3. Design and Analysis

Experience and judgment are the foundation of all structural design which is basically a cut-and-try process. The first trial or preliminary design may be close to the final or far away, depending upon the ability of the designer to estimate (from experience and judgment) the sizes and proportions of the various structural elements. The final step in the design process is to check the design in all of its elements by an analysis of the structure to be certain that it will resist the loads that come to it without exceeding the permissible stresses. The designer's goal is to produce plans for an adequate, safe, and economical structure; analysis is but one step in the process and is important only as a check on the designer's judgment.

3.1 Fundamental Requirements. A structural designer must meet certain basic requirements of experience, knowledge, and ability. His value as a designer will increase as his experience grows; experience is gained both from doing and from reading about what others have done.

The basic principles of structural analysis are relatively few in number and, with a few exceptions, are relatively simple. The structural designer must have a thorough, clear, and complete knowledge and conception of equilibrium; force; moment; couple; the basic laws and propositions regarding the composition and resolution of forces, moments, and couples; the laws of statics; and the geometry of continuous frames. The basic theory is simple; the difficulties arise in applying the principles to the many types of structures and loading conditions encountered. It is important to realize that unless the basic principles are thoroughly understood, their application to actual structures can be exceedingly difficult and often erroneous. Frequent review of good texts on analytical mechanics and structural theory will help fix these principles in the mind.

The equations of statics are so important that they are listed below for emphasis. For planar structures they are:

\[ \Sigma H = 0 \]  \hspace{1cm} (6.3-1)
\[ \Sigma V = 0 \]  \hspace{1cm} (6.3-2)
\[ \Sigma M = 0 \]  \hspace{1cm} (6.3-3)

In words, these equations say that for a body to be in equilibrium, (1) the algebraic sum of the horizontal components of all forces acting on the body must equal zero; (2) the algebraic sum of the vertical components of all forces acting on the body must equal zero; and (3) the algebraic sum of the moments of all the forces acting on the body about any point in the plane of the forces must equal zero. These equations are necessary and sufficient for the solution of any statically determinate planar structure.

Free Body Diagrams. One of the most powerful tools of structural analysis is the free body diagram. A good designer will develop skill in their preparation and use; he will know and be able to apply the following steps:
1. Isolate a portion of the structure by passing a section (not necessarily straight) that cuts the member or members in which unknown forces or stresses are to be found.

2. Draw the free body diagram and show carefully all of the forces both internal and external acting on this free body.

3. Compute the unknown forces from the equations of statics.

Free body diagrams are also of value in the determination of the correct sense of shears, moments, rotations, and deflections; they give credence to the proverb that "a picture is worth 1000 words."

The use of free body diagrams will be illustrated numerous times in other sections of this handbook that deal with the design of specific structures.

A designer's analytical ability can be lost through slovenly design notes and inadequate, sloppy engineering drawings. After a designer knows the fundamentals and how to apply them to specific problems, he must present his ideas in clear, neat, complete design notes and good drawings, or his effort and ability will not be recognized and appreciated. Anyone who has attempted to check a poorly prepared set of design notes or a carelessly prepared drawing will agree with the above comment. The reference value of cold, inadequately recorded engineering work is almost nil.

3.2 Shear and Moment Curves. Any of the modern textbooks on elementary structural theory and many books on strength of materials contain thorough discussions on the preparation of shear and moment curves and on the interrelationships between load, shear, and moment.

To aid in the computations involved in such work, several drawings have been prepared and included herein. Use of these drawings will facilitate the preparation of shear and moment curves on many of the cantilevers, beams, slabs, and rectangular frames encountered in soil conservation engineering. Your attention is especially directed to drawing ES-1, "Shear and Moments for Trapezoidal Load on Cantilever." The data contained in the three sheets of this drawing has found increasing use over the past 8 to 10 years since its original preparation.

Use of the following drawings will be illustrated in other sections of this handbook.
Consider one foot slice of cantilever.

\[ h = \text{depth of weir, height of surcharge, etc. in ft.} \]
\[ M = \text{moment in ft.-lb. (for one foot slice).} \]
\[ p = \text{pressure at depth } y \text{ in lb. per sq.ft.} \]
\[ S = \text{shear in lb. (for one foot slice)} \]
\[ w = \text{weight of equivalent fluid in lb. per cu. ft.} \]
\[ y = \text{vertical distance from top to any point in ft.} \]
Structural Design: Moments for Trapezoidal Load on Cantilever

\[ M = \frac{w(y-h)^2}{(y+2h)} \]

\[ w = 1 \]

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Reference: U.S. Department of Agriculture
Soil Conservation Service
Engineering Standards Unit

Revised 6-4-51
\[ S = \frac{W}{(y-2h)^2} \]
\[ W = 1 \]
\[ M_x = M_{ke} = \frac{qL^2}{2} k(1-k) = \frac{WL}{2} k(1-k) \]

or \[ M_x = CWL, \text{ where } C = \frac{k}{2}(1-k) \]

