HOW TO DESIGN?

TYPICAL CONTOURS FOR RESIDENTIAL SLAB EXPERIENCING CENTER LIFT OR EDGE DRYING CONDITIONS IN ARLINGTON, TEXAS (Tucker and Pogorelc, 1977)
WIDE VARIETY OF CLIMATE
SAME SOIL -- DIFFERENT CLIMATE

Expected vertical movement vs TMI for a 1/25 year return period, dam=30cm

- swell
- shrink
- total

Thornthwaite Moisture Index (TMI) vs Expected vertical movement (cm)
SITE CONDITIONS

- Rainfall and evaporation
- Tree root zones
- Flower beds, ponds
- Vertical, horizontal barriers
DESIGN NEEDS ENVELOPES

Example

Soil Support Pattern

Worst Soil Support Patterns
EDGE DRYING

- Edge Moisture Variation Distance from Charts
- Maximum Differential Movement
- Slab
- Depth of Moisture Active Zone
- Contours of Equal Suction
- Steady State Horizontal Flow
DESIGN AIDS

• SOIL MOVEMENT
• SOIL MOVEMENT TABLES
• SLAB DEFLECTION AND STRESSES
• SOIL VOLUME CHANGE
• SOIL MOISTURE VARIATION
  DISTANCE
• VERTICAL BARRIERS
SOIL SUCTION

MILEPOSTS ON THE SUCTION SPECTRUM

7: OVEN DRY
6: AIR DRY
5: TENSILE STRENGTH OF WATER
4: WILTING POINT
3: PLASTIC LIMIT
2: FIELD CAPACITY
1: LIQUID LIMIT
EXAMPLE: VOLFLO-2

GIVEN VALUES:

• $U_{\text{WET}} = 2.50 \text{ pF}$
• $U_{\text{DRY}} = 4.56 \text{ pF}$
• $Z_m = 28.08 \text{ ft}$
• $U_{\text{EQUIL.}} = 3.31 \text{ pF}$
• $U_O = 1.03 \text{ pF}$
• $n = 1 \text{ cycle/year}$
### Soil Movement

#### Suction Profiles "Tree"

- **Month of Construction:** Jan
- **Month to calc. Vol. Chg.:** Jan
- **Input $d_{\text{bar}}$:** 4.00 ft
- **Input $d_{\text{tree}}$:** 2.00 ft
- **Total Shrink for Jan:** 0.00 in
  - **Edge:** 0.00 in
  - **Center:** 0.00 in

#### Differential Movement

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Suction (pF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2.00</td>
</tr>
<tr>
<td>2</td>
<td>3.00</td>
</tr>
<tr>
<td>3</td>
<td>4.00</td>
</tr>
<tr>
<td>4</td>
<td>5.00</td>
</tr>
</tbody>
</table>

- **$d_{\text{tree}}$:** The distance the tree is away from the slab.

- **$e_m$:**
  - Center lift: 320.0 cm
  - Edge lift: 198.1 cm

- **$Z_m$:** 856.0 cm
SOIL MOVEMENT

<table>
<thead>
<tr>
<th>Time in Mo.</th>
<th>Driest Month</th>
<th>Month of Construction</th>
<th>Month to calc. Vol. Chg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00</td>
<td>jun</td>
<td>jan</td>
<td>apr</td>
</tr>
<tr>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Input $d_{bar} = 4.00$ ft

Input $d_{tree} = 2.00$ ft

Total Swell for apr = 0.03 in

Edge = 0.03 in

Center = 0.06 in

**Suction Profiles "Tree"**

- $U(z,t)_{slab CL}$
- $U(z,t)_{const} {slab CL}$
- $U(z,t)_{bar}$
- $U(z,t)_{edge}$
- $U(z,t)_{tree}$

$d_{tree}$ is the distance the tree is away from the slab.

