# A REINFORCED CONCRETE SHELL FOR THE CONVENTIONAL SINGLE-PASS, SINGLE OR MULTI-PRESSURE STEAM CONDENSERS

A PROGRESS REPORT

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# BACKGROUND

## Background

Significant economic benefits would result, for the lesser developed countries, through a coordinated program to substitute domestic material and labor in some of their more frequent import items. The substitute program would be directed toward those items which employ a lesser degree of technical know-how and a greater amount of domestic raw material and unskilled laborer. Also the items would have to be a relatively common import item between a large number of countries in order to make possible a cooperative effort toward the implementation of the programs.

Such an item has been chosen, the steam condenser utilized in power generating plants. The structure of steam condensers is relatively simple. It is composed of an outer shell enclosing tube bundles which, in turn carry cooling water. The hot steam is introduced at the top of the shell and then condenses on the tubes. This process gives rise to a vacuum in the shell. The condensate is then taken out by use of a pump. (Figure A).

It is not proposed to change the design of these condensers in a radical way at this stage. Actually the continuous improvements of the design of these condensers, for decades, have made them the most trouble free and reliable elements in a steam power plant. What has been suggested is to construct some of the components of these condensers locally so that both local labor and material can be utilized. A series of

reports will be prepared on the study and the redesign of these components. The following report deals merely with the study that has been conducted for the modification of the outer shell.

The outer shell uses a relatively large quantity of material, either welded steel or cast iron. It has been suggested that this material could be substituted with reinforced concrete, cast on the site. This kind of modification is the goal of the entire program. It consists not only of substituting local labor for the work performed elsewhere, but it also utilizes cement rather than steel or cast iron, a material produced by many of the less developed nations already.

The future reports will hopefully study the modifications of tube shells of these condensers and other accessories.

It is predicted that these reports would not only help the development of the LDC's of today but might also benefit the developed nations, as well, in the future.

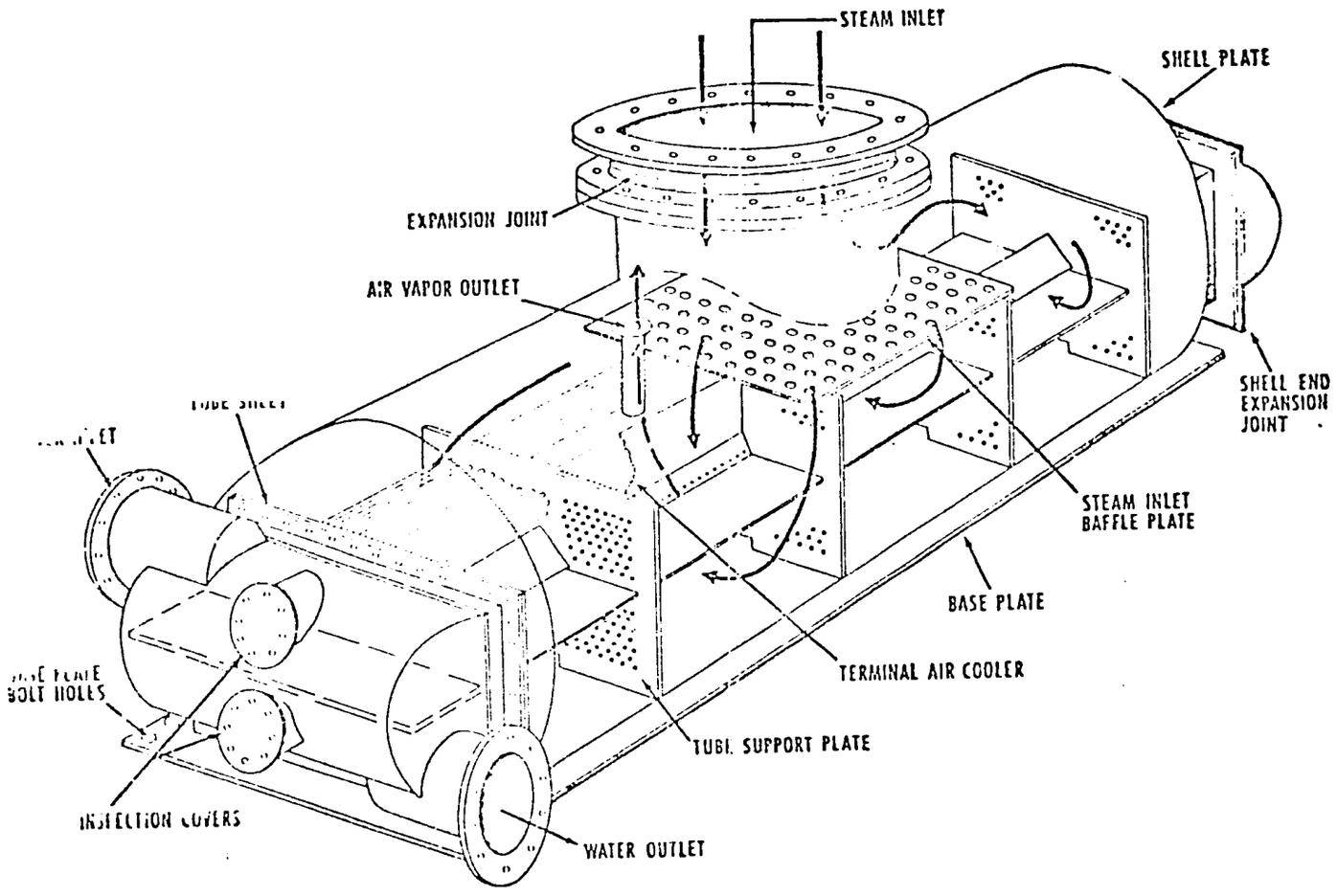
STEAM INLET
SHELL PLATE
EXPANSION JOINT
AIR VAPOR OUTLET
SHELL END
EXPANSION
JOINT
STEAM INLET
BAFFLE PLATE
BASE PLATE
TERMINAL AIR COOLER
TUBE SUPPORT PLATE
WATER OUTLET

Figure A

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Concrete Steam Condenser Shell

Construction Manual

Part I

# PREPARATION FOR THE DESIGN

# Chapter 1

# INTRODUCTION

## 1.1 Condenser Design

The basic steam condenser consists of a long outer shell enclosing a large number of tubes placed along the length of the shell. (In this particular application). (Figure 1.1/1).

Out of this basic design has grown a whole multitude of designs, some very sophisticated, some even different. We shall describe some of these shortly (Reference 1-2), but throughout our work, we shall only consider the basic design.

The basic design which is the single shell (Single pressure), single-flow design is still favored for the medium size power plants, the size most likely to be used in the LDC's.

## 1.2 The Conventional Steam Condenser

The description of all the designs and the variations of the conventional steam condenser is almost an impossible task. There is a certain number of "general design" condensers, and then a multitude of specific designs built by specific manufacturers. Sometimes the choice is merely a matter of simple engineering necessities, such as the availability of area or space, and sometimes it is the result of very complex engineering analysis especially for the larger sized condenser units. The high performance demanded on the larger power generating units requires this sort of analysis which in turn results in a multitude of designs: multi-pressure condensation units and multi-pass flow arrangements. Some of the general schemes will be described here.

The most common type of tube and shell condenser is of cylindrical shape. The water to the tube bundle is distributed by means of two waterboxes located at the ends of the shell. A very small model of this type of condenser is shown in Fig. 1.2-1 (Reference 2). The inside of the cylindrical shell consists of a tube bundle very much like the one shown in Fig. 1.1-1.

Fig. 1.2-2 shows a version of the so-called single-pressure, double-pass type of condenser (Reference 2). Two water-boxes are shown on one side of the shell. One serves as

the inlet for the cooling water, the other serves as the outlet for the cooling water. The tube bundle bends 180° at the other side and makes this sort of arrangement possible.

Three different versions of the multi-pressure, single-pass condensers are shown in Fig. 1.2-3 (Reference 2). Fig. 1.2-3/A shows a typical 2 pressure operation for single-pass condensers. It consists basically of the single-pass, single-pressure condenser divided in two sections by a wall built perpendicular to the tube bundle. Of course the modifications have provided independent steam inlets for each section Fig. 1.2-3/B shows a single-pass, three pressure condenser. Again this is merely a modified version of the first condenser and a separator and an independent steam inlet have been added on. These simple modifications are very important as far as our design is concerned. They suggest indeed that our design of reinforced concrete structures extend their uses not only to the conventional single-pass, 1 pressure, systems but also to the more sophisticated 2 and 3 pressure condenser systems. Fig. 1.2-3/C shows another modified version for a 2-pressure operation. In this design each section is built independently and arranged so that the water outlets and the water inlets are on the same side of the structure. This could be arranged by either bending the tube bundle, or building a common waterbox at the other side. It appears that in this design the latter has been done.

The condensers shown in Fig. 1.2-4 are of the specific-design type discussed before. They are designed for specific applications such as outdoor installations (Fig. 1.2-4/A) or horizontal steam inlet scheme (Fig. 1.2-4/B).

The design of headers, in conventional structures, will not be discussed as it is basically a specific design element. Its design is usually the result of the analysis carried out by individual manufacturers and usually of a standard general shape shown in Fig. 1.2-5.

In our design of the shell and the waterboxes we do not deal with the general design parameters, and we shall treat all of these parameters as constants. We should have the exact shapes and sizes and all of the details at the design stage and we would merely redesign for concrete construction.

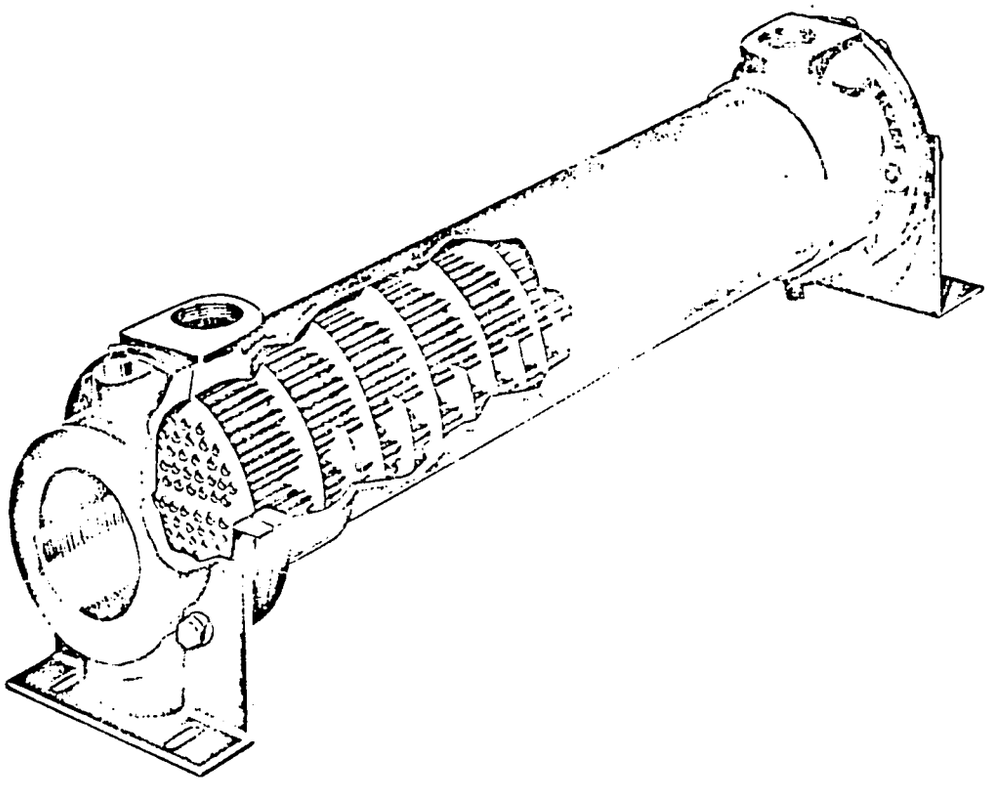


Figure 1.1-1

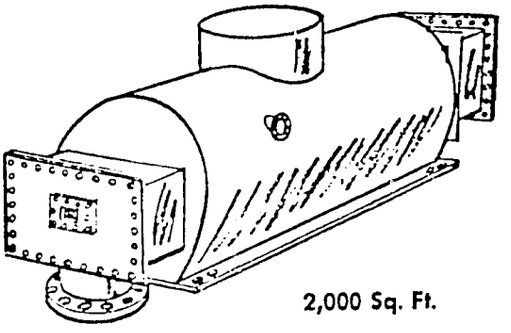



Figure 1.2-1

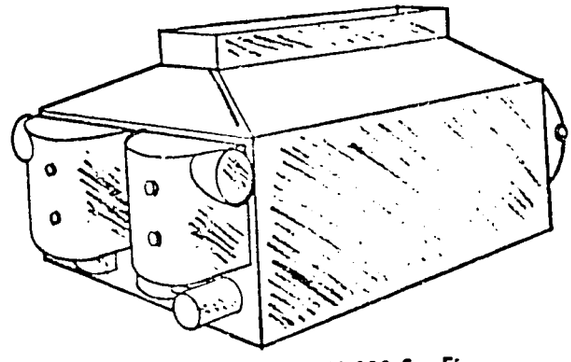
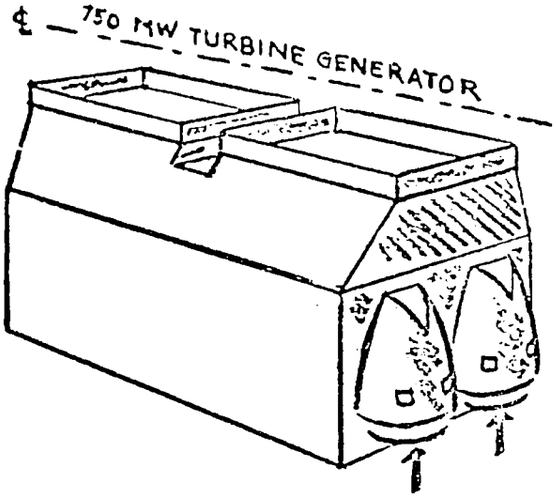
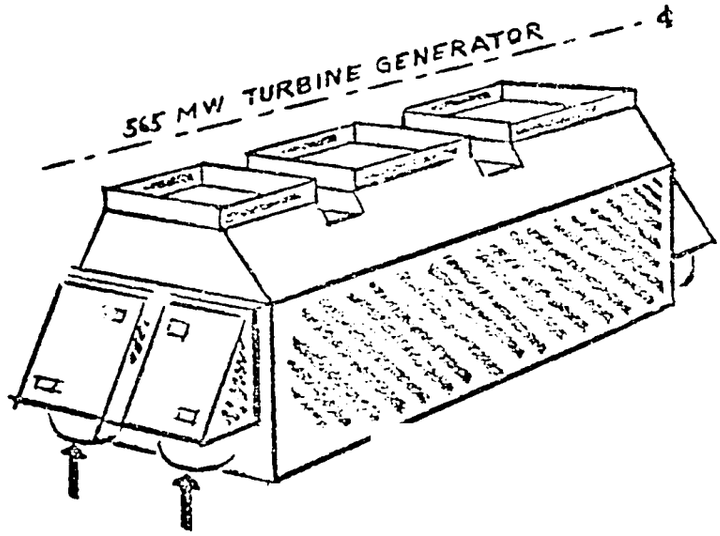



Figure 1.2-2



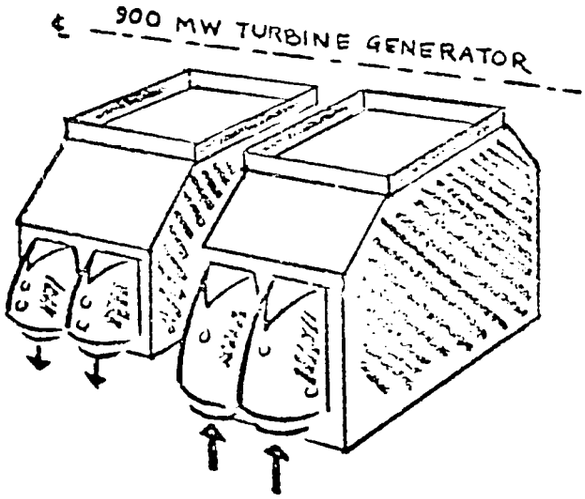

435,000 SQ. FT.
40,412 M²
SINGLE-PASS
2 PRESSURE OPERATION

Figure 1.2-3/A




240,000 SQ. FT.
22,296 M²
SINGLE-PASS
3 PRESSURE OPERATION

Figure 1.2-3/B




500,500 SQ. FT.
46,496 M²
SINGLE-PASS
2 PRESSURE OPERATION

Figure 1.2-3/C

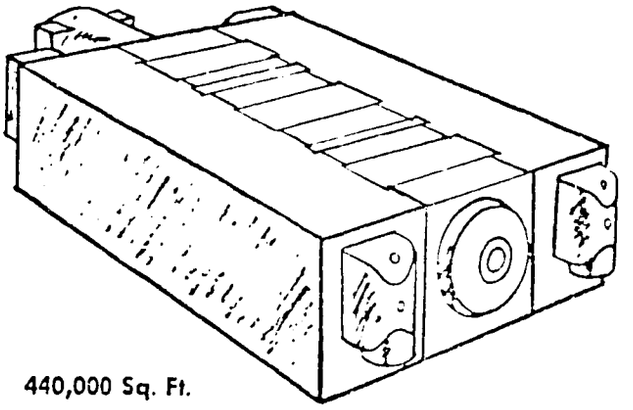



Figure 1.2-4/B

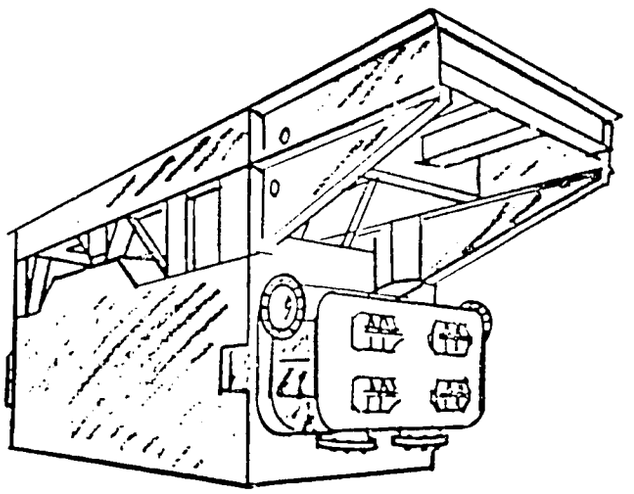



Figure 1.2-4/A

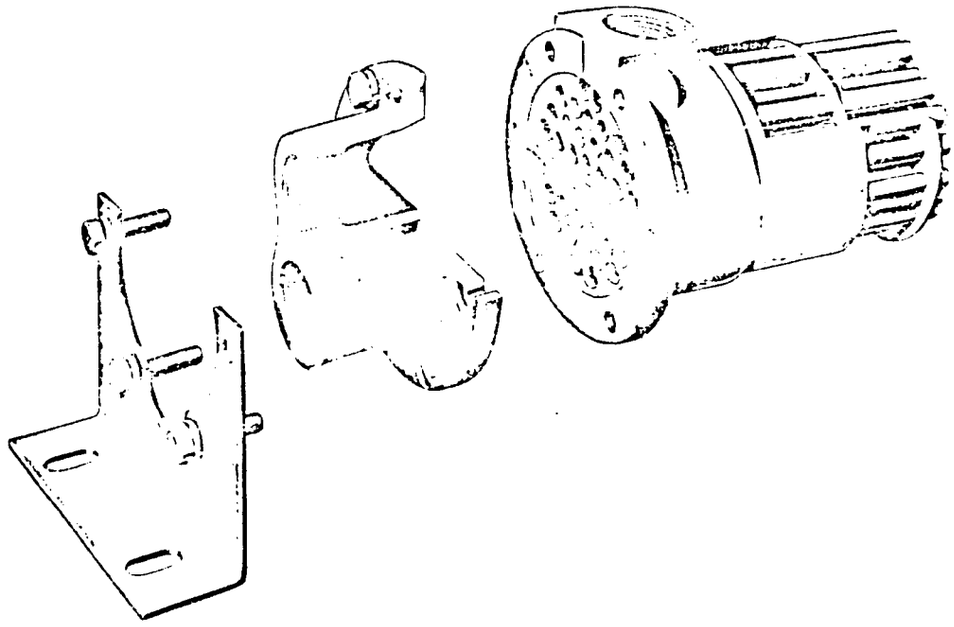


Figure 1.2-5

## 1.3 Modifications of the Shell for Concrete Construction Applications

From the beginning of this study several months ago several different modifications have been considered. At first we had decided to change the general shape of the condenser (Figure 1.3-1) and actually redesign the entire condenser. We were to be discouraged shortly thereafter (Reference 3) as we realized that we could not afford to risk a complete change of design and material. It was also revealed (Reference 3) that it would be very difficult to convince the customers to take such a risk also.

Then a cylindrical shape was considered for the shell of the condensers. (Figure 1.2-2). It seemed to be a good logical choice. Concrete cylindrical shapes are ideal for the sort of application we were going to have due to the presence of vacuum inside the cylinder. The concrete is a material with high compressive strength and a concrete cylinder produces exactly the kind of stress concrete is most able to resist. However we were discouraged again as we learned that the building of the cylinders of the size we had in mind would require not only a generally more sophisticated construction technique and manpower, but also the use of both forms and machinery that would usually not be readily available on a generating plant's construction site. (Reference 3 and Reference 4).

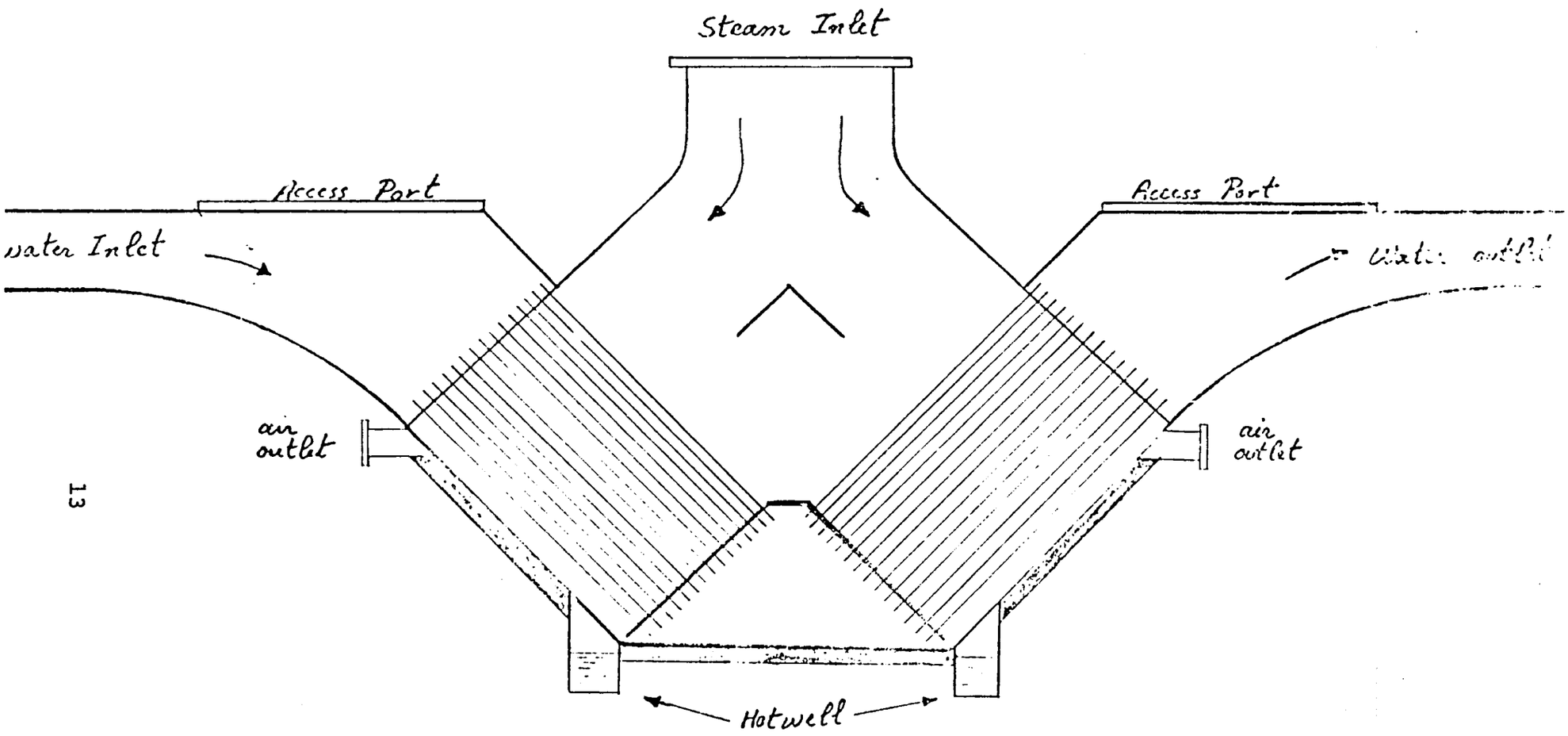

Steam Inlet
Access Port
Access Port
water Inlet
air outlet
air outlet
Hotwell

Figure 1.3-1

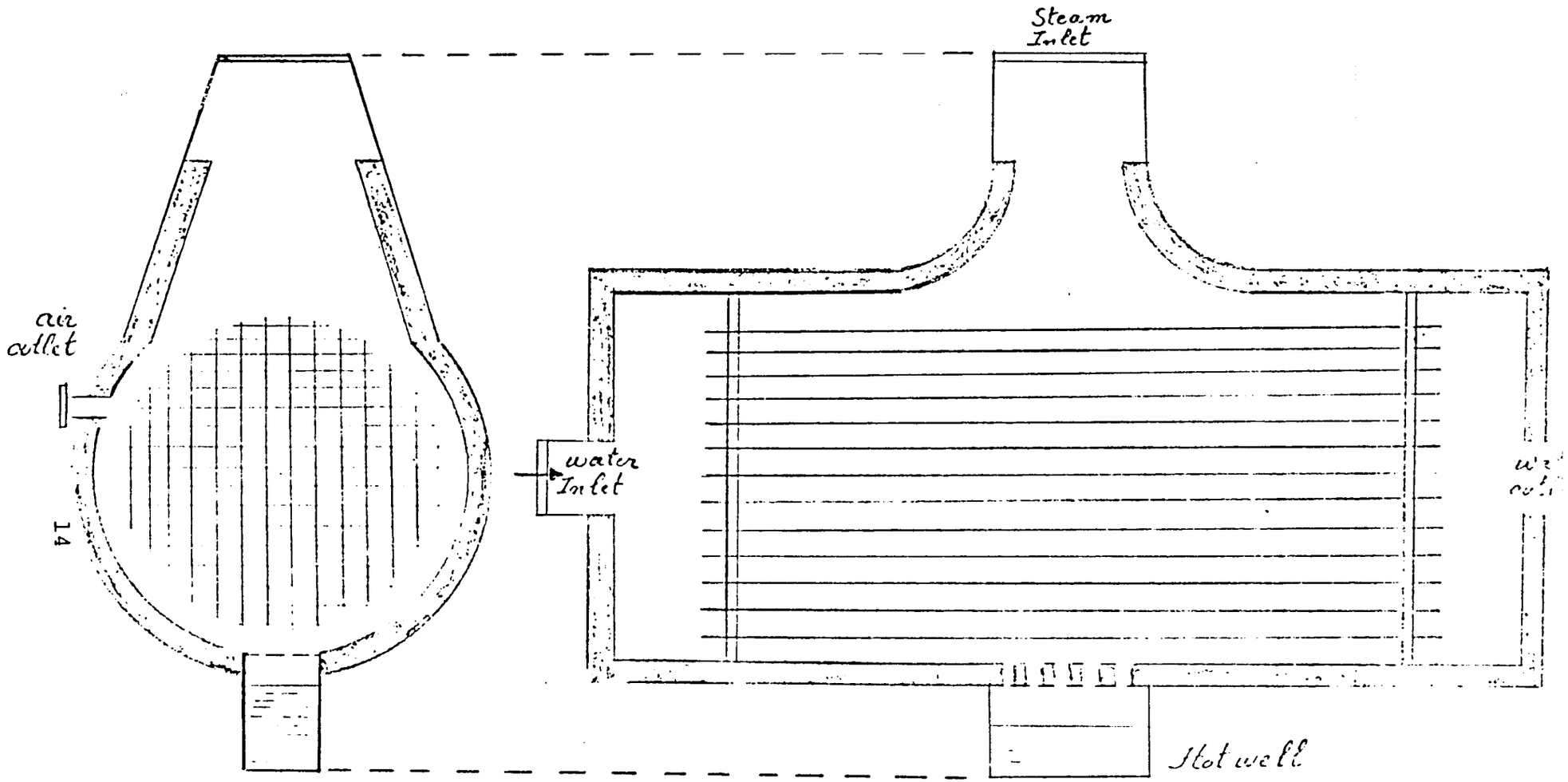



Figure 1.3-2

We then considered the next alternative, a design with, simply, vertical walls, a plain flat ceiling to contain the tube bundles, and simple rectangular waterboxes (Figure 1.3-3). This choice seemed to please almost all of those professional engineers and designers that were contracted. (References 3-5 - 6-7).

The problem we faced then was that no study had been made, a priori, on any such structure. That is a rectangular tank enclosing a vacuum condition. A search into the studies of underwater installations produced no new evidence of prior work in this field (Reference 8-9). Finally the use of the data given for rectangular concrete ranks (Reference 10) with the assistance of Professor Hong of the Civil Engineering Department at M.I.T. (Reference 11), revealed the fact that the pressure differentials we were concerned with would actually cause more conservative bending and tension stresses.

