave length of the sand dunes on the bed, ft.

λ = 7.3 h.

The component of the friction factor which is due to sand grain roughness alone is:

$$f' = 8[5.75 \log (\frac{12h}{3D_{90}})]^{-2} \qquad (7)$$

12. Sand-Wave Height

General Consideration - The sand dunes which form on the canal bed create a retarding pressure force on the flow. The magnitude of this force is proportional to the height of the sand dunes.

Criterion - The average height of the sand dunes is determined from echo soundings of the canal bed during periods of high flow. When no measurements are available, the average dune height is estimated from the expression:

$$\Delta \quad = \quad 0.11\, h\left(\frac{D_{50}}{h}\right)^{0.3} \left[1-\exp(0.5\, T_S)\right] (25-T_S) \tag{8}$$

in which D_{50} = Equivalent sieve size of the bed material for which 50% is finer by weight, ft.

T_S = Dimensionless shear parameter defined as:

$$T_S \quad = \quad \frac{\Theta'}{\Theta_c} - 1 \tag{9}$$

in which Θ' = Shields parameter for the flow over the sand grains.

Θ_c = Critical Shields parameter.

The Shields parameter for the flow over sand grains is:

$$\Theta' \quad = \quad \frac{f'\, V^2}{8gD_{50}(S_s-1)} \tag{10}$$

The specific gravity (S_s) is 2.65 for the sand in Pakistan canals.

The value of critical Shields parameter are obtained from the following:

Particle Parameter Range	Critical Shields Parameter
$D_* \leq 4$	$\Theta_c = 0.24\, D_*^{-1}$
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$10 < D_* \leq 20$	$\Theta_c = 0.04\, D_*^{-0.1}$
$20 < D_* \leq 150$	$\Theta_c = 0.013\, D_*^{0.29}$
$D_* > 150$	$\Theta_c = 0.055$

The particle parameter (D_*) is:

$$D_* \quad = \quad D_{50}\left[\frac{(S_s-1)g}{\nu^2}\right]^{1/3}$$

in which ν = Kinematic viscosity of water, ft^2 and the variables are as previously defined.

The kinematic viscosity of water is a function of its temperature and is estimated from the expression:

$$\nu = [1.23 - 0.333(t-15) + 0.00073\ (t-15)^2] \times 10^{-5} \qquad (12)$$

in which T = Water temperature, ° Celsius.

The water temperature in the canal varies from 15° to 35° Celsius throughout the year. The temperature for design should be selected from that period in which the canal is running at peak discharge. If there are no temperature data available, a value of 25° Celsius is suitable for all of Pakistan.

13. Sediment Transport Capacity

General Consideration - The water flowing in the canal carries some of its sediment load as particles in suspension (suspended load) and the rest as particles rolling, sliding or bounding along the bed (bed load). That part of the suspended load consisting of sizes smaller than those found in appreciable quantities on the bed is known as wash load. The sum of the remainder of the suspended load and the bed load is called the bed material load.

The flowing water has the capacity to carry a certain amount of sediment. When more sediment is added to the flow than the canal is capable of carrying, deposition occurs. Conversely, when the canal is capable of carrying more sediment than is being supplied at the headworks, the flow picks up sediment from the bed and erosion occurs.

Criterion - All material finer than 0.0625 mm is considered wash load which can be transported at all concentrations without deposition on the bed.

The capacity of the canal to transport bed materials is determined by measurements in the field. When there are no measurements, the bed material load is estimated from the expression:

$$S_t = \frac{0.4b\ (h \times i)^{2.5}\ g^{0.5}}{(S_s - 1)^2\ D_{50}\ \ f} \qquad (13)$$

in which S_t = Bed material transport rate, ft^3/s.

14. Sediment Balance

General Consideration - When the inflow of bed material sediment is not equal to the transport capacity of the canal, the canal bed aggrades or degrades. In equilibrium canals, the bed aggrades and at other times it degrades during the year. When these variations of the bed level are within acceptable limits over a long period of time and the canal banks are stable, the canal is said to be "in-regime".

Criterion - The "in-regime" condition for the canal bed is obtained by achieving a balance between sediment inflow and transport capacity. The balance everywhere along the canal is :

$$\int_0^{t_1} (S_1 - S_t)\, dt = 0$$

in which

S_1 = Inflow of bed material load, ft^3/s.

S_t = Transport capacity of the canal, ft^3/s.

t = Time

t_1 = A long period of time. As a minimum $t_1 \geq$ 1-year.

D. Small Lined Canals with Sediment Transport

Small canals are defined as those not where the depth of flow is limited to a maximum of 3.0 feet.

1. Water Discharge

General Consideration - The requirement of the canal is to deliver an amount of water equal to the sanctioned discharge to the service area.

Criterion - The determination of the sanctioned discharge is beyond the scope of these criteria. Herein, it is assumed that the design water discharge is known at all locations in the canal. Water will be proportioned to all outlets as equitably as possible throughout the normal range of flows.

2. <u>Canal Alignment</u>

<u>General Consideration</u> - The alignment of the canal is an important consideration in the initial design. The alignment is chosen to supply a command area at a minimum capital cost while observing ownership and other constraints.

<u>Criterion</u> - The alignment of a rehabilitated canal remain unchanged unless land owners and other agree on a relocation.

3. <u>Bed Slope</u>

<u>General Consideration</u> - The canal bed slope is set so that the canal is capable of carrying sediment load through the headgate or outlet without significant changes to the bed elevation. For rehabilitated canals the bed slope can be modified within limits from that which the original had established prior to rehabilitation, by inserting, changing control elevations or removing structures.

<u>Criterion</u> - As a first estimate, the bed slope is taken as that existing in the field immediately prior to the time of rehabilitation.

4. <u>Bed Width</u>

<u>General Consideration</u> - The width of small canals is limited to a series of standard widths to facilitate construction. Therefore, discharge variances are compensated for in the depth of flow.

<u>Criterion</u> - Design bottoms widths for small lined canals will be limited to 1, 1.5, 2, 2.5 and 3 feet with increments of one foot up to 10 feet.

5. <u>Side Slopes</u>

<u>General Consideration</u> - The side slope for the banks is chosen to minimize construction costs, remain stable under adverse soil conditions and can be constructed by local labor from local materials. The height of bank has considerable effect on stability. Slopes are defined with respect to a variable horizontal distance (z) to a vertical distance of one (1) wherein both units are the same. Steep side slopes cause considerable safety

problems when canal banks exceed 2.5 to 3.0 feet in height because animals and people cannot climb out.

Criterion - Distributaries and minors where height of lining is limited to a maximum of 2.5 feet the value of z will range from 0.3 to 0.5.

Distributaries and minors where the height of lining will be limited to 3.5 feet the value of z will range from 0.5 to 1.

6. Width-to-Depth Ratio

General Consideration - The ratio of canal bed width (b) to depth of flow (h) is chosen to minimize construction costs. The cost of lining usually far exceeds the cost of excavation or fill, ərefore, minimizing the wetted perimeter will generally govern cost.

Criterion - For a trapezoidal section the optimum width to depth ratio (b/h) varies with the side slope (z) as follows:

b/h	Side Slope (z)
2.0	0 (vertical)
1.24	0.5
1.16	0.577 (60°)
0.83	1.0
0.61	1.5
0.47	2.0

7. Manning's Roughness Coefficient

General Consideration - Manning's roughness coefficient is different for a lined canal free of sediment than it is for one transporting sand on its bed. The sand can form waves on the bed increasing the roughness coefficient for the bed portion of the wetted perimeter.

Criterion - Manning's roughness coefficient (n) for lined canals with sand on their beds is:

$$n_2 = n_2 \left[\frac{1 + 2(1+z^2)^{\frac{1}{2}} h/b \, (n_1/n_2)^{3/2}}{1 + 2(1+z^2)^{\frac{1}{2}} h/b} \right]^{2/3} \tag{15}$$

in which n_1 = Manning's roughness coefficient for the canal lining.

n_2 = Manning's roughness coefficient for the sand bed.

z = Water depth over the canal bed, ft.

b = Bed width of the canal, ft.

Values of n_1 for various types of lining are as follows:

Material	New	Aged	Recommended to use for Design
Concrete lined	.014	.018	0.018
Brick masonry	.016	.020	0.020
Rock masonry(smooth)	.016	.020	0.020
Rock masonry (rough)	.020	.028	0.025

The quality of construction work affects the value of ni. The values shown above are for surface finishes which can be realized by normal construction methods, with proper inspection. The value of n_i increases with age due to cracking and aquatic growth.

The value of n_2 for sand ripples on the bed up to 2 inches in height is 0.024.

For reaches of canal which are sinuous, the Manning's roughness coefficient should be increased by 10%.

8. Flow Velocity

General Consideration - The velocity of flow in a canal is the principal measure of transport, for both water and sediment. Low velocities tend to induce sedimentation whereas higher velocities reduce the risk of sedimentation but induce surface waves. In addition, low velocities require greater cross-sectional area hence more lining and possibly increased right-of-way.

Criterion - The velocity in a lined canal can be computed with the Manning's equation:

$$V = \left(\frac{8ghi}{f}\right)^{1/2} \tag{16}$$

in which V = Velocity of water, ft/s.