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STRUCTURAL DESIGN: SIMPLE BEAM MOMENTS FOR CONCENTRATED LOAD

\[ R_A = P \left( \frac{L - a}{L} \right) \]

\[ V_A = P \left( \frac{L - a}{L} \right) \]

\[ R_B = P \frac{a}{L} \]

\[ V_B = P \frac{a}{L} \]

LOAD

SHEAR DIAGRAM

MOMENT DIAGRAM

\[ M_X = P(l - a)k \text{, when } kl < a; \quad M_X = Pa(l - k) \text{ when } kl > a \]

\[ M_{\text{max}} = P \left( \frac{L - a}{L} \right) a \]

When load \( P \) is at \( \xi \) of beam \( (a = \frac{L}{2}) \)

\[ R_A = R_B = \frac{P}{2}; \quad V_{\text{max}} = \frac{P}{2} \]

\[ M_X = \frac{P}{2} l; \quad M_{\text{max}} = \frac{P l}{4} \]
**STRUCTURAL DESIGN: SIMPLE BEAM MOMENTS FOR TRAPEZOIDAL LOAD**

\[
M_x = M_{kl} = \frac{q_1 L^2}{6} \cdot D(E + C)
\]

where \( C = \frac{q_2}{q_1}, \ D = k(1 - k^2), \ E = \frac{3}{1 + k} \)

\[ M \text{ max. when } k = \frac{L}{c} \left[ -1 + \sqrt{c^2 + 3c + 3} \right] \]

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**NOTE:** Ordinarily it is not necessary to compute the maximum moment. It can usually be determined from the moment diagram with sufficient accuracy. The maximum moment will occur between \( k = 0.500 \) and \( k = 0.577 \).

---

**REFERENCE**

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING STANDARDS UNIT

STANDARD DWG. NO. ES-3
SHEET 1 OF 1
DATE 11-1-49
\[ M_x = M_kl = \frac{1}{6} gl^2 (k-k^3) = \frac{1}{3} Wl (k-k^3) \]

\[ C = \frac{1}{3} (k-k^3) \]

\[ M_kl = CWl \]

\[ M \text{ is maximum when } k = 0.577 \]

\[ V_x = V_kl = W \left( \frac{1}{3} - k^2 \right) \]

<table>
<thead>
<tr>
<th>( k )</th>
<th>( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.033</td>
</tr>
<tr>
<td>0.2</td>
<td>0.064</td>
</tr>
<tr>
<td>0.3</td>
<td>0.091</td>
</tr>
<tr>
<td>0.4</td>
<td>0.112</td>
</tr>
<tr>
<td>0.5</td>
<td>0.125</td>
</tr>
<tr>
<td>0.577</td>
<td>0.1283</td>
</tr>
<tr>
<td>0.6</td>
<td>0.128</td>
</tr>
<tr>
<td>0.7</td>
<td>0.119</td>
</tr>
<tr>
<td>0.8</td>
<td>0.096</td>
</tr>
<tr>
<td>0.9</td>
<td>0.057</td>
</tr>
</tbody>
</table>

STRUCTURAL DESIGN: FIXED ENDED BEAM MOMENTS FOR CONCENTRATED LOAD, UNIFORMLY DISTRIBUTED LOAD, AND HYDROSTATIC LOAD ON PRISMATIC BEAMS

CONCENTRATED LOAD

Moment Diagram

Shear Diagram

HYDROSTATIC LOAD

Moment Diagram

Shear Diagram

EXAMPLE

Fixed End Moments

Simple Beam Moments in Ft. Lbs.

* See ES-1, ES-2, and ES-23
** The Uniform load and Hydrostatic load can be combined and ES-23 used.

REFERENCE

**STRUCTURAL DESIGN: FIXED ENDED BEAM MOMENTS FOR PARTIAL UNIFORMLY DISTRIBUTED LOAD—PRISOMATIC BEAMS**

**Fixed End Moments**

\[ M_{Ax} = \frac{1}{2} l (6 - 8x + 3x^2) W \]
\[ M_{By} = \frac{1}{2} l (4 - 3x) W \]

**Simple Beam Reactions**

\[ R_A^s = V_A^s = \frac{1}{2} W (2 - x) \]
\[ R_B^s = V_B^s = \frac{1}{2} W e \]

**Fixed End Reactions**

\[ R_A^f = V_A^f = R_A^s + \frac{(M_{Ax} - M_{By})}{l} \]
\[ R_B^f = V_B^f = R_B^s - \frac{(M_{Ax} - M_{By})}{l} \]

**Simple Beam Moment at C**

\[ M_C^s = R_B^s (2 - x) \]

**Plotting Moment Diagram**

1. Plot \( M_C^s \) at C
2. Plot simple beam moment diagram for span \((xL)\) and load \(W\) vertically above line AC (See ES-1)
3. Plot \( M_{Ax} \) at A
4. Plot \( M_{By} \) at B