The use of the concrete rectangular tank was then considered appropriate for our purpose. An immediate result of this would be of course to have thicker walls than actually necessary. However, it seemed better to stay on the safe side at the early stages, until the analysis and the data for this new type of application for reinforced concrete becomes available anyway.

It should be noted that at all times concern was given to the basic problem of thermal stresses resulting from

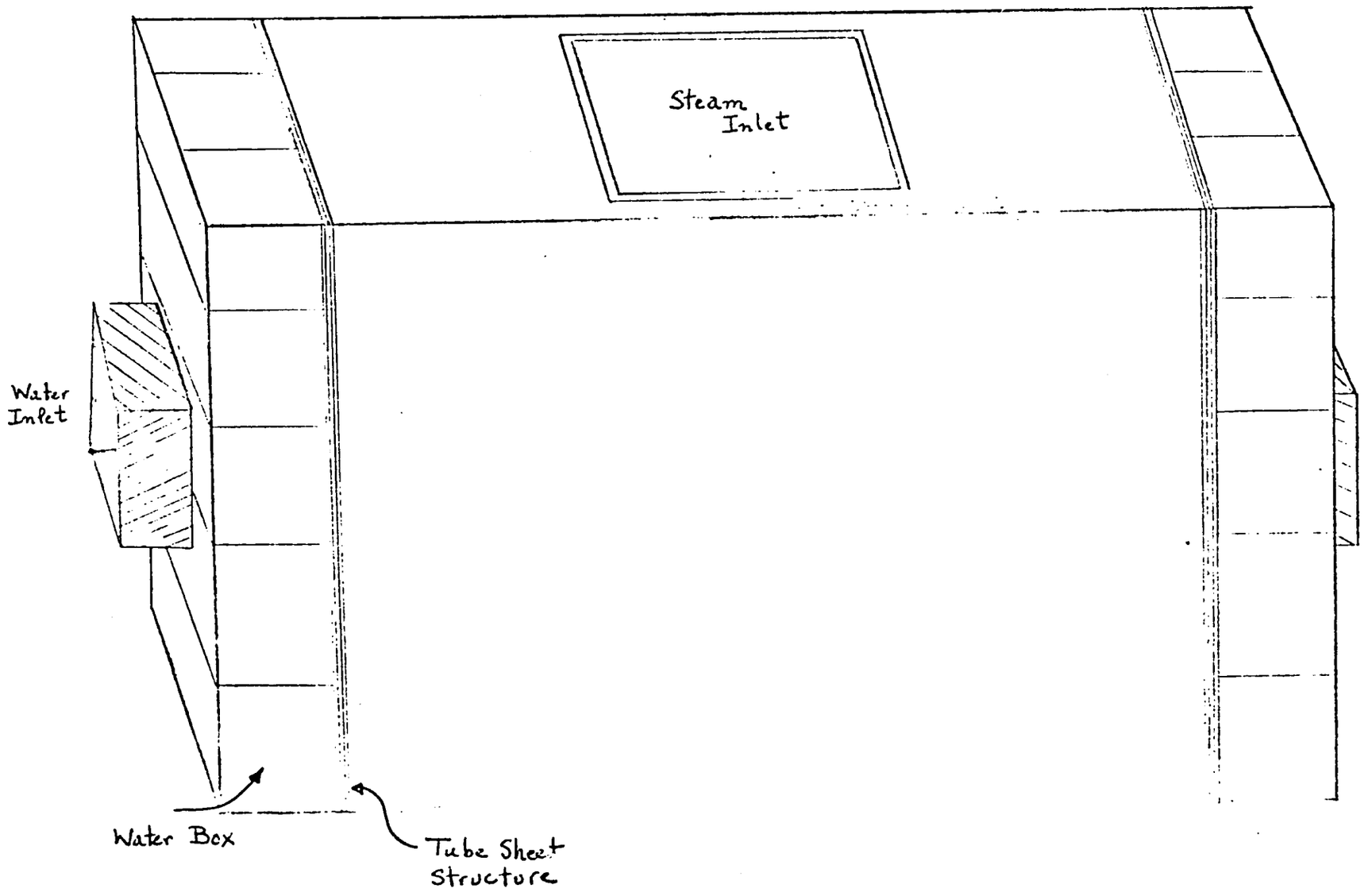



Figure 1.3-3

temperature changes. These changes were however in the range given for standard applications of concrete (Reference 13) and the design accordingly took this matter into account.

## 1.4 The Description of the Design

The foundation of the design was essentially separated into three major parts (Figure 1.4-1).

A. The waterboxes.

B. The shell.

C. The tube sheet supports and other accessories.

A. The Waterboxes

The waterboxes operate at relatively constant temperatures. Their design therefore does not have to consider the same stresses as the shell. The waterboxes were therefore designed as stationary structures anchored to the floor. The design details of these waterboxes were drawn (Fig. 1.4-2).

Although the outer side of each waterbox is provided with manholes covered with the regular steel covers and the inner sides are connected to the tube sheet section of the structure by expansion joints, it was assumed that the design analysis of "Closed single-cell tanks" (Reference 14) would apply. The waterbox structures were designed accordingly.

B. The central section of the steam condenser, its shell, has merely a containing function. It was recognized that the thermal stresses applied to this section would require an expandable design. (Reference 15). This section was designed accordingly as a square cylindrical box built on a smooth surface and anchored only in the center. The two

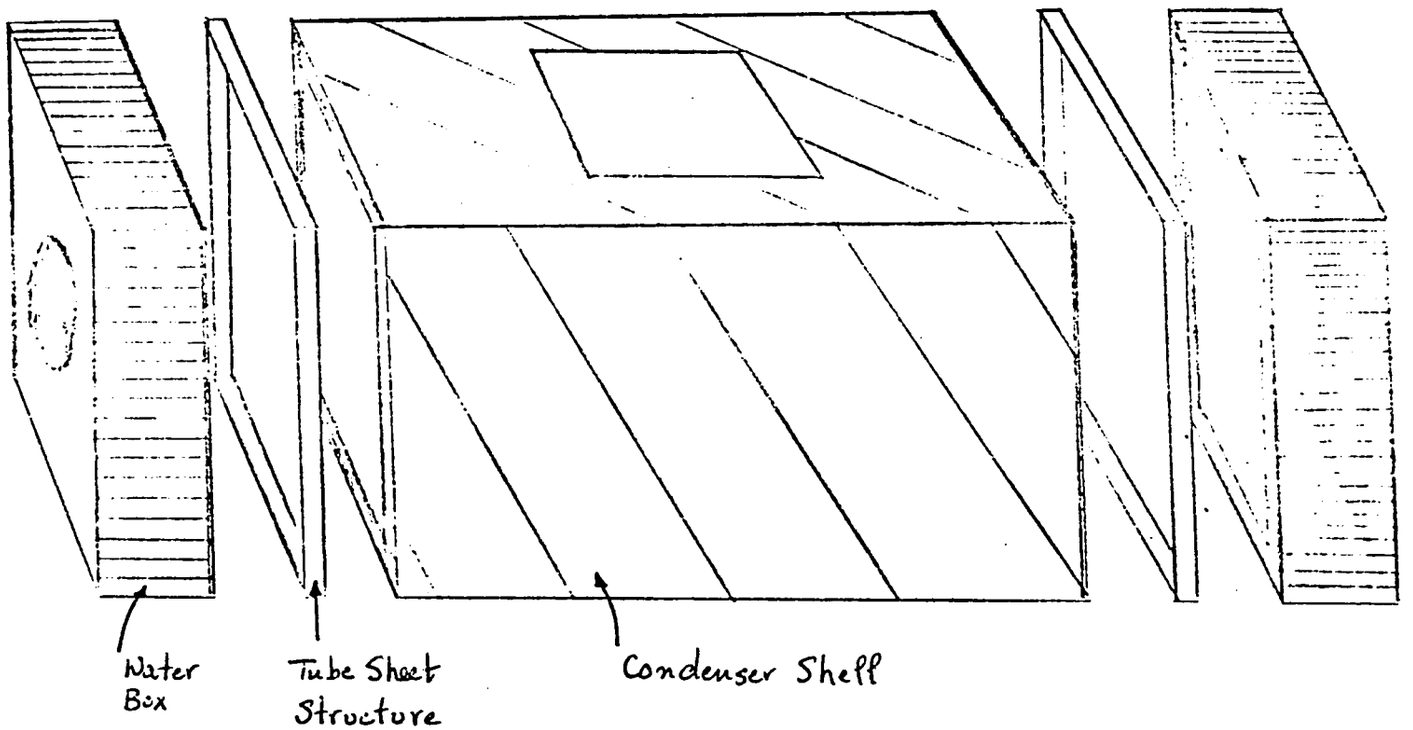



Figure 1.4-1

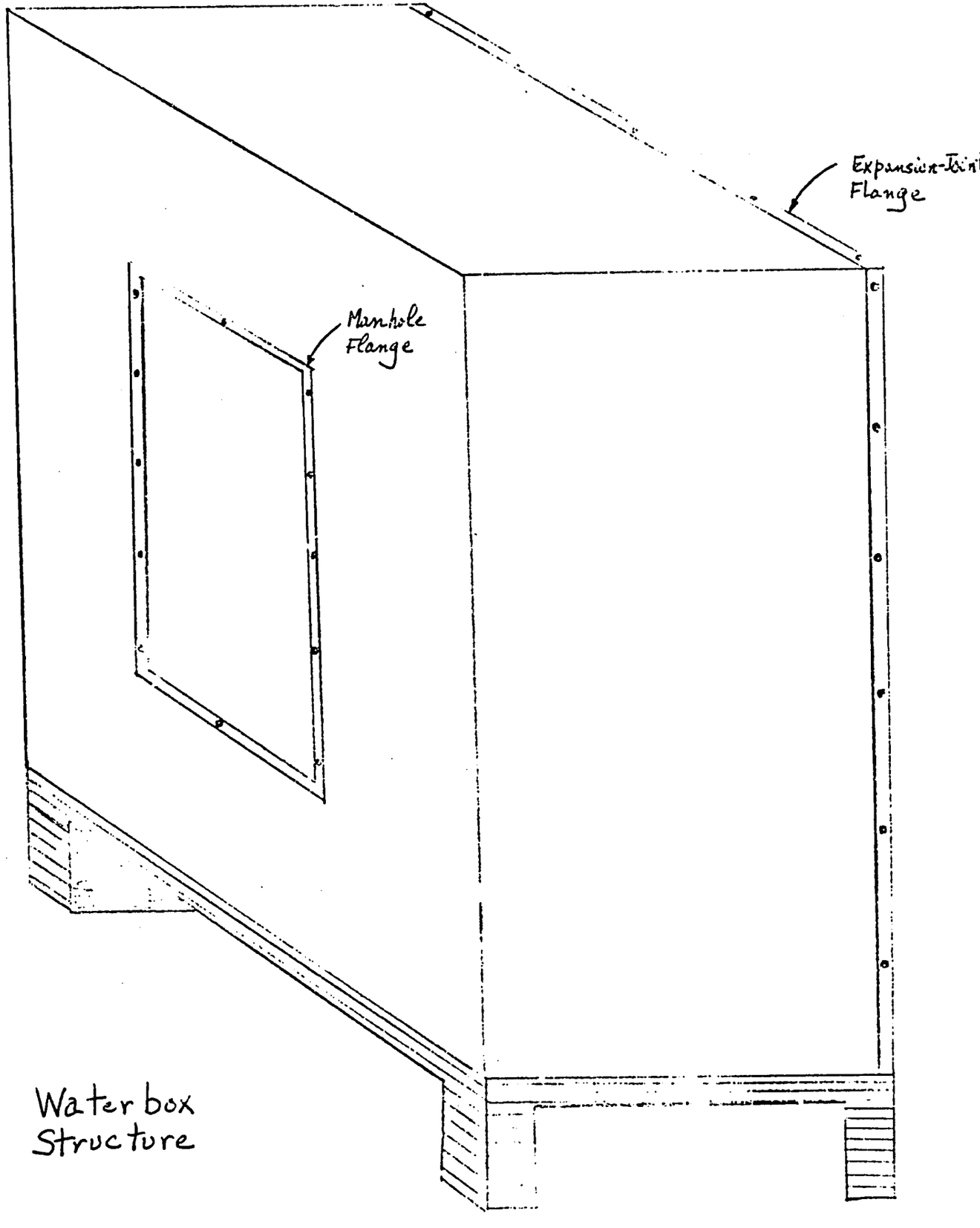

Expansion-Joint Flange
Manhole Flange
Water box Structure

Figure 1.4-2

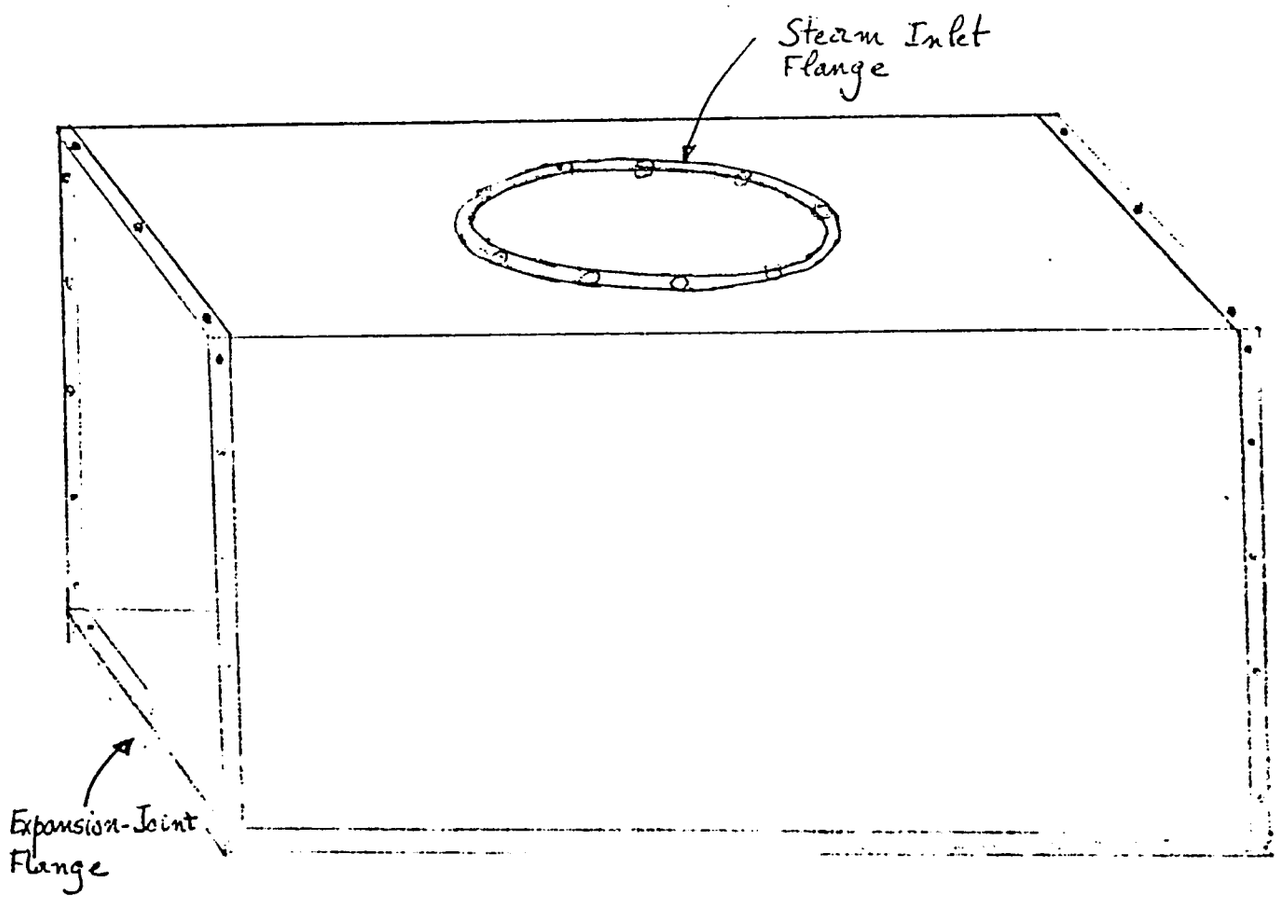
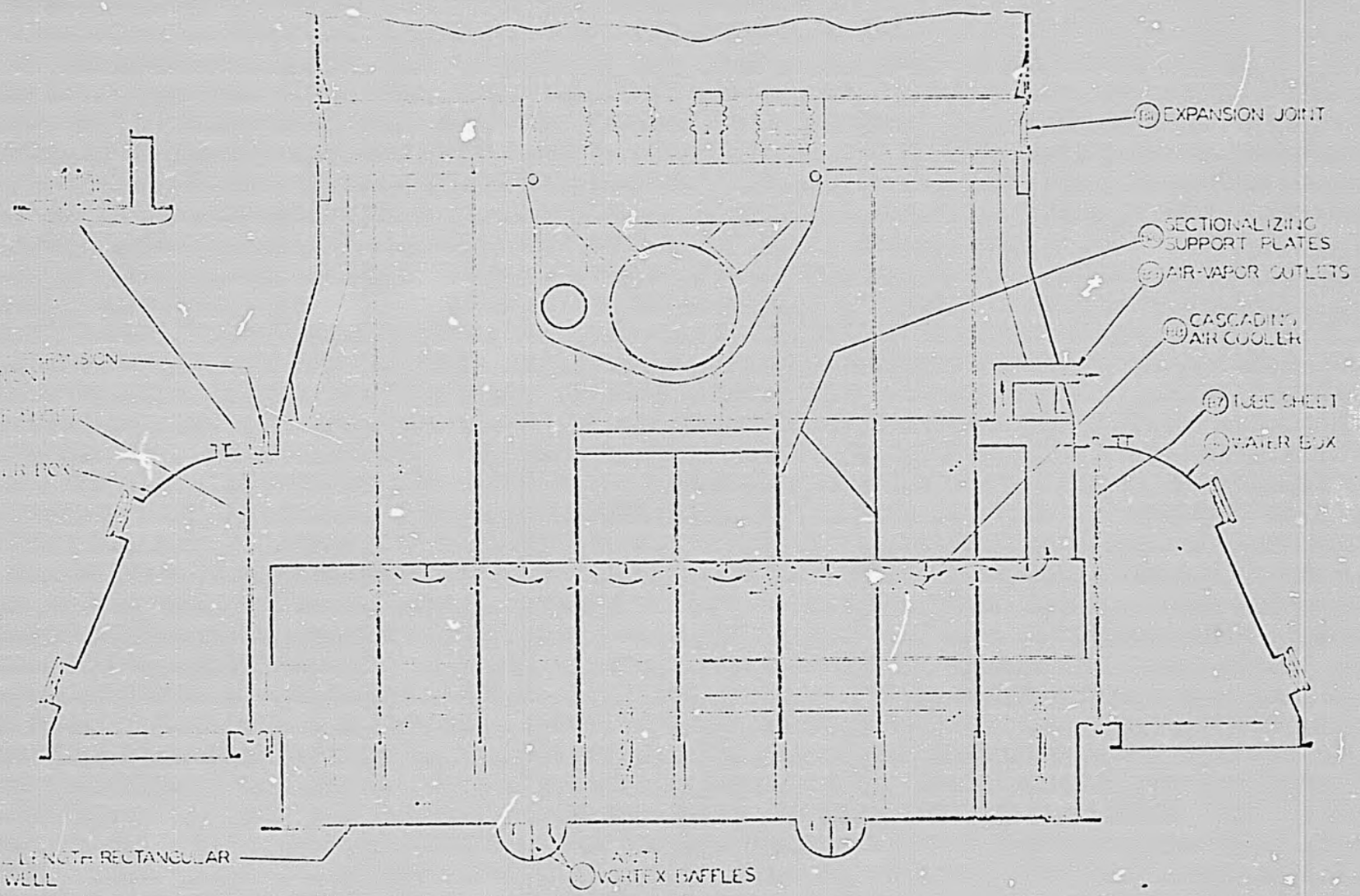



Figure 1.4-3

ends of the shell could merely be connected through expansion joints to the tube sheet structures. The main reason for the independence of the shell structure from those of the tube sheets is the unequal expansion rates of concrete and the metal tubes permitted in this design. Each side of the shell was considered as a flat slab doweled to the adjacent sides and the analysis and data of the flat slabs supporting a uniform load was used (Reference 16). The details of the design of the shell are drawn specifically (Fig. 1.4-3). The top slab would provide for the steam inlet consisting of a large circular opening. (Sometimes rectangular openings are used). On the edge of the opening steel flanges would be placed to assure a conventional connection with the expansion joint. The expansion joint provides the connection between the turbine exhaust and the condenser inlet. (Reference 17).

The bottom slab of this section would have to support the weight of all the tubes, baffles, and so forth, through the tube support plates. The internal's design and materials are not changed from the original design. Only those areas in which connection is made between concrete and tube plates would be studied to guarantee a safe, corrosionless, and free-sliding contact. These modifications will be all considered separately. The bottom slab will also be shaped as in conventional designs to accommodate for a full length rectangular hot-well, with all the details such as the anti-vortex baffles, outlet, etc. (Fig. 1.4-4) (Reference 18).




DRAWING B



Fig. 1.4-4

C. The Tube Sheet Supports and Other Accessories.

Finally the third part of the design consists of basically the tube sheet supports (Fig. 1.4-5). This section will consist simple of a thin vertical structure supporting and enclosing the tube sheet. This structure will be built in the space between the waterboxes and the central section (shell) and connected to them by two proper expansion joints. One of the most important reasons to make this section an independent design problem, aside from the thermal stress complications, is proposed future modification of the tube sheet design. An independent design at this stage would assure greater flexibility and independence in the future.

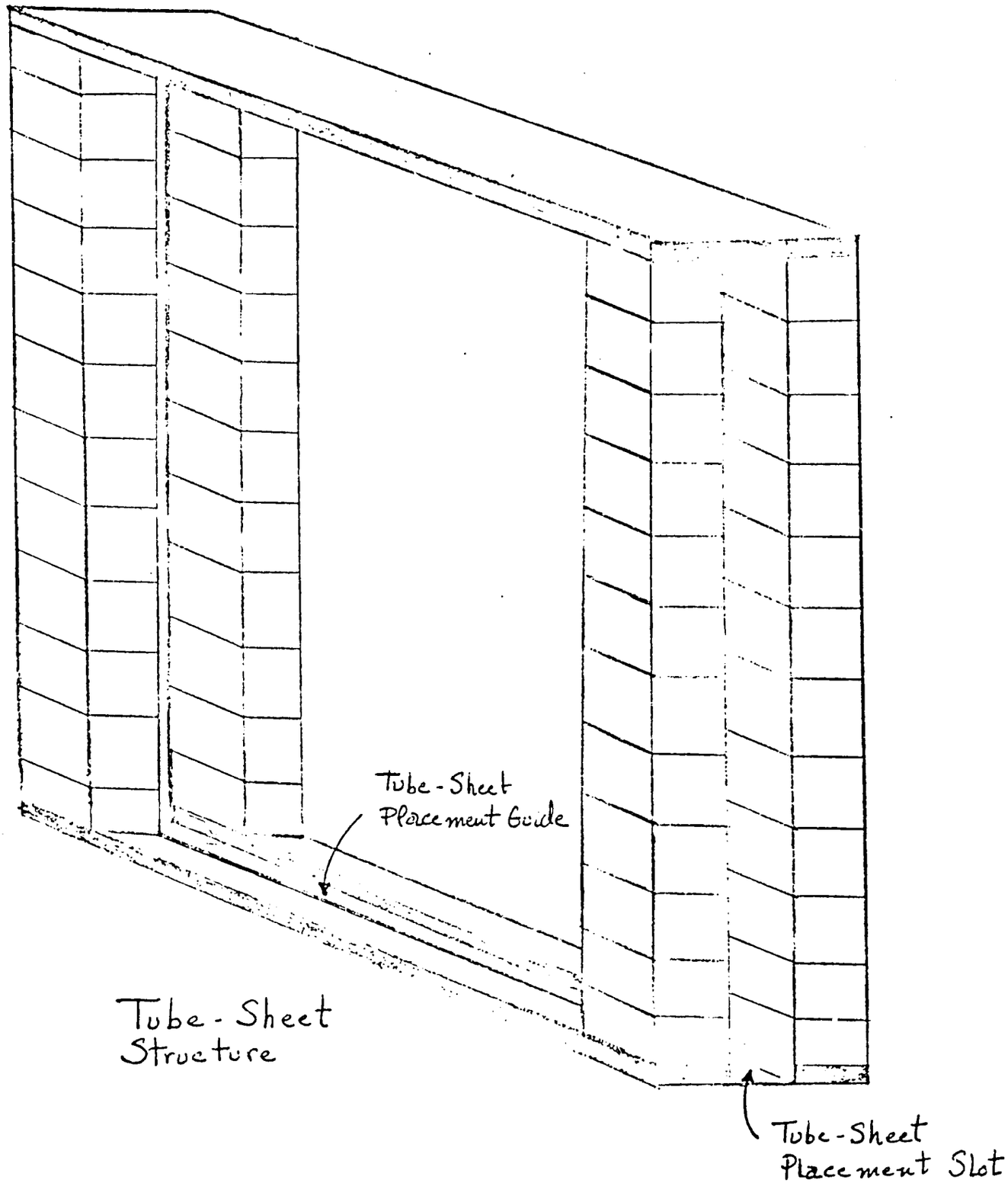

Tube-Sheet
Placement Guide
Tube-Sheet
Structure
Tube-Sheet
Placement Slot

Figure 1.4-5

# Chapter 2

# MODIFICATIONS PROCEDURE

## 2.1 Introduction

This chapter is introduced to prepare the builder for the actual calculations that he should perform in the following chapters for the design and the construction. The first step, in the lengthy and detailed design of the reinforced shell for the condenser of thetype discussed here, i.e. boxed-shape structure, is to obtain the plans of the condenser structure for the specific application. An example is inserted in the Appendix (A1/I). These plans have, generously been furnished by the Ingersoll-Rand Corporation of New Jersey. The plans are actually for condensers larger than the ones we are concerned with. However, the general features remain. Before we discuss the general modifications to be performed on the condenser structure we should mention the features of the condenser structure of A-1.I that we are concerned with.

A. The Shell

This part of the structure is of primary importance in the design as it consists of the largest single section to be dealt with. It should be noted however, that the part of the plans showing the connection between the shell and the turbine exhaust and attached in this case to the shell is not of our concern. The reason for this is the designs we are concerned with do not have such a large connecting section and therefore that part of the construction has been omitted from this manual. An expansion joint will be

provided at the shell's inlet where proper flanges for this purpose will be placed. If there is a necessity for a more complicated connecting section the conventional structure will be used.

B. The Waterboxes

The waterbox structures will be dealt with separately. The shapes will be modified to rectangular for ease of construction as far as a reinforced concrete construction is concerned.

C. The Tube Sheets

The tube sheets are not shown in the A.1/I. This is because tube sheets are considered internals and not part of the outer structural design. However, in our design as explained in the Introduction, the tube sheets are placed on separate structures placed between the shell and the waterboxes and will be dealt with separately.

D. The Inlets and Outlets

The inlets and outlets will not be modified in any way except to provide for their connections to the concrete structure.

E. Expansion Joints

Four sets of bellow-type expansion joints will be placed to connect the two tube sheets to respective waterboxes and to the shell.

## 2.2 The Shell

The cross section of the shell is rectangular or square according to the design. The inside measurements of the cross section of the steel or the cast iron shell are considered as the inside cross section of the reinforced concrete shell. The length of the actual shell and the concrete shell will be equivalent.

The steam inlet will be lined with a steel flange to ensure proper connection with the expansion joint. The design of this flange would be made according to the specifications provided by the expansion joint manufacturer. Each end of the shell will also be provided with one of these flanges, designed again according to the given specifications. All of these flanges will be welded to the reinforcement of the shell itself by means of steel rods of the same number as the shells' reinforcement.

The floor of the shell will be designed exactly as the original. A full rectangular hot well with all the necessary details. Care should be taken to include all of these details in the original forms so that once the floor section is cast no more shaping would be necessary. In the same manner, all the openings for inlets and outlets, for instrumentation, manholes, etc., specified on the original plan, should be taken care of in the original framework and designed so that it can be lined with steel flanges.

It is very important to note that although the thermal expansion of concrete is not expected to be of major magnitude, care should be taken in leaving allowances, in all of the flanges, for continuous expansion. This should be achieved by cutting the flanges at the corners of the smaller rectangular holes, at both corners and mid-section of the sides of the larger rectangular holes, and on 4 sides of circular holes (Fig. 2.2-1).