R = Hydraulic radius of cross-section, ft.

i = Slope of canal, ft.

g = Acceleration of gravity, ft^2/s.

f = The f value for the lined canal can be calculated from $f = (117n^2)R^{1/3}$

in which n = Manning's roughness coefficient for the lined canal.

Velocity for full supply level should neither be less than 0.5 ft/s below which even the wash load will drop out nor exceed a Froude number of $0.6(gR)^{1/2}$ which ensures being in the low regime.

9. Freeboard

General Consideration - Freeboard is an allowance for uncertainties in design, construction tolerances, operating errors and behavior of sediment in the canal. Lined freeboard is height above the maximum water surface level (full supply level) and the top of the lining.

Criterion - Freeboard allowances for rigid canal lining are as follows:

Depth of Flow ft	Top of Lining: Without Sediment ft	Top of Lining: With Sediment ft	Top of Embankment ft
< 1.0	0.20	0.3	1.0
1.0 - 1.5	0.25	0.35	1.0
1.5 - 2.0	0.3	0.4	1.0
2.0 - 2.5	0.4	0.5	1.0
2.5 - 3.0	0.5	0.75	1.5

10. Incoming Sediment Load

General Consideration - Sediment accompanies the water entering the headgate of the canal. The amount and sizes of this sediment determines the functioning and design of the canal.

<u>Criterion</u> - The average annual amount of sediment inflow and its sizes must be estimated. This can be obtained by regularly sampling the sediment at the headgate and determining its sizes. The size of the bed material can be obtained from the bed of the existing canal.

11. Darcy's Friction Factor

<u>General Consideration</u> - The friction factor is a roughness coefficient having two components; one is the roughness resulting from the movement of the fluid over the particles of sand on the bed (grain roughness); the other caused by the movement of the water over the sand waves formed on the bed by the flow (form roughness).

<u>Criterion</u> - Darcy's friction factor is estimated from field measurements of h, q_b and i for flow within 10% of the design discharge prior to rehabilitation. Equation (3) is employed. When no measurements are available the function is estimated from the expression:

$$f = 8\left[5.75 \log\left(\frac{12h}{3D_{90} + \kappa}\right)\right]^{-2} \qquad (5)$$

in which log = Logarithm to the base 10.

D_{90} = Equivalent sieve size of the bed material for which 90% is finer by weight, ft.

κ = Roughness parameter for sand waves on the bed, ft.

The roughness parameter κ is defined as:

$$\kappa = \kappa_{ripple} + \kappa_{dune}$$

The ripple roughness (κ_r) is directly related to the velocity:

$\kappa = 0.3$ for $V < 1.3$ (ft/s)

$\kappa = 0.3[(2.5-V)/1.2]$ for $1.3 < V \leq 2.5$ (ft/s)

$\kappa = 0$ for $V > 2.5$ (ft/s)

The dune roughness (κ_d) is defined as:

$$\kappa_d = 1.1\,\Delta\,[1-\exp(-25\,\frac{\Delta}{\lambda})] \qquad (6)$$

in which Δ = Average height of the sand dunes on the bed, ft.

λ = Average wave length of the sand dunes on the bed, ft.

λ = 7.3 h.

The component of the friction factor which is due to sand grain roughness alone is:

$$f' = 8[5.75 \log (\frac{12h}{3D_{90}})]^{-2} \qquad (7)$$

12. Sand-Wave Height

General Consideration - The sand dunes which form on the canal bed create a retarding pressure force on the flow. The magnitude of this force is proportional to the height of the sand dunes.

Criterion - The average height of the sand dunes is determined from echo soundings of the canal bed during periods of high flow. When no measurements are available, the average dune height is estimated from the expression:

$$\Delta = 0.11\ h(\frac{D_{50}}{h})^{0.3}\ [1-\exp(-0.5\ T_s)]\ (25-T_s) \qquad (8)$$

in which D_{50} = Equivalent sieve size of the bed material for which 50% is finer by weight, ft.

T_s = Dimensionless shear parameter defined as:

$$T_s = \frac{\Theta'}{\Theta_c} - 1 \qquad (9)$$

in which Θ' = Shields parameter for the flow over the sand grains.

Θ_c = Critical Shields parameter.

The Shields parameter for the flow over sand grains is:

$$\Theta' = \frac{f'\ V^2}{8gD_{50}\ (S_s-1)} \qquad (10)$$

The specific gravity (S_s) is 2.65 for the sand in Pakistan canals.

The value of critical Shields parameter are obtained from the following:

Particle Parameter Range	Critical Shields Parameter
$D_* \leq 4$	$\Theta_c = 0.24\ D_*^{-1}$
$4 \leq D_* \leq 10$	$\Theta_c = 0.14\ D_*^{-0.64}$
$10 < D_* \leq 20$	$\Theta_c = 0.04\ D_*^{-0.1}$
$20 < D_* \leq 150$	$\Theta_c = 0.013\ D_*^{0.29}$
$D_* > 150$	$\Theta_c = 0.055$

The particle parameter (D_*) is:

$$D_* = D_{50}\left(\frac{(S_s-1)g}{\nu^2}\right)^{1/3} \qquad (11)$$

in which ν = Kinematic viscosity of water, ft^2/sec and the variables are as previously defined.

The kinematic viscosity of water is a function of its temperature and is estimated from the expression:

$$\nu = [1.23 - 0.333(t-15) + 0.00073\ (t-15)^2] \times 10^{-5} \qquad (12)$$

in which T = Water temperature, ° Celsius.

The water temperature in the canal varies from 15° to 35° Celsius throughout the year. The temperature for design should be selected from that period in which the canal is running at peak discharge. If there are no temperature data available, a value of 25° Celsius is suitable for all of Pakistan.

13. Sediment Transport Capacity

General Consideration - The water flowing in the canal carries some of its sediment load as particles in suspension (suspended load) and the rest as particles rolling, sliding or bounding along the bed (bed load). That part of the suspended load consisting of sizes smaller than those found in appreciable quantities on the bed is known as wash load. The sum of the remainder of the suspended load and the bed load is called the bed material load.

The flowing water has the capacity to carry a certain amount of sediment. When more sediment is added to the flow than the canal is capable of carrying, deposition occurs. Conversely, when the canal is capable of carrying more sediment than is being supplied at the headworks, the flow picks up sediment from the bed and erosion occurs.

Criterion - All material finer than 0.0625 mm is considered wash load which can be transported at all concentrations without deposition on the bed.

The capacity of the canal to transport bed materials is determined by measurements in the field. When there are no measurements, the bed material load is estimated from the expression:

$$S_t = \frac{0.4b\ (h \times i)^{2.5}\ g^{0.5}}{(S_s - 1)^2\ D_{50}\ f} \tag{13}$$

in which S_t = Bed material transport rate, ft^3/s.

14. Sediment Balance

General Consideration - When the inflow of bed material sediment is not equal to the transport capacity of the canal, the canal bed aggrades or degrades. In equilibrium canals, the bed aggrades and at other times it degrades during the year. When these variations of the bed level are within acceptable limits over a long period of time and the canal banks are stable, the canal is said to be "in-regime".

Criterion - The "in-regime" condition for the canal bed is obtained by achieving a balance between sediment inflow and transport capacity. The balance everywhere along the canal is:

$$\int_0^{t_i} (S_s - S_t)\,dt = 0 \tag{14}$$

in which

S_i = Inflow of bed material load, ft^3/s.

S_t = Transport capacity of the canal, ft^3/s.

t = Time

t_1 = A long period of time. As a minimum $t_1 \geq$ 1-year.

SECTION 3

EMBANKMENT CRITERIA

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SECTION 3 : EMBANKMENT DESIGN CRITERIA

A. General

Mass failure (also referred to as shear failure or slope failure) is not a widespread problem in alluvial canals in Pakistan. Some slope failures have occurred, but many of these are explained by subsurface piping often due to inadequate surface and subsurface drainage. Erosion of sand layers unfortunately incorporated into berms or embankments (possibly during cleaning) have resulted in some wedge failures after sections have been undercut by such erosion.

Erosion and retreat of berms are more attributed to wave action and disturbance of the berms by animals and men. Animals are thought to be the single greatest cause of berm disturbance and erosion on all sizes of canals. As the berms retreat, the toe of embankments can be exposed, whereupon erosion can accelerate dramatically with some embankments materials. Except on canals of less than 2.50 feet in depth, berms will be required to protect the toe.

Soils typically used in canal embankment construction and in sediment berm formation are at best moderately resistant to fluvial erosion. Most soils do exhibit some cohesion and are resistant to normal canal design velocities. The root structure of plant material in the silt berms does contribute to the resistance of the berms to erosion. These embankment soils are particularly susceptible to piping, bulking and surface erosion with subsequent collapse or excessive settlement, if not compacted adequately. Uncompacted silty fine sands and silts contribute to embankment failures and high maintenance costs.

The embankment criteria contained herein are for the design capacities determined by using the criterion in Section 2. Operation of canals in excess of design discharge for long periods of time could contribute to a rapid degradation of the berms and possibly the embankment. Peak period surcharges should be limited to 1.2 times design flow for a period not to exceed 14 days. Successive peak periods are not allowed. A waiting period of 14 days is required between freeboard encroachments.