---

**Fixed End Moments**

\[ M_{Ab} = \frac{1}{2} l (6 - 8x + 3x^2) q \ell^2 - q (6 - 8a + 3a^2) e l \]
\[ M_{Bc} = \frac{1}{2} l (4 - 3x) q \ell^2 - q (4 - 3a) a l \]

**Simple Beam Reactions**

\[ R_A^s = V_A^s = \frac{1}{2} q (x + e) \]
\[ R_B^s = V_B^s = \frac{1}{2} q (2 - a - e) \]

**Fixed End Reactions**

\[ R_A^f = V_A^f = R_A^s + \frac{(M_{Ab} - M_{Bc})}{l} \]
\[ R_B^f = V_B^f = R_B^s - \frac{(M_{Ab} - M_{Bc})}{l} \]

**Simple Beam Moments at C & D**

\[ M_C^s = R_B^s (L - x) \]
\[ M_D^s = R_A^s (xL) \]

**Plotting Moment Diagram**

1. Plot \( M_C^s \) at C
2. Plot \( M_D^s \) at D
3. Plot simple beam moment diagram for span \((xL)\) and load \(W\) vertically above line CD (See ES-1)
4. Plot \( M_{Ab} \) at A
5. Plot \( M_{Bc} \) at B

---

**Reference**


**U.S. Department of Agriculture SOIL CONSERVATION SERVICE**

**Engineering Standards Unit**

**Standard Dwg. No.: ES-32**

**Sheet 1 of 1**

**Date: 5-26-50**

Revised 6-4-51
Assumptions:
1. Loads and frame are symmetrical about center line of frame.
2. The analysis is based on center line dimensions.
3. The effect of small fillets is neglected.

\[
\begin{align*}
H &= h + t_s \\
L &= L + t_w \\
\frac{k_s}{k_w} &= C = \left(\frac{t_s}{t_w}\right)^3 \frac{H}{L} \\
p &= \frac{C}{(C+2)^2} - 1 \\
q &= C + 2 \\
U_a^e &= M_{ab} + M_{ad} \\
U_c^e &= M_{cd} + M_{cb} \\
M_{ab} &= M_{ab}^F - p(U_c^F + qU_a^F) \\
M_{dc} &= M_{dc}^F + p(U_d^F + qU_c^F) \\
M_{dc} + M_{da} &= 0 \\
M_{ab} + M_{ad} &= 0
\end{align*}
\]

Sign convention - A moment acting in a clockwise direction on a joint is positive.

Caution: Use proper sign of fixed end moments when substituting them in the given equations.

Nomenclature:
- \( M_{ab} \): Moment at end "a" of member "ab".
- \( M_{ab}^F \): Fixed end moment at end "a" of member "ab".
- \( U_a^e \): Algebraic sum of fixed end moments at \( a \) = unbalanced fixed end moment at \( a \).
- \( k_w \): Stiffness of wall.
- \( k_s \): Stiffness of slab.
\[ M_{ab} = M_{ab}^F + 2m\left(U_f^F - nU_a^F\right) \]
\[ M_{ba} = M_{ba}^F + m\left(U_f^F - nU_a^F\right) \]
\[ M_{ef} = M_{ef}^F + m\left(U_a^F - nU_f^F\right) \]
\[ M_{fe} = M_{fe}^F + 2m\left(U_a^F - nU_f^F\right) \]
\[ M_{ab} + M_{af} = 0; \quad M_{fa} + M_{fe} = 0; \]
\[ M_{be} = M_{eb} = 0. \]

**Assumptions:**
1. Loads and frame are symmetrical about center line of frame.
2. The analysis is based on center line dimensions.
3. The effect of small fillets is neglected.

\[ H = h + t_s \]
\[ L = L + \frac{t_w + t_c}{2} \]
\[ \frac{K_s}{K_w} = C = \left(\frac{t_s}{t_w}\right)^3 \cdot \frac{H}{L} \]
\[ m = \frac{C}{4(C+1)^2 - 1} \]
\[ n = 2(C+1) \]
\[ U_f^F = M_{fa}^F + M_{fe}^F \]
\[ U_a^F = M_{ab}^F + M_{af}^F \]

**Nomenclature:**
- \( M_{ab} \): Moment at end "a" of member "ab".
- \( M_{ab}^F \): Fixed end moment at end "a" of member "ab".
- \( U_a^F \): Algebraic sum of fixed end moments at joint a = unbalanced fixed end moment at a.
- \( K_w \): Stiffness of wall.
- \( K_s \): Stiffness of slab.