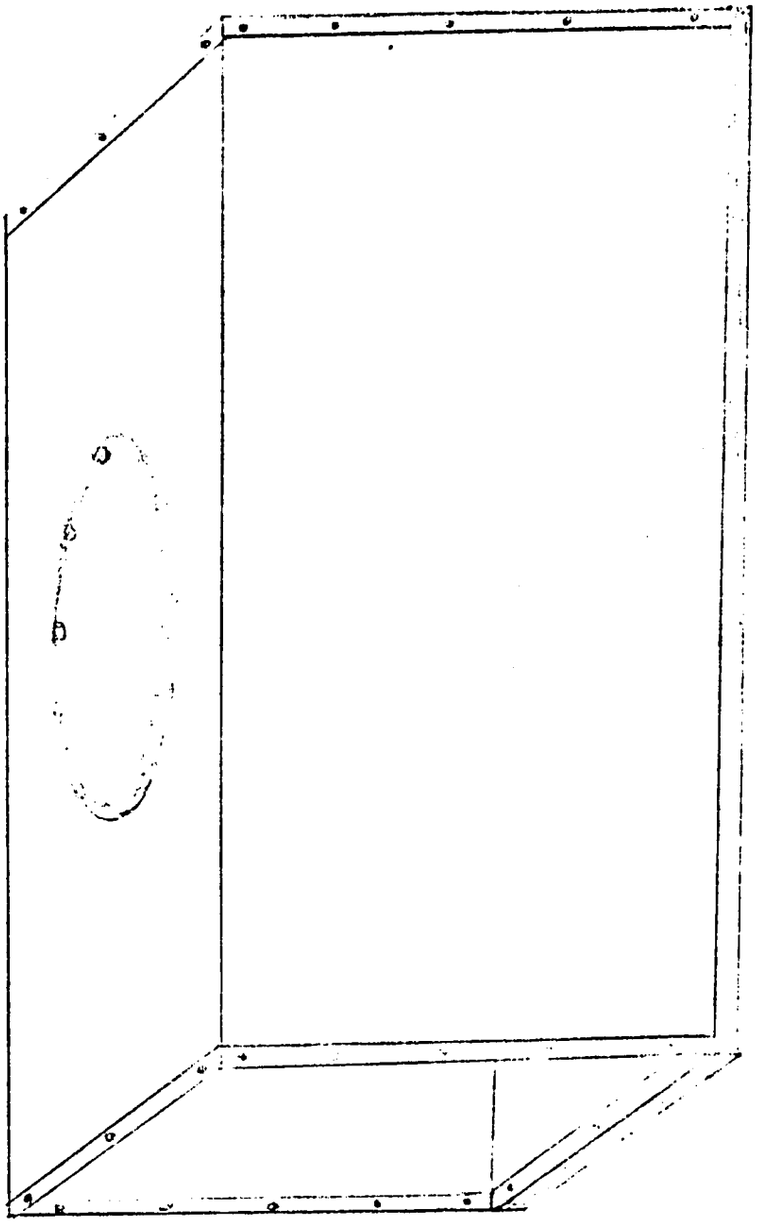


Figure 2.2-1

## 2.3 The Waterbox

The structure of the waterbox will be rectangular and not circular. In some of the conventional designs the waterbox is of rectangular shape but, in most cases, it has a half-spherical shape. In either case the waterbox will be redesigned to have a rectangular shape extending all the way to the ground level. This is the same level on which all of the condenser structure will be built). This is an area in the design where major changes will be made. The waterbox structure will have the following characteristics.

a. Its width will be the same as the largest width of the actual waterbox (inside measurements). Its height will be the same as the inside length of shell. Its length (measured along the direction of the tube bundle) will be the same as the largest length in the actual design.

b. Since we do not intend to change the flow characteristics inside the waterbox and thereby alter the whole performance analysis, we shall install an aluminium plate inside the waterbox, shaped exactly like the original waterbox and place it in the concrete structured waterbox. It should be noted that the water inlets should be exactly as shown in the plans of the conventional condenser. The same is of course true for the second waterbox and the water outlet. The plate will not have any containing functions. It will merely direct the flow of water. Actually there will be clearance between the

walls and the plates so as to let the water get behind the plate. This clearance will be insured by a suitable material placed at equal distances. The only firm connection between the flow-director (this is the name with which we shall refer to the steel plate) and the structure will be right at the inlet (or outlet) where they will be welded or secured by proper joints. The flange should be made of the same material as the flow-director therefore and if steel is used both should be of steel or both of aluminium etc.

The manholes again will be designed according to the design and flanged according to the instructions given in Section 2.2 (Fig. 2.3-1).

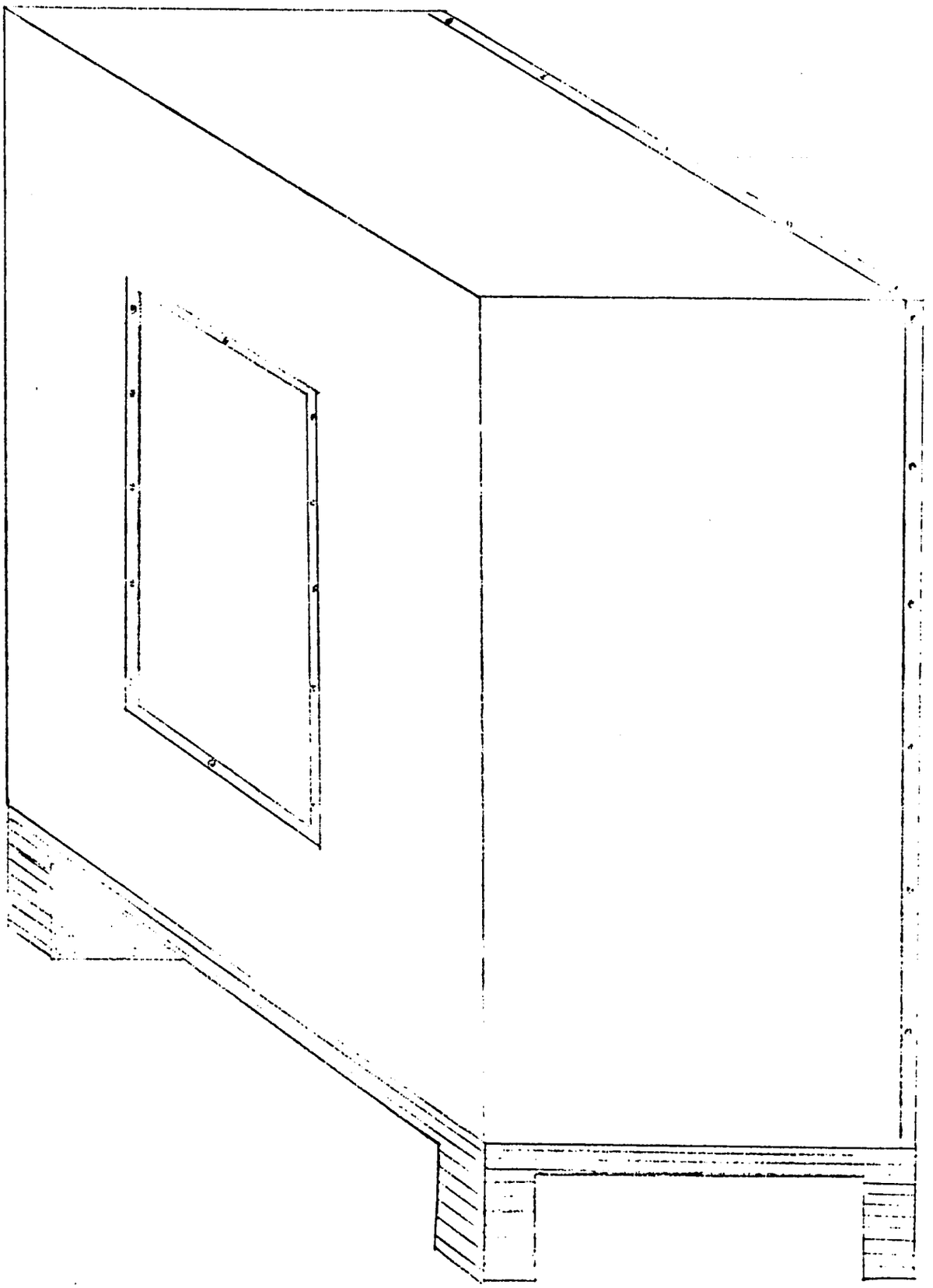


Figure 2.3-1

## 2.4 The Tube Sheet Structure

The tube sheet section of the condenser is probably one area in which a complete design is achieved. For the reasons discussed in the introductory portion of this Manual, the tube sheet, usually considered an internal design item, has been treated as an independent design subject. The actual tube sheet will remain exactly as it has been in the conventional condenser; however, instead of being installed in the shell, it will be placed in a structure specifically designed to support and enclose it. This structure is built independent from the shell (Fig. 1.4-1). Expansion joints (Bellow-type) will connect the structure with the shell and the waterbox. Again proper flanges will be placed and welded to the reinforcement network.

The material of the tube sheet can conceivably consist of anything, even cement (hopefully). To the worst case, let us suppose a material is being used where its behavior when contacted with cement is concerned. To account for this case the tube sheet will be separated from the structure by a suitable sealant on all four sides. One of the vertical sides is going to be used for installation of the tube sheet.

A slit will be formed in the center of this side to permit sliding of the tube sheet into the structure. On the other three sides proper grooves will be formed to permit introduction of the tube sheet and placing of sealant, therefore

insuring a strong adhesion of the tube sheet to the supporting structure.

Finally, it should be mentioned that as opposed to the waterbox, the tube sheet will not be anchored to the ground, but rather, like the shell, permitted to slide on a smooth surface (Fig. 2.4-1) (Reference 26).

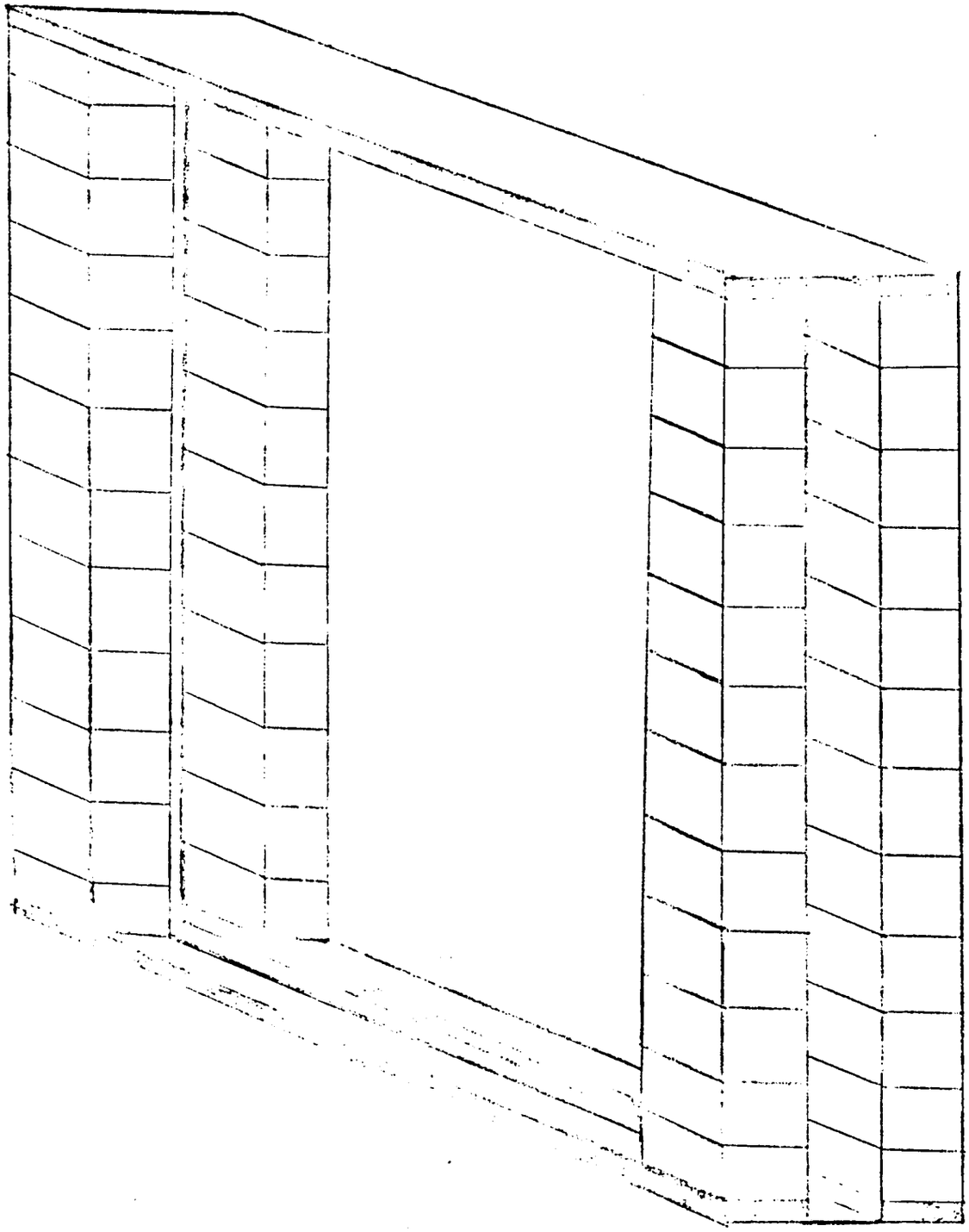


Figure 2.4-1

## 2.5 Notation

For the purpose of design of the walls and top and bottom slabs, the notation in Reference 14 (Rectangular Concrete Tanks) will be used. The reason for this is so that the charts and tables given from that reference throughout the Manual would not have to be changed. Figure 2.5-1 shows the notations used for heights, widths, etc. of each section.

As far as the notation used for the design of concrete walls themselves and the reinforcement goes, the notation presented in Table 2.5/1 (Reference 19) is used throughout the Manual, except when indicated otherwise.

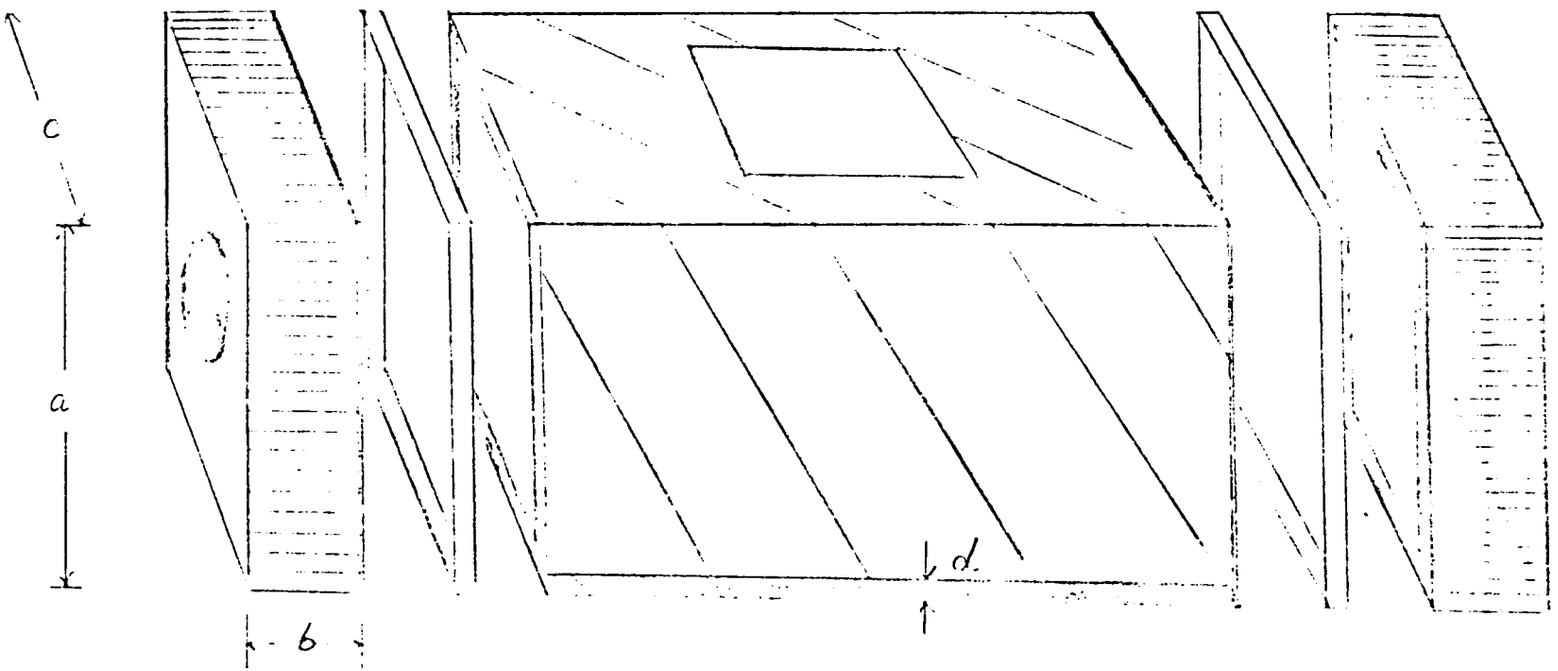



Figure 2.5-1

Table 2.2/1

SYMBOLS AND NOTATIONS

a - coefficient used in $A_s = \frac{M}{ad}$ and in $A_s = \frac{NE}{adi}$

$A_g$ - gross area of concrete section

$A_s$ - area of tensile reinforcement of beams or columns

$A'_s$ - area of compressive reinforcement in flexural members, or equivalent area of reinforcement in columns reinforced on four faces

b - width of rectangular beam, width of flange of T-beam, or column dimension

c - coefficient used in $A's = \frac{M - KF}{cd}$ and in $A's = \frac{NE - KF}{cd}$
size of bar reinforcement

d - effective depth of flexural members

d - distance from extreme fiber to compressive reinforcement

e - eccentricity measured from tensile steel axis (in.)

E - eccentricity measured from tensile steel axis (ft.)

$E_c$ - modulus of elasticity of concrete

$E_s$ - modulus of elasticity of steel

$f_c$ - compressive stress in extreme fiber

$f'_c$ - ultimate compressive strength of concrete

$f_s$ - stress in tensile reinforcement or in column reinforcement

$f'_s$ - stress in compressive reinforcement in flexural members

$f_y$ - yield strength of reinforcement

F - $\frac{bd^2}{12,000}$, used in determination of resisting moment of concrete sections

i - $\frac{1}{1 - \frac{jd'}{e}}$, used for sections subject to bending and axial load

I - moment of inertia

j - ratio of distance (jd) between resultants of compressive and tensile stresses to effective depth

k - ratio of distance (kd or ki) between extreme fiber and neutral axis to effective depth or to total depth

K - $1/2 f_c jk$ for flexural computations, or $\frac{A_{s2}}{A_{s1}}$ for column design using reinforcement on four faces

M - external moment (ft. kips or in.kips)

n - ratio of modulus of elasticity of steel ($E_s$) to that of concrete ($E_c$)

N - external force or load (kips); also number of stirrups

NA - neutral axis

p - ratio of area of tensile reinforcement to effect area of concrete in beams and columns

p' - ratio of area of compressive reinforcement to effective area of concrete in beams

$p_g$ - ratio of area of vertical reinforcement to gross area, $A_g$

P - axial load capacity (kips)

$P_b$ - the value of P below which the allowable eccentricity is controlled by tension, and above which by compression

R - radius of gyration, or design coefficient for deflections

s - spacing of stirrups (in.)

$T$ - resultant of tensile stresses

$u$ - bond stress

$v$ - shearing stress

$v_c$ - allowable shearing stress for concrete

$V$ -total shear

$w$ - uniformly distributed load

$W$ - concentrated load on flexural members

$\Sigma_o$ - sum of perimeters of bars

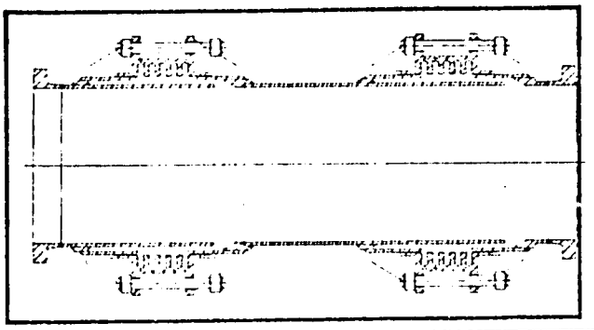
## 2.6 Specific Modifications

In this section we shall discuss some initial specific modifications necessary to the proper execution of the design. In this area we shall note some specific position changes. Since the tube sheet structure is taken as an independent structure in this Manual, we shall provide space to permit the insertion of this structure between the waterbox structure and that of the shell.

For each tube-sheet structure there will be need for two expansion joints (fig. 2.6-1) and for each of these a 1 foot width shall be provided. The structure of the tube sheet shall have a thickness of 1.5 ft. The tube sheet is placed at the center of the structure and therefore a total length of 1.5/2 + 1 = 1.75 ft. which is added to the tube lengths outside the shell structure shall be diminished from the shell on each side so that on the overall the tube lengths have not been changed. This in turn would mean that the entire shell would be 3.5 ft shorter thant the original. In addition, since 1 ft. is added to the length of the waterbox (length taken along the directionof the tube bundle) by means of a second expansion joint, 1 ft. shall be diminished from the overall length of the waterbox.

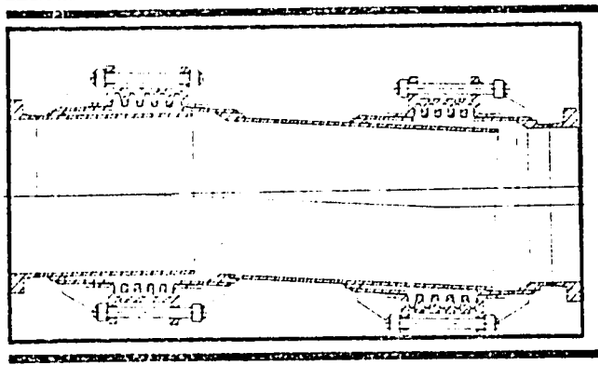
These line drawings illustrate the many ways in which a Zallea Universal Expansion Joint may function.

In each case, the rectangle shows the original position of the expansion joint.



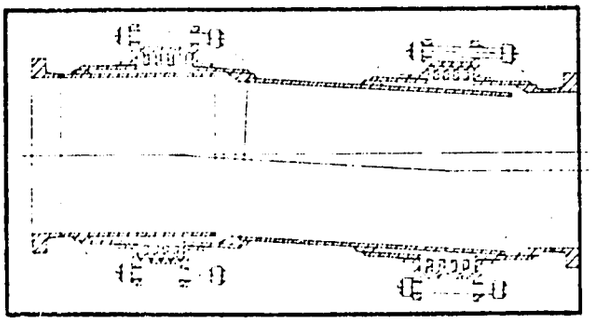
### Case 1—Axial Movement Only

A Universal Expansion Joint is usually not required unless this axial movement is combined with lateral or angular deflection. However, it may be used for axial movement only, where the traverse is such as to require more than one expansion joint and it is not possible to install an anchor between the two expansion joints. In such cases, the tie rods take the place of an intermediate anchor.



### Case 2—Lateral Deflection Only

The corrugated bellows on one end closes on one side and opens on the other, permitting a slight angular deflection. The corrugated bellows on the other end is similarly deflected in the opposite direction. The longer the section of pipe between the two corrugated bellows, the greater the lateral deflection. Notice that the flanges remain parallel indicating that there is no bending in the adjacent pipe. Here the tie rods take the place of pipe anchors.



### Case 3—Axial Movement and Lateral Deflection

This is a combination of the movements illustrated in Cases 1 and 2, the most frequent application for Zallea Universal Expansion Joints.

The limit rods shown in all cases are an essential part of the Zallea Universal Expansion Joint. They are designed so that the rods will withstand the full line pressure in the event of failure of the anchors on the piping. They also distribute the movement equally between the two corrugated bellows.

Figure 2.6-1

## 2.7 Preparation for the Design

By preparation we mean all that should be secured before the actual design has begun. We divide these preparations in two parts. The first consists of all the things that are expected to be performed for the designer so that he can implement his design. The second consists of all the preparations that the designer should fulfill before he starts designing.

As far as the first goes, we assume that the surface of the condenser level floor has been prepared to take the necessary loads, proper reinforcement type or joint type anchorage provided for anchoring the waterbox structures and the center of the shell, and a smooth surface provided under the strucutre and surrounding the structure to a reasonable distance. As far as the second part goes we shall assume that the person undertaking the design has familarity with construction design although not necessarily in the field of rectangular tanks. We shall also assume that the proper methods of concrete mixing and reinforcing are know. Although these processes are discussed in this Manual, experience plays an important role in proper planning and reinforcing of concrete and is of vital importance.

# Part II

# THE ACTUAL DESIGN

The purpose of Chapters 3 and 4 is to give the exact procedure for the structural part of the design. In Chapter 3 the wall thickness, the top and bottom floor thicknesses, and the other design parameters of the concrete itself is considered. In Chapter 4 the reinforcement characteristics are considered. The reinforcing bars are described both in size and position and the placement of reinforcement in general is discussed.

# Chapter 3

# STRUCTURAL DESIGN

## Section 3.1

## The Waterbox Structure

We should note that the design of the waterbox is considered as an exercise in the same category as the closed-single-cell tank. (References 10-14) Before we get into the actual design we provide a Table 3.1/1 and a Figure 3.1-2. The Table 3.1/1 gives the values of moments resulting from fluid pressure on the walls of a single-cell closed tank, and for the figure (3.1-2) gives the values of the shear for the same. If all the coefficients for x = 0 (top edge) and x = a (bottom edge) are omitted, being equal to zero, we get Table 3.1/3.

Maximum $M_x$ is .052 $wa^3$ and maximum My is -.053 $wa^3$. The greater magnitude being that of My, it will be considered as the design moment.

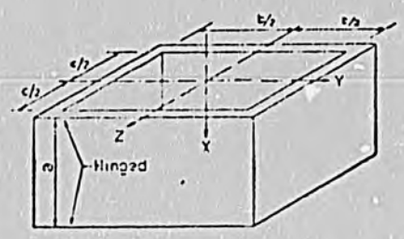
Design Moment = .053 $wa^3$

(The negative sign is omitted since it mainly shows the direction and is immaterial in the design). It should be noted that w is in $lb/ft^2$.

Now according to the Handbook of Concrete Construction (Reference 19), with a given ratio of the moment (M) and also the desired qualities of steel and concrete (fs/nfc'), the effective depth of the walls (d") can be determined. Table 3.1/3 (Table 2 of the Handbook. Reference 19) serves this purpose and since M and f/s/n/f'c are known in our case, d" can readily be determined.