$e_m$ = 320.0 cm (center lift)

$e_m$ = 198.1 cm (edge lift)

$Z_m$ = 856.0 cm
SOIL MOVEMENT

<table>
<thead>
<tr>
<th>Time in Mo.</th>
<th>Driest Month =</th>
<th>Jan</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00</td>
<td>Month of Construction =</td>
<td>Jan</td>
</tr>
<tr>
<td>14.00</td>
<td>Month to calc. Vol. Chg. =</td>
<td>Aug</td>
</tr>
</tbody>
</table>

**Input**
- $d_{bar} = 4.00$ ft
- $d_{tree} = 2.00$ ft

**Total Shrink** for Aug = 2.00 in

**Differential Movement**
- Aug = 2.00 in

$d_{tree}$ is the distance the tree is away from the slab.

$e_m = 320.0$ cm (center lift)
$e_m = 198.1$ cm (edge lift)
$Z_m = 856.0$ cm
SOIL MOVEMENT

<table>
<thead>
<tr>
<th>Time in Mo.</th>
<th>Driest Month</th>
<th>Month of Construction</th>
<th>Month to calc. Vol. Chg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00</td>
<td>jun</td>
<td>jan</td>
<td>aug</td>
</tr>
<tr>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Input**

- $d_{\text{bar}} = 0.00$ ft
- $d_{\text{tree}} = 2.00$ ft

**Total Shrink**

- aug = 3.42 in
- Edge = -3.55 in
- Center = -0.13 in

**Suction Profiles**

- $U(z,t)_{\text{slab CL}}$
- $U(z,t)_{\text{const slab CL}}$
- $U(z,t)_{\text{bar}}$
- $U(z,t)_{\text{edge}}$
- $U(z,t)_{\text{tree}}$

**Differential Movement**

- aug
- 2.00
- -8.00

$d_{\text{tree}}$ is the distance the tree is away from the slab.

- $e_m = 320.0$ cm (center lift)
- $e_m = 198.1$ cm (edge lift)
- $Z_m = 856.0$ cm

root depth 20'
**SOIL MOVEMENT**

<table>
<thead>
<tr>
<th>Time in Mo.</th>
<th>Driest Month</th>
<th>Month of Construction</th>
<th>Month to calc. Vol. Chg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00</td>
<td>Jun</td>
<td>Jan</td>
<td>Aug</td>
</tr>
<tr>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Input**
- $d_{bar} = 4.00$ ft
- $d_{tree} = 2.00$ ft

**Total Shrink**
- $aug = 2.63$ in

**Edge**
- $-2.81$ in

**Center**
- $-0.18$ in

**Suction Profiles "Tree"**

**Differential Movement**
- $aug = 2.00$ in

$d_{tree}$ is the distance the tree is away from the slab.

\[
ed_m = 320.0 \text{ cm (center lift)}
\]

\[
ed_m = 198.1 \text{ cm (edge lift)}
\]

\[
Z_m = 856.0 \text{ cm}
\]
SOIL MOVEMENT TABLES

Design Differential Soil Movement, $y_m$, Guide Number for Slab Design

<table>
<thead>
<tr>
<th>Measured Suction pF at Depth, $z_m$, m</th>
<th>$y_m$ Guide Numbers</th>
<th>Controlling Surface Suction, pF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5</td>
<td>2.7</td>
</tr>
<tr>
<td>2.7</td>
<td>+3.2</td>
<td>0</td>
</tr>
<tr>
<td>3.0</td>
<td>+9.6</td>
<td>+5.1</td>
</tr>
<tr>
<td>3.3</td>
<td>+17.7</td>
<td>+12.1</td>
</tr>
<tr>
<td>3.6</td>
<td>+27.1</td>
<td>+20.7</td>
</tr>
<tr>
<td>3.9</td>
<td>+38.1</td>
<td>+30.8</td>
</tr>
<tr>
<td>4.2</td>
<td>+50.4</td>
<td>+42.1</td>
</tr>
<tr>
<td>4.5</td>
<td>+63.6</td>
<td>+54.7</td>
</tr>
</tbody>
</table>

Note: The positive sign indicates heave and the negative sign indicates shrinkage.
Design Differential Soil Movement, $y_m$, Guide Number for Slab Design: Lawn Irrigation