B. Embankment Criteria

1. Stability

General Consideration - Canal embankments in Pakistan were constructed with little or no compaction. Main and branch canals were often constructed by staunching, a puddling process that minimized pore space. The process could take several years to complete. Berms were added to reduce seepage losses and provide a factor of safety. Canal embankments are considered to be stable unless there is visual evidence of an impending failure. Flatter embankment slopes will reduce erosion caused by heavy rainfall. Embankment stability is defined by the constructed embankment slope.

Criterion - The embankment slopes are defined according to three conditions: inside slope, outside slope and the condition where canal depths are greater than 12 feet. In all cases, the existing slopes must be cleared of organic material and scarified before new embankment material is placed. All new embankment materials must be compacted to specification.

(1) Inside Slope - The minimum inside slope will be 1.5 horizontal to 1.0 vertical for all embankments up to 15 feet above bed level, including freeboard. The original design constructed slope will be maintained if it is flatter than 1.5:1.

(2) Outside Slope - The minimum outside slope will be 1.5 horizontal to 1.0 vertical for all embankments up to 11.0 feet above ground level. Embankments higher than 11.0 feet will have a slope of 2.0 horizontal to 1.0 vertical. The original design/constructed slope(s) will be maintained during rehabilitation.

(3) Canal embankments with water depths in excess of 12 feet will require a special study to determine both embankment slopes and safety against failure. Any embankments exhibiting mass failure with or without berms

will also be studied. Rapid drawdown will be a major consideration. Special studies may include complete soil testing and analysis.

2. **Berms**

General Consideration - Berms are used to reduce seepage and improve factors of safety. An inside berm protects the embankment against erosion of the toe materials, provides extra weight on the embankment to prevent a stability failure and reduces seepage losses. The outside berm is also placed to add weight and prevent sliding failure. Outside embankments with seep areas are potential failure zones. The canals are currently considered to be in-regime, therefore, the potential for berm erosion at these flows is considerably less than when the original design/construction was accomplished. Berm requirements can be reduced accordingly.

Criterion - The criterion for berms are according to location i.e., on the inside or outside slope, see Table 4-1.

(1) Inside Berm - An inside berm is required to protect the toe of the canal bank and is located between the designed hydraulic prism and the bank. The width of the berm is measured from the toe and depends on the design depth of flow (FSL).

The berm widths (b_1) for various flow depths are as follows:

Design Depth of Flow (h) (ft)	Berm Width (b_1) (ft)
< 2.50	0
2.5 - 3.99	2
4.0 - 4.99	3
5.0 - 5.99	4
6.0 - 7.99	5
8.0 - 9.99	6
10.0 - 11.99	7
> 12.00	Special Study Required

The minor and small distributary canals are constructed without berms. The prism side slope is considered to be 0.5 horizontal to 1.0 vertical for hydraulic design and 1.5:1 for design and construction.

The hydraulic design criteria, Paragraph 2.B.7, allows the bed width to vary ±10% before a field investigation is required. This variation is absorbed in the berms. The objective is to maintain the distance between the toes of the two embankments, $b + 2b_1$. For small canals, where $h \leq 2.5$ feet, the existing width, b, will govern as berms are not required.

(2) Outside Berm - The outside berm is required where seep areas are observed on the embankment or where shear cracks are observed in the embankment top. The top level of the berm will be placed 2.0 feet above the top of the seep area and will be 6.0 feet wide. The phreatic or hydraulic grade line of the seep is defined as the line which goes from the intersection of the FSL with the canal bank and the top of the seep area. This line will be extended until it strikes the ground surface. The back slope of the berm will be 2.0 horizontal : 1.0 vertical unless it does not cover the HGL intersection by a minimum of 1.0 foot. In the latter case, a flatter slope that will provide the 1.0 foot cover will be used.

3. Minimum Top Width of Embankment

General Consideration - There is a minimum width for the top of the embankment that will provide stability and safety. The top of embankment is often used for roads and other uses that do not involve stability. These conditions are covered in Section 4. The top width provides adequate safety against failure.

Criterion - The minimum top width required for various design depths of flow are:

Depth of Flow (h) (ft)	Minimum Top Width W_1 (ft)
< 2.50	4
2.5 - 3.99	5
4.0 - 4.99	6
5.0 - 5.99	8
6.0 - 7.99	10
8.0 - 9.99	12
10.0 - 11.99	15
> 12.00	Special Study Required

Where existing embankment top widths are greater than those shown above, the existing widths will be maintained for rehabilitation designs.

4. Compaction

General Consideration - Under current rehabilitation procedures replacement fill material is not compacted even though it may be required in the construction specifications. Observation of recently rehabilitated embankments shows excessive raincuts and surface erosion after or single wet season. Compacted soils will resist surface erosion, excessive settlement and piping. Soil moisture content is critical in obtaining optimum strength and water will have to be added if borrow material is not at correct moisture content for placement. The mechanical equipment to obtain proper compaction is available.

Criterion - All rehabilitated canal embankments will be compacted to a minimum of 85% of standard Proctor, ASTM D-698. Lifts will be limited to 8 inches of loose fill (6 inches compacted) and moisture content of soil must be in the range of 10-12% dry weight when placed unless otherwise specified. Soil moisture should lean towards the wet side of optimum and not the dry side.

5. Soil Material

General Consideration - Rehabilitation requires the replacement of soil eroded off the embankment. Therefore, because of this, the soil requirements are less severe than for new embankments. Local soils are considered only marginal for unlined canal embankments, particularly if not adequately compacted. Sands have special requirements before they can be used on rehabilitated embankment.

Criterion - Soil material and placement criteria are as follows:

(1) Inside Berm - All excavated material placed on inside berms must have a liquid limit of 25% or higher and a plasticity index equal to or greater than 3%. The material must be classified as having moderate resistance to erosion as shown in Figure 3-1.

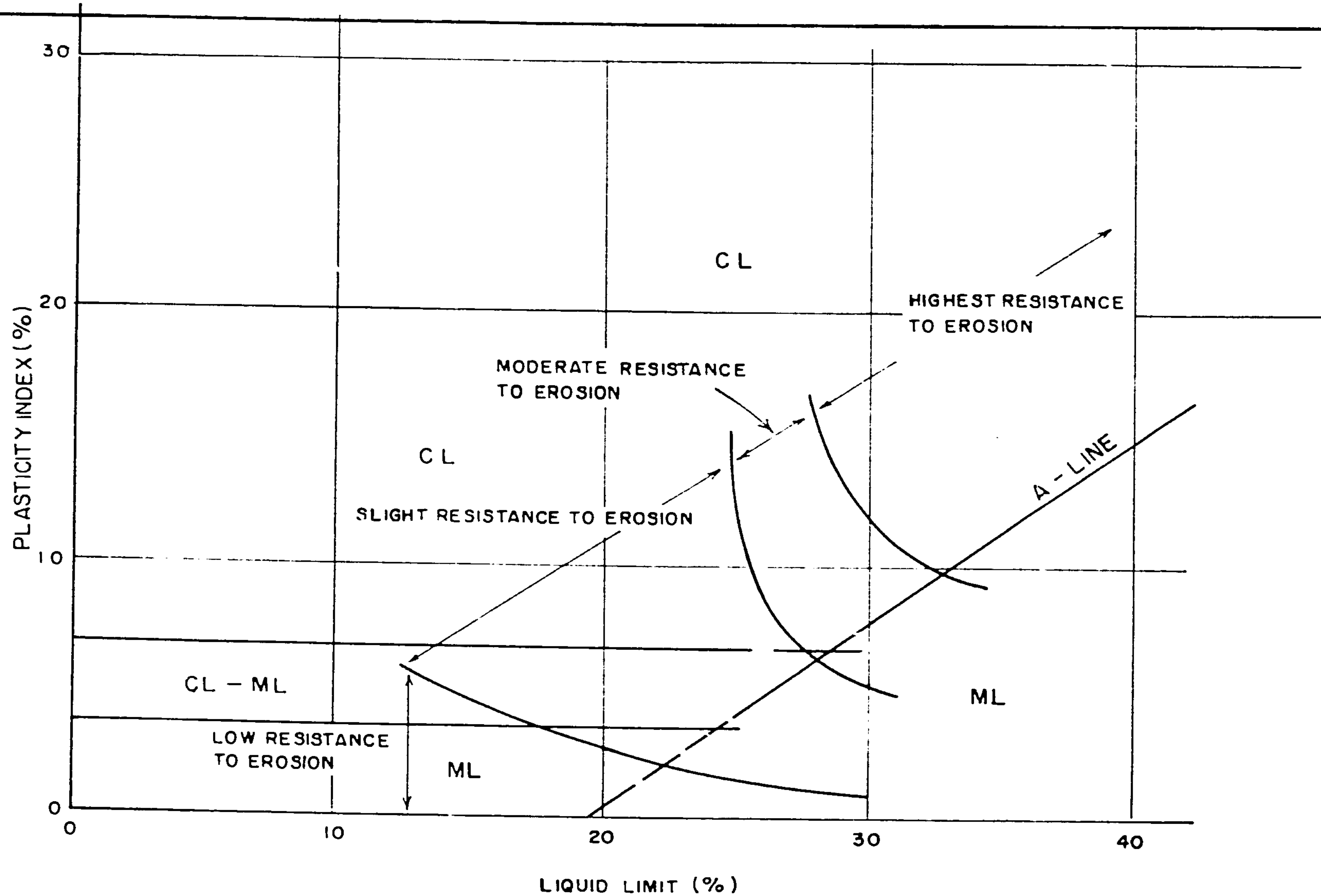
(2) Embankment - Cohesionless bed sediment can only be used in the canal embankment if contained by compacted silty or clayey soil as shown in Figures 3-2 and 3-3. Soils classified as having only slight resistance to erosion should not be placed on outside slope surfaces if it can be avoided. Materials classified as low resistance must be treated as bed material.