The effective depth computed in this manner, is the

**Moment = Coef. × $wa^3$**




### b/a = 3.0

| c/a | z/a | y = 0 | | y = b/4 | | y = b/2 | | z = c/4 | | z = 0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_z$ | $M_x$ | $M_z$ |
| 3.00 | 1/4 | +.035 | +.010 | +.026 | +.011 | -.008 | -.039 | +.026 | +.011 | +.035 | +.010 |
| | 1/2 | +.057 | +.016 | +.044 | +.017 | -.013 | -.063 | +.044 | +.017 | +.057 | +.016 |
| | 3/4 | +.051 | +.013 | +.041 | +.014 | -.011 | -.055 | +.041 | +.014 | +.051 | +.013 |
| 2.50 | 1/4 | +.035 | +.010 | +.026 | +.011 | -.008 | -.039 | +.021 | +.010 | +.031 | +.011 |
| | 1/2 | +.057 | +.016 | +.044 | +.017 | -.012 | -.062 | +.036 | +.017 | +.052 | +.017 |
| | 3/4 | +.051 | +.013 | +.041 | +.014 | -.011 | -.055 | +.036 | +.014 | +.047 | +.014 |
| 2.00 | 1/4 | +.035 | +.010 | +.026 | +.011 | -.008 | -.039 | +.015 | +.010 | +.025 | +.013 |
| | 1/2 | +.057 | +.016 | +.045 | +.017 | -.012 | -.062 | +.028 | +.015 | +.043 | +.020 |
| | 3/4 | +.051 | +.013 | +.042 | +.014 | -.011 | -.054 | +.029 | +.013 | +.041 | +.016 |
| 1.75 | 1/4 | +.035 | +.010 | +.027 | +.011 | -.007 | -.037 | +.011 | +.008 | +.020 | +.013 |
| | 1/2 | +.057 | +.015 | +.045 | +.017 | -.012 | -.060 | +.021 | +.013 | +.035 | +.020 |
| | 3/4 | +.051 | +.013 | +.042 | +.014 | -.011 | -.053 | +.024 | +.012 | +.035 | +.016 |
| 1.50 | 1/4 | +.035 | +.010 | +.027 | +.011 | -.007 | -.035 | +.007 | +.006 | -.014 | +.013 |
| | 1/2 | +.057 | +.015 | +.045 | +.017 | -.011 | -.057 | +.015 | +.010 | +.027 | +.020 |
| | 3/4 | +.051 | +.013 | +.042 | +.014 | -.010 | -.051 | +.019 | +.011 | +.029 | +.017 |
| 1.25 | 1/4 | +.035 | +.010 | +.027 | +.011 | -.006 | -.032 | +.003 | +.003 | -.005 | +.011 |
| | 1/2 | +.057 | +.015 | +.046 | +.017 | -.011 | -.053 | +.008 | +.006 | -.017 | +.017 |
| | 3/4 | +.051 | +.013 | +.042 | +.014 | -.010 | -.048 | +.013 | +.008 | +.021 | +.016 |
| 1.00 | 1/4 | +.035 | +.010 | +.027 | +.011 | -.006 | -.029 | -.001 | +.000 | -.002 | +.008 |
| | 1/2 | +.057 | +.015 | +.046 | +.017 | -.010 | -.048 | +.002 | +.002 | -.007 | +.014 |
| | 3/4 | +.051 | +.013 | +.043 | +.014 | -.009 | -.044 | +.007 | +.004 | -.013 | +.013 |
| 0.75 | 1/4 | +.035 | +.010 | +.028 | +.011 | -.005 | -.025 | -.003 | -.005 | -.002 | +.001 |
| | 1/2 | +.057 | +.015 | +.046 | +.017 | -.008 | -.042 | -.003 | -.005 | -.001 | +.007 |
| | 3/4 | +.052 | +.013 | +.043 | +.014 | -.008 | -.039 | +.002 | -.002 | -.006 | +.007 |
| 0.50 | 1/4 | +.036 | +.010 | +.028 | +.011 | -.004 | -.021 | -.004 | -.011 | -.005 | -.008 |
| | 1/2 | +.057 | +.015 | +.047 | +.017 | -.007 | -.035 | -.007 | -.016 | -.006 | -.010 |
| | 3/4 | +.052 | +.013 | +.043 | +.014 | -.007 | -.033 | -.004 | -.010 | -.001 | -.004 |

### b/a = 2.5

| c/a | z/a | y = 0 | | y = b/4 | | y = b/2 | | z = c/4 | | z = 0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_z$ | $M_x$ | $M_z$ |
| 2.50 | 1/4 | +.031 | +.011 | +.021 | +.010 | -.008 | -.038 | +.021 | +.010 | -.031 | +.011 |
| | 1/2 | +.052 | +.017 | +.036 | +.017 | -.012 | -.062 | +.036 | +.017 | -.052 | +.017 |
| | 3/4 | +.047 | +.015 | +.036 | +.014 | -.011 | -.055 | +.036 | +.014 | +.047 | +.015 |
| 2.00 | 1/4 | +.031 | +.011 | +.021 | +.010 | -.008 | -.038 | +.015 | +.009 | -.025 | +.012 |
| | 1/2 | +.052 | +.017 | +.036 | +.017 | -.012 | -.061 | +.028 | +.015 | -.042 | +.020 |
| | 3/4 | +.047 | +.015 | +.036 | +.014 | -.011 | -.054 | +.029 | +.013 | +.041 | +.016 |
| 1.75 | 1/4 | +.032 | +.011 | +.021 | +.010 | -.007 | -.037 | +.011 | +.008 | -.020 | +.012 |
| | 1/2 | +.052 | +.018 | +.036 | +.017 | -.012 | -.059 | +.022 | +.013 | -.035 | +.021 |
| | 3/4 | +.047 | +.015 | +.036 | +.014 | -.011 | -.053 | +.024 | +.012 | -.035 | +.017 |
| 1.50 | 1/4 | +.032 | +.011 | +.022 | +.010 | -.007 | -.035 | +.007 | +.006 | -.014 | +.013 |
| | 1/2 | +.052 | +.018 | +.037 | +.017 | -.011 | -.057 | +.015 | +.010 | -.027 | +.021 |
| | 3/4 | +.047 | +.015 | +.036 | +.014 | -.010 | -.051 | +.019 | +.010 | -.029 | +.017 |
| 1.25 | 1/4 | +.032 | +.011 | +.022 | +.010 | -.006 | -.032 | +.003 | +.004 | -.007 | +.012 |
| | 1/2 | +.052 | +.018 | +.038 | +.017 | -.011 | -.053 | +.008 | +.007 | +.018 | +.019 |
| | 3/4 | +.048 | +.015 | +.037 | +.014 | -.010 | -.048 | +.014 | +.008 | -.022 | +.016 |
| 1.00 | 1/4 | +.032 | +.011 | +.023 | +.011 | -.006 | -.028 | -.001 | +.000 | -.002 | +.008 |
| | 1/2 | +.053 | +.018 | +.038 | +.017 | -.010 | -.048 | +.002 | +.002 | -.007 | +.014 |
| | 3/4 | +.048 | +.015 | +.038 | +.015 | -.009 | -.044 | +.007 | +.001 | -.013 | +.013 |
| 0.75 | 1/4 | +.033 | +.011 | +.024 | +.011 | [illegible] | [illegible] | -.003 | -.005 | -.002 | -.002 |
| | 1/2 | +.054 | +.018 | +.039 | +.017 | [illegible] | [illegible] | [illegible] | -.005 | [illegible] | +.005 |
| | 3/4 | +.049 | +.015 | +.039 | +.015 | [illegible] | [illegible] | [illegible] | -.002 | -.006 | +.006 |
| 0.50 | 1/4 | +.033 | +.012 | +.024 | +.011 | [illegible] | [illegible] | -.004 | -.011 | -.005 | -.008 |
| | 1/2 | +.054 | +.018 | +.040 | +.017 | [illegible] | [illegible] | -.007 | -.016 | [illegible] | -.010 |
| | 3/4 | +.049 | +.015 | +.039 | +.015 | -.007 | [illegible] | -.004 | -.010 | -.001 | -.004 |

### b/a = 2.0

| c/a | z/a | y = 0 | | y = b/4 | | y = b/2 | | z = c/4 | | z = 0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_z$ | $M_x$ | $M_z$ |
| 2.00 | 1/4 | +.025 | +.013 | +.015 | +.009 | -.007 | -.037 | +.015 | +.009 | +.025 | +.013 |
| | 1/2 | +.042 | +.020 | +.028 | +.015 | -.012 | -.059 | +.028 | +.015 | +.042 | +.020 |
| | 3/4 | +.040 | +.016 | +.029 | +.013 | -.011 | -.053 | +.029 | +.013 | +.040 | +.016 |
| 1.75 | 1/4 | +.025 | +.013 | +.015 | +.009 | -.007 | -.036 | +.011 | +.008 | +.020 | +.013 |
| | 1/2 | +.042 | +.020 | +.028 | +.015 | -.012 | -.058 | +.022 | +.013 | +.035 | +.021 |
| | 3/4 | +.040 | +.016 | +.029 | +.013 | -.010 | -.052 | +.024 | +.012 | +.035 | +.017 |
| 1.50 | 1/4 | +.025 | +.013 | +.016 | +.009 | -.007 | -.034 | +.007 | +.006 | +.014 | +.013 |
| | 1/2 | +.043 | +.020 | +.029 | +.015 | -.011 | -.056 | +.015 | +.011 | +.027 | +.021 |
| | 3/4 | +.041 | +.016 | +.029 | +.013 | -.010 | -.050 | +.019 | +.010 | +.028 | +.017 |
| 1.25 | 1/4 | +.026 | +.013 | +.016 | +.010 | -.006 | -.032 | +.003 | +.003 | +.007 | +.011 |
| | 1/2 | +.043 | +.020 | +.029 | +.015 | -.010 | -.052 | +.008 | +.007 | +.018 | +.019 |
| | 3/4 | +.041 | +.016 | +.030 | +.013 | -.010 | -.048 | +.013 | +.008 | +.021 | +.016 |
| 1.00 | 1/4 | +.026 | +.013 | +.017 | +.010 | -.006 | -.028 | -.001 | +.000 | +.002 | +.008 |
| | 1/2 | +.044 | +.020 | +.030 | +.016 | -.009 | -.046 | +.002 | +.002 | +.007 | +.014 |
| | 3/4 | +.041 | +.016 | +.031 | +.014 | -.009 | -.044 | +.007 | +.004 | +.013 | +.013 |
| 0.75 | 1/4 | +.027 | +.013 | +.018 | +.010 | -.005 | -.024 | -.003 | -.004 | -.001 | +.002 |
| | 1/2 | +.045 | +.020 | +.031 | +.016 | -.008 | -.040 | -.002 | -.004 | +.000 | +.005 |
| | 3/4 | +.042 | +.016 | +.032 | +.014 | -.008 | -.041 | +.002 | -.002 | +.005 | +.005 |
| 0.50 | 1/4 | +.027 | +.013 | +.019 | +.010 | -.004 | -.021 | -.004 | -.010 | -.004 | -.007 |
| | 1/2 | +.046 | +.020 | +.033 | +.017 | -.007 | -.034 | -.006 | -.015 | -.005 | -.009 |
| | 3/4 | +.042 | +.016 | +.032 | +.015 | -.007 | -.037 | -.003 | -.010 | -.002 | -.003 |

### b/a = 1.5

| c/a | z/a | y = 0 | | y = b/4 | | y = b/2 | | z = c/4 | | z = 0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_z$ | $M_x$ | $M_z$ |
| 1.50 | 1/4 | +.015 | +.013 | +.008 | +.007 | -.006 | -.032 | +.008 | +.007 | +.015 | +.013 |
| | 1/2 | +.028 | +.021 | +.016 | +.011 | -.010 | -.052 | +.016 | +.011 | +.028 | +.021 |
| | 3/4 | +.030 | +.017 | +.020 | +.011 | -.010 | -.048 | +.020 | +.011 | +.030 | +.017 |
| 1.25 | 1/4 | +.016 | +.013 | +.009 | +.008 | -.006 | -.029 | +.004 | +.004 | +.009 | +.012 |
| | 1/2 | +.029 | +.021 | +.017 | +.012 | -.010 | -.049 | +.009 | +.008 | +.018 | +.019 |
| | 3/4 | +.030 | +.017 | +.020 | +.012 | -.009 | -.045 | +.014 | +.009 | +.023 | +.016 |
| 1.00 | 1/4 | +.016 | +.013 | +.010 | +.009 | -.005 | -.025 | +.000 | +.001 | +.003 | +.008 |
| | 1/2 | +.030 | +.021 | +.019 | +.012 | -.009 | -.043 | +.003 | +.003 | +.008 | +.014 |
| | 3/4 | +.031 | +.017 | +.021 | +.013 | -.008 | -.041 | +.008 | +.005 | +.014 | +.014 |
| 0.75 | 1/4 | +.018 | +.014 | +.011 | +.010 | -.004 | -.021 | -.002 | -.003 | -.001 | +.002 |
| | 1/2 | +.032 | +.022 | +.021 | +.014 | -.007 | -.036 | -.002 | -.004 | +.001 | +.005 |
| | 3/4 | +.032 | +.018 | +.022 | +.014 | -.007 | -.036 | +.002 | -.000 | +.006 | +.005 |
| 0.50 | 1/4 | +.020 | +.016 | +.013 | +.012 | -.003 | -.017 | -.003 | -.009 | -.004 | -.006 |
| | 1/2 | +.035 | +.024 | +.023 | +.018 | -.006 | -.031 | -.006 | -.014 | -.005 | -.007 |
| | 3/4 | +.034 | +.020 | +.024 | +.016 | -.007 | -.033 | -.003 | -.008 | -.001 | -.001 |

### b/a = 1.0

| c/a | z/a | y = 0 | | y = b/4 | | y = b/2 | | z = c/4 | | z = 0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_y$ | $M_x$ | $M_z$ | $M_x$ | $M_z$ |
| 1.00 | 1/4 | +.005 | +.009 | +.002 | +.003 | -.001 | -.020 | +.002 | +.003 | +.005 | +.009 |
| | 1/2 | +.011 | +.016 | +.006 | +.006 | -.007 | -.035 | +.006 | +.006 | +.011 | +.015 |
| | 3/4 | +.016 | +.015 | +.009 | +.007 | -.007 | -.035 | +.009 | +.007 | +.016 | +.015 |
| 0.75 | 1/4 | +.006 | +.010 | +.003 | +.004 | -.003 | -.016 | +.000 | +.006 | [illegible] | [illegible] |
| | 1/2 | +.013 | +.017 | +.008 | +.008 | -.006 | -.029 | +.001 | +.001 | [illegible] | [illegible] |
| | 3/4 | +.017 | +.016 | +.010 | +.008 | -.006 | -.031 | +.004 | +.005 | [illegible] | [illegible] |
| 0.50 | 1/4 | +.007 | +.011 | +.005 | +.005 | -.002 | -.010 | -.002 | -.005 | [illegible] | [illegible] |
| | 1/2 | +.015 | +.018 | +.010 | +.010 | -.004 | -.021 | -.003 | -.007 | [illegible] | [illegible] |
| | 3/4 | +.018 | +.016 | +.012 | +.010 | -.005 | -.025 | -.001 | -.004 | [illegible] | +.001 |

Table 3.1/1

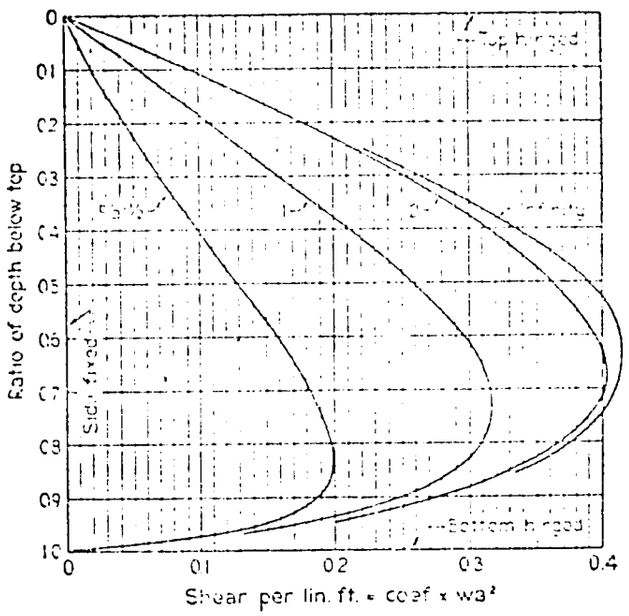

Ratio of depth below top
Shear per lin. ft. = coef × wa²
0
0.1
0.2
0.3
0.4
Bottom hinged

Figure 3.1-2

| $f'_c$ and n | $f_c$ | Effective depth, d | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 10 | 11 | 12 | 13 | 14 |
| | | $f_s$ = 20,000 | | | | | | | | | | | | | | | | | | | | |
| 2500 | 875 | .48 | .75 | 1.08 | 1.47 | 1.93 | 2.4 | 3.0 | 3.6 | 4.3 | 5.1 | 5.9 | 6.8 | 7.7 | 8.7 | 9.8 | 12.0 | 14.6 | 17.3 | 20.3 | 23.6 |
| | 1000 | .60 | .93 | 1.34 | 1.83 | 2.38 | 3.0 | 3.7 | 4.5 | 5.4 | 6.3 | 7.3 | 8.4 | 9.5 | 10.8 | 12.1 | 14.9 | 18.0 | 21.5 | 25.2 | 29.2 |
| | 1125 | .72 | 1.12 | 1.61 | 2.20 | 2.87 | 3.6 | 4.5 | 5.4 | 6.5 | 7.6 | 8.8 | 10.1 | 11.5 | 12.9 | 14.5 | 17.9 | 21.7 | 25.8 | 30.3 | 35.1 |
| 10.1 | 1250 | .84 | 1.32 | 1.90 | 2.59 | 3.37 | 4.3 | 5.3 | 6.4 | 7.6 | 8.9 | 10.3 | 11.9 | 13.5 | 15.2 | 17.1 | 21.1 | 25.5 | 30.3 | 35.6 | 41.3 |
| | 1500 | 1.11 | 1.73 | 2.49 | 3.39 | 4.43 | 5.6 | 6.9 | 8.4 | 10.0 | 11.7 | 13.6 | 15.6 | 17.7 | 20.0 | 22.4 | 27.7 | 33.5 | 39.9 | 46.8 | 54.3 |
| 3000 | 1050 | .61 | .95 | 1.37 | 1.87 | 2.44 | 3.1 | 3.8 | 4.6 | 5.5 | 6.4 | 7.5 | 8.6 | 9.8 | 11.0 | 12.3 | 15.2 | 18.4 | 21.9 | 25.8 | 29.9 |
| | 1200 | .75 | 1.18 | 1.69 | 2.30 | 3.01 | 3.8 | 4.7 | 5.7 | 6.8 | 7.9 | 9.2 | 10.6 | 12.0 | 13.6 | 15.2 | 18.6 | 22.8 | 27.1 | 31.8 | 36.9 |
| | 1350 | .90 | 1.41 | 2.03 | 2.76 | 3.61 | 4.6 | 5.6 | 6.8 | 8.1 | 9.5 | 11.1 | 12.7 | 14.4 | 16.3 | 18.3 | 22.6 | 27.3 | 32.5 | 38.1 | 44.2 |
| 9.2 | 1500 | 1.06 | 1.65 | 2.38 | 3.24 | 4.23 | 5.4 | 6.6 | 8.0 | 9.5 | 11.2 | 13.0 | 14.9 | 16.9 | 19.1 | 21.4 | 26.5 | 32.0 | 38.1 | 44.7 | 51.9 |
| | 1600 | 1.38 | 2.16 | 3.12 | 4.24 | 5.54 | 7.0 | 8.7 | 10.5 | 12.5 | 14.6 | 17.0 | 19.5 | 22.2 | 25.0 | 28.0 | 34.6 | 41.9 | 49.8 | 58.5 | 67.8 |
| 4000 | 1400 | .88 | 1.38 | 1.99 | 2.71 | 3.54 | 4.5 | 5.5 | 6.7 | 8.0 | 9.3 | 10.8 | 12.4 | 14.2 | 16.0 | 17.9 | 22.1 | 26.8 | 31.9 | 37.4 | 43.4 |
| | 1600 | 1.09 | 1.70 | 2.44 | 3.33 | 4.35 | 5.5 | 6.8 | 8.2 | 9.8 | 11.5 | 13.3 | 15.3 | 17.4 | 19.6 | 22.0 | 27.2 | 32.9 | 39.1 | 45.9 | 53.2 |
| | 1800 | 1.30 | 2.03 | 2.92 | 3.97 | 5.19 | 6.6 | 8.1 | 9.6 | 11.7 | 13.7 | 15.9 | 18.2 | 20.7 | 23.4 | 26.3 | 32.4 | 39.2 | 46.7 | 54.8 | 63.5 |
| 8.0 | 2000 | 1.51 | 2.37 | 3.41 | 4.64 | 6.06 | 7.7 | 9.5 | 11.5 | 13.6 | 16.0 | 18.6 | 21.3 | 24.2 | 27.4 | 30.7 | 37.9 | 45.8 | 54.5 | 64.0 | 74.2 |
| | 2400 | 1.97 | 3.07 | 4.43 | 6.02 | 7.87 | 10.0 | 12.3 | 14.9 | 17.7 | 20.8 | 24.1 | 27.7 | 31.5 | 35.5 | 39.8 | 49.2 | 59.5 | 70.8 | 83.1 | 96.4 |
| 5000 | 1750 | 1.17 | 1.83 | 2.63 | 3.58 | 4.68 | 5.9 | 7.3 | 8.8 | 10.5 | 12.4 | 14.3 | 16.5 | 18.7 | 21.1 | 23.7 | 29.2 | 35.4 | 42.1 | 49.4 | 57.3 |
| | 2000 | 1.43 | 2.24 | 3.22 | 4.38 | 5.72 | 7.2 | 8.9 | 10.8 | 12.9 | 15.1 | 17.5 | 20.1 | 22.9 | 25.8 | 29.0 | 35.8 | 43.3 | 51.5 | 60.5 | 70.1 |
| | 2250 | 1.70 | 2.66 | 3.83 | 5.21 | 6.81 | 8.6 | 10.6 | 12.9 | 15.3 | 18.0 | 20.9 | 23.9 | 27.2 | 30.8 | 34.5 | 42.6 | 51.5 | 61.3 | 71.9 | 83.4 |
| 7.1 | 2500 | 1.98 | 3.10 | 4.46 | 6.07 | 7.93 | 10.0 | 12.4 | 15.0 | 17.8 | 20.9 | 24.3 | 27.9 | 31.7 | 35.8 | 40.1 | 49.6 | 60.0 | 71.4 | 83.8 | 97.1 |
| | 3000 | 2.56 | 4.00 | 5.77 | 7.85 | 10.25 | 13.0 | 16.0 | 19.4 | 23.1 | 27.1 | 31.4 | 36.0 | 41.0 | 46.3 | 51.9 | 64.1 | 77.5 | 92.2 | 108 | 126 |
| | | $f_s$ = 22,000 | | | | | | | | | | | | | | | | | | | | |
| 2500 | 875 | .45 | .71 | 1.02 | 1.39 | 1.81 | 2.3 | 2.8 | 3.4 | 4.1 | 4.8 | 5.6 | 6.4 | 7.3 | 8.2 | 9.2 | 11.3 | 13.7 | 16.3 | 19.2 | 22.2 |
| | 1000 | .56 | .88 | 1.27 | 1.73 | 2.25 | 2.9 | 3.5 | 4.3 | 5.1 | 5.9 | 6.9 | 7.9 | 9.0 | 10.2 | 11.4 | 14.1 | 17.0 | 20.3 | 23.8 | 27.6 |
| | 1125 | .68 | 1.06 | 1.53 | 2.08 | 2.72 | 3.4 | 4.2 | 5.1 | 6.1 | 7.2 | 8.3 | 9.6 | 10.9 | 12.3 | 13.8 | 17.0 | 20.5 | 24.5 | 28.7 | 33.3 |
| 10.1 | 1250 | .80 | 1.25 | 1.80 | 2.45 | 3.20 | 4.1 | 5.0 | 6.1 | 7.2 | 8.5 | 9.8 | 11.3 | 12.8 | 14.5 | 16.2 | 20.0 | 24.2 | 28.8 | 33.8 | 39.2 |
| | 1500 | 1.06 | 1.65 | 2.38 | 3.24 | 4.23 | 5.4 | 6.6 | 8.0 | 9.5 | 11.2 | 13.0 | 14.9 | 16.9 | 19.1 | 21.4 | 26.4 | 32.0 | 38.1 | 44.7 | 51.8 |
| 3000 | 1050 | .58 | .90 | 1.30 | 1.76 | 2.30 | 2.9 | 3.6 | 4.4 | 5.2 | 6.1 | 7.1 | 8.1 | 9.2 | 10.4 | 11.7 | 14.4 | 17.4 | 20.7 | 24.3 | 28.2 |
| | 1200 | .71 | 1.11 | 1.60 | 2.18 | 2.85 | 3.6 | 4.5 | 5.4 | 6.4 | 7.5 | 8.7 | 10.0 | 11.4 | 12.9 | 14.4 | 17.8 | 21.6 | 25.7 | 30.1 | 34.9 |
| | 1350 | .86 | 1.34 | 1.93 | 2.62 | 3.43 | 4.3 | 5.4 | 6.5 | 7.7 | 9.1 | 10.5 | 12.1 | 13.7 | 15.5 | 17.4 | 21.4 | 25.9 | 30.9 | 36.2 | 42.0 |
| 9.2 | 1500 | 1.01 | 1.57 | 2.27 | 3.09 | 4.03 | 5.1 | 6.3 | 7.6 | 9.1 | 10.6 | 12.3 | 14.2 | 16.1 | 18.2 | 20.4 | 25.2 | 30.5 | 36.3 | 42.6 | 49.4 |
| | 1800 | 1.32 | 2.07 | 2.98 | 4.06 | 5.30 | 6.7 | 8.3 | 10.0 | 11.9 | 14.0 | 16.2 | 18.6 | 21.2 | 23.9 | 26.8 | 33.1 | 40.1 | 47.7 | 56.0 | 64.9 |
| 4000 | 1400 | .84 | 1.31 | 1.89 | 2.57 | 3.35 | 4.2 | 5.2 | 6.3 | 7.5 | 8.9 | 10.3 | 11.8 | 13.4 | 15.1 | 17.0 | 21.0 | 25.4 | 30.2 | 35.4 | 41.1 |
| | 1600 | 1.03 | 1.61 | 2.32 | 3.16 | 4.13 | 5.2 | 6.5 | 7.8 | 9.3 | 10.9 | 12.7 | 14.5 | 16.5 | 18.7 | 20.9 | 25.8 | 31.2 | 37.2 | 43.6 | 50.6 |
| | 1800 | 1.24 | 1.93 | 2.78 | 3.79 | 4.95 | 6.3 | 7.7 | 9.4 | 11.1 | 13.1 | 15.1 | 17.4 | 19.8 | 22.3 | 25.0 | 30.9 | 37.4 | 44.5 | 52.2 | 60.6 |
| 8.0 | 2000 | 1.43 | 2.26 | 3.26 | 4.43 | 5.79 | 7.3 | 9.0 | 10.9 | 13.0 | 15.3 | 17.7 | 20.4 | 23.2 | 26.2 | 29.3 | 36.2 | 43.8 | 52.1 | 61.2 | 70.9 |
| | 2400 | 1.89 | 2.95 | 4.25 | 5.79 | 7.56 | 9.6 | 11.8 | 14.3 | 17.0 | 20.0 | 23.1 | 26.6 | 30.2 | 34.1 | 38.3 | 47.2 | 57.2 | 68.0 | 79.8 | 92.6 |
| 5000 | 1750 | 1.11 | 1.74 | 2.50 | 3.40 | 4.45 | 5.6 | 6.9 | 8.4 | 10.0 | 11.7 | 13.6 | 15.6 | 17.8 | 20.1 | 22.5 | 27.8 | 33.6 | 40.0 | 47.0 | 54.5 |
| | 2000 | 1.36 | 2.13 | 3.07 | 4.18 | 5.46 | 6.9 | 8.5 | 10.3 | 12.3 | 14.4 | 16.7 | 19.2 | 21.8 | 24.6 | 27.6 | 34.1 | 41.3 | 49.1 | 57.6 | 66.8 |
| | 2250 | 1.63 | 2.54 | 3.66 | 4.98 | 6.51 | 8.2 | 10.2 | 12.3 | 14.6 | 17.2 | 19.9 | 22.9 | 26.0 | 29.4 | 33.0 | 40.7 | 49.2 | 58.6 | 68.8 | 79.8 |
| 7.1 | 2500 | 1.90 | 2.97 | 4.28 | 5.82 | 7.60 | 9.6 | 11.9 | 14.4 | 17.1 | 20.1 | 23.3 | 26.7 | 30.4 | 34.3 | 38.5 | 47.5 | 57.5 | 68.4 | 80.3 | 93.1 |
| | 3000 | 2.47 | 3.86 | 5.55 | 7.56 | 9.87 | 12.5 | 15.4 | 18.7 | 22.2 | 26.1 | 30.2 | 34.7 | 39.5 | 44.6 | 50.0 | 61.7 | 74.6 | 88.8 | 104 | 121 |
| | | $f_s$ = 24,000 | | | | | | | | | | | | | | | | | | | | |
| 2500 | 875 | .43 | .67 | .96 | 1.31 | 1.71 | 2.2 | 2.7 | 3.2 | 3.9 | 4.5 | 5.3 | 6.0 | 6.9 | 7.7 | 8.7 | 10.7 | 13.0 | 15.4 | 18.1 | 21.0 |
| | 1000 | .53 | .83 | 1.20 | 1.64 | 2.14 | 2.7 | 3.3 | 4.0 | 4.8 | 5.6 | 6.5 | 7.5 | 8.5 | 9.6 | 10.8 | 13.3 | 16.2 | 19.2 | 22.6 | 26.2 |
| | 1125 | .65 | 1.01 | 1.45 | 1.98 | 2.58 | 3.3 | 4.0 | 4.9 | 5.8 | 6.8 | 7.9 | 9.1 | 10.3 | 11.7 | 13.1 | 16.1 | 19.5 | 23.2 | 27.3 | 31.6 |
| 10.1 | 1250 | .76 | 1.19 | 1.72 | 2.34 | 3.05 | 3.9 | 4.8 | 5.8 | 6.9 | 8.1 | 9.3 | 10.7 | 12.2 | 13.8 | 15.4 | 19.1 | 23.1 | 27.5 | 32.2 | 37.4 |
| | 1500 | 1.01 | 1.58 | 2.28 | 3.10 | 4.04 | 5.1 | 6.3 | 7.6 | 9.1 | 10.7 | 12.4 | 14.2 | 16.2 | 18.3 | 20.5 | 25.3 | 30.6 | 36.4 | 42.7 | 49.5 |
| 3000 | 1050 | .55 | .85 | 1.23 | 1.67 | 2.18 | 2.8 | 3.4 | 4.1 | 4.9 | 5.8 | 6.7 | 7.7 | 8.7 | 9.8 | 11.0 | 13.6 | 16.5 | 19.6 | 23.0 | 26.7 |
| | 1200 | .68 | 1.06 | 1.52 | 2.07 | 2.71 | 3.4 | 4.2 | 5.1 | 6.1 | 7.1 | 8.3 | 9.5 | 10.8 | 12.2 | 13.7 | 16.9 | 20.5 | 24.4 | 28.6 | 33.2 |
| | 1350 | .82 | 1.28 | 1.84 | 2.50 | 3.26 | 4.1 | 5.1 | 6.2 | 7.3 | 8.6 | 10.0 | 11.5 | 13.1 | 14.7 | 16.5 | 20.4 | 24.7 | 29.4 | 34.5 | 40.0 |
| 9.2 | 1500 | .96 | 1.50 | 2.16 | 2.95 | 3.85 | 4.9 | 6.0 | 7.3 | 8.7 | 10.2 | 11.8 | 13.5 | 15.4 | 17.4 | 19.5 | 24.0 | 29.1 | 34.6 | 40.6 | 47.1 |
| | 1800 | 1.27 | 1.98 | 2.86 | 3.89 | 5.08 | 6.4 | 7.9 | 9.6 | 11.4 | 13.4 | 15.6 | 17.9 | 20.3 | 22.9 | 25.7 | 31.7 | 38.4 | 45.7 | 53.6 | 62.2 |
| 4000 | 1400 | .80 | 1.24 | 1.79 | 2.44 | 3.19 | 4.0 | 5.0 | 6.0 | 7.2 | 8.4 | 9.8 | 11.2 | 12.7 | 14.4 | 16.1 | 19.9 | 24.1 | 28.7 | 33.6 | 39.0 |
| | 1600 | .98 | 1.54 | 2.21 | 3.01 | 3.94 | 5.0 | 6.2 | 7.4 | 8.9 | 10.4 | 12.1 | 13.8 | 15.7 | 17.8 | 19.9 | 24.6 | 29.8 | 35.4 | 41.6 | 48.2 |
| | 1800 | 1.18 | 1.85 | 2.66 | 3.62 | 4.73 | 6.0 | 7.4 | 8.9 | 10.6 | 12.5 | 14.5 | 16.6 | 18.9 | 21.3 | 23.9 | 29.5 | 35.7 | 42.5 | 49.9 | 57.9 |
| 8.0 | 2000 | 1.39 | 2.17 | 3.12 | 4.25 | 5.55 | 7.0 | 8.7 | 10.5 | 12.5 | 14.6 | 17.0 | 19.5 | 22.2 | 25.0 | 28.1 | 34.7 | 41.9 | 49.9 | 58.6 | 67.9 |
| | 2400 | 1.82 | 2.84 | 4.09 | 5.57 | 7.27 | 9.2 | 11.4 | 13.7 | 16.4 | 19.2 | 22.3 | 25.6 | 29.1 | 32.8 | 36.8 | 45.4 | 55.0 | 65.4 | 76.8 | 89.0 |
| 5000 | 1750 | 1.06 | 1.65 | 2.38 | 3.24 | 4.23 | 5.4 | 6.6 | 8.0 | 9.5 | 11.2 | 13.0 | 14.9 | 16.9 | 19.1 | 21.4 | 26.5 | 32.0 | 38.1 | 44.7 | 51.8 |
| | 2000 | 1.30 | 2.04 | 2.93 | 3.99 | 5.21 | 6.6 | 8.1 | 9.9 | 11.7 | 13.8 | 16.0 | 18.3 | 20.8 | 23.5 | 26.4 | 32.6 | 39.4 | 46.9 | 55.0 | 63.8 |
| | 2250 | 1.56 | 2.44 | 3.51 | 4.77 | 6.24 | 7.9 | 9.7 | 11.8 | 14.0 | 16.5 | 19.1 | 21.9 | 24.9 | 28.2 | 31.6 | 39.0 | 47.2 | 56.1 | 65.9 | 76.4 |
| 7.1 | 2500 | 1.82 | 2.85 | 4.11 | 5.59 | 7.30 | 9.2 | 11.4 | 13.8 | 16.4 | 19.3 | 22.4 | 25.7 | 29.2 | 33.0 | 36.9 | 45.6 | 55.2 | 65.7 | 77.1 | 89.4 |
| | 3000 | 2.38 | 3.72 | 5.35 | 7.29 | 9.52 | 12.0 | 14.9 | 18.0 | 21.4 | 25.1 | 29.1 | 33.5 | 38.1 | 43.0 | 48.2 | 59.5 | 72.0 | 85.6 | 101 | 117 |

Table 3.1/3

depth of concrete necessary to maintain the given maximum moment. However, there is a shear stress acting on the walls and the thickness of the walls should be sufficient to take this force as well. A calculation is made now to determine this necessary thickness or effective depth and if it is greater than the previous value, it will be taken as the design effective depth, otherwise the effective depth computed for the moment will be considered. So Figure 3.1-2 is considered and it is seen that the maximum shear is given by the value of {coefficient ($wa^2$)} for different values of b/a. The proper value for the designs' b/a is obtained, introduced in Table 3.1/3 again and the necessary effective depth for shear is obtained. Now as we mentioned before, whichever of the two selected depths are of a greater value, will be considered as the proper design effective depth d".