**Sign Convention:** A moment acting in a clockwise direction on a joint is positive.

**Caution:** Use proper sign of fixed end moments when substituting them in the given equations.
STRUCTURAL DESIGN: Cartesian grid point designation system, positive sign convention, symbols and nomenclature

CARTESIAN GRID POINT DESIGNATION SYSTEM

SYMBOLS AND NOMENCLATURE

a = vertical dimension of fixed slab, ft
b = horizontal dimension of fixed slab, ft
Mx = vertical moment, lb ft/ft
My = horizontal moment, lb ft/ft
p = intensity of pressure, lbs/ft²
v = shearing reactions per unit length acting normal to the plane of the slab, lbs/ft
w = weight, lbs/ft³
x, y = rectangular coordinates in the plane of the slab

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 1 OF 85
DATE 4-13-56
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = 0 \)

Vertical moment determines tension in vertical steel

\[ M_x = \left[ \text{Moment coefficient} \right]_x \text{ pa}^2 \]

Graph showing the variation of \( M_x \) along section \( y = 0 \).
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.1\text{lb}$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] \times \text{lb} \cdot \text{in}^2$$

![Diagram showing the relationship between moment coefficients and tension in vertical steel.](image)

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 3 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.2b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right]_x p a^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
EO-104

DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.3b \).

Vertical moment determines tension in vertical steel

\[
M_x = \left[ \text{Moment coefficient} \right]_x \text{ pa}^2
\]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES.104

SHEET 5 OF 85
DATE 8/1/55
Vertical moment determines tension in vertical steel

\[ M_x = [\text{Moment coefficient}]_x \text{ pa}^2 \]
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.5b \)

Vertical moment determines tension in vertical steel

\[ M_x = [\text{Moment coefficient}]_x \text{ pa}^2 \]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 7 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice. \( x=0 \)

Horizontal moment determines tension in horizontal steel

\[ M_y = \left( \text{Moment coefficient} \right)_y \text{pa}^2 \]

---

**REFERENCE**
U.S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

**U.S. DEPARTMENT OF AGRICULTURE**
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

**STANDARD DWG. NO.**
ES-104

**SHEET** 8 OF 85
**DATE** 8-1-56
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice. $x = 0.2a$

Horizontal moment determines tension in horizontal steel

$$M_y = \text{[Moment coefficient]}_y \text{ pa}^2$$

[Graph showing moment coefficients along section $x = 0.2a$]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 9 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.4a$

Horizontal moment determines tension in horizontal steel

$$M_y = \left[ \text{Moment coefficient} \right] y \, \text{pa}^2$$
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x=0.6a$

Horizontal moment determines tension in horizontal steel $M_y = [\text{Moment coefficient}]y \text{ pa}^2$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 11 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.8a \)

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right] y \mathrm{pa}^2
\]

![Graph showing horizontal moment along section \( x = 0.8a \)]
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = a$

Horizontal moment determines tension in horizontal steel $M_y = [\text{Moment coefficient}]_y \, \text{pa}^2$

```
 y = \pm 0.5b

 y = \pm 0.4b

 y = \pm 0.3b

 y = \pm 0.2b

 y = \pm 0.1b

 y = 0

 x = a
```

Ratio $\frac{a}{b}$

```
0.25
0.5
1.0
1.5
2.0
2.5
3.0
-0.025
-0.020
-0.015
-0.010
-0.005
0

[Moment coefficient]_y along section $x = a$
```

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 13 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for shear at fifth points on fixed side edges $y = \pm 0.5b$

Shear = [Shear coefficient] $\times p$ a

![Diagram showing shear coefficient distribution along vertical section $y = \pm 0.5b$]

Ratio $\frac{b}{a}$

Shear coefficient along vertical section $y = \pm 0.5b$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 14 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with hydrostatic load; coefficients for shear at tenth points on fixed bottom edge \( x = a \)

Shear = \[ \text{Shear coefficient} \] \( p a \)

![Diagram showing shear calculation and graph with plotted points](image-url)
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = 0$.

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right]_x \text{pa}^2$$

![Graph showing moment coefficient along section $y = 0$.]
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for vertical moment, $M_X$, at fifth points on vertical slice $y = \pm 0.1b$

Vertical moment determines tension in vertical steel

$$M_X = \left[ \text{Moment coefficient} \right]_X pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.2b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right]_x \rho a^2$$

---

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 80, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 18 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.3b$

Vertical moment determines tension in vertical steel

$$M_x = [\text{Moment coefficient}]_x \text{pa}^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 36, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-104
SHEET 19 OF 85
DATE 8-1-55

$y = \pm 0.3b$
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.4b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] x \text{ Pa}^2$$

REFERENCE

U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 20 OF 85

DATE 8-1-58.
STRUCTURAL DESIGN: Rectangular slabs with $2/3$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.5b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] x \ p a^2$$
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0$

Horizontal moment determines tension in horizontal steel

$$M_y = \left[ \text{Moment coefficient} \right] y \rho a^2$$
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.2a \)

Horizontal moment determines tension in horizontal steel

\[ M_y = [\text{Moment coefficient}]y \text{ pa}^2 \]
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.4a$

Horizontal moment determines tension in horizontal steel

$$M_y = \text{[Moment coefficient]} \cdot y \cdot pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.6a \)

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right] y a^2
\]
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.8a \).