<table>
<thead>
<tr>
<th>Measured Suction pF at Depth, $z_m$, m</th>
<th>$y_m$ Guide Numbers</th>
<th>Controlling Surface Suction Due to Lawn Watering</th>
<th>With 4 ft. Deep Moisture Barrier pF -- units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pF – units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>2.7</td>
<td>3.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3.0</td>
<td>9.6</td>
<td>5.1</td>
<td>0</td>
</tr>
<tr>
<td>3.3</td>
<td>17.7</td>
<td>12.1</td>
<td>5.1</td>
</tr>
<tr>
<td>3.6</td>
<td>27.1</td>
<td>20.7</td>
<td>12.1</td>
</tr>
<tr>
<td>3.9</td>
<td>38.1</td>
<td>30.8</td>
<td>20.7</td>
</tr>
<tr>
<td>4.2</td>
<td>50.4</td>
<td>42.1</td>
<td>30.8</td>
</tr>
<tr>
<td>4.5</td>
<td>63.6</td>
<td>54.7</td>
<td>42.1</td>
</tr>
</tbody>
</table>

$y_m$ Guide Numbers for Slab Design: Lawn Irrigation

- **Controlling Surface Suction Due to Lawn Watering**
- **With 4 ft. Deep Moisture Barrier pF -- units**
Design Differential Soil Movement, $y_m$, Guide Number for Slab Design: Flower Bed Case (4 ft Deep Flower Bed Moisture)

<table>
<thead>
<tr>
<th>Measured Suction pF at Depth, $z_m$, m</th>
<th>$y_m$ Guide Numbers</th>
<th>Controlling Surface Suction Due to Flower Bed Watering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pF – units</td>
<td>With 4 ft. Deep Moisture Barrier pF -- units</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>2.7</td>
<td>3.2</td>
<td>0</td>
</tr>
<tr>
<td>3.0</td>
<td>13.1</td>
<td>0</td>
</tr>
<tr>
<td>3.3</td>
<td>27.3</td>
<td>7.0</td>
</tr>
<tr>
<td>3.6</td>
<td>48.7</td>
<td>14.2</td>
</tr>
<tr>
<td>3.9</td>
<td>69.5</td>
<td>35.1</td>
</tr>
<tr>
<td>4.2</td>
<td>90.3</td>
<td>56.0</td>
</tr>
<tr>
<td>4.5</td>
<td>111.0</td>
<td>76.7</td>
</tr>
</tbody>
</table>
Design Differential Soil Movement, $y_m$, Guide Number for Slab Design: Tree Drying Case (Without Moisture Barrier)

<table>
<thead>
<tr>
<th>Depth of Tree Root Zone, ft</th>
<th>$y_m$ Guide Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured Equilibrium Suction at Depth, $z_m$ pF -- units</td>
</tr>
<tr>
<td></td>
<td>2.7</td>
</tr>
<tr>
<td>4</td>
<td>-79.1</td>
</tr>
<tr>
<td>10</td>
<td>-169.6</td>
</tr>
<tr>
<td>15</td>
<td>-244.7</td>
</tr>
<tr>
<td>20</td>
<td>-333.4</td>
</tr>
</tbody>
</table>

* Movement active zone, $z_A = 11.5$ ft.
* Movement active zone, $z_A = 7.5$ ft.
* Movement active zone, $z_A = 3.5$ ft.

Movement active zone, $z_A = 11.5$ ft.
Movement active zone, $z_A = 7.5$ ft.
Movement active zone, $z_A = 3.5$ ft.
## SOIL MOVEMENT TABLES

### Design Differential Soil Movement, $y_m$, Guide Number for Slab Design: Tree Drying Case (With Moisture Barrier)

<table>
<thead>
<tr>
<th>Depth of Tree Root Zone, ft</th>
<th>y_m Guide Numbers</th>
<th>Measured Equilibrium Suction at Depth, $z_m$ (With 4 ft Deep Moisture Barrier)</th>
<th>pF -- units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.7</td>
<td>3.0</td>
<td>3.3</td>
</tr>
<tr>
<td>4</td>
<td>-36.5</td>
<td>-25.2</td>
<td>-15.8</td>
</tr>
<tr>
<td>10</td>
<td>-116.3</td>
<td>-102.4</td>
<td>-88.4</td>
</tr>
<tr>
<td>15</td>
<td>-193.5</td>
<td>-170.5</td>
<td>-147.5</td>
</tr>
<tr>
<td>20</td>
<td>-278.2</td>
<td>-246.1</td>
<td>-214.2</td>
</tr>
</tbody>
</table>

*Movement active zone, $z_A = 11.5$ ft.