## Section 3.2

## The Central Shell Structure

As we have mentioned before the shell will be designed as a rectangular cyclindrical shape. The sides will be designed as if they were rectangular slabs doweled to each other. The bottom side will be designed accordingly.

Each slab should be designed to take one atmosphere pressure, plus 300 psf for live load and of course the weight of the concrete itself. This latter is of course true only for the top and bottom slabs, and since the bottom slab will be considered as uniformly supported, only to the top slab. However, for the sake of uniformity, which is very important for the purpose of placing of the concrete and forms, etc., all four sides will be considered with this additional load.

Total load is therefore

$w = (15)(144) + 300 + d\ (12.5)$

The procedure for finding d is one of trial and error. The steps are:

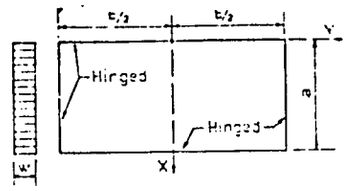
1. With an estimated d, w is computed.

2. The value found for w, and proper b/a, an introduced in the Table 3.2/1 (Table IV of Reference 14). A value for M (the moment is obtained).

3. With this value of M and selected values of fs/n/f'c (20,000/9.2/1350 in our case). A value for d is obtained. The total depth considered in the first step is (d + 2).

## Table IV

**Moment = Coef. × $wa^2$**




| $b/a$ | $x/a$ | $y = 0$ | | $y = b/4$ | |
|---|---|---|---|---|---|
| | | $M_x$ | $M_y$ | $M_x$ | $M_y$ |
| 3.00 | 1/4 | +.089 | +.022 | +.077 | +.025 |
| | 1/2 | +.118 | +.029 | +.101 | +.034 |
| 2.50 | 1/4 | +.085 | +.024 | +.070 | +.027 |
| | 1/2 | +.112 | +.032 | +.092 | +.037 |
| 2.00 | 1/4 | +.076 | +.027 | +.061 | +.028 |
| | 1/2 | +.100 | +.037 | +.078 | +.038 |
| 1.75 | 1/4 | +.070 | +.029 | +.054 | +.029 |
| | 1/2 | +.091 | +.040 | +.070 | +.039 |
| 1.50 | 1/4 | +.061 | +.031 | +.047 | +.029 |
| | 1/2 | +.078 | +.043 | +.059 | +.040 |
| 1.25 | 1/4 | +.049 | +.033 | +.038 | +.029 |
| | 1/2 | +.063 | +.044 | +.047 | +.039 |
| 1.00 | 1/4 | +.036 | +.033 | +.027 | +.027 |
| | 1/2 | +.044 | +.044 | +.033 | +.036 |
| 0.75 | 1/4 | +.022 | +.029 | +.016 | +.023 |
| | 1/2 | +.025 | +.038 | +.018 | +.030 |
| 0.50 | 1/4 | +.010 | +.020 | +.007 | +.015 |
| | 1/2 | +.009 | +.025 | +.007 | +.019 |

Table 3.2/1

# Chapter 4

# REINFORCEMENT DESIGN

## Section 4.1

### Waterbox Reinforcement Calculations

In this section the size and the spacing of the reinforcing elements will be considered. Then a guideline for the placement of the reinforcing rods will be described briefly.

Horizontal moment at the mid-depth of the corner was computed and it is what we called maximum moment (M). Axial tension will be taken as $N = .37\ wa^2$ (kips), which will be used with a negative sign to indicate that it is in tension, otherwise disregarded in the calculations.

Now follow procedure in Example 8 given in the handbook (Reference 19, Appendix 4-1) and compute

$$e = 12\ \frac{M}{N} = d''$$

$$E = \frac{e}{12}$$

Now from Table 4.1/1 (Table 4 of Reference 19 - The Handbook) with b = 12 in (one foot width) and the value of d equal to d" computed in section 3.1, we select a value of F by introducing E.

Then $K = \frac{NE}{F}$

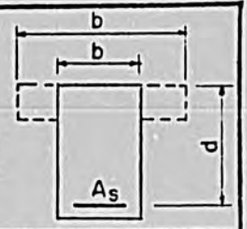
A ratio of K up to 226 is allowed for fs/n/f'c of 20000/9.2/1350, so compressive stresses are low. We find that for our purpose j = 9.1 and a = 1.44

from table 4.1/2 (Table 1 of Handbook).

Then $i = \frac{e}{e-jd}$ and $As = \frac{NE}{adi}$

## Coefficients *(F)* for Resisting Moments of Rectangular and T-Sections

**Values of** $F = \dfrac{bd^2}{12{,}000}$




(a) Enter table with known value of $F = \dfrac{M}{K}$ or $\dfrac{NE}{K}$ ($M$ or $NE$ in ft.kips; $K$ from Tables 1 or 8); select $b$ and $d$ (in.)

(b) Enter table with known value of $b$ and $d$; compute resisting moment in concrete: $K \times F$ (ft.kips)

| d | b: Width of compressive area | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 7½ | 8 | 9 | 9½ | 10 | 11½ | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 30 | 36 | 42 | 48 |
| 5 | .008 | .010 | .013 | .015 | .016 | .017 | .019 | .020 | .021 | .024 | .025 | .027 | .031 | .035 | .040 | .044 | .048 | .052 | .062 | .075 | .088 | .100 |
| 5½ | .010 | .013 | .015 | .018 | .019 | .020 | .023 | .024 | .025 | .029 | .030 | .033 | .038 | .043 | .048 | .053 | .058 | .063 | .076 | .091 | .106 | .121 |
| 6 | .012 | .015 | .018 | .021 | .023 | .024 | .027 | .029 | .030 | .035 | .036 | .039 | .045 | .051 | .057 | .063 | .069 | .075 | .090 | .108 | .126 | .144 |
| 6½ | .014 | .018 | .021 | .025 | .026 | .028 | .032 | .033 | .035 | .040 | .042 | .046 | .053 | .060 | .067 | .074 | .081 | .088 | .106 | .127 | .148 | .169 |
| 7 | .016 | .020 | .025 | .029 | .031 | .033 | .037 | .039 | .041 | .047 | .049 | .053 | .061 | .069 | .078 | .086 | .094 | .102 | .123 | .147 | .172 | .196 |
| 7½ | .019 | .023 | .028 | .033 | .036 | .038 | .042 | .045 | .047 | .054 | .056 | .061 | .070 | .080 | .089 | .098 | .108 | .117 | .141 | .169 | .197 | .225 |
| 8 | .021 | .027 | .032 | .037 | .040 | .043 | .048 | .051 | .053 | .061 | .064 | .069 | .080 | .091 | .101 | .112 | .123 | .133 | .160 | .192 | .224 | .256 |
| 8½ | .024 | .030 | .036 | .042 | .045 | .048 | .054 | .057 | .060 | .069 | .072 | .078 | .090 | .102 | .114 | .126 | .138 | .151 | .181 | .217 | .253 | .289 |
| 9 | .027 | .034 | .041 | .047 | .051 | .054 | .061 | .064 | .068 | .078 | .081 | .088 | .101 | .115 | .128 | .142 | .155 | .169 | .203 | .243 | .284 | .324 |
| 9½ | .030 | .038 | .045 | .053 | .056 | .060 | .068 | .071 | .075 | .087 | .090 | .098 | .113 | .128 | .143 | .158 | .173 | .188 | .226 | .271 | .316 | .361 |
| 10 | .033 | .042 | .050 | .058 | .063 | .067 | .075 | .079 | .083 | .096 | .100 | .108 | .125 | .142 | .158 | .175 | .192 | .208 | .250 | .300 | .350 | .400 |
| 10½ | .037 | .046 | .055 | .064 | .069 | .074 | .083 | .087 | .092 | .106 | .110 | .119 | .138 | .156 | .175 | .193 | .211 | .230 | .276 | .331 | .386 | .441 |
| 11 | .040 | .050 | .061 | .071 | .076 | .081 | .091 | .096 | .101 | .116 | .121 | .131 | .151 | .171 | .192 | .212 | .232 | .252 | .303 | .363 | .424 | .484 |
| 11½ | .044 | .055 | .066 | .077 | .083 | .088 | .099 | .105 | .110 | .127 | .132 | .143 | .165 | .187 | .209 | .231 | .253 | .276 | .331 | .397 | .463 | .529 |
| 12 | .048 | .060 | .072 | .084 | .090 | .096 | .108 | .114 | .120 | .138 | .144 | .156 | .180 | .204 | .228 | .252 | .276 | .300 | .360 | .432 | .504 | .576 |
| 12½ | .052 | .065 | .078 | .091 | .098 | .104 | .117 | .124 | .130 | .150 | .156 | .169 | .195 | .221 | .247 | .273 | .299 | .326 | .391 | .469 | .547 | .625 |
| 13 | .056 | .070 | .085 | .099 | .106 | .113 | .126 | .134 | .141 | .162 | .169 | .183 | .211 | .239 | .268 | .296 | .324 | .352 | .422 | .507 | .592 | .676 |
| 13½ | .061 | .076 | .091 | .106 | .114 | .122 | .137 | .144 | .152 | .175 | .182 | .197 | .228 | .258 | .289 | .319 | .349 | .380 | .456 | .547 | .638 | .729 |
| 14 | .065 | .082 | .098 | .114 | .122 | .131 | .147 | .155 | .163 | .188 | .196 | .212 | .245 | .278 | .310 | .343 | .376 | .408 | .490 | .588 | .686 | .784 |
| 14½ | .070 | .088 | .105 | .123 | .131 | .140 | .158 | .166 | .175 | .201 | .210 | .228 | .263 | .298 | .333 | .368 | .403 | .438 | .526 | .631 | .736 | .841 |
| 15 | .075 | .094 | .113 | .131 | .141 | .150 | .169 | .178 | .188 | .216 | .225 | .244 | .281 | .319 | .356 | .394 | .431 | .469 | .563 | .675 | .788 | 0.90 |
| 15½ | .080 | .100 | .120 | .140 | .150 | .160 | .180 | .190 | .200 | .230 | .240 | .260 | .300 | .340 | .380 | .421 | .461 | .500 | .601 | .721 | .842 | 0.96 |
| 16 | .085 | .107 | .128 | .149 | .160 | .171 | .192 | .203 | .213 | .245 | .256 | .277 | .320 | .363 | .405 | .448 | .491 | .533 | .640 | .768 | .896 | 1.02 |
| 16½ | .091 | .113 | .136 | .159 | .170 | .182 | .204 | .216 | .227 | .261 | .272 | .295 | .340 | .386 | .431 | .476 | .522 | .568 | .681 | .817 | .953 | 1.09 |
| 17 | | .120 | .145 | .169 | .181 | .193 | .217 | .229 | .241 | .277 | .289 | .313 | .361 | .409 | .458 | .506 | .554 | .602 | .723 | 0.87 | 1.01 | 1.16 |
| 17½ | | .128 | .153 | .179 | .191 | .204 | .230 | .242 | .255 | .294 | .306 | .332 | .383 | .434 | .485 | .536 | .587 | .638 | .766 | 0.92 | 1.07 | 1.23 |
| 18 | | .135 | .162 | .189 | .203 | .216 | .243 | .257 | .270 | .311 | .324 | .351 | .405 | .459 | .513 | .567 | .621 | .675 | .810 | 0.97 | 1.13 | 1.30 |
| 18½ | | .143 | .171 | .200 | .214 | .228 | .257 | .271 | .285 | .328 | .342 | .371 | .428 | .485 | .542 | .599 | .656 | .713 | .856 | 1.03 | 1.20 | 1.37 |
| 19 | | | .180 | .211 | .226 | .241 | .271 | .286 | .301 | .346 | .361 | .391 | .451 | .511 | .572 | .632 | .692 | 0.75 | 0.90 | 1.08 | 1.26 | 1.44 |
| 20 | | | .200 | .233 | .250 | .267 | .300 | .317 | .333 | .383 | .400 | .433 | .500 | .567 | .633 | .700 | .767 | 0.83 | 1.00 | 1.20 | 1.40 | 1.60 |
| 21 | | | .221 | .257 | .276 | .294 | .331 | .349 | .368 | .423 | .441 | .478 | .551 | .625 | .698 | .772 | .845 | 0.92 | 1.10 | 1.32 | 1.54 | 1.76 |
| 22 | | | .242 | .282 | .302 | .323 | .363 | .383 | .403 | .464 | .484 | .524 | .605 | .686 | .766 | .847 | .928 | 1.01 | 1.21 | 1.45 | 1.69 | 1.94 |
| 23 | | | | .309 | .331 | .353 | .397 | .419 | .441 | .507 | .529 | .573 | .661 | .749 | 0.84 | 0.93 | 1.01 | 1.10 | 1.32 | 1.58 | 1.85 | 2.12 |
| 24 | | | | .336 | .360 | .384 | .432 | .456 | .480 | .552 | .576 | .624 | .720 | .816 | 0.91 | 1.01 | 1.10 | 1.20 | 1.44 | 1.73 | 2.02 | 2.30 |
| 25 | | | | .365 | .391 | .417 | .469 | .495 | .521 | .599 | .625 | .677 | .781 | .885 | 0.99 | 1.09 | 1.20 | 1.30 | 1.56 | 1.87 | 2.19 | 2.50 |
| 26 | | | | .394 | .422 | .451 | .507 | .535 | .563 | .648 | .676 | .732 | .845 | .958 | 1.07 | 1.18 | 1.30 | 1.41 | 1.69 | 2.03 | 2.37 | 2.70 |
| 27 | | | | | .456 | .486 | .547 | .577 | .608 | .699 | .729 | .790 | 0.91 | 1.03 | 1.15 | 1.28 | 1.40 | 1.52 | 1.82 | 2.19 | 2.55 | 2.92 |
| 28 | | | | | .490 | .523 | .588 | .621 | .653 | .751 | .784 | .849 | 0.98 | 1.11 | 1.24 | 1.37 | 1.50 | 1.63 | 1.96 | 2.35 | 2.74 | 3.14 |
| 29 | | | | | .526 | .561 | .631 | .666 | .701 | .806 | .841 | .911 | 1.05 | 1.19 | 1.33 | 1.47 | 1.61 | 1.75 | 2.10 | 2.52 | 2.94 | 3.36 |
| 30 | | | | | .562 | .600 | .675 | .712 | .750 | .862 | .900 | .975 | 1.13 | 1.28 | 1.43 | 1.58 | 1.73 | 1.88 | 2.25 | 2.70 | 3.15 | 3.60 |
| 31 | | | | | | .641 | .721 | .761 | .801 | 0.92 | 0.96 | 1.04 | 1.20 | 1.36 | 1.52 | 1.68 | 1.84 | 2.00 | 2.40 | 2.88 | 3.36 | 3.85 |
| 32 | | | | | | .683 | .768 | .811 | .853 | 0.98 | 1.02 | 1.11 | 1.28 | 1.45 | 1.62 | 1.79 | 1.96 | 2.13 | 2.56 | 3.07 | 3.58 | 4.10 |
| 33 | | | | | | .726 | .817 | .862 | .906 | 1.04 | 1.09 | 1.18 | 1.36 | 1.54 | 1.72 | 1.91 | 2.09 | 2.27 | 2.72 | 3.27 | 3.81 | 4.36 |
| 34 | | | | | | .771 | .867 | .915 | .963 | 1.11 | 1.16 | 1.25 | 1.45 | 1.64 | 1.83 | 2.02 | 2.22 | 2.41 | 2.89 | 3.47 | 4.05 | 4.62 |
| 36 | | | | | | | | | 0.97 | 1.03 | 1.08 | 1.24 | 1.30 | 1.40 | 1.62 | 1.84 | 2.05 | 2.27 | 2.48 | 2.70 | 3.24 | 3.89 | 4.54 | 5.18 |
| 38 | | | | | | | | | 1.08 | 1.14 | 1.20 | 1.38 | 1.44 | 1.56 | 1.81 | 2.05 | 2.29 | 2.53 | 2.77 | 3.01 | 3.61 | 4.33 | 5.05 | 5.78 |
| 40 | | | | | | | | | 1.20 | 1.27 | 1.33 | 1.53 | 1.60 | 1.73 | 2.00 | 2.27 | 2.53 | 2.80 | 3.07 | 3.33 | 4.00 | 4.80 | 5.60 | 6.40 |
| 42 | | | | | | | | | 1.32 | 1.40 | 1.47 | 1.69 | 1.76 | 1.91 | 2.21 | 2.50 | 2.79 | 3.09 | 3.36 | 3.63 | 4.41 | 5.29 | 6.17 | 7.06 |
| 44 | | | | | | | | | | 1.53 | 1.61 | 1.86 | 1.94 | 2.10 | 2.42 | 2.74 | 3.07 | 3.39 | 3.71 | 4.03 | 4.84 | 5.81 | 6.78 | 7.74 |
| 46 | | | | | | | | | | 1.67 | 1.76 | 2.03 | 2.12 | 2.29 | 2.64 | 3.00 | 3.35 | 3.70 | 4.05 | 4.41 | 5.29 | 6.35 | 7.40 | 8.46 |
| 48 | | | | | | | | | | 1.82 | 1.92 | 2.21 | 2.30 | 2.50 | 2.88 | 3.26 | 3.65 | 4.03 | 4.42 | 4.80 | 5.76 | 6.91 | 8.06 | 9.22 |
| 50 | | | | | | | | | | 1.98 | 2.08 | 2.40 | 2.50 | 2.71 | 3.13 | 3.54 | 3.96 | 4.38 | 4.79 | 5.21 | 6.25 | 7.50 | 8.75 | 10.0 |
| 52 | | | | | | | | | | | 2.25 | 2.59 | 2.70 | 2.93 | 3.38 | 3.83 | 4.28 | 4.73 | 5.18 | 5.63 | 6.76 | 8.11 | 9.46 | 10.8 |
| 54 | | | | | | | | | | | 2.43 | 2.79 | 2.92 | 3.16 | 3.65 | 4.16 | 4.62 | 5.11 | 5.59 | 6.08 | 7.29 | 8.75 | 10.2 | 11.7 |
| 56 | | | | | | | | | | | 2.61 | 3.01 | 3.17 | 3.40 | 3.92 | 4.44 | 4.97 | 5.49 | 6.01 | 6.54 | 7.84 | 9.41 | 11.0 | 12.5 |
| 58 | | | | | | | | | | | 2.80 | 3.23 | 3.39 | 3.64 | 4.21 | 4.77 | 5.33 | 5.89 | 6.45 | 7.01 | 8.41 | 10.1 | 11.8 | 13.5 |
| 60 | | | | | | | | | | | | 3.45 | 3.60 | 3.90 | 4.50 | 5.10 | 5.70 | 6.30 | 6.90 | 7.50 | 9.00 | 10.8 | 12.6 | 14.4 |
| 64 | | | | | | | | | | | | 3.93 | 4.09 | 4.43 | 5.12 | 5.80 | 6.48 | 7.17 | 7.85 | 8.53 | 10.2 | 12.3 | 14.3 | 16.4 |
| 68 | | | | | | | | | | | | 4.43 | 4.62 | 5.01 | 5.78 | 6.55 | 7.32 | 8.09 | 8.86 | 9.63 | 11.6 | 13.9 | 16.2 | 18.5 |
| 72 | | | | | | | | | | | | | 5.18 | 5.61 | 6.48 | 7.34 | 8.21 | 9.07 | 9.93 | 10.8 | 13.0 | 15.5 | 18.1 | 20.7 |

**K - Values***

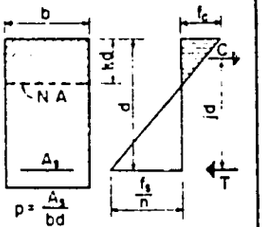
| $f_s$ ksi | $f'_c$ 2500 | 3000 | 3750 | 4000 | 5000 |
|---|---|---|---|---|---|
| 16 | 201 | 252 | 331 | 359 | 468 |
| 18 | 190 | 238 | 314 | 341 | 446 |
| 20 | 179 | 226 | 298 | 324 | 426 |
| 22 | 170 | 214 | 284 | 309 | 407 |
| 24 | 161 | 204 | 271 | 295 | 390 |
| 27 | 150 | 190 | 254 | 277 | 366 |
| 30 | 140 | 178 | 238 | 260 | 346 |
| 33 | 132 | 168 | 225 | 246 | 327 |

*The values of K correspond to $f_c = 0.45 f'_c$

Table 4.1/1

## Coefficients *(K, k, j, p)* for Rectangular Sections

| $f'_c$ and n | $f_c$ | K | k | j | p | K | k | j | p |
|---|---|---|---|---|---|---|---|---|---|
| | | $f_s$ = 16,000 | | a = 1.13 | | $f_s$ = 18,000 | | a = 1.29 | |
| 2500 | 875. | 137. | .356 | .881 | .0097 | 128. | .329 | .890 | .0080 |
| | 1000. | 169. | .387 | .871 | .0121 | 158. | .359 | .880 | .0100 |
| | 1125. | 201. | .415 | .862 | .0146 | 190. | .387 | .871 | .0121 |
| 10.1 | 1250. | 235. | .441 | .853 | .0172 | 222. | .412 | .863 | .0143 |
| | 1500. | 306. | .486 | .838 | .0228 | 241. | .457 | .848 | .0190 |
| | 1050. | 173. | .376 | .875 | .0124 | 162. | .349 | .884 | .0102 |
| 3000 | 1200. | 212. | .408 | .864 | .0153 | 199. | .380 | .873 | .0127 |
| | 1350. | 252. | .437 | .854 | .0184 | 238. | .408 | .864 | .0153 |
| 9.2 | 1500. | 294. | .463 | .846 | .0217 | 278. | .434 | .855 | .0181 |
| | 1800. | 385. | .509 | .830 | .0286 | 362. | .479 | .840 | .0240 |
| | 1400. | 249. | .412 | .863 | .0180 | 234. | .384 | .872 | .0149 |
| 4000 | 1600. | 303. | .444 | .852 | .0222 | 286. | .416 | .861 | .0185 |
| | 1800. | 359. | .474 | .842 | .0266 | 341. | .444 | .852 | .0222 |
| 8.0 | 2000. | 417. | .500 | .833 | .0313 | 397. | .471 | .843 | .0261 |
| | 2400. | 536. | .545 | .818 | .0409 | 513. | .516 | .828 | .0344 |
| | 1750. | 327. | .437 | .854 | .0239 | 309. | .408 | .864 | .0199 |
| 5000 | 2000. | 397. | .470 | .843 | .0294 | 376. | .441 | .853 | .0245 |
| | 2250. | 468. | .500 | .833 | .0351 | 446. | .470 | .843 | .0294 |
| 7.1 | 2500. | 542. | .526 | .825 | .0411 | 518. | .497 | .835 | .0345 |
| | 3000. | 694. | .571 | .810 | .0535 | 666. | .542 | .819 | .0452 |
| | | $f_s$ = 20,000 | | a = 1.44 | | $f_s$ = 22,000 | | a = 1.60 | |
| 2500 | 875. | 120. | .336 | .893 | .0067 | 113. | .287 | .904 | .0057 |
| | 1000. | 149. | .336 | .888 | .0084 | 141. | .315 | .895 | .0072 |
| | 1125. | 179. | .362 | .879 | .0102 | 170. | .341 | .886 | .0087 |
| 10.1 | 1250. | 211. | .387 | .871 | .0121 | 200. | .365 | .878 | .0104 |
| | 1500. | 277. | .431 | .856 | .0162 | 264. | .408 | .864 | .0139 |
| | 1050. | 152. | .326 | .891 | .0085 | 144. | .305 | .898 | .0073 |
| 3000 | 1200. | 188. | .356 | .881 | .0107 | 178. | .334 | .889 | .0091 |
| | 1350. | 226. | .383 | .872 | .0129 | 214. | .361 | .880 | .0111 |
| 9.2 | 1500. | 265. | .408 | .864 | .0153 | 252. | .385 | .872 | .0131 |
| | 1800. | 346. | .453 | .849 | .0204 | 331. | .429 | .857 | .0176 |
| | 1400. | 221. | .359 | .880 | .0126 | 210. | .337 | .888 | .0107 |
| 4000 | 1600. | 272. | .390 | .870 | .0156 | 258. | .368 | .877 | .0134 |
| | 1800. | 324. | .419 | .860 | .0188 | 309. | .396 | .868 | .0162 |
| 8.0 | 2000. | 379. | .444 | .852 | .0222 | 362. | .421 | .860 | .0191 |
| | 2400. | 492. | .490 | .837 | .0294 | 472. | .466 | .845 | .0254 |
| | 1750. | 292. | .383 | .872 | .0168 | 278. | .361 | .880 | .0144 |
| 5000 | 2000. | 358. | .415 | .862 | .0216 | 341. | .392 | .869 | .0178 |
| | 2250. | 426. | .444 | .852 | .0250 | 407. | .421 | .860 | .0215 |
| 7.1 | 2500. | 496. | .470 | .843 | .0294 | 475. | .447 | .851 | .0254 |
| | 3000. | 641. | .516 | .828 | .0367 | 617. | .492 | .836 | .0335 |
| | | $f_s$ = 27,000 | | a = 7.00 | | $f_s$ = 30,000 | | a = 2.24 | |
| 2500 | 875. | 99. | .247 | .918 | .0040 | 92. | .228 | .924 | .0033 |
| | 1000. | 124. | .272 | .909 | .0050 | 115. | .252 | .916 | .0042 |
| | 1125. | 150. | .296 | .901 | .0062 | 140. | .275 | .908 | .0052 |
| 10.1 | 1250. | 176. | .319 | .894 | .0074 | 167. | .296 | .901 | .0062 |
| | 1500. | 237. | .359 | .880 | .0100 | 224. | .336 | .888 | .0084 |
| | 1050. | 126. | .264 | .912 | .0051 | 117. | .244 | .919 | .0043 |
| 3000 | 1200. | 157. | .290 | .903 | .0064 | 147. | .269 | .910 | .0054 |
| | 1350. | 190. | .315 | .895 | .0079 | 178. | .293 | .902 | .0066 |
| 9.2 | 1500. | 225. | .338 | .887 | .0094 | 211. | .315 | .895 | .0079 |
| | 1800. | 299. | .380 | .873 | .0127 | 282. | .356 | .881 | .0107 |
| | 1400. | 185. | .293 | .902 | .0076 | 173. | .272 | .909 | .0063 |
| 4000 | 1600. | 230. | .322 | .893 | .0095 | 215. | .299 | .900 | .0080 |
| | 1800. | 277. | .348 | .884 | .0116 | 260. | .324 | .892 | .0097 |
| 8.0 | 2000. | 326. | .372 | .876 | .0138 | 308. | .348 | .884 | .0116 |
| | 2400. | 430. | .416 | .861 | .0185 | 407. | .390 | .870 | .0156 |
| | 1750. | 247. | .315 | .895 | .0102 | 231. | .293 | .902 | .0085 |
| 5000 | 2000. | 305. | .345 | .885 | .0128 | 287. | .321 | .893 | .0107 |
| | 2250. | 366. | .372 | .876 | .0155 | 346. | .347 | .884 | .0130 |
| 7.1 | 2500. | 430. | .397 | .868 | .0184 | 407. | .372 | .876 | .0155 |
| | 3000. | 564. | .441 | .853 | .0245 | 537. | .415 | .862 | .0208 |




$p = \frac{A_s}{bd}$

$k = \frac{1}{1 + f_s/nf_c}$ | $j = 1 - \frac{1}{3}k$

$p^* = \frac{f_c}{2f_s} \times k$ | $K = \frac{f_c}{2}kj$

$a = \frac{f_s}{12{,}000} \times$ (aver. j-value)

for use in $A_s = \frac{M}{ad}$ or $A_s = \frac{NE}{acl}$

| K | k | j | p |
|---|---|---|---|
| $f_s$ = 24,000 | | a = 1.76 | |
| 107. | .269 | .910 | .0049 |
| 133. | .296 | .901 | .0062 |
| 161. | .321 | .893 | .0075 |
| 191. | .345 | .885 | .0090 |
| 253. | .387 | .871 | .0121 |
| 136. | .287 | .904 | .0063 |
| 169. | .315 | .895 | .0079 |
| 204. | .341 | .886 | .0096 |
| 240. | .365 | .878 | .0114 |
| 317. | .408 | .864 | .0153 |
| 199. | .318 | .894 | .0093 |
| 246. | .348 | .884 | .0116 |
| 295. | .375 | .875 | .0141 |
| 347. | .400 | .867 | .0167 |
| 454. | .444 | .852 | .0222 |
| 265. | .341 | .886 | .0124 |
| 326. | .372 | .876 | .0155 |
| 390. | .400 | .867 | .0187 |
| 456. | .425 | .858 | .0221 |
| 595. | .470 | .843 | .0294 |
| $f_s$ = 33,000 | | a = 2.48 | |
| 86. | .211 | .930 | .0028 |
| 108. | .234 | .922 | .0036 |
| 132. | .256 | .915 | .0044 |
| 157. | .277 | .908 | .0052 |
| 211. | .315 | .895 | .0072 |
| 110. | .226 | .925 | .0036 |
| 138. | .251 | .916 | .0046 |
| 168. | .273 | .909 | .0056 |
| 199. | .295 | .902 | .0067 |
| 267. | .334 | .889 | .0091 |
| 162. | .253 | .916 | .0054 |
| 203. | .279 | .907 | .0068 |
| 246. | .304 | .899 | .0083 |
| 291. | .327 | .891 | .0099 |
| 387. | .368 | .877 | .0134 |
| 218. | .274 | .909 | .0073 |
| 271. | .301 | .900 | .0091 |
| 327. | .326 | .891 | .0111 |
| 386. | .350 | .883 | .0132 |
| 511. | .392 | .869 | .0178 |

a "Balanced steel ratio" applies to problems involving bending only

Table 4.1/2

## Areas and Perimeters of Bars in Sections 1 Ft. Wide (Slabs)

Areas $A_s$ (or $A'_s$) (top) sq. in.; Perimeters $\Sigma o$, (bottom) in.