Horizontal moment determines tension in horizontal steel

\[ M_y = \text{[Moment coefficient]} ypa^2 \]
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = \alpha \).

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right] \gamma \rho a^2
\]
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) hydrostatic load; coefficients for shear at fifth points on fixed side edges \( y = \pm 0.5b \)

\[
\text{Shear} = [\text{Shear coefficient}] \, pa
\]

\[
\begin{array}{c}
x = 0.6a \\
x = 0.8a \\
x = 0.4a \\
x = 0.2a \\
x = 0.0a \\
\end{array}
\]

\[
\begin{array}{c}
\text{Ratio } \frac{b}{a} \\
0.25 \\
0.5 \\
1.0 \\
1.5 \\
2.0 \\
2.5 \\
3.0 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Shear coefficient} \text{ along vertical section } y = \pm 0.5b \\
0.15 \\
0.10 \\
0.05 \\
0.00 \\
-0.02 \\
\end{array}
\]

[Diagram of rectangular slab with labeled dimensions and shear coefficient curves.]
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) hydrostatic load; coefficients for shear at tenth points on fixed bottom edge \( x = a \)

Shear = \( \text{Shear coefficient} \) \( pa \)

\[
\begin{align*}
0.5b & \quad 0.5b \\
\text{Origin} & \\
+y & \\
x & \\
\end{align*}
\]

Along fixed bottom edge \( x = a \)

Shear coefficient

\[
\begin{align*}
\text{Ratio } b/a & \\
0.25 & 0.5 & 1.0 & 1.5 & 2.0 & 2.5 & 3.0 \\
0 & 0.25 & 0.5 & 0.75 & 1.0 & 1.25 & 1.5 \\
+0.05 & +0.10 & +0.15 & +0.20 & +0.25 & +0.30 & +0.35 \\
\end{align*}
\]
STRUCTURAL DESIGN: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = 0$

Vertical moment determines tension in vertical steel

$$M_x = [\text{Moment coefficient}]_x \cdot p a^2$$
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.1b \).

Vertical moment determines tension in vertical steel

\[
M_x = [\text{Moment coefficient}]_x \cdot p a^2
\]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954
STRUCTURAL DESIGN: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.2b$.

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] x a^2$$

[Graph showing moment coefficient versus ratio $b/a$ along section $y = \pm 0.2b$.]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.3b \)

Vertical moment determines tension in vertical steel

\[
M_x = \left[ \text{Moment coefficient} \right]_x \text{ pa}^2
\]

REFERENCE

U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 33 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.4b \)

Vertical moment determines tension in vertical steel

\[
M_x = \text{[Moment coefficient]}_x \cdot p a^2
\]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 34 OF 85

DATE 8-1-55
Structural Design: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.5b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right]_x \Delta a^2$$

Graph showing $M_x$ as a function of $\frac{b}{a}$ for various $x$ values:

$$x = 0.2a, x = 0.4a, x = 0.6a, x = 0.8a$$

Graph also shows:
- $y = -0.5b$
- $y = 0.5b$
- Origin

Reference:
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-104
SHEET 35 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0$

Horizontal moment determines tension in horizontal steel

$$M_y = \text{[Moment coefficient]} \cdot y \cdot a^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 36 OF 85
DATE 8-1-55.
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.2a \).

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right] y a^2
\]

![Diagram showing moment coefficient along section \( x = 0.2a \)]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-104
SHEET 37 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.4a \)

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right] y \, p a^2
\]
STRUCTURAL DESIGN: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.6a$

Horizontal moment determines tension in horizontal steel

$$M_y = [\text{Moment coefficient}] y \ p \ a^2$$

[Diagram of moment distribution along section $x = 0.6a$]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 39 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.8a$.

Horizontal moment determines tension in horizontal steel:

$$M_y = \text{[Moment coefficient]}_y \cdot pa^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-104
SHEET 40 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = a \)

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right]_y \cdot p a^2
\]
STRUCTURAL DESIGN: Rectangular slabs with $\frac{1}{3}$ hydrostatic load; coefficients for shear at fifth points on fixed side edges $y=\pm 0.5b$

Shear = $[\text{Shear coefficient}] pa$

![Graph showing shear distribution with various x values](image)

Ratio $\frac{b}{a}$

---

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 42 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{1}{3} \) hydrostatic load; coefficients for shear at tenth points on fixed bottom edge 
\( x = a \)

Shear = \([\text{Shear coefficient}] \ pa\)
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = 0$.