(3) Outside Berm - Same criterion as the embankment. Use of cohesionless material as shown in Figure 3-3 would improve internal drainage.

6. Bank Stabilization

General Consideration - Where a change in canal alignment is sharp enough that the outside bank curvature within the wetted prism cannot be maintained, bank failure may occur due to scour and erosion. These and areas located downstream of structures where eddy currents cause similar failures should be protected.

Criterion - Eroded bank sections should be protected by non-erodible material. Burnt brick or burnt clay tile masonry lining should be used where suitable soils are not available. If more economical materials, such as rock pitching, are available they should be used.



EROSION RESISTENCE WITH RESPECT TO PLASTICITY

FIGURE - 3 - 1

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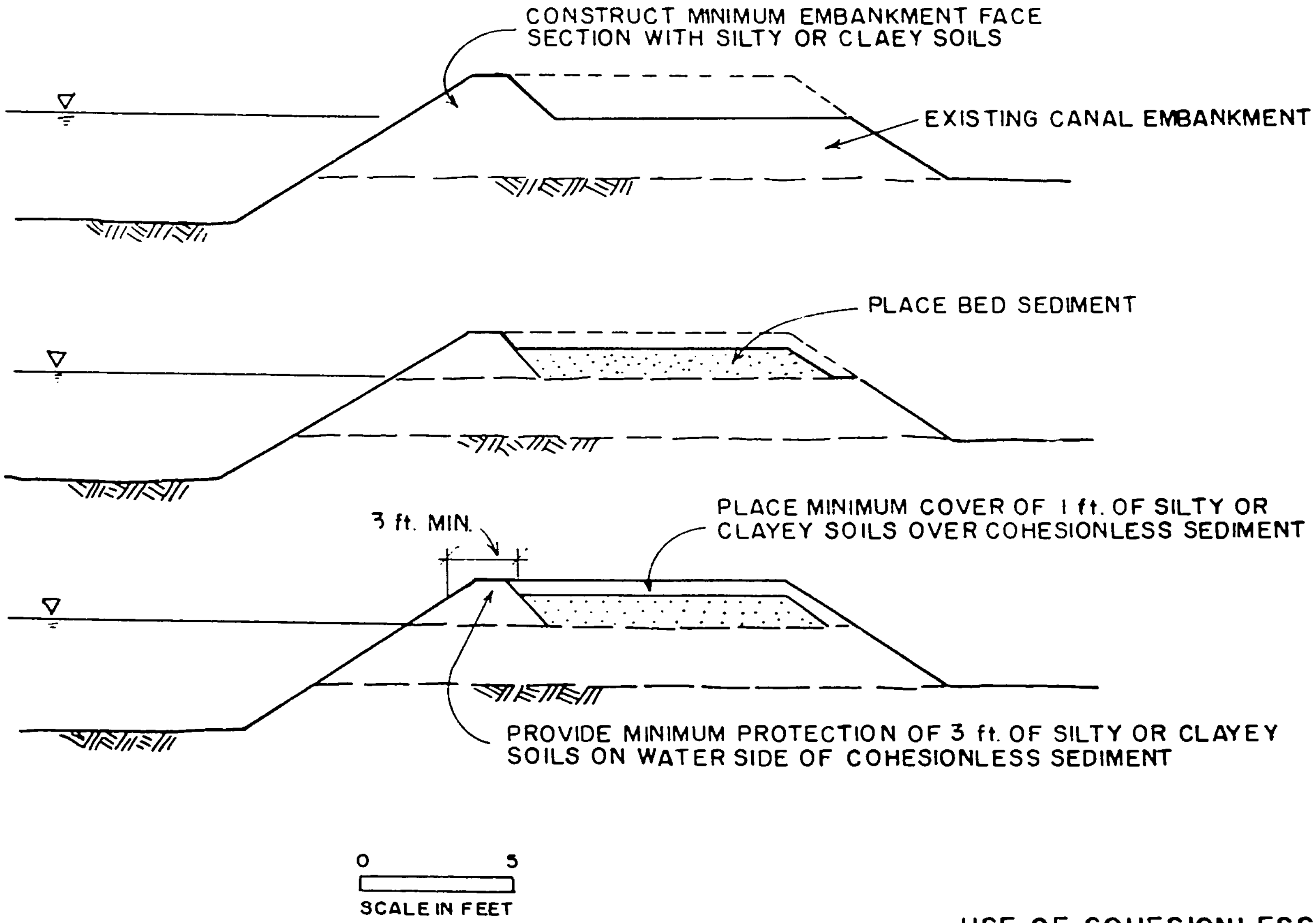

USE OF COHESIONLESS MATERIAL ON CREST

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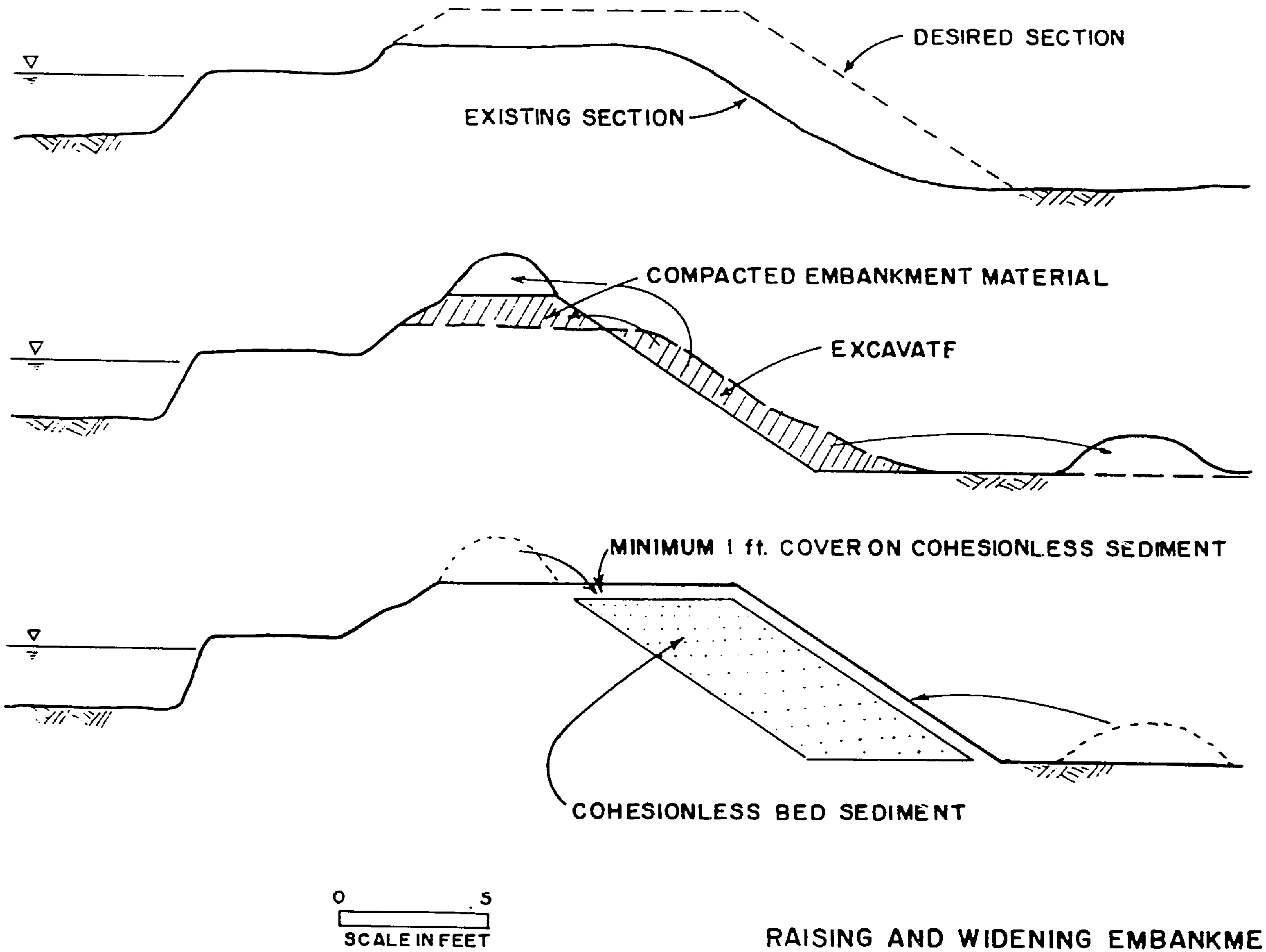
FIGURE 3-2



RAISING AND WIDENING EMBANKMENT WITH BED SEDIMENT

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FIGURE 3-3

SECTION 4

NON-HYDRAULIC CRITERIA

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SECTION 4: NON-HYDRAULIC CANAL DESIGN CRITERIA

A. General

There are many features of a canal that must be designed in addition to the hydraulic parameters. At this time, seepage control utilizing hard surface (exposed lining), exposed membranes, buried membranes and compacted earth linings with or without additives are usually not feasible except for special cases involving right-of-way constraints. Bank protection using exposed lining may be required downstream of water control structures and in curved reaches.