Enter table with values of $A_s$ (or $A'_s$) and $\Sigma o = \frac{V}{1.75\,jd}$ (V:lb; d:in.; u:psi)

Coefficients $a = \frac{f_s}{12{,}000} \times j$ inserted in table are for use in $A_s = \frac{M}{aj}$ or $A_s = \frac{NF}{aj}$

| Spacing | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 | Spacing |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.30<br>4.7 | 0.66<br>7.1 | 1.20<br>9.4 | 1.86<br>11.8 | 2.64<br>14.2 | | | | | | 2 |
| 2-1/2 | 0.24<br>3.8 | 0.53<br>5.7 | 0.96<br>7.5 | 1.49<br>9.4 | 2.11<br>11.3 | 2.88<br>13.2 | 3.79<br>15.1 | | | | 2-1/2 |
| 3 | 0.20<br>3.1 | 0.44<br>4.7 | 0.80<br>6.3 | 1.24<br>7.8 | 1.76<br>9.4 | 2.40<br>11.0 | 3.16<br>12.6 | 4.00<br>14.2 | | | 3 |
| 3-1/2 | 0.17<br>2.7 | 0.38<br>4.0 | 0.69<br>5.4 | 1.06<br>6.7 | 1.51<br>8.1 | 2.06<br>9.4 | 2.71<br>10.8 | 3.43<br>12.2 | 4.36<br>13.7 | | 3-1/2 |
| 4 | 0.15<br>2.4 | 0.33<br>3.5 | 0.60<br>4.7 | 0.93<br>5.9 | 1.32<br>7.1 | 1.80<br>8.3 | 2.37<br>9.4 | 3.00<br>10.6 | 3.81<br>12.0 | 4.68<br>13.3 | 4 |
| 4-1/2 | 0.13<br>2.1 | 0.29<br>3.1 | 0.53<br>4.2 | 0.83<br>5.2 | 1.17<br>6.3 | 1.60<br>7.3 | 2.11<br>8.4 | 2.67<br>9.5 | 3.39<br>10.6 | 4.16<br>11.8 | 4-1/2 |
| 5 | 0.12<br>1.9 | 0.26<br>2.8 | 0.48<br>3.8 | 0.74<br>4.7 | 1.06<br>5.7 | 1.44<br>6.6 | 1.90<br>7.5 | 2.40<br>8.5 | 3.05<br>9.6 | 3.74<br>10.6 | 5 |
| 5-1/2 | 0.11<br>1.7 | 0.24<br>2.6 | 0.44<br>3.4 | 0.68<br>4.3 | 0.96<br>5.1 | 1.31<br>6.0 | 1.72<br>6.9 | 2.18<br>7.7 | 2.77<br>8.7 | 3.40<br>9.7 | 5-1/2 |
| 6 | 0.10<br>1.6 | 0.22<br>2.4 | 0.40<br>3.1 | 0.62<br>3.9 | 0.88<br>4.7 | 1.20<br>5.5 | 1.58<br>6.3 | 2.00<br>7.1 | 2.54<br>8.0 | 3.12<br>8.9 | 6 |
| 6-1/2 | 0.09<br>1.4 | 0.20<br>2.2 | 0.37<br>2.9 | 0.57<br>3.6 | 0.81<br>4.4 | 1.11<br>5.1 | 1.46<br>5.8 | 1.85<br>6.5 | 2.35<br>7.4 | 2.88<br>8.2 | 6-1/2 |
| 7 | 0.09<br>1.3 | 0.19<br>2.0 | 0.34<br>2.7 | 0.53<br>3.4 | 0.75<br>4.0 | 1.03<br>4.7 | 1.35<br>5.4 | 1.71<br>6.1 | 2.18<br>6.8 | 2.67<br>7.6 | 7 |
| 7-1/2 | 0.08<br>1.3 | 0.18<br>1.9 | 0.32<br>2.5 | 0.50<br>3.1 | 0.70<br>3.8 | 0.96<br>4.4 | 1.26<br>5.0 | 1.60<br>5.7 | 2.03<br>6.4 | 2.50<br>7.1 | 7-1/2 |
| 8 | 0.08<br>1.2 | 0.17<br>1.8 | 0.30<br>2.4 | 0.47<br>2.9 | 0.66<br>3.5 | 0.90<br>4.1 | 1.19<br>4.7 | 1.50<br>5.3 | 1.91<br>6.0 | 2.34<br>6.6 | 8 |
| 8-1/2 | 0.07<br>1.1 | 0.16<br>1.7 | 0.28<br>2.2 | 0.44<br>2.8 | 0.62<br>3.3 | 0.85<br>3.9 | 1.12<br>4.4 | 1.41<br>5.0 | 1.79<br>5.6 | 2.20<br>6.2 | 8-1/2 |
| 9 | 0.07<br>1.0 | 0.15<br>1.6 | 0.27<br>2.1 | 0.41<br>2.6 | 0.59<br>3.1 | 0.80<br>3.7 | 1.05<br>4.2 | 1.33<br>4.7 | 1.69<br>5.3 | 2.08<br>5.9 | 9 |
| 9-1/2 | 0.06<br>1.0 | 0.14<br>1.5 | 0.25<br>2.0 | 0.39<br>2.5 | 0.56<br>3.0 | 0.76<br>3.5 | 1.00<br>4.0 | 1.26<br>4.5 | 1.60<br>5.0 | 1.97<br>5.6 | 9-1/2 |
| 10 | 0.06<br>0.9 | 0.13<br>1.4 | 0.24<br>1.9 | 0.37<br>2.4 | 0.53<br>2.8 | 0.72<br>3.3 | 0.95<br>3.8 | 1.20<br>4.3 | 1.52<br>4.9 | 1.87<br>5.3 | 10 |
| 10-1/2 | 0.06<br>0.9 | 0.13<br>1.3 | 0.23<br>1.8 | 0.35<br>2.2 | 0.50<br>2.7 | 0.69<br>3.1 | 0.90<br>3.6 | 1.14<br>4.0 | 1.45<br>4.6 | 1.78<br>5.1 | 10-1/2 |
| 11 | 0.05<br>0.9 | 0.12<br>1.3 | 0.22<br>1.7 | 0.34<br>2.2 | 0.48<br>2.6 | 0.65<br>3.0 | 0.86<br>3.4 | 1.09<br>3.9 | 1.39<br>4.4 | 1.70<br>4.8 | 11 |
| 11-1/2 | 0.05<br>0.08 | 0.11<br>1.2 | 0.21<br>1.6 | 0.32<br>2.0 | 0.46<br>2.5 | 0.63<br>2.9 | 0.82<br>3.3 | 1.04<br>3.7 | 1.33<br>4.2 | 1.63<br>4.6 | 11-1/2 |
| 12 | 0.05<br>0.8 | 0.11<br>1.2 | 0.20<br>1.6 | 0.31<br>2.0 | 0.44<br>2.4 | 0.60<br>2.8 | 0.79<br>3.1 | 1.00<br>3.5 | 1.27<br>4.0 | 1.56<br>4.4 | 12 |
| 13 | $f_s$ | a | 0.15<br>1.4 | 0.29<br>1.8 | 0.41<br>2.2 | 0.55<br>2.5 | 0.73<br>2.9 | 0.92<br>3.3 | 1.17<br>3.7 | 1.44<br>4.1 | 13 |
| 14 | 16,000<br>18,000 | 1.13<br>1.29 | 0.17<br>1.3 | 0.27<br>1.7 | 0.38<br>2.0 | 0.51<br>2.4 | 0.68<br>2.7 | 0.86<br>3.0 | 1.09<br>3.4 | 1.34<br>3.8 | 14 |
| 15 | 20,000<br>22,000 | 1.44<br>1.60 | 0.16<br>1.3 | 0.25<br>1.6 | 0.35<br>1.9 | 0.48<br>2.2 | 0.63<br>2.5 | 0.80<br>2.8 | 1.02<br>3.2 | 1.25<br>3.5 | 15 |
| 16 | 24,000<br>27,000 | 1.76<br>2.00 | 0.15<br>1.2 | 0.23<br>1.5 | 0.33<br>1.8 | 0.45<br>2.1 | 0.59<br>2.4 | 0.75<br>2.7 | 0.95<br>3.0 | 1.17<br>3.3 | 16 |
| 17 | 30,000<br>33,000 | 2.24<br>2.48 | 0.14<br>1.1 | 0.22<br>1.4 | 0.31<br>1.7 | 0.42<br>1.9 | 0.56<br>2.2 | 0.71<br>2.5 | 0.90<br>2.8 | 1.10<br>3.1 | 17 |
| 18 | | | 0.13<br>1.0 | 0.21<br>1.3 | 0.29<br>1.6 | 0.40<br>1.8 | 0.53<br>2.1 | 0.67<br>2.4 | 0.85<br>2.7 | 1.04<br>3.0 | 18 |

Table 4.1/3

Now with the given value of N and using the following equation find the required bar perimeter.

$$20 = \frac{N}{7/8\ ud} \qquad \text{where } u = .05(f_c)$$

since we are considering the use of concrete with $f_c = 3000$, u in our case would have a value of 150. Now from Table 4.1/3 (Table 3a of Handbook) the size of the reinforcing bars, indicated by numbers and their spacing, from center to center (OC), can be determined.

## Section 4.2

## The Main Shell's Reinforcements

We shall consider the reinforcement in each of the slabs throught the following:

### 4.2-1 Side Walls

If all the load were carried the shorter way, shear would be (.50 wa). Actually in accordance with method I, Table 1 of ACI Handbook (Reference 20), shear would only be .44 wa. This would give V = .44 wa per linear foot. Now we have:

$$V = \frac{v(1b)}{7/8\ bd} \qquad \text{where } d = \text{effective depth}$$

$$b = 1 \text{ linear foot.}$$

Now perimeter of bars required at end of strip extending the short way is:

$$\Sigma o = \frac{V}{7/8\ ud} \qquad \text{where } u = .05f_c$$

$$d = \text{effective depth}$$

Steel area required at end of strip extending the short span is: $As = \frac{M}{ad}$

where a = 1.44 for 20000/9.2/1350

Introducing these values into the Table (4.2/1) (3a of Handbook) the size number and the spacing of the reinforcing bars is determined. At the corners nominal top reinforcement should be supplied, say .005 bd sq. in per foot in

each direction. Length of these bars may be taken as 1/4 a.

### 4.2-2 The Base Slab

The weight of the base slab and the liquid does not create any bending or shearing stresses in concrete provided that the subsoil is uniformly well compacted.

The total weight transferred to the base through the bottom of the walls, however, causes stresses. This total weight is equivalent to

Total weigth = weight of top slab + weight of walls

The average load w = Total weight/Area. Now following exactly the same procedure described in 4.2-1 the reinforcement for the bottom slab can be designed.

## Areas and Perimeters of Bars in Sections 1 Ft. Wide (Slabs)

**Areas $A_s$ (or $A'_s$) (top) sq. in.; Perimeters $\Sigma o$, (bottom) in.**

Enter table with values of $A_s$ (or $A'_s$) and $\Sigma o = \frac{V}{7/5\ du}$ (V: lb, d: in.; u: psi)

Coefficients $a = \frac{f_s}{12{,}000} \times j$ inserted in table are for use in $A_s = \frac{M}{aj}$ or $A_s = \frac{NE}{12j}$

| Spacing | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 | Spacing |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.30<br>4.7 | 0.66<br>7.1 | 1.20<br>9.4 | 1.86<br>11.8 | 2.64<br>14.2 | | | | | | 2 |
| 2-1/2 | 0.24<br>3.8 | 0.53<br>5.7 | 0.96<br>7.5 | 1.49<br>9.4 | 2.11<br>11.3 | 2.88<br>13.2 | 3.79<br>15.1 | | | | 2-1/2 |
| 3 | 0.20<br>3.1 | 0.44<br>4.7 | 0.80<br>6.3 | 1.24<br>7.8 | 1.76<br>9.4 | 2.40<br>11.0 | 3.16<br>12.6 | 4.00<br>14.2 | | | 3 |
| 3-1/2 | 0.17<br>2.7 | 0.38<br>4.0 | 0.69<br>5.4 | 1.06<br>6.7 | 1.51<br>8.1 | 2.06<br>9.4 | 2.71<br>10.8 | 3.43<br>12.2 | 4.36<br>13.7 | | 3-1/2 |
| 4 | 0.15<br>2.4 | 0.33<br>3.5 | 0.60<br>4.7 | 0.93<br>5.9 | 1.32<br>7.1 | 1.80<br>8.3 | 2.37<br>9.4 | 3.00<br>10.6 | 3.81<br>12.0 | 4.68<br>13.3 | 4 |
| 4-1/2 | 0.13<br>2.1 | 0.29<br>3.1 | 0.53<br>4.2 | 0.83<br>5.2 | 1.17<br>6.3 | 1.60<br>7.3 | 2.11<br>8.4 | 2.67<br>9.5 | 3.39<br>10.6 | 4.16<br>11.8 | 4-1/2 |
| 5 | 0.12<br>1.9 | 0.26<br>2.8 | 0.48<br>3.8 | 0.74<br>4.7 | 1.06<br>5.7 | 1.44<br>6.6 | 1.90<br>7.5 | 2.40<br>8.5 | 3.05<br>9.6 | 3.74<br>10.6 | 5 |
| 5-1/2 | 0.11<br>1.7 | 0.24<br>2.6 | 0.44<br>3.4 | 0.68<br>4.3 | 0.96<br>5.1 | 1.31<br>6.0 | 1.72<br>6.9 | 2.18<br>7.7 | 2.77<br>8.7 | 3.40<br>9.7 | 5-1/2 |
| 6 | 0.10<br>1.6 | 0.22<br>2.4 | 0.40<br>3.1 | 0.62<br>3.9 | 0.89<br>4.7 | 1.20<br>5.5 | 1.58<br>6.3 | 2.00<br>7.1 | 2.54<br>8.0 | 3.12<br>8.9 | 6 |
| 6-1/2 | 0.09<br>1.4 | 0.20<br>2.2 | 0.37<br>2.9 | 0.57<br>3.6 | 0.81<br>4.4 | 1.11<br>5.1 | 1.46<br>5.8 | 1.85<br>6.5 | 2.35<br>7.4 | 2.88<br>8.2 | 6-1/2 |
| 7 | 0.09<br>1.3 | 0.19<br>2.0 | 0.34<br>2.7 | 0.53<br>3.4 | 0.75<br>4.0 | 1.03<br>4.7 | 1.35<br>5.4 | 1.71<br>6.1 | 2.18<br>6.8 | 2.67<br>7.6 | 7 |
| 7-1/2 | 0.09<br>1.3 | 0.18<br>1.9 | 0.32<br>2.5 | 0.50<br>3.1 | 0.70<br>3.8 | 0.96<br>4.4 | 1.26<br>5.0 | 1.60<br>5.7 | 2.03<br>6.4 | 2.50<br>7.1 | 7-1/2 |
| 8 | 0.08<br>1.2 | 0.17<br>1.8 | 0.30<br>2.4 | 0.47<br>2.9 | 0.66<br>3.5 | 0.90<br>4.1 | 1.19<br>4.7 | 1.50<br>5.3 | 1.91<br>6.0 | 2.34<br>6.6 | 8 |
| 8-1/2 | 0.07<br>1.1 | 0.16<br>1.7 | 0.28<br>2.2 | 0.44<br>2.8 | 0.62<br>3.3 | 0.85<br>3.9 | 1.12<br>4.4 | 1.41<br>5.0 | 1.79<br>5.6 | 2.20<br>6.2 | 8-1/2 |
| 9 | 0.07<br>1.0 | 0.15<br>1.6 | 0.27<br>2.1 | 0.41<br>2.6 | 0.59<br>3.1 | 0.80<br>3.7 | 1.05<br>4.2 | 1.33<br>4.7 | 1.69<br>5.3 | 2.08<br>5.9 | 9 |
| 9-1/2 | 0.06<br>1.0 | 0.14<br>1.5 | 0.25<br>2.0 | 0.39<br>2.5 | 0.56<br>3.0 | 0.76<br>3.5 | 1.00<br>4.0 | 1.26<br>4.5 | 1.60<br>5.0 | 1.97<br>5.6 | 9-1/2 |
| 10 | 0.06<br>0.9 | 0.13<br>1.4 | 0.24<br>1.9 | 0.37<br>2.4 | 0.53<br>2.8 | 0.72<br>3.3 | 0.95<br>3.8 | 1.20<br>4.3 | 1.52<br>4.8 | 1.87<br>5.3 | 10 |
| 10-1/2 | 0.06<br>0.9 | 0.13<br>1.3 | 0.23<br>1.8 | 0.35<br>2.2 | 0.50<br>2.7 | 0.69<br>3.1 | 0.90<br>3.6 | 1.14<br>4.0 | 1.45<br>4.6 | 1.78<br>5.1 | 10-1/2 |
| 11 | 0.05<br>0.9 | 0.12<br>1.3 | 0.22<br>1.7 | 0.34<br>2.2 | 0.48<br>2.6 | 0.65<br>3.0 | 0.86<br>3.4 | 1.09<br>3.9 | 1.39<br>4.4 | 1.70<br>4.8 | 11 |
| 11-1/2 | 0.05<br>0.08 | 0.11<br>1.2 | 0.21<br>1.6 | 0.32<br>2.0 | 0.46<br>2.5 | 0.63<br>2.9 | 0.82<br>3.3 | 1.04<br>3.7 | 1.33<br>4.2 | 1.63<br>4.6 | 11-1/2 |
| 12 | 0.05<br>0.8 | 0.11<br>1.2 | 0.20<br>1.6 | 0.31<br>2.0 | 0.44<br>2.4 | 0.60<br>2.8 | 0.79<br>3.1 | 1.00<br>3.5 | 1.27<br>4.0 | 1.56<br>4.4 | 12 |
| 13 | $f_s$ | a | 0.18<br>1.4 | 0.29<br>1.8 | 0.41<br>2.2 | 0.55<br>2.5 | 0.73<br>2.9 | 0.92<br>3.3 | 1.17<br>3.7 | 1.44<br>4.1 | 13 |
| 14 | 16,000<br>18,000 | 1.13<br>1.29 | 0.17<br>1.3 | 0.27<br>1.7 | 0.38<br>2.0 | 0.51<br>2.4 | 0.68<br>2.7 | 0.86<br>3.0 | 1.09<br>3.4 | 1.34<br>3.8 | 14 |
| 15 | 20,000<br>22,000 | 1.44<br>1.60 | 0.16<br>1.3 | 0.25<br>1.6 | 0.35<br>1.9 | 0.48<br>2.2 | 0.63<br>2.5 | 0.80<br>2.8 | 1.02<br>3.2 | 1.25<br>3.5 | 15 |
| 16 | 24,000<br>27,000 | 1.76<br>2.00 | 0.15<br>1.2 | 0.23<br>1.5 | 0.33<br>1.8 | 0.45<br>2.1 | 0.59<br>2.4 | 0.75<br>2.7 | 0.95<br>3.0 | 1.17<br>3.3 | 16 |
| 17 | 30,000<br>33,000 | 2.24<br>2.48 | 0.14<br>1.1 | 0.22<br>1.4 | 0.31<br>1.7 | 0.42<br>1.9 | 0.56<br>2.2 | 0.71<br>2.5 | 0.90<br>2.8 | 1.10<br>3.1 | 17 |
| 18 | | | 0.13<br>1.0 | 0.21<br>1.3 | 0.29<br>1.6 | 0.40<br>1.8 | 0.53<br>2.1 | 0.67<br>2.4 | 0.85<br>2.7 | 1.04<br>3.0 | 18 |

Table 4.2/1

# CHAPTER 5

# THE CONCRETE MIX DESIGN

## 5.1 Introduction

The purpose of this chapter of the manual is to indicate the guidelines within which the concrete mix should be designed and prepared. The main reason for the insertion of this chapter is to preserve the independence of the steam condenser construction. Otherwise since concrete is utilized throughout the construction of a powerplant, it would be most suitable and also economically desirable to integrate the construction of the condenser into the overall building of the whole plant. This sort of construction scheme will be strongly suggested for the waterboxes, anchored to the foundation, and requiring ordinary concrete mix. The same line of reasoning might apply to the shell structure as well, however, there are good indications that special mixes could be designed for the shell so as to decrease its permeability. A mix ensuring lower permeability of the concrete in the shell might help decrease the amount of coating necessary to achieve low rates of permeability for the structure.

## MAIN TYPES OF PORTLAND CEMENT

| English description | A.S.T.M. description |
|---|---|
| Ordinary Portland | Type I |
| Rapid Hardening Portland | Type III |
| Speed (Portland) | |
| Extra Rapid Hardening Portland | |
| Low Heat Portland | Type IV |
| (Modified cement) | Type II |
| Sulphate Resisting Portland | Type V |
| Portland Blast-furnace | Type IS |
| White Portland | |
| Portland-Pozzolana | Type IP |

*Note:* Cements Type I, IS, IP, II and III are also available with an interground air-entraining agent, and are then denoted by letter A, e.g. Type IA.

Table 5.2/1

## TYPICAL VALUES OF COMPOUND COMPOSITION OF PORTLAND CEMENTS OF DIFFERENT TYPES *

| Cement | Value | Compound composition, per cent | | | | | | | | Number of samples |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | $CaSO_4$ | Free CaO | MgO | Ignition Loss | |
| Type I | Max. | 67 | 31 | 14 | 12 | 3·4 | 1·5 | 3·8 | 2·3 | |
| | Min. | 42 | 8 | 5 | 6 | 2·6 | 0·0 | 0·7 | 0·6 | |
| | Mean | 49 | 25 | 12 | 8 | 2·9 | 0·8 | 2·4 | 1·2 | 21 |
| Type II | Max. | 55 | 39 | 8 | 16 | 3·4 | 1·8 | 4·4 | 2·0 | |
| | Min. | 37 | 19 | 4 | 6 | 2·1 | 0·1 | 1·5 | 0·5 | |
| | Mean | 46 | 29 | 6 | 12 | 2·8 | 0·6 | 3·0 | 1·0 | 28 |
| Type III | Max. | 70 | 38 | 17 | 10 | 4·6 | 4·2 | 4·8 | 2·7 | |
| | Min. | 34 | 0 | 7 | 6 | 2·2 | 0·1 | 1·0 | 1·1 | |
| | Mean | 56 | 15 | 12 | 8 | 3·9 | 1·3 | 2·6 | 1·9 | 5 |
| Type IV | Max. | 44 | 57 | 7 | 18 | 3·5 | 0·9 | 4·1 | 1·9 | |
| | Min. | 21 | 34 | 3 | 6 | 2·6 | 0·0 | 1·0 | 0·6 | |
| | Mean | 30 | 46 | 5 | 13 | 2·9 | 0·3 | 2·7 | 1·0 | 16 |
| Type V | Max. | 54 | 49 | 5 | 15 | 3·9 | 0·6 | 2·3 | 1·2 | |
| | Min. | 35 | 24 | 1 | 6 | 2·4 | 0·1 | 0·7 | 0·8 | |
| | Mean | 43 | 36 | 4 | 12 | 2·7 | 0·4 | 1·6 | 1·0 | 22 |

Table 5.2/2

## 5.2 Portland Cement

We are not going to go in detail into the history, property and different types of Portland cement. There are some very valuable tests in this field and we refer the reader to them (Ref. 21-22-23). However, we shall introduce the reader to a general overall view of the subject by reviewing the important items of discussion. Since the render should know at the very start what kind of Portland cement he is dealing with, we introduce here two tables giving different types of Portland cement (Table 5.2/1) and Typical values of Compound Composition of Portland cements of different (Table 5.2/2) (Ref. 21).

In our design we will primarily deal with Portland cement Type I, however, if the user recognizes that another type is either more economical or solely available, he should, by identifying the type with comparison with the given tables and subsequent information, design his mix accordingly.

## 5.3 Aggregates and Their Properties

Almost 3/4 of the volume of concrete is occupied by aggregates, so it is not surprising that its quality is of considerable importance. The size of the aggregate used in concrete ranges from several inches down to particles of a few thousandths of an inch in cross section. In making low grade concrete, the aggregate contains a whole range of particles, but in good quality concrete, the procedure is to use aggregate in two distinct sizes. One is the sand composed of particles smaller than 3/16 in., called fine aggregate, and the other containing particles larger than 3/16 in. and referred to as coarse aggregates.

These aggregates can either be obtained naturally or manufactured. We shall only consider the natural aggregates, for the manufactured aggregates are mostly used for specific applications not related to ours. The natural aggregates can be classified according to the Table 5.3/1. The shape of the natural aggregates can also be classified in the manner shown in Table 5.3/2 (Ref. 21)

Since fine and coarse aggregates should be batched separately, the grading of each type of aggregate should be known and controlled. For this purpose the following tables, from British Standars and A.S.T.M. (Ref. 21), arepresented here. Table 5.3/3 gives the grading requirements for fine aggregates and table 5.3/4 indicates the grading requirements for coarse aggregates. Finally Table 5.3/5 presents the grading requirements for all-in aggregate.