Vertical moment determines tension in vertical steel:

$$M_x = [\text{Moment coefficient}] x \text{pa}^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 44 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for vertical moment, $M_x$, at five points on vertical slice $y = \pm 0.1\text{lb}$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] x \text{pa}^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 45 OF 85
DATE 8-1-55
Vertical moment determines tension in vertical steel

\[ M_x = \left[ \text{Moment coefficient} \right] \times p \cdot a^2 \]
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.3b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] \times pa^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 47 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.4b$

Vertical moment determines tension in vertical steel

$$M_x = \text{[Moment coefficient]} x \ pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.5b$

Vertical moment determines tension in vertical steel:

$$M_x = \left[ \text{Moment coefficient} \right]_x pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0$

Horizontal moment determines tension in horizontal steel

$$M_y = [\text{Moment coefficient}]_y p a^2$$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.2a$

Horizontal moment determines tension in horizontal steel

$$M_y = \text{[Moment coefficient]} y pa^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 51 OF 85
DATE 8-1-55

$x = 0.2a$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.4a$

Horizontal moment determines tension in horizontal steel

$$M_y = \text{[Moment coefficient]}_y \times p a^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 52 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.6a$

Horizontal moment determines tension in horizontal steel

$$M_y = \text{[Moment coefficient]}_y pa^2$$

REFERENCE
U.S. Bureau of Reclamation photoelastic analysis report No. 30, December 1954

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 53 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.8a$

Horizontal moment determines tension in horizontal steel

$$M_y = \left[ \text{Moment coefficient} \right] y pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = a$

Horizontal moment determines tension in horizontal steel

$$M_y = \left[ \text{Moment coefficient} \right]_y pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for shear at fifth points on fixed side edges $y = \pm 0.5b$

$$\text{Shear} = \text{[Shear coefficient]} p a$$

$0.5b \quad 0.5b$

$y = -5b \quad y = 5b$

Origin

$+y$

$+x$

$0.2a$

$0.4a$

$0.6a$

$0.8a$

$a$

Ratio $b/a$

Shear coefficient along fixed side edges $y = \pm 0.5b$

$y = \pm 0.5b$
STRUCTURAL DESIGN: Rectangular slabs with uniform load; coefficients for shear at tenth points on fixed bottom edge $x = a$

Shear = \left[ \text{Shear coefficient} \right] p a
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) uniform load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = 0 \).

Vertical moment determines tension in vertical steel:

\[
M_x = \left[ \text{Moment coefficient} \right]_x \text{p}a^2
\]
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) uniform load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.1b \)

Vertical moment determines tension in vertical steel

\[ M_x = [\text{Moment coefficient}] \times a \]

REFERENCE
U.S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-104
SHEET 59 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $2/3$ uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.2b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right] x p a^2$$

[Diagram showing the relationship between $M_x$, $p$, and $a$ along a section $y = \pm 0.2b$.]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET .60 OF .85
DATE 8-1-55
Structural Design: Rectangular slabs with \( \frac{2}{3} \) uniform load; coefficients for vertical moment, \( M_x \), at fifth points on vertical slice \( y = \pm 0.3b \).

Vertical moment determines tension in vertical steel

\[
M_x = \left[ \text{Moment coefficient} \right]_x \text{pa}^2
\]

[Graph showing moment coefficient for different values of \( x \) along the section \( y = \pm 0.3b \).]

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 61 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $\tfrac{2}{3}$ uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.4b$

Vertical moment determines tension in vertical steel

$$M_x = [\text{Moment coefficient}]_x p a^2$$

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 62 OF 85

DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ uniform load; coefficients for vertical moment, $M_x$, at fifth points on vertical slice $y = \pm 0.5b$

Vertical moment determines tension in vertical steel

$$M_x = \left[ \text{Moment coefficient} \right]_x p a^2$$
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0$.

Horizontal moment determines tension in horizontal steel

$$M_y = \left[ \text{Moment coefficient} \right]_y \, \text{pa}^2$$
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.2a$

Horizontal moment determines tension in horizontal steel

$$M_y = [\text{Moment coefficient}]_y \, pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) uniform load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.4a \).

Horizontal moment determines tension in horizontal steel

\[
M_y = \left[ \text{Moment coefficient} \right] y \, \text{pa}^2
\]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 66 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ uniform load; coefficients for horizontal moment, $M_y$, at tenth points on horizontal slice $x = 0.6a$

Horizontal moment determines tension in horizontal steel

$$M_y = [\text{Moment coefficient}] y pa^2$$
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) uniform load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = 0.8a \)

Horizontal moment determines tension in horizontal steel

\[ M_y = \text{[Moment coefficient]}y \ pa^2 \]

[Graph showing moment coefficients along section \( x = 0.8a \)]
STRUCTURAL DESIGN: Rectangular slabs with \( \frac{2}{3} \) uniform load; coefficients for horizontal moment, \( M_y \), at tenth points on horizontal slice \( x = a \).