B. Design Criteria

1. Right-of-way

General Consideration - The right-of-way must be sufficient to contain all parts of the canal section and associated patrol roads. Since the alignment would not be changed, there is little possibility that the right-of-way will be changed.

Criterion - The right-of-way will remain as is currently defined. Where necessary for improvement of embankments acquisition will be limited to a distance of 5 feet beyond the proposed toe.

2. Freeboard

General Consideration - Freeboard is added to a canal to protect the canal bank from:

1. Irregularities in design and construction.
2. Short periods of encroachment to meet peak demands.
3. Short term increases in water surface levels due to sedimentation and resulting loss of capacity.
4. Operational errors.

When maintenance of freeboard replacement is to be deferred for a period of 5 years an additional 0.5 foot of freeboard is required during rehabilitation to allow for the annual loss rate of 1-inch per year.

Criterion - Freeboard requirements are defined as follows:

Depth of flow h (ft)	Design (ft)	Rehabilitation (ft)	Rigid Lining (ft)	Metalled Road (ft)
< 2.50	1.0	1.5	0.5	1.0
2.5 - 3.99	1.5	2.0	0.5	1.5
4.0 - 4.99	1.5	2.0	0.6	1.5
5.0 - 5.99	2.0	2.5	0.75	2.0
6.0 - 7.99	2.5	3.0	1.0	2.5
8.0 - 9.99	2.5	3.0	1.5	2.5
10.0 - 11.99	3.0	3.5	1.6	3.0
> 12.0	Site Specific Study Required			

The design freeboard can not be violated, therefore, during rehabilitation additional freeboard must be added to mitigate the encroachment on the freeboard by erosion that occurs over a given period. This was based on the replacement of 5 inches of freeboard every five years. The rigid lining (brick or concrete) freeboard is taken from the FSL to the top of the lining. The normal embankment freeboard is required in conjunction with the lining. Metalled roads do not wear off, therefore, only design freeboard is required.

3. Roads

General Consideration - Canal operation and maintenance procedures for rehabilitated canals will require increased use of mechanized transport equipment. Authorization to use patrol roads as village roads may be given by Provincial authorities. Roads would have to be widened to allow passing. In a few cases, highways have been built on canal banks. The current local use should be discouraged unless O&M budgets will reflect such use.

Criterion - Patrol roads are required on one bank of all main, branch and distributary canals. Main and branch canals require periodic movement of equipment along the full length on both banks. Distributaries will also required an equipment maintenance access road but since the equipment is lighter, the road requirement is narrower. Patrol roads for canals with less than 2.5 feet of water depth (<4-foot in total height) may be located adjacent to embankment. The minimum required roads widths are:

Depth of Flow (ft)	Equipment Maintenance1/ (ft)	Patrol (ft)	Village (ft)	Highway (ft)
< 2.50	5	0	18	30
2.5 - 3.99	7	7	18	30
4.0 - 4.99	7	10	18	30
5.0 - 5.99	9	10	18	30
6.0 - 7.99	9	15	18	35
8.0 - 9.99	12	15	18	40
10.0 - 11.99	12	18	18	40
> 12.0	Depends on results of special studies.			

Note 1/ Road is grass sodded.

4. Minimum Curvature

General Consideration - Curves should not be provided except where necessary. Introduction of a curve in a canal disturbs the regime flow. The concave side is always under erosion and the convex side has a tendency for deposition. Minimum radius curves are used to minimize the problem.

Criterion - Curves are already in place in systems to be rehabilitated. Therefore, if maintenance can not provide control of erosion on the concave side, it must be protected. Protection is started 1/6th of the way along the length of curvature and extends the same distance beyond the point of tangency.

5. Top of Embankment Details

General Consideration - There are several details that can be considered on top of the canal embankments. Only the cross slope required for drainage has to be included. The other are historic items including dowels and avenues. Trees should no longer be allowed on canal embankments because they prevent equipment oriented maintenance and compaction of embankments. Rotted tree roots, vegetation and organic material in embankments facilitate piping.

Criterion - The following are the criteria for top of bank details:

(1) The cross-slope shall be constructed perpendicular to the line of the canal at a horizontal slope (z) of 60 feet to 1 foot vertical drop away from the prism.

(2) A dowel is optional. It requires roughly 5 feet of additional top width. The dowel has a bank slopes of 1.5 to 1.0 vertical. The top width is 2.0 feet and the height is 1.0 foot. The dowel is constructed out of compacted soil material similar to that used in the embankment.

(3) An avenue or shoulder is optional. It requires a width of 5 feet placed on the land side of the patrol road. It is grassed and has the same cross slope as the bank top. Trees are not allowed on avenues.

(4) A drainage parallel to the top of bank is required on the land side of the bank top when the canal goes through a cut section and the natural ground level is above the top of the bank. The drain must discharge into a waterway that leads to the borrow areas on either end of the cut reach.

6. Embankment Erosion Control

General Consideration - Intense rainfall can cause erosion of the canal banks; both inside above the water line and on the outside slope. The outside slope also must carry the surface runoff from the patrol road or the regular bank top. Areas or locations where erosion has formed raincuts or incised gullies will require that the bank surface be restored to the original cross-section.

Criterion - The embankment top and outside slope must be protected by a grass sod. The variety of grass to be grown should be one that forms a tightly, deep rooted mat and is drought tolerant.

7. Spoil and Borrow Areas

General Consideration - In rehabilitating canals, there is a need to find areas for excavated material not required for use in cross-section (spoil) or to obtain soil to construct additional cross-section (borrow).

Criterion - Old borrow areas that contain excessive amounts of plant material, saturated soil or standing water cannot be used as a source of material for rehabilitating the canal embankment. Where permitted excavation of borrow material should not be allowed any closer than 5 feet from the toe of the embankment. Where borrow is not available in the right-of-way, special borrow areas will have to be located and right to the material obtained under normal contract procedures.

Spoil may be placed on the outside bank provided there is room in the right-of-way or additional right-of-way may be obtained. Otherwise, spoil will have to be transported to designated spoil areas.

All borrow and spoil areas should be defined on construction drawings and contracts negotiated for the rights to use them. Low or swampy areas should be used for spoil if available within feasible haul distance.

8. Village Road Base and Surface Material

General Consideration - Patrol roads that are used on a daily basis for village roads require a base course and surface material that must be capable of sustaining vehicle traffic during the rainy season.

Criterion - The material used should meet Pakistan requirements to provide an all weather surface.

9. Washing Facilities

General Consideration - Washing facilities (steps) are desireable on main, branch and large distributaries canals to minimize bank damage.

Criterion - Washing facilities should be constructed near all villages to provide the local women with a place for washing through controlled access. These facilities should be located upstream of any animal facilities at the same village.

10. Animal Bathing Facilities (Ghats)

General Consideration - In general, animals should not be allowed to enter the canal right-of-way. Grazing on the banks may be allowed provided it does not destroy the vegetative cover. If animals are allowed to enter the canal for drinking or bathing, the entrance and exit locations should be controlled.

Criterion - Animals should be allowed to enter the canal only at specified control points which would be specially designed ramps leading into canals. The banks adjacent to the ramps will require that the bank be protected by a hard surface lining; such as brick or tile masonry. Both banks will be lined for a distance of 200 feet or more depending on intended carrying capacity and needs of the village. Two entrances are required.

The alternative is to construct special watering and bathing facilities outside of the canal banks in low areas wherein water can be released into the animal washing facilities.

11. Bridge Access

General Consideration - The access to bridges which are perpendicular to the canal embankments do not have adequate room for vehicles to swing or turn to use the bridge without damaging the bridge railings. Flared wing walls can be utilized to provide more room for turning radius or the embankment must be widened out to accommodate the required turning radius.

Criterion - The minimum inside turning radius for trucks is 22 feet and the outside radius is 33 feet. Figure 4-1 shows two arrangements for bridge access.

12. Distance Marks

General Consideration - Distance marks are provided along every channel and on every structure. The number on the mark denotes the reduced distances in thousand feet.

Criterion - The distance marks are fixed 1000 feet apart. The zero location is either of the following:

(a) the downstream face of the head regulator of the canal; or
(b) the point of intersection of the center line of the canal with that of the parent channel.