*Movement active zone, $z_A = 7.5$ ft.
SLAB DEFLECTIONS
AND STRESSES

EXAMPLE NO. 1
P.T.I. DESIGN MANUAL

FLAT SLAB
RIBBED SLAB
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Displacements (in.)(CT)
Example 1: Center Lift (\(em=5.5\text{ ft}, \ ym=3.608\text{ in.}\)), Displacements (\text{in.}) (CT)
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Displacements (in.)
Example 1: Center Lift (em=5.5 ft, ym=3.608 in.), Displacements (in.)
Example 1: Center Lift \((e_m=5.5, y_m=3.608\text{ in.})\), Moment, \(M_x\) (kips ft/ft), (CT)
Example 1: Center Lift (em=5.5, ym=3.608in.), Moment, Mx (kips ft/ft), (CT)
Example 1: Center Lift \((em=5.5\text{ft}, \ ym=3.608\text{in.})\), Moment, \(M_x\) (kips ft/ft)
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Moment, Mx (kips ft/ft)
Example 1: Center Lift (em=5.5, ym=3.608in.), Moment, My (kips ft/ft), (CT)
Example 1: Center Lift ($em=5.5$, $ym=3.608\text{in.}$), Moment, $My$ (kips ft/ft), (CT)
Example 1: Center Lift (em=5.5 ft, ym=3.608 in.), Moment, My (kips ft/ft)
Example 1: Center Lift (em=5.5, ym=3.608in.), Moment, Mxy (kips ft/ft), (CT)
Example 1: Center Lift (em=5.5, ym=3.608in.), Moment, Mxy (kips ft/ft), (CT)
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Moment, Mxy (kips ft/ft)
Example 1: Center Lift (em=5.5 ft, ym=3.608 in.), Moment, Mxy (kips ft/ft)
Example 1: Center Lift ($e_m=5.5$, $y_m=3.608\text{in.}$), Shear Force, $Q_x$ (kips/ft), (CT)
Example 1: Center Lift \((e_m=5.5, \, y_m=3.608\, \text{in.})\), Shear Force, \(Q_x\) (kips/ft), (CT)
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Shear Force, Qx (kips/ft)

![Heatmap diagram showing shear force distribution with coordinates and values indicated.]
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Shear Force, Qx (kips/ft)
Example 1: Center Lift (em=5.5, ym=3.608in.), Shear Force, Qy (kips/ft), (CT)
Example 1: Center Lift (em=5.5, ym=3.608in.), Shear Force, Qy (kips/ft), (CT)
Example 1: Center Lift (em=5.5ft, ym=3.608in.), Shear Force, Q_y (kips/ft)
Example 1: Edge Lift, \((em=2.5\text{ft, } y_m=0.752\text{in.})\), Displacements (in.), (CT)
Example 1: Edge Lift, (em=2.5ft, ym=0.752in.), Displacements (in.), (CT)
Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Displacements (in.)
Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Displacements (in.)
Example 1: Edge Lift (em=2.5, ym=0.752 in.), Moment, Mx (kips ft/ft) (CT)
Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Moment, Mx (kips ft/ft)
Example 1: Edge Lift ($e_m=2.5\text{ft}$, $y_m=0.752\text{in.}$), Moment, $M_x$ (kips ft/ft)
Example 1: Edge Lift (em=2.5, ym=0.752in.), Moment, My (kips ft/ft), (CT)
Example 1: Edge Lift (em=2.5 ft, ym=0.752 in.), Moment, My (kips ft/ft)
Example 1: Edge Lift (em=2.5ft, ym=0.752 in.), Moment, My (kips ft/ft)
Example 1: Edge Lift ($e_m=2.5$, $y_m=0.752\text{in.}$), Moment, $M_{xy}$ (kips ft/ft), (CT)
Example 1: Edge Lift ($e_m=2.5$, $y_m=0.752$in.), Moment, $M_{xy}$ (kips ft/ft), (CT)
Example 1: Edge Lift ($e_m=2.5\text{ft}$, $y_m=0.752\text{in.}$), Moment, $M_{xy}$ (kips ft/ft)
Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Moment, Mxy (kips ft/ft)
Example 1: Edge Lift (em=2.5, ym=0.752in.), Shear Force, Qx (kips/ft), (CT)
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Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Shear Force, Qx (kips/ft)
Example 1: Edge Lift ($em=2.5$, $ym=0.752\text{in.}$), Shear Force, $Q_y$ (kips/ft), (CT)