Horizontal moment determines tension in horizontal steel

\[
M_y = \text{[Moment coefficient]} y \text{ pa}^2
\]
STRUCTURAL DESIGN: Rectangular slabs with $2/3$ uniform load
Coefficients for shear at fifth points on fixed side edges
$y = \pm 0.5b$

Shear = $[\text{Shear coefficient}] pa$

Shear coefficient along vertical section $y = \pm 0.5b$

Ratio $b/a$

Shear coefficient

0.5b

0.5b

y = -0.5b

y = 0.5b

Origin

$+y$

$+x$

$y = \pm 0.5b$
STRUCTURAL DESIGN: Rectangular slabs with $\frac{2}{3}$ uniform load; coefficients for shear at tenth points on fixed bottom edge $x = a$

\[
\text{Shear} = [\text{Shear coefficient}] \times a
\]

REFERENCE
U. S. Bureau of Reclamation photoelastic analysis unit report No. 30, December 1954

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES.104
SHEET 71 OF 85
DATE 8-1-55
STRUCTURAL DESIGN: DESIGN EXAMPLE;
Dimensions and design loads

DESIGN EXAMPLE

This is strictly an academic example and is only complete insofar as it illustrates the use of the Moment and Shear curves of ES-104. The following figure shows the essential dimensions and possible loads on the interior panel of a counterforted retaining wall. Both the wall slab and the heel slab approximate a plate fixed on three edges and free on the fourth. Center line dimensions have been used for both slabs.

![Diagram showing front and side elevations of a retaining wall](image)

**FRONT ELEVATION**

**SIDE ELEVATION**

**Unit Weights**

- Concrete: 150 lbs/ft³
- Moist Earth: 125 lbs/ft³
- Saturated Earth: 140 lbs/ft³
- Water: 62.4 lbs/ft³

**Equivalent Fluid Weights**

- Moist Earth: 65 lbs/ft³
- Saturated Earth: 85 lbs/ft³
STRUCTURAL DESIGN : DESIGN EXAMPLE ;
Component wall slab loads

COMPONENT WALL SLAB LOADS

\[ P_w = wh = (62.4)(6.33) = 395 \text{ lbs/ft}^2 \]
\[ P_s = wh = (65)(2) = 130 \text{ lbs/ft}^2 \]
\[ P_e = wh = (65)(19) = 1235 \text{ lbs/ft}^2 \]
\[ P_p = wh = (20)(14.5) = 290 \text{ lbs/ft}^2 \]

\[ P_{w\text{a}} = (0.395)(19) = 7.5 \text{ kips/ft} \]
\[ P_{s\text{a}} = (0.130)(19) = 2.5 \text{ kips/ft} \]
\[ P_{e\text{a}} = (1.235)(19) = 23.5 \text{ kips/ft} \]
\[ P_{p\text{a}} = (0.290)(19) = 5.5 \text{ kips/ft} \]

\[ P_{wa} = (0.395)(19)^2 = 142.6 \text{ ft kips/ft} \]
\[ P_{sa} = (0.130)(19)^2 = 46.9 \text{ ft kips/ft} \]
\[ P_{ea} = (1.235)(19)^2 = 445.8 \text{ ft kips/ft} \]
\[ P_{pa} = (0.290)(19)^2 = 104.7 \text{ ft kips/ft} \]

\[ \frac{b}{a} = \frac{14}{19} = 0.737 \]
<table>
<thead>
<tr>
<th>Values</th>
<th>Moment Coefficients</th>
<th>Moments (ft kips)</th>
<th>Total Moment (ft kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y/b$</td>
<td>$x/a$ P_W P_S P_E P_P M_W M_S M_E M_P</td>
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<td></td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>± 0.1</td>
<td>0.2</td>
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<td>+ 0.0026 + 0.0045 + 0.0048 + 0.0047 - 0.37 + 0.21 + 2.14 + 0.49</td>
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<td>- 2.00</td>
</tr>
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</table>

REFERENCE

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD Dwg. No.
ES 104

SHEET 74 OF 85
DATE 4-12-56
## Structural Design; Design Example; Horizontal Moments (M_y) in Wall Slab

<table>
<thead>
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<th>( \frac{X}{a} )</th>
<th>( \pm \frac{X}{b} )</th>
<th>( P_w )</th>
<th>( P_b )</th>
<th>( P_e )</th>
<th>( P_p )</th>
<th>( M_w )</th>
<th>( M_b )</th>
<th>( M_e )</th>
<th>( M_p )</th>
<th>( \text{Total Moment (ft kips)} )</th>
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**Structural Design: Design Example**

Example of interpolation, horizontal and vertical moments in wall slab

![Graph showing moment coefficients](image)

**Example of Interpolation of Moment Coefficient** ($M_y$) 
For 0.76 Hydrostatic Load along section $x = 0$

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<th>$x$</th>
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Horizontal and Vertical Moments in ft kips/ft in Wall Slab

- **Horizontal Moment**
- **Vertical Moment**

---

**Reference**

U.S. Department of Agriculture

Soil Conservation Service

Engineering Division - Design Section

**Standard Draw. No.**

ES-104

Sheet 76 of 85

Date: 4-13-56
### Structural Design: Design Example

Shears in wall slab

<table>
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<th>Shear Coefficients</th>
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**Shear Along Fixed Edges** x = a AND y = ± 0.5b IN WALL SLAB

The magnitude and location of the maximum shear may readily be obtained from the above table.
Heel slab loads

Heel Slab

$W = 32,710 \text{ lbs}$

$H = 16,330 \text{ lbs}$

Determine the total vertical load $W$.