13. Road Barriers and Gates

General Consideration - Local traffic should be prohibited from the patrol roads and equipment maintenance access roads unless roads are designed and budgeted for such use. Standard practice is to provide gates with locks or barriers. Where roads are to be used for village access, additional base course material is required for wearing surface and additional maintenance funds should be provided for the added maintenance costs.

Criterion - All road crossing should be gated or controlled by barriers located or protected so that vehicles cannot bypass the structure. Clearance on barriers is 8.0 feet in width and 6.0 feet in height. Gates should be 14.0 feet wide to allow equipment access.

14. Rigid Lining

General Consideration - Lining may be required in special instances to protect one or both canal banks from scour. Complete lining will seldom be warranted. Three types of lining are available but in most cases only one type will be economical for a given location. Brick lining is the most common but stone masonry and concrete are feasible in some areas. Standard practices will be used where applicable to fit local conditions.

Criterion - The lining will be designed to meet the following minimum standards:

(1) Depth

Design Depth of flow = h	Brick 2/ Number of layers	Brick 2/ Thickness (inch) 3/	Stone Masonry (inch)	Concrete (inch)
< 2.5	1	3.15	5	3
2.5 - 3.99	1	3.25	6	4
4.0 - 4.99	1	3.25	6	4
5.0 - 5.99	2	6.50	6	5
6.0 - 7.99	2	6.50	6	6
8.0 - 9.99	2	6.50	8	6
10.0 - 11.99	2	8.50	8	8
> 12.0				

Notes 1/ These are minimum requirements based on adequate internal drainage/weep holes, compacted embankment, and controlled drawdown. Stability must be checked by design for local conditions.

2/ Bricks assumed to be 12" x 4-7/8" x 2-3/4".

3/ 1:3 mortar bed and sandwich layer ½" thick.

(2) Slope - Bank slope shall be 1½ horizontal to 1 vertical.

(3) Toe Protection - An adequate toe wall made of the same material as the lining must be provided to improve stability and protect against potential scour.

(4) Cut-off-Walls - Cut-off walls will be provided on both upstream and downstream ends of lined reach.

(5) Cap - A 10-inch wide cap will be provided on top of the lined bank with the top face parallel to the water surface. This is considered part of the lining with respect to the freeboard allowance.

(6) Compacted Back Fill - The lining will be placed against a compacted backfill trimmed to the design of slope.

(7) Drainage - In cut sections, adequate drainage will be provided behind the lining to prevent excessive hydrostatic forces from developing. Weep holes with adequate filters to prevent the movement of soil particles is acceptable.

15. Design Standards for Rehabilitated Canals

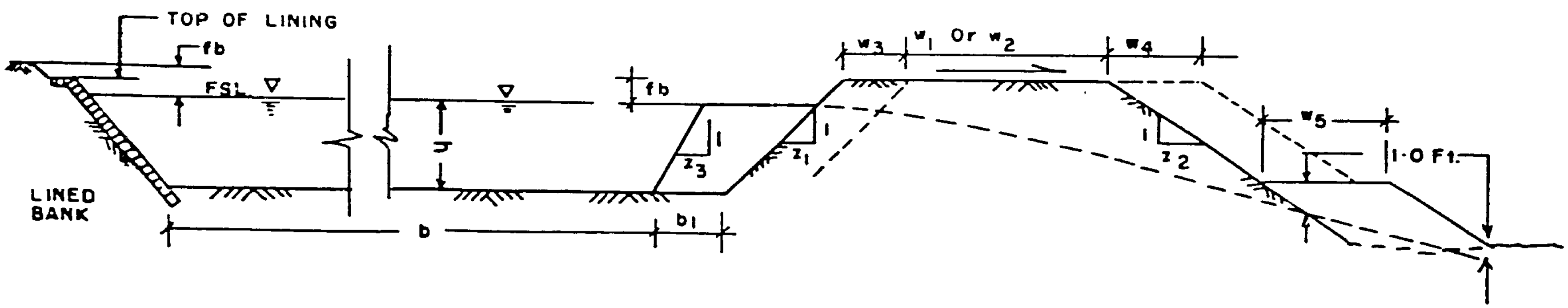
Table 4-1 is provided to consolidate the design criteria presented above onto a single table for easy reference.

TABLE 4 - 1

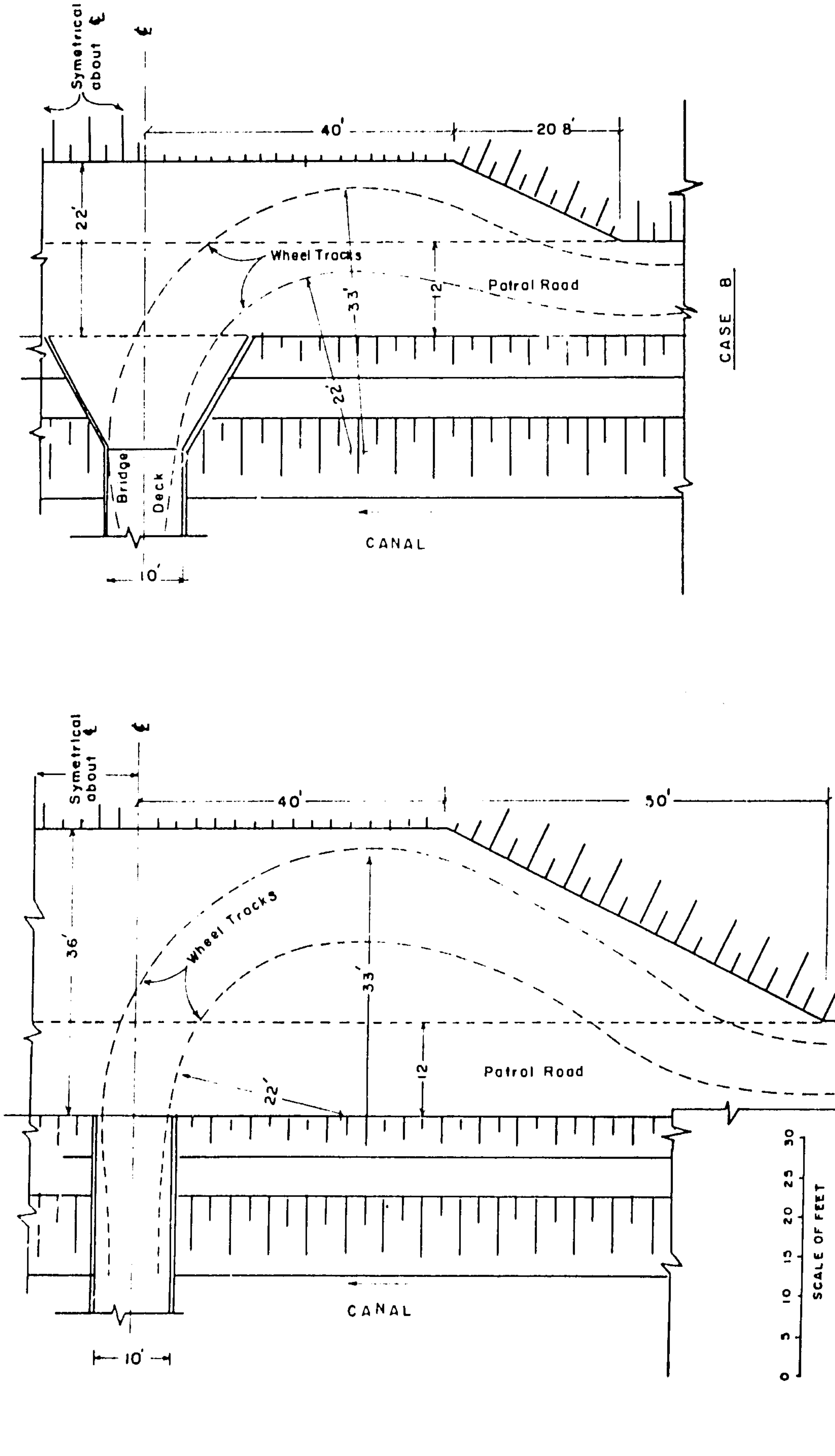
REHABILITATED CANAL EMBANKMENT DESIGN STANDARDS

Depth of flow h (ft)	Freeboard - fb: Design (ft)	Freeboard - fb: Rehab. (ft)	Freeboard - fb: Rigid Lining 1/ (ft)	Freeboard - fb: Metalled (ft)	Min. top Width W_1 (ft)	Roads W_2: Equip Maint. (ft)	Roads W_2: Patrol (ft)	Roads W_2: Village (ft)	Roads W_2: Highway (ft)	Berm Width b_1 (ft)	Slopes: Inside (z_1)	Slopes: Outside (z_2)	Slopes: Berm (z_3)
< 2.50	1.0	1.5	0.5	1.0	4	5	0	18	30	0	1.5	1.5	1.5
2.5 - 3.99	1.5	2.0	0.5	1.5	5	7	12	18	30	2	1.5	1.5	0.5
4.0 - 4.99	1.5	2.0	0.6	1.5	6	7	12	18	30	3	1.5	1.5	0.5
5.0 - 5.99	2.0	2.5	0.75	2.0	8	9	15	18	30	4	1.5	1.5	0.5
6.0 - 7.99	2.5	3.0	1.0	2.5	10	9	15	18	35	5	1.5	1.5	0.5
8.0 - 9.99	2.5	3.0	1.5	2.5	12	12	20	20	40	6	1.5	2.0	0.5
10.0 - 11.99	3.0	3.5	1.6	3.0	15	12	20	20	40	7	1.5	2.0	0.5
> 12.0	Site Specific Study Required												

Notes:
1. Distance from FSL to top of lining (earth freeboard also required)
2. W_3 = Dowel and W_4 = Avenue; W_3 = W_4 = 5 foot; neither are required but may be retained if already on existing embankment.
3. W_1 = Min. top width where maintenance road not required.
4. W_5 = Outside berm required to cover existing seepage surface if necessary.
5. b_1 = designed to protect toe; maintained using top width.