**B.S. 812: 1960 CLASSIFICATION OF NATURAL AGGREGATES ACCORDING TO ROCK TYPE**

| *Basalt Group* | *Chert Group* | *Gabbro Group* |
|---|---|---|
| Andesite | Chert | Basic diorite |
| Basalt | Flint | Basic gneiss |
| Basic Porphyrites | | Gabbro |
| Diabase | | Hornblende-rock |
| Dolerites of all kinds including therzolite and tesselite | | Norite |
| Epidiorite | | Peridotite |
| Hornblende-schist | | Picrite |
| Lamprophyre | | Serpentine |
| Quartz-dolerite | | |
| Spilite | | |

| *Granite Group* | *Gritstone Group* | *Hornfels Group* |
|---|---|---|
| Gneiss | Agglomerate | Contact-altered rocks of all kinds except marble |
| Granite | Arkose | |
| Granodiorite | Breccia | |
| Granulite | Conglomerate | |
| Pegmatite | Greywacke | |
| Quartz-diorite | Grit | |
| Syenite | Sandstone | |
| | Tuff | |

| *Limestone Group* | *Porphyry Group* | *Quartzite Group* |
|---|---|---|
| Dolomite | Aplite | Ganister |
| Limestone | Dacite | Quartzitic sandstones |
| Marble | Felsite | Re-crystallized quartzite |
| | Granophyre | |
| | Keratophyre | |
| | Microgranite | |
| | Porphyry | |
| | Quartz-Porphyrite | |
| | Rhyolite | |
| | Trachyte | |

| | *Schist Group* |
|---|---|
| | Phyllite |
| | Schist |
| | Slate |
| | All severely sheared rocks |

Table 5.3/1

PARTICLE SHAPE CLASSIFICATION OF B.S. 812: 1960

| Classification | Description | Examples |
|---|---|---|
| Rounded | Fully water-worn or completely shaped by attrition | River or seashore gravel, desert, seashore and wind-blown sand |
| Irregular | Naturally irregular, or partly shaped by attrition and having rounded edges | Other gravels; land or dug flint |
| Flaky | Material of which the thickness is small relative to the other two dimensions | Laminated rock |
| Angular | Possessing well-defined edges formed at the intersection of roughly planar faces | Crushed rocks of all types; talus; crushed slag |
| Elongated | Material, usually angular in which the length is considerably larger than the other two dimensions | — |
| Flaky and Elongated | Material having the length considerably larger than the width, and the width considerably larger than the thickness | — |

Table 5.3/2

B.S. AND A.S.T.M. GRADING REQUIREMENTS FOR FINE AGGREGATE

| B.S. sieve size | Percentage by weight passing B.S. sieves | | | | |
|---|---|---|---|---|---|
| | B.S. 882: 1954 | | | | A.S.T.M. Standard C 33 – 57 |
| | Grading zone 1 | Grading zone 2 | Grading zone 3 | Grading zone 4 | |
| ⅜ in. | 100 | 100 | 100 | 100 | 100 |
| ⅛ in. | 90 – 100 | 90 – 100 | 90 – 100 | 95 – 100 | 95 – 100 |
| 7 | 60 – 95 | 75 – 100 | 85 – 100 | 95 – 100 | 80 – 100 |
| 14 | 30 – 70 | 55 – 90 | 75 – 100 | 90 – 100 | 50 – 85 |
| 25 | 15 – 34 | 35 – 59 | 60 – 79 | 80 – 100 | 25 – 60 |
| 52 | 5 – 20 | 8 – 30 | 12 – 40 | 15 – 50 | 10 – 30 |
| 100 | 0 – 10* | 0 – 10* | 0 – 10* | 0 – 15* | 2 – 10 |

* For crushed stone sands the permissible limit is increased to 20 per cent.

U.S. BUREAU OF RECLAMATION GRADING REQUIREMENTS FOR FINE AGGREGATE

| Equivalent B.S. sieve size | Individual percentage retained |
|---|---|
| $\frac{3}{16}$ in. | 0 – 5 |
| 7 | 5 – 15 |
| 14 | 10 – 25 |
| 25 | 10 – 30 |
| 52 | 15 – 35 |
| 100 | 12 – 20 |
| smaller than 100 | 3 – 7 |

(5 – 15 and 10 – 25) or (5 – 20, 10 – 20)

Table 5.3/3

GRADING REQUIREMENTS FOR COARSE AGGREGATE (B.S. 882:1954)

| B.S. sieve size | Percentage by weight passing B.S. sieves | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Nominal size of graded aggregate | | | Nominal size of single-sized aggregate | | | | |
| | 1½ in. to 3/16 in. | ¾ in. to 3/16 in. | ½ in. to 3/16 in. | 2½ in. | 1½ in. | ¾ in. | ½ in. | ⅜ in. |
| 3 in. | 100 | – | – | 100 | – | – | – | – |
| 2½ in. | – | – | – | 85–100 | 100 | – | – | – |
| 1½ in. | 95–100 | 100 | – | 0–30 | 85–100 | 100 | – | – |
| ¾ in. | 30–70 | 95–100 | 100 | 0–5 | 0–20 | 85–100 | 100 | – |
| ½ in. | – | – | 90–100 | – | – | – | 85–100 | 100 |
| ⅜ in. | 10–35 | 25–55 | 40–85 | – | 0–5 | 0–20 | 0–45 | 85–100 |
| 3/16 in. | 0–5 | 0–10 | 0–10 | – | – | 0–5 | 0–10 | 0–20 |
| 7 | – | – | – | – | – | – | – | 0–5 |

GRADING REQUIREMENTS FOR COARSE AGGREGATE
(A.S.T.M. STANDARD C 33-61)

| Equivalent B.S. sieve size | Percentage by weight passing B.S. sieves | | | | |
|---|---|---|---|---|---|
| | Nominal size of graded aggregate | | | Nominal size of single-sized aggregate | |
| | 1½ in. to 3/16 in. | ¾ in. to 3/16 in. | ½ in. to 3/16 in. | 2½ in. | 1½ in. |
| 3 in. | – | – | – | 100 | – |
| 2½ in. | – | – | – | 90–100 | – |
| 2 in. | 100 | – | – | 35–70 | 100 |
| 1½ in. | 95–100 | – | – | 0–15 | 90–100 |
| 1 in. | – | 100 | – | – | 20–55 |
| ¾ in. | 35–70 | 90–100 | 100 | 0–5 | 0–15 |
| ½ in. | – | – | 90–100 | – | – |
| ⅜ in. | 10–30 | 20–55 | 40–70 | – | 0–5 |
| 3/16 in. | 0–5 | 0–10 | 0–15 | – | – |
| 7 | – | 0–5 | 0–5 | – | – |

Table 5.3/4

Table 3.29

GRADING REQUIREMENTS FOR ALL-IN AGGREGATE (B.S. 882: 1954)

| B.S. sieve size | Percentage by weight passing B.S. sieves | |
|---|---|---|
| | 1½ in. nominal size | ¾ in. nominal size |
| 3 in. | 100 | -- |
| 1½ in. | 95–100 | 100 |
| ¾ in. | 45–75 | 95–100 |
| ⅜ in. | 25–45 | 30–50 |
| 25 | 8–30 | 10–35 |
| 100 | 0–6 | 0–6 |

Table 5.3/5

It should be noted at this point that the recommended types of aggregates for the purposes of the condenser shell construction are natural sand (for fine aggregate) and irregular gravel (for coarse aggregate). This decision has been made mainly on the basis of environments in which the construction will be carried on. Should there be availability of more desirable aggregates, it would be completely satisfactory to utilize such aggregates. The desirability of the aggregates will be mainly based on the following factors.

--- Compressive Strength

Obviously aggregates with higher compressive strengths would be more desirable. Table 5.3/6 indicates the compressive strength of several available aggregates (Ref. 21).

--- Thermal Expansion

The thermal expansion rate of the concrete is effected directly by the thermal expansion rates of the aggregates contained in it. The requirement of having a lower expansion factor for the shell clearly indicates the desirability of using aggregates of low thermal expansion rates. Table 5.3/7 presents the thermal expansion rates of several common aggregates (Ref. 21).

--- Porosity

As mentioned before a low porosity concrete is desired for our purpose. For this purpose the use of low porosity aggregates is recommended. Table 5.3/8 shows the porosity

COMPRESSIVE STRENGTH OF AMERICAN ROCKS COMMONLY USED AS CONCRETE AGGREGATES*

| Type of rock | Number of Samples* | Compressive strength, lb/in² | | |
|---|---|---|---|---|
| | | Average † | After deletion of extremes‡ | |
| | | | Maximum | Minimum |
| Granite | 278 | 26,200 | 37,300 | 16,600 |
| Felsite | 12 | 47,000 | 76,300 | 17,400 |
| Trap | 59 | 41,100 | 54,700 | 29,200 |
| Limestone | 241 | 23,000 | 34,900 | 13,500 |
| Sandstone | 79 | 19,000 | 34,800 | 6,400 |
| Marble | 34 | 16,900 | 35,400 | 7,400 |
| Quartzite | 26 | 36,500 | 61,300 | 18,000 |
| Gneiss | 36 | 21,300 | 34,100 | 13,600 |
| Schist | 31 | 24,600 | 43,100 | 13,200 |

* For most samples, the compressive strength is an average of 3 to 15 specimens. † Average of all samples. ‡ 10 per cent of all samples tested with highest or lowest values have been deleted as not typical of the material.

Table 5.3/6

LINEAR COEFFICIENT OF THERMAL EXPANSION OF DIFFERENT ROCK TYPES[27]

| Rock type | Thermal coefficient of linear expansion $10^{-6}$ per °F |
|---|---|
| Granite | 1·0 to 6·6 |
| Diorite, andesite | 2·3 to 5·7 |
| Gabbro, basalt, diabase | 2·0 to 5·4 |
| Sandstone | 2·4 to 7·7 |
| Dolomite | 3·7 to 4·8 |
| Limestone | 0·5 to 6·8 |
| Chert | 4·1 to 7·3 |
| Marble | 0·6 to 8·9 |

Table 5.3/7

POROSITY OF SOME COMMON ROCKS

| Rock group | Porosity, per cent |
|---|---|
| Gritstone | 0·0–48·0 |
| Quartzite | 1·9–15·1 |
| Limestone | 0·0–37·6 |
| Granite | 0·4– 3·8 |

Table 5.3/8

levels of common aggregates. Granite would be a desirable aggregate from this point of view.

Finally we shall review the standards and sieve sites necessary for the final choice on aggregates. This paragraph is mainly prepared to simplify some of the tables and figures given in the following section on mix design. Two tables and three figures will be given here for that purpose. Table 5.3/9 presents the Standard Fine series classification both for British and U.S. Standards Table 5.3/10 shows the standards used for the grading zones. Of the fine aggregates according to the B.S. 882. Figure 5.3-1 thru 5.3-3 indicate the grading curves for 3 classes of aggregates based on the maximum size. The curves have been numbered so that the higher numbers refer to the gradings which represent a higher proportion of fine particles.

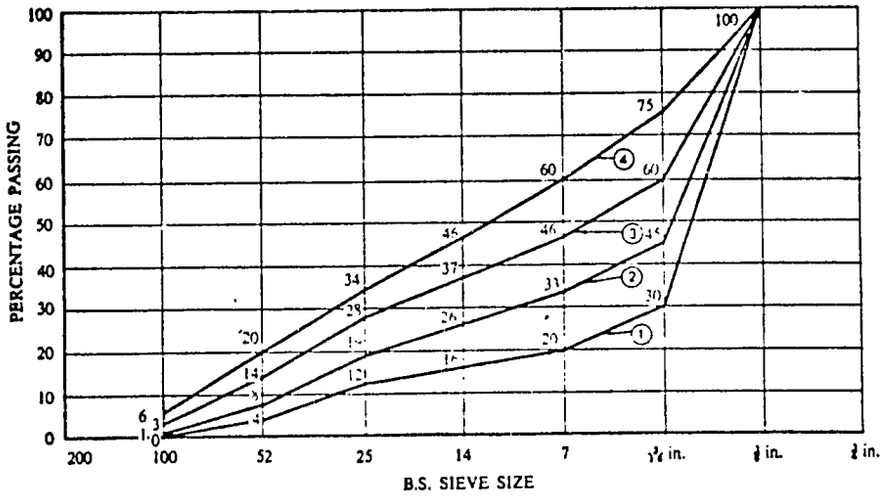



Figure 5.3-1 Grading curves for $\frac{3}{8}$ in. maximum size aggregate.

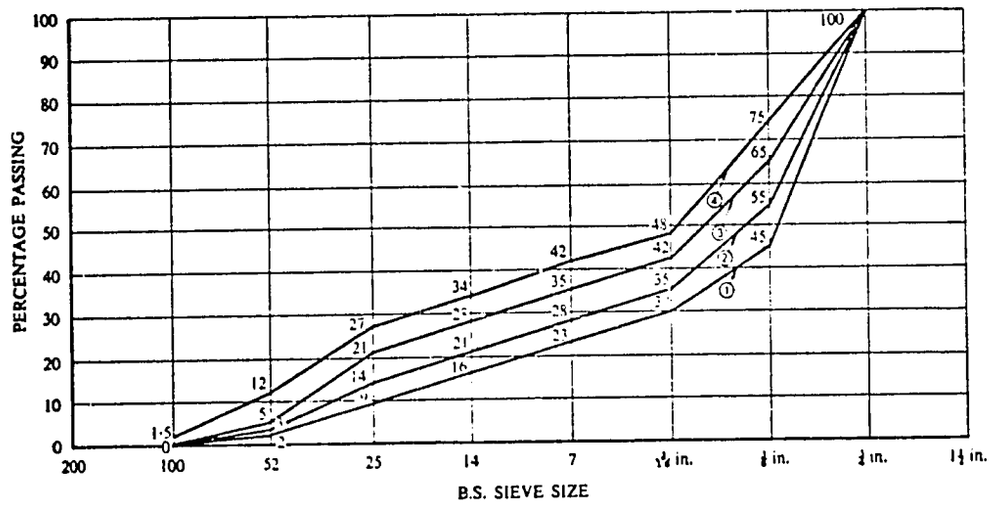



Figure 5.3-2 Grading curves for $\frac{3}{4}$ in. maximum size aggregate.

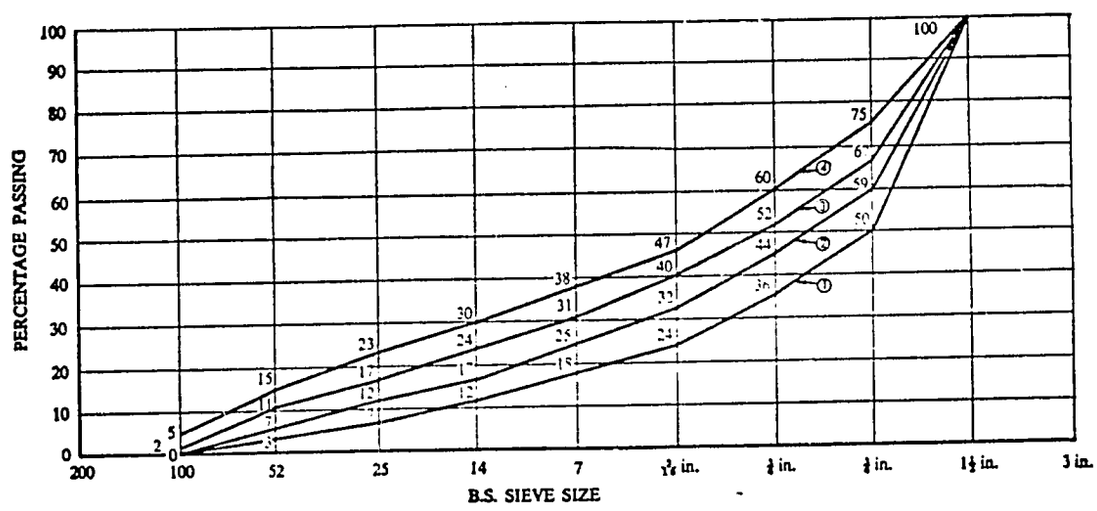



Figure 5.3-3 Grading curves for $1\frac{1}{2}$ in. maximum size aggregate.

## 5.4 Mix Design

Specifications for concrete have long been expressed in terms of the nominal volume proportions of cement and aggregates. However, this system of specifications has serious limitations and various ways have been adopted to make it more suitable for today's concrete needs. Various adjustments are proposed for different aggregate or workability conditions. The bulking of damp fine aggregate, the size distribution of fine and coarse aggregates and various other parameters effect the adjustments to be made. We shall present a standard of concrete mixing proportions used in the British Standard here that is actually a sophisticated version of the traditional 1:2:4 system of mixing (Table 5.4/1).Although this standard is based on weight proportions). It can be used for most of the ordinary uses of concrete. It gives satisfactory results even in jobs that require very specific mix proportions for very specialized applications. But of course not good enough and that is why we shall discuss the actual procedure of design of mix for specialized applications. What will follow is essentially an outline of what has been presented in detail in "Concrete Mix Design" by McIntosh (Ref. 25).

Before we discuss the actual design, we shall review the general features of mix design so that an understanding can be developed for the actual design.

### A. Design for Minimum Strength

The specification of design of concrete mix for a minimum strength is probably the most widely method of mix design.

Weights of dry fine and coarse aggregates per 112 lb of cement based on aggregates having a specific gravity of 2·6 and a natural sand having a grading within the limits of grading zone 2 in B.S. 882.

If a crushed stone sand or a crushed gravel sand is used instead of a natural sand, the weight of coarse aggregate should be reduced by at least 25 lb.

If the grading of the fine aggregate is within the limits of grading zone 3 of B.S. 882 the weight of fine aggregate should be decreased by at least 25 lb, or if within grading zone 1 increased by at least 25 lb; the weight of coarse aggregate should be increased or decreased, respectively, by the same amount so that the total weight of aggregate remains the same. Adjustments larger than 25 lb are more likely to be required with the leaner mixes.

If the specific gravity of either the coarse or the fine aggregate differs sufficiently from 2·6 to alter the weight of the absolute volume of the material in the batch by more than 15 lb, the weight of each type of aggregate should be adjusted in proportion to the specific gravity of the aggregate.

| *Standard deviation*[2] (*lb/in*$^2$) | *Specified minimum strength at 7/28 days* (*lb/in*$^2$) | *Weight of dry sand* (*lb*) | *Weight of dry gravel or crushed rock coarse aggregate*[3] (*lb*) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ⅜ *in. maximum size* | | | ½ *in. maximum size* | | | ¾ *in. maximum size* | | | 1½ *in. maximum size* | | |
| | *Workability*[4] *Slump* (*in.*) *Compacting factor* | | *Low* 0–¼ 0·80–0·86 | *Medium* ¼–1 0·86–0·92 | *High* 1–2 0·92–0·97 | *Low* ¼–¾ 0·81–0·87 | *Medium* ¾–1½ 0·87–0·93 | *High* 1½–4 0·93–0·97 | *Low* ½–1 0·82–0·88 | *Medium* 1–2 0·88–0·94 | *High* 2–5 0·94–0·97 | *Low* 1–2 0·82–0·88 | *Medium* 2–4 0·88–0·94 | *High* 4–7 0·94–0·97 |
| 500 | 2,000/3,000 | 300 | 350 | 275 | 225 | 400 | 325 | 275 | 450 | 375 | 325 | (5) | (5) | 425 |
| | 2,500/3,750 | 250 | 350 | 275 | 225 | 400 | 325 | 275 | 450 | 375 | 325 | (5) | 450 | 400 |
| | 3,000/4,500 | 200 | 325 | 250 | 200 | 375 | 300 | 250 | 425 | 350 | 300 | 500 | 425 | 375 |
| 1,000 | 2,000/3,000 | 200 | 325 | 250 | 200 | 375 | 300 | 250 | 425 | 350 | 300 | 500 | 425 | 375 |
| | 2,500/3,750 | 175 | 275 | 200 | 150 | 325 | 250 | 200 | 375 | 300 | 250 | 450 | 375 | 325 |
| | 3,000/4,500 | 150 | 225 | (5) | (5) | 275 | 200 | (5) | 325 | 250 | 200 | 375 | 300 | 250 |

NOTES 1. *Standard mixes apply only to concrete made with cement complying with B.S. 12 or B.S. 146 and with aggregates complying with B.S. 882 or B.S. 1047. Fine aggregates in grading zone 4 of B.S. 882 and air-entraining agents should not be used with standard mixes.*

2. *Interpolation is permissible, the weights of each aggregate fraction being rounded off to the nearest 25 lb lower.*

3. *Single-sized coarse aggregates should be used in proportions which will produce combined gradings within the limits of B.S. 882 or B.S. 1047 for graded aggregate of the appropriate size.*

4. *Interpolation is permissible, the weight of coarse aggregate being rounded off to the nearest 25 lb lower.*

5. *These mixes would have cement contents outside the limits of 500 and 900 lb of cement per yd*$^3$ *of concrete.*

Table 5.4/1

The minimum strength is related to the average strength according to the degree of control, and the approach used in designing a mix for a minimum strength is to chose proportions which will give an average strength high enough to provide a margin which has been found from past experience to be adequate.

B. Interpretation of Minimum Strength

The relation between the average strength and the minimum strength for any particular degree of control can be estimated from a method of statistical measure where the standard deviation is substracted from the average strength and the difference between the average strength and this statistical minimum strength is equal to the product of the standard deviation and a factor k. This factor k can be deduced from Figure 5.4-2. The British Codes of Practice has adopted a value of 2 for this factor (Ref. 25).

C. Quality Control

The standard deviation is the measure of quality control. Table 5.4/2 gives the values of standard deviation for different standards of quality control. The values of control ratio given in the same table are for use in another method of statistical measure.

C. Water/Cement Ratio

The precise meaning of water/cement ratio is uncertain because the water in the damp aggregate occurs partly on the surface of particles and partly absorbed into the pores where it is not readily available to affect the properties of concrete. In view of this uncertainty the values of water/cement

ratio given in this manual are based on total amounts of water added to concrete made with air-dry aggregate. In any case the value of water/cement ratio is the most important factor affecting the strength of the concrete.

## The Actual Mix Design

In the method of design that we have chosen the minimum compressive strength required is first indicated. Once this has been done table 5.4/2 is used to find the proper standard deviation and Figure 5.4-1 to find k, then the average strength is:

$$\text{Average strength} = \text{minimum strength} + K\ (\text{Standard Deviation}).$$

When the average compressive strength is calculated, the water-cement ratio can be found. This is done by using figure 5.4-2 which shows the curves of compressive strengths vs. water-cement ratios for different time periods. Once the water-cement ratio is indicated attention is directed toward the aggregates and the aggregate/cement ratio.

Table 5.4/3 gives the nominal maximum sizes of aggregates (inches) corresponding to different placing conditions and the required workability. The same table indicates the measure of slump in inches. Once the maximum nominal size of the aggregate is estimated, it should be used to find the requirement of aggregate/cement ratio according to any one of the given Tables that corresponds to the maximum aggregate size. (Tables 5.4/4 - 5.4/12). In each table there are four values of aggregate/cement ratio given for any one degree of workability, indicated by grading numbers 1 thru 4. These are the same numbers used in Figures 5.3-1 to 5.3/3 for continuous grading of aggregates. In each table it has been indicated which figure the numbers refer to.

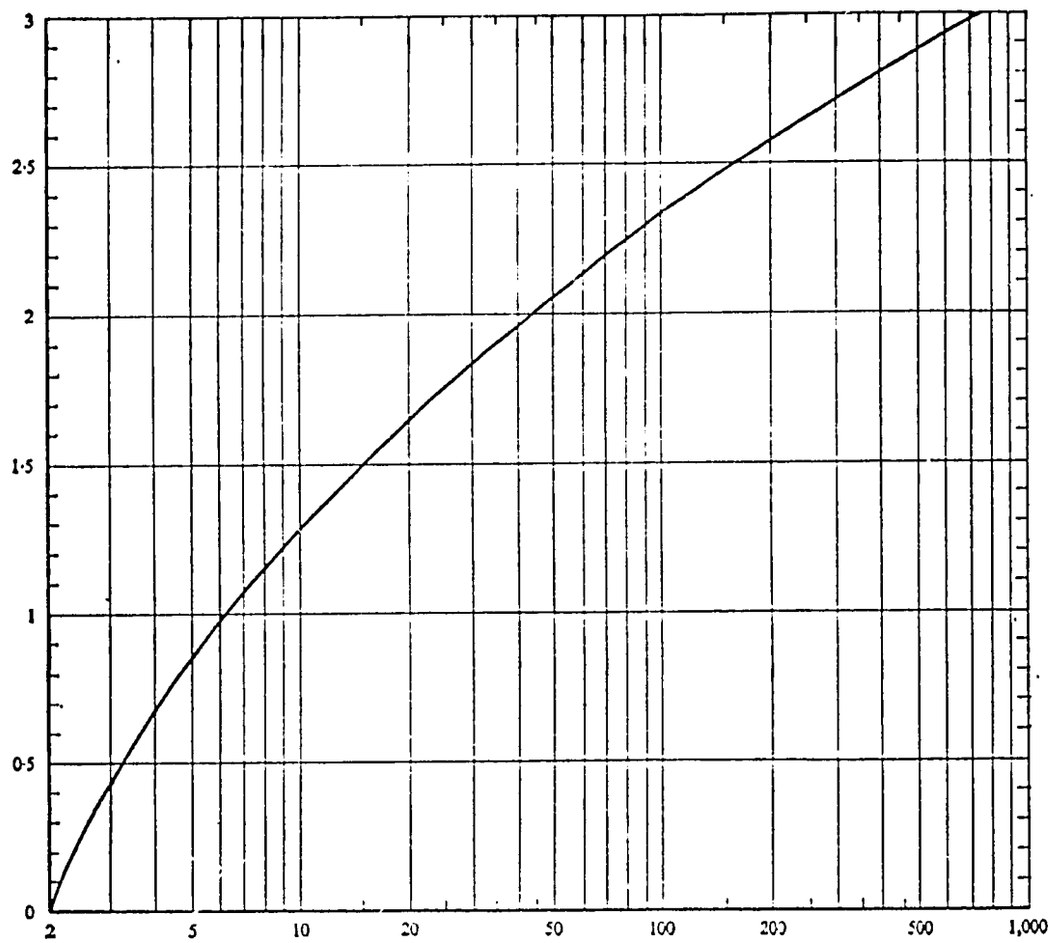
TABLE 2: Values of standard deviation and control ratio for different standards of quality control

| Batching | | Supervision | Standard deviation for average strength above 5,000 lb/in² (lb/in²) | Control ratio for 1 result in 44 below the minimum |
|---|---|---|---|---|
| Cement | Aggregate | | | |
| Weight (servo-operation) | Weight (servo-operation) | Poor | 810 | 0·78 |
| | | Normal | 670 | 0·82 |
| | | Good | 520 | 0·86 |
| Weight | Weight | Poor | 930 | 0·75 |
| | | Normal | 780 | 0·79 |
| | | Good | 630 | 0·83 |
| Weight | Volume | Poor | 1,030 | 0·72 |
| | | Normal | 860 | 0·77 |
| | | Good | 670 | 0·82 |
| Volume | Volume | Poor | 1,100 | 0·70 |
| | | Normal | 930 | 0·75 |
| | | Good | 750 | 0·80 |

**NOTES:** *For the special method of quality control referred to in CP* 115 (1959) *and CP* 2007 (1960) *the standard deviation should not be likely to exceed* 750 *lb/in*². *This corresponds to a minimum control ratio of* 0·80 *where the average strength is above* 5,000 *lb/in*².

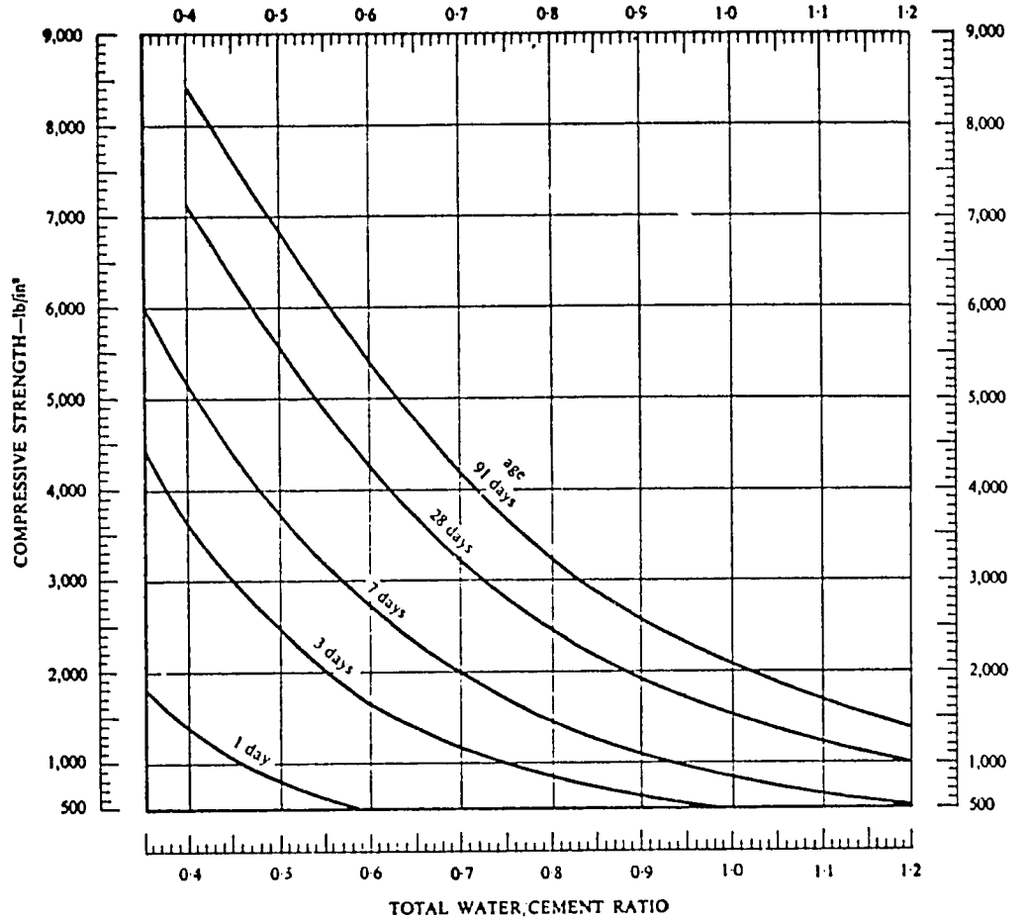
*For the calculation of the control ratio appropriate to other proportions of results expected below the minimum see Section* 4.2.1.

Table 5.4/2




. Relation between the factor $k$ and the proportion of results expected to be below the minimum strength.

Figure 5.4-1




Relation between compressive strength of medium-strength concrete and total water/cement ratio at various ages using ordinary Portland cement.