- **Wall Stem**
  - $1 \times 18 \times 150 = 2,700 \times 9.5 = 25,650$
  - $0.5 \times 18 \times 150 = 1,350 \times 8.67 = 11,705$

- **Footing**
  - $2 \times 14 \times 150 = 4,200 \times 7 = 29,400$

- **Moist Earth**
  - $8 \times 20 \times 125 = 20,000 \times 4 = 80,000$
  - $0.5 \times 18 \times 125 = 1,125 \times 8.33 = 9,370$

- **Saturated Earth**
  - $8 \times 13.5 \times 15 = 1,620 \times 4 = 6,480$
  - $0.38 \times 13.5 \times 15 = 79 \times 8.33 = 660$

- **Counterfort**
  - $1 \times 4.5 \times 25 = 10 \times 8.17 = 80$
  - $\frac{5 \times 13.5 \times 10}{14} = 50 \times 5.50 = 275$

- **Water**
  - $4 \times 5.33 \times 62.4 = 1,330 \times 12 = 15,960$

$\sum W = 32,710$

$x = \frac{\sum M}{\sum W} = 181,665$

$\sum M = 181,665$

Determine the horizontal load $H$.

- **Water**
  - $-\frac{7.52^2 \times 62.4}{2} = -1,675 \times 2.44 = -4,090$

- **Surcharge**
  - $130 \times 20 = 2,600 \times 10 = 26,000$

- **Earth Load**
  - $20^2 \times 65 = 13,000 \times 6.67 = 86,710$

- **Pore Pressure Load**
  - $\frac{15.5^2 \times 20}{2} = 2,405 \times 5.17 = 12,435$

$\sum W = 16,330$

$\sum M = 121,055$

$x' = \frac{(32,710)(8.45) - (16,330)(7.41)}{32,710} = 4.75 \text{ ft}$

$e = 7.00 - 4.75 = 2.25 \text{ ft}$
Max Pressure = \left( \frac{W}{b} \right) \left[ 1 + \frac{6e}{b} \right] = \left( \frac{32.710}{14} \right) \left( 1 + \frac{(6)(2.25)}{14} \right) = 4588 \text{ lbs/ft}^2

Min Pressure = \left( \frac{W}{b} \right) \left[ 1 - \frac{6e}{b} \right] = \left( \frac{32.710}{14} \right) \left( 1 - \frac{(6)(2.25)}{14} \right) = 84 \text{ lbs/ft}^2

HEEL SLAB LOAD DIAGRAM

\[ P_v = (4588 - 84) \left( \frac{9}{14} \right) = 2895 \text{ lbs/ft}^2 \]
\[ P_u = (20)(125) + (13.5)(15) + (2)(150) - 84 = 2918 \text{ lbs/ft}^2 \]
\[ P_v a^2 = (2.895)(9)^2 = 234.5 \text{ ft kips/ft} \]
\[ P_u a^2 = (2.918)(9)^2 = 236.4 \text{ ft kips/ft} \]
### Structural Design: Design Example

**Moments (M_x) in heel slab**

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## Structural Design: Design Example

Moments ($M_y$) in heel slab

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STRUCTURAL DESIGN: DESIGN EXAMPLE;
Moments ($M_x$) in heel slab

$\frac{D}{X}$ vs. $\frac{M_x}{\text{IN FT KIPS/FT}}$

REFERENCE

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104
SHEET 83 OF 85
DATE 4-13-56
STRUCTURAL DESIGN: DESIGN EXAMPLE;
Moments ($M_y$) in heel slab

![Graph showing moments in heel slab](image)

REFERENCE
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-104

SHEET 84 of 35

DATE 4-13-56
STRUCTURAL DESIGN; DESIGN EXAMPLE;
Moments and shears in heel slab

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    & -5.51 & -2.04 & +0.41 & +2.06 & +2.69 & +3.09 \\
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    & -3.83 & -1.49 & +0.27 & +1.96 & +2.20 & +2.58 \\
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    & -2.12 & -1.18 & -0.70 & -0.51 & -0.28 & -0.26 \\
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    & -0.60 & -1.56 & -3.02 & -4.73 & -5.54 & -5.96 \\
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\]

MOMENTS \((M_y)\) AND \((M_x)\) IN ft kips/ft IN HEEL SLAB

\[
\begin{array}{c}
(M_y) \\
(M_x)
\end{array}
\]

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SHEAR ALONG FIXED EDGES \(x = a\) AND \(y = \pm 0.5b\) IN HEEL SLAB

The magnitude and location of the maximum shear may be readily obtained from the above table.