SCHEMATIC DESIGN SECTION



WIDENING EMBANKMENT FOR BRIDGE ACCESS

SECTION 5

STRUCTURAL CRITERIA

PRC Engineering / CHECCHI

SECTION 5 : BASIC STRUCTURAL DESIGN CRITERIA

A. General

Basic structural design criteria shall be applicable to all pertinent canal structures, either new or those to be rehabilitated. They may be modified and/or supplemented as the actual design and field work progresses according to the prescribed procedures.

B. Design Codes and Specifications

The design of concrete works and other construction items shall be done in accordance with the relevant sections of the Codes shown in Table 5-1. In general, local consultants use American Codes while individual Departments have their own guidelines, particularly the highway and railway departments.

C. Structural Materials

1. Reinforced Concrete

The minimum and maximum reinforcing bar size for cast-in-place concrete shall be # 4 and # 9 respectively. The clear distance between parallel bars shall not be less than the nominal bar diameter, 1½ times the maximum size coarse aggregate, or 1 inch. The main stress-carrying steel shall be centered not farther apart than 3 times the member thickness nor more than 18 inches. Where a structure is constructed on curves, steel shall be placed radially from the maximum spacing and special attention shall be given to steel details to ensure that the spacing on the inside of curves is not less than the allowable.

Main stress-carrying steel shall comply with ASTM A-615, including S1. Longitudinal steel shall comply with either ASTM A-615, Grade 40 or Grade 60. Anchorage requirements for reinforcing steel shall be as specified in ACI 318-83. Development and splices shall be as required in Chapter 12 of ACI Code but not less than 12 inches. Shear stress shall be calculated in accordance with Chapter 11 of ACI 318-83.

The 28-day compressive strength of the concrete shall be specified to be 3,000 psi. However, in design, all structures shall be designed on the basis of 2,000 psi concrete.

Design criteria not specifically covered in this criteria shall be as specified in the 1983 edition of the "Building Code Requirements for Reinforced Concrete" (ACI 318-83) published by the American Concrete Institute. Table 5-2 provides the basic allowable concrete stresses.

2. Structural Steel

Design of structural steel members shall be in accordance with the current edition of the AISC Manual of Steel Construction. Allowable stresses for members subjected to temporary loadings, such as debris barriers, may be increased by one-third.

Structural steel used in canal structures is primarily for gate guide frames and hand rails. Nominal size members are used to provide sufficient rigidity. Strength requirements for steel shapes used to fabricate safety devices such as hand rails and ladders are nominal. Table 5-3 provides some general working stresses.

3. Stone (Rubble Masonry)

Stone masonry is defined as stone, rubble, or broken rock set in a cement mortar. Special attention must be given to filling all voids. Weep holes are required to relieve hydrostatic pressures, the same as with concrete structures. The mortar must meet local building and/or PID codes, see Table 5-1.

Where the existing masonry structures have to be rehabilitated or where additions and minor alternations are required, mass stone masonry may be used. The maximum allowable compressive stress in stone masonry shall not be greater than 110 lbs. per square inch unless laboratory tests prove that a higher stress can be used. Tensile stress in stone masonry shall not be allowed.

Stone masonry may also be used in transitions to structures, wing walls, bridge piers and abutments of new structures. Stone masonry construction is preferred because of traditional practice, availability of stone and/or rubble, and the availability of skilled labor.

Dry pitching refers to stone or broken rock placed without mortar and its use is limited to erosion protection. Dry stone pitching will not be permitted unless a graded filter or an approved woven plastic material manufactured for such purpose is placed behind the pitching.

4. <u>Brick Masonry</u>

Brick masonry is defined as burnt bricks set in a cement mortar. The mortar used must meet or exceed local building code and/or PID specifications.

Dry pitching refers to burnt bricks or burnt brick tiles placed in a prescribed pattern. The pattern dry pitching is placed in when used in canals must be such that all cracks between bricks/tiles are covered except at intersections. Care must be exercised to prevent moving water from removing the fine soil particles underlying the pitching.

Where the existing brick masonry structures have to be rehabilitated or where additions and minor alterations are required, mass brick masonry may be used. The maximum allowable compressive stress in brick masonry shall not be greater than 110 lbs. per square inch unless laboratory tests prove that a higher stress can be used, see Table 5-4. Tensile stress in brick masonry shall not be allowed. Special attention must be paid to relieving hydrostatic pressures, particularly in canal banks.

Burnt brick masonry may also be used in transitions to structures, wing walls, bridge piers and abutments of new structures where brick masonry construction is preferred.

5. Timber Work

All timber work shall conform to the standards used in country, see Table 5-1.

D. Joints

1. Contraction and Expansion Joints

General Consideration - Contraction or expansion joints are provided as required to relieve shrinkage or thermal expansion stresses in continuous concrete slabs.

Criterion - The maximum distance between expansion or contraction joints shall not exceed 75 feet. Rubber or Polyvinyl chloride (PVC) water stops shall be provided in expansion or contraction joints where water tightness is necessary.

2. Construction Joints

General Consideration - Construction joints are provided for practical reasons in construction of structures. There location is dependent on equipment, forming and other constraints. Masonry type construction seldom has a formal construction joints except as required by reinforcement.

Criterion - Construction joints shall be provided where necessary for the practical placing of concrete. Reinforcement shall be continuous across construction joints. Unless required to resist heavy shear, keys shall not be placed in construction joints.

E. Loadings

In the absence of detailed field and laboratory tests and investigations to determine the applicable material strengths and other characteristics, design loadings shall be based on information contained in the standards shown below or described in the standards listed in Table 5-1, with modifications as necessary.

Some of the more commonly used items in general design work are summarized in the following subsections. Investigations shall be carried out to establish the validity of the minimum values proposed.

1. Dead Loads

General Consideration - The dead loads are used in design of structures. Field investigations shall be carried out to establish the validity of unit weights tentatively adopted for backfill and rockfill.

Criterion - The dead loads to be used for structural design are:

Item	Unit Weight
Reinforced Concrete	150 lb./ft^3
Plain Concrete	145 lb./ft^3
Stone Masonry	140 lb./ft^3
Brick Masonry	110 lb./ft^3
Structural Steel	490 lb./ft^3
Cast Iron	450 lb./ft^3
Water	62.4 lb./ft^3
Dry Earth	100 lb./ft^3
Backfill-Unsaturated	120 lb./ft^3
Backfill-Saturated	135 lb./ft^3
Backfill-Submerged	70 lb./ft^3
Rockfill-Submerged	110 lb./ft^3

Timber as stipulated in Timber Specifications.

2. Design Loads

General Consideration - Design loads shall be established in accordance with the standards of contemporary engineering practice. The load data are presented as unit values. The loading combinations on the structures shall be determined on an individual basis according to its function; however, whenever applicable, the following loads shall be considered.

Criterion

a) Water Pressure

All structures permanently or temporarily submerged shall be designed for a hydrostatic pressure of 62.4 $lb./ft^3$ per feet of water depth.

b) Backfill Pressure

The lateral earth loads against backfilled structures shall be calculated using the following equivalent fluid pressure:

Active Pressure (unsaturated backfill)	35 $lb./ft^3$
Active Pressure (saturated backfill)	40 $lb./ft^3$
Active Pressure (submerged backfill)	22 $lb./ft^3$
At-rest Pressure (unsaturated backfill)	94 $lb./ft^3$
At-rest Pressure (saturated backfill)	100 $lb./ft^3$
At-rest Pressure (submerged backfill)	50 $lb./ft^3$

Where construction or operating equipment may come close to a structure or where a slope failure may develop, an appropriate surcharge load will be added.

c) Live Loads

The design of bridges and culverts require the use of live loads as mentioned in the standards listed in Table 5-1 shall be used. The following impact factor for buried conduits shall be used when considering the live loads conditions:

For fills	0 to 1.0 ft	Impact = 30%
For fills	1.01 to 2.0 ft	Impact = 20%
For fills	2.01 to 3.0 ft	Impact = 10%
For fills	more than 3.0 ft	Impact = 0

Operating platforms where stoplogs are not used shall be designed for a live load of 100 lbs/ft^2 and where stoplogs are used 150 lb/ft^2.

d) <u>Live Load Distribution on Highway Structures</u>

Distribution of live loads on highway structures shall be in accordance with the specifications and standards for highway bridges as used in country or its equivalent as in American Association of State Highway and Transportation Officials (AASHTO) specifications.

e) <u>Uplift Pressure</u>

Uplift shall be considered for the design of all structures which are fully or partially submerged. The uplift pressure shall be assumed to be effective over 100 percent of the base ares when the structures subjected to water-loads on one side only, or to waterloads of different magnitude on opposite sides, the uplift pressure shall be assumed to vary uniformly between the hydrostatic heads on the two sides of the structure.