![Diagram showing a contour plot with axes labeled x-axis and y-axis. The plot represents shear force $Q_y$ with various values indicated by color gradients.]
Example 1: Edge Lift (em=2.5, ym=0.752in.), Shear Force, Qy (kips/ft), (CT)
Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Shear Force, Oy (kips/ft)
Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Shear Force, Qy (kips/ft)
SOIL VOLUME CHANGE
CHARTS

NATURAL RESOURCES
CONSERVATION SERVICE
U.S.D.A.
DATA BASE
(130,000 SAMPLES)
EXPANSIVE SOILS ZONES
(A. P. COVAR)

Any mineral plotting in this zone should be included in Zone I.

- Montmorillonite
  - PI = 0.90(LL-8)

- Mixed Minerals
  - PI = 0.85(LL-11)

- Illites
  - PI = 0.81(LL-14)

- Kaolinites
  - PI = 0.73(LL-20)

- Chlorites
  - PI = 0.68(LL-25)

- Halloysites

Upper Limit of Chart (PI=LL)

B-Line

U-Line

A-Line
EXPANSIVE SOIL VOLUME CHANGE GUIDE NUMBER (A. P. COVAR)

ZONE 1
EXPANSIVE SOIL VOLUME CHANGE GUIDE NUMBER

ZONE 2
EXPANSIVE SOIL VOLUME CHANGE GUIDE NUMBER
(A. P. COVAR)

ZONE 3
VOLUME CHANGE COEFFICIENT, $\gamma_h$

$\quad = \quad$  

PERCENT FINE CLAY $\quad \times \quad$  

VOLUME CHANGE GUIDE NUMBER
EDGE MOISTURE VARIATION DISTANCE,

$e_m$, ft
EDGE MOISTURE VARIATION DISTANCE

\( e_m (ft) \), Edge Moisture Variation Distance

\( \alpha (cm^2/sec) \), Unsaturated Diffusivity Coefficient

\( 10^{-2} e \), Edge Moisture Variation Distance

S, Slope of pF--vs--Water Content Curve

Percent Passing #200 Sieve (%)

PLASTICITY INDEX (PI, %)

LIQUID LIMIT (LL, %)

CENTER LIFT

EDGE LIFT

VOLUME CHANGE CoEFFICIENT

(\( \gamma_h \), Suction Compression Index)
EFFECT OF VERTICAL MOISTURE BARRIER
MOISTURE BARRIER

(T = 1.5 ft)

Depth of Perimeter Beam Below Ground Level or Depth of Vertical Moisture Barrier Below Ground Level, D', FT

Design Value of the Edge Moisture Variation Distance, e' m, ft.
MOISTURE BARRIER

\( (T = 2.0 \text{ ft}) \)

- Depth of Perimeter Beam Below Ground Level or Depth of Vertical Moisture Barrier Below Ground Level, \( D' \), FT
- Edge Moisture Variation Distance for Moisture Flow, \( e_m \), ft.

Design Value of the Edge Moisture Variation Distance, \( e'_m \), ft.
MOISTURE BARRIER

(T = 2.5 ft)

Depth of Perimeter Beam Below Ground Level or Depth of Vertical Moisture Barrier Below Ground Level, D', FT

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>6'</td>
<td>5.5'</td>
<td>5'</td>
<td>4.5'</td>
<td>4'</td>
<td>3.5'</td>
<td>3'</td>
<td>2.5'</td>
<td>2'</td>
<td>1.5'</td>
<td>1'</td>
</tr>
</tbody>
</table>

Edge Moisture Variation Distance for Moisture Flow, em, ft.

Design Value of the Edge Moisture Variation Distance, e'_m, ft.
DESIGN AIDS FOR SLABS ON EXPANSIVE SOILS