Figure 5.4-2

. Selected values of compacting factor and slump for different conditions of placing

| *Placing conditions* | *Degree of workability* | *Nominal maximum size of aggregate (in.)* | *Compacting factor* | *Slump (in.)* |
|---|---|---|---|---|
| Sections subject to extremely intensive or prolonged vibration or to vibration accompanied by pressure | "Extremely Low" | $\frac{3}{8}$<br>$\frac{3}{4}$ | 0·65<br>0·68 | 0<br>0 |
| Small sections subject to intensive vibration, large sections with normal vibration | "Very Low" | $\frac{3}{8}$<br>$\frac{3}{4}$<br>$1\frac{1}{2}$ | 0·75<br>0·78<br>0·78 | 0<br>0–$\frac{1}{2}$<br>0–1 |
| Simply reinforced sections with vibration, large sections without vibration | "Low" | $\frac{3}{8}$<br>$\frac{3}{4}$<br>$1\frac{1}{2}$ | 0·83<br>0·85<br>0·85 | 0–$\frac{1}{4}$<br>$\frac{1}{2}$–1<br>1–2 |
| Simply reinforced sections without vibration, heavily reinforced sections with vibration | "Medium" | $\frac{3}{8}$<br>$\frac{3}{4}$<br>$1\frac{1}{2}$ | 0·90<br>0·92<br>0·92 | $\frac{1}{4}$–1<br>1–2<br>2–4 |
| Heavily reinforced sections without vibration. Not normally suitable for vibration | "High" | $\frac{3}{8}$<br>$\frac{3}{4}$<br>$1\frac{1}{2}$ | 0·95<br>0·95<br>0·95 | 1–4<br>2–5<br>4–7 |

Table 5.4/3

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

$\frac{3}{8}$ IN. ROUNDED GRAVEL AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | *"Very Low"* | | | | *"Low"* | | | | *"Medium"* | | | | *"High"* | | | |
| *Grading number (Figure 12)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·40 | 5·6 | 5·0 | 4·2 | 3·2 | 4·5 | 3·9 | 3·3 | 2·6 | 3·9 | 3·5 | 3·0 | 2·4 | 3·5 | 3·2 | 2·8 | 2·3 |
| | 0·45 | 7·2 | 6·4 | 5·3 | 4·1 | 5·5 | 4·9 | 4·1 | 3·2 | 4·7 | 4·3 | 3·7 | 3·0 | 4·2 | 3·9 | 3·4 | 2·9 |
| | 0·50 | | 7·8 | 6·4 | 4·9 | 6·5 | 5·8 | 4·9 | 3·8 | 5·4 | 5·0 | 4·3 | 3·5 | 4·8 | 4·5 | 4·0 | 3·4 |
| | 0·55 | | | 7·5 | 5·7 | 7·4 | 6·7 | 5·7 | 4·4 | 6·1 | 5·7 | 4·9 | 4·0 | 5·3 | 5·1 | 4·5 | 3·9 |
| | 0·60 | | | | 6·5 | | 7·5 | 6·4 | 5·0 | 6·7 | 6·3 | 5·5 | 4·5 | 5·8 | 5·6 | 5·0 | 4·3 |
| | 0·65 | | | | 7·2 | | | 7·1 | 5·6 | 7·3 | 6·9 | 6·1 | 5·0 | S | 6·1 | 5·5 | 4·7 |
| | 0·70 | | | | | | | 7·7 | 6·2 | 7·9 | 7·5 | 6·7 | 5·5 | | 6·6 | 6·0 | 5·1 |
| | 0·75 | | | | | | | | 6·7 | | | 7·2 | 5·9 | | 7·1 | 6·5 | 5·5 |
| | 0·80 | | | | | | | | 7·2 | | | 7·7 | 6·3 | | 7·6 | 6·9 | 5·9 |
| | 0·85 | | | | | | | | | | | | 6·8 | | | 7·3 | 6·3 |
| | 0·90 | | | | | | | | | | | | 7·2 | | | 7·7 | 6·7 |
| | 0·95 | | | | | | | | | | | | | | | | 7·0 |
| | 1·00 | | | | | | | | | | | | | | | | 7·3 |

S *Indicates that the mix would segregate.*

Table 5.4/4

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

¾ IN. IRREGULAR GRAVEL AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | "*Very Low*" | | | | "*Low*" | | | | "*Medium*" | | | | "*High*" | | | |
| *Grading number (Figure 12)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·40 | 4·1 | 3·8 | 3·3 | 2·8 | 3·3 | 3·1 | 2·8 | 2·3 | | | | | | | | |
| | 0·45 | 5·1 | 4·8 | 4·3 | 3·6 | 4·1 | 3·9 | 3·5 | 3·0 | 3·5 | 3·4 | 3·2 | 2·8 | 3·2 | 3·1 | 3·0 | 2·7 |
| | 0·50 | 6·1 | 5·8 | 5·2 | 4·4 | 4·8 | 4·6 | 4·2 | 3·7 | 4·2 | 4·1 | 3·8 | 3·4 | S | 3·8 | 3·6 | 3·2 |
| | 0·55 | 7·0 | 6·7 | 6·1 | 5·2 | 5·5 | 5·3 | 4·9 | 4·3 | S | 4·7 | 4·4 | 4·0 | | 4·4 | 4·2 | 3·7 |
| | 0·60 | 7·9 | 7·6 | 7·0 | 6·0 | S | 6·0 | 5·6 | 4·9 | | 5·3 | 5·0 | 4·5 | | 4·9 | 4·7 | 4·2 |
| | 0·65 | | | 7·8 | 6·8 | | 6·6 | 6·2 | 5·5 | | 5·9 | 5·6 | 5·0 | | 5·4 | 5·2 | 4·6 |
| | 0·70 | | | | | | 7·2 | 6·8 | 6·1 | | 6·4 | 6·1 | 5·5 | | 5·9 | 5·7 | 5·0 |
| | 0·75 | | | | | | 7·8 | 7·4 | 6·7 | | 6·9 | 6·6 | 6·0 | | 6·4 | 6·1 | 5·4 |
| | 0·80 | | | | | | | 8·0 | 7·3 | | 7·4 | 7·1 | 6·4 | | 6·8 | 6·5 | 5·8 |
| | 0·85 | | | | | | | | | | 7·9 | 7·5 | 6·8 | | 7·2 | 6·9 | 6·2 |
| | 0·90 | | | | | | | | | | | 8·0 | 7·2 | | 7·6 | 7·3 | 6·6 |
| | 0·95 | | | | | | | | | | | | | | S | 7·7 | 6·9 |
| | 1·00 | | | | | | | | | | | | | | | 8·0 | 7·2 |

S *Indicates that the mix would segregate.*

Table 5.4/5

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

$\frac{3}{4}$ IN. CRUSHED ROCK AGGREGATE*

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | *"Very Low"* | | | | *"Low"* | | | | *"Medium"* | | | | *"High"* | | | |
| *Grading number (Figure 12)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·40 | 3·7 | 3·3 | 2·8 | 2·0 | | | | | | | | | | | | |
| | 0·45 | 4·5 | 4·1 | 3·5 | 2·6 | 3·8 | 3·6 | 3·0 | 2·2 | 3·3 | 3·1 | 2·7 | 2·1 | | | | |
| | 0·50 | 5·2 | 4·9 | 4·2 | 3·2 | 4·4 | 4·2 | 3·6 | 2·7 | 3·8 | 3·7 | 3·2 | 2·6 | S | 3·2 | 2·9 | 2·4 |
| | 0·55 | 5·9 | 5·6 | 4·9 | 3·8 | 4·9 | 4·8 | 4·2 | 3·2 | S | 4·2 | 3·7 | 3·0 | | 3·7 | 3·4 | 2·8 |
| | 0·60 | 6·6 | 6·3 | 5·5 | 4·3 | S | 5·3 | 4·7 | 3·7 | | 4·7 | 4·2 | 3·4 | | 4·2 | 3·8 | 3·2 |
| | 0·65 | 7·3 | 7·0 | 6·1 | 4·8 | | 5·8 | 5·2 | 4·2 | | 5·1 | 4·6 | 3·8 | | 4·6 | 4·2 | 3·6 |
| | 0·70 | 7·9 | 7·6 | 6·7 | 5·3 | | 6·3 | 5·7 | 4·6 | | 5·6 | 5·1 | 4·2 | | 5·0 | 4·6 | 4·0 |
| | 0·75 | | | 7·3 | 5·8 | | 6·8 | 6·2 | 5·0 | | 6·0 | 5·5 | 4·6 | | 5·4 | 5·0 | 4·4 |
| | 0·80 | | | 7·8 | 6·3 | | 7·2 | 6·6 | 5·5 | | 6·4 | 5·9 | 5·0 | | 5·8 | 5·4 | 4·7 |
| | 0·85 | | | | 6·8 | | 7·6 | 7·1 | 6·0 | | 6·7 | 6·3 | 5·4 | | 6·1 | 5·8 | 5·1 |
| | 0·90 | | | | 7·3 | | | 7·5 | 6·4 | | 7·1 | 6·7 | 5·8 | | 6·4 | 6·1 | 5·4 |
| | 0·95 | | | | | | | 7·9 | 6·8 | | 7·5 | 7·1 | 6·1 | | 6·7 | 6·4 | 5·7 |
| | 1·00 | | | | | | | | 7·2 | | 7·8 | 7·5 | 6·5 | | 7·0 | 6·7 | 6·1 |
| | 1·05 | | | | | | | | | | | 7·8 | 6·9 | | 7·3 | 7·0 | 6·4 |
| | 1·10 | | | | | | | | | | | | 7·2 | | 7·6 | 7·3 | 6·7 |
| | 1·15 | | | | | | | | | | | | | | S | 7·6 | 7·0 |
| | 1·20 | | | | | | | | | | | | | | | 7·9 | 7·3 |

* *With crushed aggregate of poorer shape than that tested, segregation may occur at a lower aggregate/cement ratio.*

S *Indicates that the mix would segregate.*

Table 5.4/6

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

¾ IN. ROUNDED GRAVEL AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | "*Very Low*" | | | | "*Low*" | | | | "*Medium*" | | | | "*High*" | | | |
| *Grading number (Figure 13)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·35 | 4·5 | 4·2 | 3·7 | 3·2 | 3·8 | 3·6 | 3·3 | 3·0 | 3·1 | 3·0 | 2·8 | 2·6 | | | | |
| | 0·40 | 6·6 | 6·1 | 5·4 | 4·5 | 5·3 | 5·1 | 4·6 | 4·1 | 4·2 | 4·2 | 3·9 | 3·6 | 3·7 | 3·8 | 3·6 | 3·3 |
| | 0·45 | 8·1 | 7·6 | 6·7 | 5·8 | 6·9 | 6·6 | 5·9 | 5·1 | 5·3 | 5·3 | 5·0 | 4·6 | 4·6 | 4·8 | 4·5 | 4·1 |
| | 0·50 | | | 8·0 | 7·0 | 8·2 | 8·0 | 7·0 | 6·0 | 6·3 | 6·3 | 6·0 | 5·5 | 5·5 | 5·7 | 5·4 | 4·8 |
| | 0·55 | | | | 8·1 | | | 8·2 | 6·9 | 7·3 | 7·3 | 7·0 | 6·3 | 6·3 | 6·5 | 6·1 | 5·5 |
| | 0·60 | | | | | | | | 7·7 | | | 8·0 | 7·1 | S | 7·2 | 6·8 | 6·1 |
| | 0·65 | | | | | | | | 8·4 | | | | 7·8 | | 7·7 | 7·4 | 6·6 |
| | 0·70 | | | | | | | | | | | | | | | 7·9 | 7·1 |
| | 0·75 | | | | | | | | | | | | | | | | 7·6 |

S *Indicates that the mix would segregate.*

Table 5.4/7

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

¾ IN. IRREGULAR GRAVEL AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | "*Very Low*" | | | | "*Low*" | | | | "*Medium*" | | | | "*High*" | | | |
| *Grading number (Figure 13)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·35 | 3·6 | 3·6 | 3·5 | 3·0 | 3·0 | 3·0 | 3·0 | 2·7 | | | | | | | | |
| | 0·40 | 4·9 | 4·8 | 4·6 | 4·1 | 3·9 | 3·9 | 3·9 | 3·5 | 3·3 | 3·4 | 3·4 | 3·2 | 3·1 | 3·2 | 3·2 | 2·9 |
| | 0·45 | 6·0 | 5·8 | 5·5 | 5·0 | 4·8 | 4·8 | 4·7 | 4·3 | 4·0 | 4·1 | 4·1 | 3·9 | S | 3·8 | 3·8 | 3·5 |
| | 0·50 | 7·2 | 6·8 | 6·4 | 5·9 | 5·5 | 5·5 | 5·4 | 5·0 | 4·6 | 4·8 | 4·8 | 4·5 | | 4·4 | 4·4 | 4·1 |
| | 0·55 | 8·3 | 7·8 | 7·3 | 6·7 | 6·2 | 6·2 | 6·1 | 5·7 | S | 5·4 | 5·3 | 5·1 | | 4·9 | 4·9 | 4·7 |
| | 0·60 | 9·4 | 8·7 | 8·1 | 7·4 | 6·9 | 6·9 | 6·7 | 6·3 | | 6·0 | 5·9 | 5·6 | | S | 5·4 | 5·2 |
| | 0·65 | | | | 8·0 | 7·5 | 7·5 | 7·3 | 6·8 | | S | 6·4 | 6·1 | | | 5·8 | 5·7 |
| | 0·70 | | | | | 8·0 | 8·0 | 7·8 | 7·3 | | | 6·8 | 6·6 | | | 6·2 | 6·1 |
| | 0·75 | | | | | | | | 7·9 | | | 7·2 | 7·0 | | | 6·6 | 6·5 |
| | 0·80 | | | | | | | | | | | 7·5 | 7·4 | | | S | 7·0 |
| | 0·85 | | | | | | | | | | | 7·8 | 7·8 | | | | 7·4 |
| | 0·90 | | | | | | | | | | | S | 8·1 | | | | 7·7 |
| | 0·95 | | | | | | | | | | | | | | | | 8·0 |
| | 1·00 | | | | | | | | | | | | | | | | S |

S *Indicates that the mix would segregate.*

Table 5.4/8

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

¾ IN. CRUSHED ROCK AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | "*Very Low*" | | | | "*Low*" | | | | "*Medium*" | | | | "*High*" | | | |
| *Grading number (Figure 13)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·40 | 4·5 | 4·1 | 3·8 | 3·5 | 3·5 | 3·5 | 3·2 | 3·0 | | | | | | | | |
| | 0·45 | 5·5 | 5·0 | 4·6 | 4·3 | 4·3 | 4·2 | 3·9 | 3·7 | 3·7 | 3·7 | 3·4 | 3·3 | 3·5 | 3·5 | 3·2 | 3·1 |
| | 0·50 | 6·5 | 5·9 | 5·4 | 5·0 | 5·0 | 4·9 | 4·5 | 4·3 | 4·2 | 4·2 | 3·9 | 3·8 | S | 3·9 | 3·8 | 3·5 |
| | 0·55 | 7·2 | 6·6 | 6·0 | 5·7 | 5·7 | 5·5 | 5·0 | 4·8 | 4·7 | 4·7 | 4·5 | 4·3 | | S | 4·3 | 4·0 |
| | 0·60 | 7·8 | 7·2 | 6·6 | 6·3 | 6·3 | 6·0 | 5·6 | 5·3 | S | 5·2 | 4·9 | 4·8 | | | 4·7 | 4·5 |
| | 0·65 | 8·3 | 7·7 | 7·2 | 6·9 | 6·9 | 6·5 | 6·1 | 5·8 | | 5·7 | 5·4 | 5·2 | | | 5·2 | 4·9 |
| | 0·70 | 8·7 | 8·2 | 7·7 | 7·5 | 7·4 | 7·0 | 6·6 | 6·3 | | 6·2 | 5·8 | 5·7 | | | 5·5 | 5·3 |
| | 0·75 | | | 8·2 | 8·0 | 7·9 | 7·5 | 7·0 | 6·7 | | S | 6·2 | 6·1 | | | 5·8 | 5·7 |
| | 0·80 | | | | | | | 7·4 | 7·2 | | | 6·6 | 6·5 | | | 6·1 | 6·0 |
| | 0·85 | | | | | | | 7·8 | 7·6 | | | 7·1 | 6·9 | | | 6·4 | 6·3 |
| | 0·90 | | | | | | | | | | | 7·5 | 7·3 | | | S | 6·7 |
| | 0·95 | | | | | | | | | | | 8·0 | 7·6 | | | | 7·0 |
| | 1·00 | | | | | | | | | | | | | | | | 7·3 |

S *Indicates that the mix would segregate.*

Table 5.4/9

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

1½ IN. ROUNDED GRAVEL AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | *"Very Low"* | | | | *"Low"* | | | | *"Medium"* | | | | *"High"* | | | |
| *Grading number (Figure 14)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·35 | 5·0 | 4·5 | 3·9 | 3·4 | 4·3 | 3·9 | 3·5 | 3·1 | 3·4 | 3·1 | 2·9 | 2·7 | | | | |
| | 0·40 | 7·0 | 6·5 | 5·7 | 4·9 | 5·9 | 5·6 | 5·0 | 4·4 | 4·7 | 4·6 | 4·3 | 3·8 | 4·1 | 4·0 | 3·9 | 3·5 |
| | 0·45 | 8·9 | 8·6 | 7·7 | 6·5 | 7·6 | 7·4 | 6·7 | 5·8 | 6·0 | 6·1 | 5·7 | 5·0 | 5·2 | 5·3 | 5·0 | 4·6 |
| | 0·50 | | | | 8·0 | | | 8·2 | 7·2 | 7·5 | 7·6 | 7·1 | 6·3 | 6·3 | 6·5 | 6·2 | 5·7 |
| | 0·55 | | | | | | | | 8·4 | | 8·9 | 8·1 | 7·3 | S | 7·7 | 7·4 | 6·7 |
| | 0·60 | | | | | | | | | | | | | | | | 7·6 |

S *Indicates that the mix would segregate.*

NOTE: *These values have been obtained by extrapolation of other data and are not based directly on the results of trial mixes.*

Table 5.4/10

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

$1\frac{1}{2}$ IN. IRREGULAR GRAVEL AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | "*Very Low*" | | | | "*Low*" | | | | "*Medium*" | | | | "*High*" | | | |
| *Grading number (Figure 14)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·35 | 4·0 | 3·9 | 3·6 | 3·2 | 3·4 | 3·3 | 3·2 | 2·9 | | | | | | | | |
| | 0·40 | 5·3 | 5·2 | 4·8 | 4·3 | 4·5 | 4·5 | 4·2 | 3·8 | 3·8 | 3·8 | 3·7 | 3·4 | 3·4 | 3·5 | 3·3 | 3·1 |
| | 0·45 | 6·6 | 6·5 | 6·0 | 5·3 | 5·6 | 5·6 | 5·3 | 4·8 | 4·6 | 4·7 | 4·6 | 4·3 | 4·1 | 4·4 | 4·3 | 4·0 |
| | 0·50 | 7·8 | 7·7 | 7·1 | 6·3 | 6·6 | 6·6 | 6·3 | 5·7 | 5·5 | 5·7 | 5·5 | 5·1 | 4·8 | 5·2 | 5·1 | 4·8 |
| | 0·55 | | | 8·1 | 7·3 | 7·6 | 7·6 | 7·2 | 6·6 | 6·2 | 6·5 | 6·3 | 5·9 | S | 5·9 | 5·9 | 5·5 |
| | 0·60 | | | | | | | | 7·4 | 7·0 | 7·3 | 7·1 | 6·6 | | S | 6·7 | 6·3 |
| | 0·65 | | | | | | | | 8·1 | 7·8 | 8·1 | 7·8 | 7·3 | | | 7·3 | 6·9 |
| | 0·70 | | | | | | | | | | | | 7·9 | | | | 7·4 |
| | 0·75 | | | | | | | | | | | | | | | | 8·0 |

S *Indicates that the mix would segregate.*

Table 5.4/11

Aggregate/cement ratio required to give four degrees of workability with different water/cement ratios and gradings

$1\frac{1}{2}$ IN. CRUSHED ROCK AGGREGATE

| | | *Aggregate/cement ratio by weight* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Degree of workability (Table 6)* | | *"Very Low"* | | | | *"Low"* | | | | *"Medium"* | | | | *"High"* | | | |
| *Grading number (Figure 14)* | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total water/cement ratio by weight | 0·35 | 3·4 | 3·4 | 3·2 | 2·9 | | | | | | | | | | | | |
| | 0·40 | 4·9 | 4·6 | 4·2 | 3·8 | 4·0 | 3·8 | 3·6 | 3·3 | 3·3 | 3·3 | 3·2 | 3·0 | 3·1 | 3·1 | 2·9 | 2·7 |
| | 0·45 | 6·0 | 5·7 | 5·2 | 4·7 | 4·9 | 4·7 | 4·4 | 4·2 | 4·1 | 4·1 | 3·9 | 3·8 | 3·7 | 3·8 | 3·7 | 3·4 |
| | 0·50 | 7·2 | 6·8 | 6·2 | 5·6 | 5·8 | 5·6 | 5·3 | 5·0 | 4·8 | 4·8 | 4·7 | 4·6 | 4·4 | 4·5 | 4·5 | 4·2 |
| | 0·55 | 8·1 | 7·7 | 7·1 | 6·4 | 6·6 | 6·4 | 6·1 | 5·8 | 5·5 | 5·5 | 5·4 | 5·3 | S | 5·2 | 5·2 | 4·8 |
| | 0·60 | | 8·6 | 8·0 | 7·2 | 7·4 | 7·2 | 6·9 | 6·6 | 6·1 | 6·2 | 6·1 | 6·0 | | S | 5·9 | 5·6 |
| | 0·65 | | | 8·8 | 7·9 | 8·1 | 7·9 | 7·6 | 7·3 | S | 6·9 | 6·8 | 6·6 | | | 6·5 | 6·2 |
| | 0·70 | | | | 8·6 | | 8·5 | 8·3 | 7·9 | | 7·5 | 7·5 | 7·3 | | | 7·1 | 6·8 |
| | 0·75 | | | | | | | | 8·5 | | | 8·1 | 7·8 | | | | 7·4 |

S *Indicates that the mix would segregate.*

NOTE: *These values have been obtained by extrapolation of other data and are not based directly on the results of trial mixes.*

Table 5.4/12

It has been shown that the properties of concrete are more or less independent of the over-all grading of the aggregate provided changes in the grading are such that the specific surface of the particles is not altered.

## 5.5 Permeability of Concrete

The leakage of air through a concrete slab subjected to a pressure differential has been recognized as an operational problem. The presence of even very small quantities of air in a condenser decreases the rate of condensation drastically (because of the low conductivity of air and the resistance that it creates to the transfer of heat), and although there is a device for deaerating the condenser, its capacity is limited. Any increase of this capacity would create an economical disadvantage. The only solution therefore lies in minimizing, if not eliminating, the permeability to air of the concrete.

Fong has, in a related project, (Reference 26) studied the effect of a protective coating (coal tar epoxy) on the permeability of concrete. Unfortunately very little decrease was observed in the rate of air leakage:

"A permeability coefficient K is defined as the volume of air at 1 atmosphere flowing in 1 second through a 1 foot thick slab of concrete 1 square foot in area, under a head of 1 mm. Hg. For bare concrete it is found to be:

$$K = 1.8 \times 10^{-7} (ft^3\text{-}ft/ft^2\text{-}mm\text{-}sec).$$

For a coated concrete there appear to be two regions of flow. At low pressures (0 mm. to 224 mm. Hg):

$$K_1 = 2.6 \times 10^{-8} \ (ft^3 - ft/ft^2 - mm\text{-}sec).$$

At high pressures (224 mm. to 687 + mm. Hg):

$K_2 = 1.2 \times 10^{-8}$ ($ft^3$ - $ft/ft^2$ - mm - sec)."

His work has however led to a better understanding of the air leakage phenomena. Discussing the factors affecting permeability, he writes:

"Though no thorough research into the air permeability of concrete has been made, an extensive literature search (in English only) has disclosed the effects of many factors. The W/C ratio is one of the most important, since whatever permeates through concrete must completely pass through the paste and this ratio governs the capillary volume. For example, there is a thousand fold reduction in water permeability with a W/C ratio reduction from .8 to .4. The air permeability of concrete has been found to be inversely proportional to area. The effect of humidity is to decrease permeability through adsorption of water in the pores, hence blockage of flow paths. Temperature effects have not been investigaged, though it would be expected that the higher mean velocity with increasing temperature would increase the ability of a gas to seek out a flow path. However, boiling temperatures reduce permeability, probably a humidity effect rather than a temperature effect. Freezing and thawing cycles that do not induce cracking seem to have no effect. Exposure to weather and wind has been found to evaporate pore water resulting in drastically increased air permeabilities, a consideration in selecting curing methods. It would seem that air entrainment would increase permeability

but it appears not to be the case because it reduces segregation (fissures and honeycombing) and permits reductions in the W/C ratios. The addition of fly ash or pozzalan has a beneficial effect. Careful grading of aggregate is important in reducing permeability. It has been suggested that prestressing and reinforcement may decrease or eliminate permeability. It should be added that passage to air does not include other gases. There has been no correlation made between air and water permeabilities. Factors which affect the water permeability with unknown effect on air impermeability are: non-isotropism, the treatment of surfaces (cast, sawed or sand-blasted), the downstream medium (air or water), the effects of the nature and impurities in the air, and electrical conductivity between the faces."

The effect of W/C ratio has been emphasized several times throughout the work and this point should, probably, be subjected to more study. Also the effect of various additives should be investigated more vigorously. Fong concludes:

"Though a great deal of investigation must still be made into the air permeability of concrete and coatings before an optimal operational heat exchanger can be fabricated, some lessons can be learned from the present experiments to guide manufacture and future experimentation:

1. The emergence of the W/C ratio and curing as the primary factors affecting permeability.

2. The great increase in permeability due to prolonged outdoor curing which even overshadows the salutary effects of a low W/C ratio (.4).

3. The surprisingly little effect of an apparently airtight coating which points to the need of studying the permeability of coatings.

4. The important effect of outgassing from concrete in permeability measurements.

Through a semi-empirical model for flow behavior exists, determination of coefficients specifically for concrete must be made since no consistent data exist, as shown by the wide scatter of past results. Standard testing procedures and specimen sizes, shapes and mixes must be adopted for testing, and detailed systematic studies of the effects of W/C ratio, fine aggregate grain size, coarse aggregate sizes and composition, mix proportions, curing cycles, flow paths and creep are needed. The possibility of mix additives for integral air proofing--from epoxies to shredded rubber tires--should be considered. Further study into the suitability of coatings for both inside and outside the containment should be made. Obviously, all this must be done with the capital, natural resources, and the technical limitations of those people to be served kept in mind."

# Chapter 6

# COATING AND PROTECTIVE MEASURES

## 6.1 Introduction

The problem that we are faced with during the operation of the steam condenser, assuming the air leakage has been either minimized or eliminated, is the possible dissolution of concrete in the condensate. This process is not only of serious consequences in the entire plant, since the impurities in the condensate could damage the boiler and the turbine sections, but would also contribute to a very rapid corrosion of the condenser shell itself.

## 6.2 Protective Coatings

Some work has been conducted by the OSW (Reference 27) on surface treatment of concrete to water at varying conditions. These surface treatments are basically in the form of protective coatings applied onto the concrete. However in the case of the condenser shell, blistering of the coating could occur due to the very low pressures maintained inside the shell.

In order to find a coating that would not blister as a result of pressure differentials, a study was undertaken by Rashid (Reference 28). Table 6.2/1 lists the coatings that were tested and the results on whether each blisters or not.

Table 6.2/1

| COATING | DOES IT BLISTER? |
|---|---|
| Plasite No.7155/Epoxy Phenolic | |
| Tarset/Coat Tar Epoxy | |
| Colma-Kota M/Epoxy-Resin-Based | no |
| Ecomold L28/Epoxy-Resin | no |
| Cadipox/Epoxy-Polyamine | no |
| Primerce/Epoxy Polyamide | no |
| Acri-Seal/Acrylic Resin | no |
| Thompsons Water Seal | no |
| Magic Kote/Styrene-Acrylic Compound | no |
| Daracone/Silicone Water Repellent | no |
| Krylac/Vinyl-Acrylic + Block Primer | no |
| Super-Por, Seal/Silicone Resin | no |
| Parlon/Chlorinate Rubber | no |
| Endcor/Chlorinated Rubber | yes |
| G.E. Silicone Rubber | no |
| Enjau Butyl LM 450/Butyl Rubber | no |
| Bitumastic/Koppers | yes |
| Roof cement | yes |

## 6.3 Surface Preparation (Reference 28)

Surfaces of concrete substrates have to be treated such that protective treatments can be applied. Surfaces can also be treated such that complete air tightness, at the surface is achieved. Besides the requirements for maintaining structurally sound and strong concrete, there are four basic problems that arise from painting concrete surfaces.

1. Free moisture within the concrete remaining from the original mixing and curing.
2. The presence of soluble alkaline substance that are brought to the surface by outward movement of moisture and deposited as effloresence.
3. Smooth glazed areas resulting from casting against a non-absorbant form; or laitence (a weak surface deposit resulting from excessive trowelling or vibration during pouring)
4. Possible contamination with form oil or concrete curing compounds. The following steps should be taken to prepare the concrete surfaces for coatings.

1) Acid etched: Dilute solution of muriatic acid be spread on the surface. As soon as bubbling ceases the sample be flushed with water.

2) Re-entrant holes be removed by steel wool. Sand-blasted surfaces, however will provide a rougher surface and better cleaning.

Any holes bigger than 1/16" should be filled with fillers or the surface be given a sack-rub finish or else silicon tetrafluoride gas treatment (ocration).

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# APPENDIX A-1.I