When drains are provided to reduce uplift pressures, they shall be assumed to be 50 percent effective.

f) <u>Wind</u>

Structural surfaces exposed to wind shall be designed for a force of 20 lbs. per square foot.

g) <u>Earthquake Acceleration</u>

All major structures shall be designed to withstand the effect of a horizontal earthquake acceleration equivalent to 0.12 g where $g = 32.2$ ft/s^2. The earthquake force shall be applied in such a direction that it, in combination with other loadings, will produce the most severe stress condition in the structure. Major structures include diversion weirs, off-take structures for main canals, and silt traps.

h) <u>Combination Loadings</u>

where the stresses in the structures due to wind, construction loads, earthquake acceleration or other loads of temporary nature are to be combined with those due to normal service loads, the allowable unit stresses specified by building codes listed in Table 5-1 shall be increased by the following percentages:

Combined Loading	Percentage Increase of Allowable Unit Stress
Dead Load + Live Load + Wind	33-1/3
Dead Load + Live Load + Earthquake	33-1/3
Dead Load + Construction Loads	25
Dead Load + Live Load + Water + Temperature	25

F. Structural Stability

1. Safety Against Overturning

General Consideration - Structures are designed to be safe against overturning. To prevent overturning the sum of the stabilizing moments must exceed the sum of the overturning moments on the structure.

Criterion - The factor of safety for overturning shall be not less than 1.5 for normal loading conditions nor less than 1.25 when earthquake loadings are considered. The factor of safety for overturning is the ratio of the stabilizing moment under the base of the structure to the overturning moment above the base of the structure.

2. Foundation Pressure

General Consideration - Foundation bearing pressures must not be exceeded. Bearing pressures of structures on their foundations must be investigated for maximum loading conditions. Foundation treatment may be required for low density or expansive foundation soils.

Criterion - The following allowable bearing pressure for various foundation materials may be used for medium and small structures but must be confirmed by soil investigations for each location for major structures.

Foundation Material	Allowable Bearing Pressure (lb.ft^2)
Hard sound rock	120,000
Medium hard rock	80,000
Hard pan overlying rock	24,000
Compact gravel and boulder gravel formation; very compact sandy gravel	20,000
Soft rock	16,0C0
Loose gravel and sandy gravel; compact sand and gravely sand; very compact sand-inorganic silt	12,000
Hard dry consolidated clay	10,000
Loose coarse to medium sand; medium compact fine sand	8,000
Compact sand-clay soils	6,000
Loose fine sand; medium compact sand, inorganic silt soils	4,000
Firm or stiff clay	3,000
Loose saturated sand-clay soils, medium soft clay	2,000

3. Safety Against Sliding

General Consideration - The design of structures located in or adjacent to canals must be designed to resist the tendency to slide when subjected to differential lateral pressures. Resistance to sliding is developed by shearing strength along the contact surface of the structure and the foundation material or in the material itself.

Criterion - Safety of canal structures against sliding shall be evaluated according to the relationship:

$$SF = \frac{Nf}{H} \geq 1.5$$

Where

SF = safety factor;

H = summation of lateral forces acting parallel to the assumed sliding plane;

N = summation of forces, reduced by uplift pressure, acting normal to the assumed sliding plane; and

f = sliding coefficient.

Foundation Material	Maximum Allowable Sliding Coefficient "f"
Silt or clay	0.35
Coarse grained soil containing silt or clay	0.45
Coarse grained soil containing no silt or clay	0.55

The values of "f", shown above, are for concrete in contact with the foundation material. For stone and brick masonry the same values shall be adopted. If the structure rests on silts or clay, special precautions are required. Prior to placement of concrete or masonry footings, about 4 inches of soil should be removed over the area to be covered by the foundation, and replaced by a 4-inch layer of well-compacted sharp-gained sand, sand and gravel or equivalent.

4. Safety Against Uplift

General Consideration - Structures located in or adjacent to canals must be designed in such a manner that they are safe against uplift pressures. These generally will occur during rapid dewatering.

Criterion - The safety of canal structures against uplift shall be evaluated according to the relationship:

$$SF = \frac{DL}{U} > 1.5 \text{ after construction or } 1.2 \text{ during construction}$$

Where

DL = dead load of structure, mechanical equipment and embedded parts; and

U = Uplift force for maximum water surface elevation.

5. Percolation

General Consideration - The design of structures located in or adjacent to canals must be designed in such a manner that they are safe against piping. Piping failures are generally the result of a short percolation path and a lack of densification of the backfill material.

Criterion - The minimum required percolation path is calculated by following the path of the water along the structure. The design must meet Lane's weighted creep ratio criteria. The minimum recommended creep ratio for various types of foundation materials are defined as follows:

Material	Ratio (C)
Very fine sand or silt	8.5
Fine sand	7.0
Medium sand	6.0
Coarse sand	5.0
Fine gravel	4.0
Medium gravel	3.5
Coarse gravel and cobbles	3.0
Soft clay	3.0
Medium clay	2.0
Hard clay	1.8
Very hard clay or hard pan	1.6

Creep ratio criteria. The weighted creep ratio shall be determined by the following equation:

$$C = \frac{L}{H}$$

Where

C = Lane's weighted creep ratio (percolation factor);

L = length of weighted creep (weighted path);

H = maximum head (difference in water surface elevations).

The weighted creep distance is the sum of :1/3 of the horizontal path distance along the structure (flatter than 45%) and the full vertical path along the structure (steeper than 45% or two times any percolation path distance that short-cuts through the soil. Collars or extended cutoffs should be added if the computed weighted-creep ratio is less than the recommended value.

TABLE 5 - 1

APPROPRIATE DESIGN CODES, PAKISTAN

(Current editions)

1. Government of Pakistan, Public Works Department, Irrigation Branch, "Manual of Irrigation Practices", Lahore, 1963
2. American Concrete Institute Standard 211.2, "Practice for Selecting Proportions for Structural Lightweight Concrete".
3. American Concrete Institute Standard 305, "Practice for Hot Weather Concreting".
4. American Concrete Institute Standard 318/83 "Build Code Requirements for Reinforced Concrete".
5. American Concrete Institute Standard 318/77 "Build Code Requirements for Reinforced Concrete".
6. C.P. 114
7. C.P. 110
8. American Institute of Steel Construction, "Specification for Design, Fabrication, and Erection of Structural Steel for Building".
9. American Welding Society, "Structural Welding Code".
10. American Institute of Timber Construction (AITC), "Timber Construction Manual".
11. American Institute of Timber Construction (AITC), "Heavy Timber Construction".

TABLE 5 - 2

WORKING STRESSES FOR REINFORCED CONCRETE 1/

(Alternative Method; Allowable Working Stresses)

Concrete Strength, f'c (28 day)	2,000 psi
Modular Ratio, n = Es/Ec	11
Permissible Service Load Stresses	
(a) Flexure Extreme fiber stress in compression, 0.45 f'c	900 psi
(b) Shear	
Beams, one-way slabs and footings shear carried by concrete, $v_c = 1.1\ (f'c)^{1/2}$	49 psi
Maximum shear carried by concrete plus shear reinforcement, $v_c = v_c + 4.4\ (f'c)^{1/2}$	246 psi
Joists, shear carried by concrete, $v_c = 1.2\ (f'c)^{1/2}$	54 psi
Two-way slabs and footings, shear carried by concrete, $v_c = (1 + 2/B_c)(f'c)^{1/2}$	89 psi
(c) Bearing on loaded area, 0.3 f'c	600 psi
Tensile Stresses in Reinforcement, f_s	
(a) Grade 40 or Grade 50 reinforcement	20000 psi
(b) Grade 60 and welded wire fabric	24000 psi
(c) For flexural reinforcement 3/8" or less in diameter and in one-way slabs of not more than 12 foot span, 0.50 f_y but not more than	30000 psi

1/ ACI 318-83 Code, U.S.A.

TABLE 5 - 3

WORKING STRESSES FOR STRUCTURAL STEEL

Description	Allowable Unit Stresses A-242	Allowable Unit Stresses A-7
Tension on net section	27,000	18,000
Tension in extreme fiber	27,000	18,000
Compression on gross section	27,000	18,000
Compression in extreme fiber when compression flange is supported laterally	27,000	18,000
Compression in extreme fiber when compression flange is unsupported	$27{,}000 - \frac{7.5^2}{b^2}$	$18{,}000 - \frac{5L^2}{b^2}$
Maximum intensity of shear on critical gross section	15,000	11,000

TABLE 5 - 4

WORKING STRESSES FOR BRICK MASONRY

Average Compressive Strength of Brick, psi	Allowable Compression with Portland Cement Mortar, psi
1,000	100
1,500	500
2,000	200
2,500	250
3,000	300