Numerical Analysis – Case Study

- 2D Plain-Strain FEM for longitudinal frame (C.L. D)
- Column properties were divided by tributary width of frame (Plain Strain model Limitation)
- Slab trip is half the distance on each side of frame to the next frame
- Cracked section properties of concrete elements were accounted for
- Backfill modeled using elasto-plastic Mohr Coulomb and a Hardening Soil Model (HSM)
  - HSM accounts for stress dependency of stiffness modulus
### Numerical Analysis – Case Study

#### Member Actual Cross Sectional Properties (inches)

<table>
<thead>
<tr>
<th>Member</th>
<th>Actual Cross Sectional Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>12 in thick wall</td>
</tr>
<tr>
<td>W2</td>
<td>16 in thick wall</td>
</tr>
<tr>
<td>C1</td>
<td>28 x 12</td>
</tr>
<tr>
<td>C2</td>
<td>28 x 14</td>
</tr>
<tr>
<td>C3</td>
<td>12 x 28</td>
</tr>
<tr>
<td>C4</td>
<td>14 x 28</td>
</tr>
<tr>
<td>Floor Slabs</td>
<td>A = 0.7273 ft²/ft</td>
</tr>
<tr>
<td></td>
<td>l = 0.3 ft⁴/ft</td>
</tr>
</tbody>
</table>

#### Numerical Model Properties Variation (E = 485,590 kip/ft²)

<table>
<thead>
<tr>
<th></th>
<th>EA (kip/ft)</th>
<th>EI (kip.ft²/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>485,590</td>
<td>30,350</td>
</tr>
<tr>
<td>W2</td>
<td>647,455</td>
<td>71,940</td>
</tr>
<tr>
<td>C1</td>
<td>36,353</td>
<td>12,370</td>
</tr>
<tr>
<td>C2</td>
<td>42,413</td>
<td>14,438</td>
</tr>
<tr>
<td>C3</td>
<td>36,353</td>
<td>2,272</td>
</tr>
<tr>
<td>C4</td>
<td>42,413</td>
<td>3,608</td>
</tr>
<tr>
<td>Floor Slabs</td>
<td>353,170</td>
<td>110,297</td>
</tr>
</tbody>
</table>
### Numerical Analysis – Case Study

#### Soil Model Properties

<table>
<thead>
<tr>
<th>Soil Model</th>
<th>Dry Density (pcf)</th>
<th>Internal Friction Angle (Degrees)</th>
<th>Dilatancy Angle (Degrees)</th>
<th>Elasticity Modulus $E_{ref}$ (ksf)</th>
<th>Elasticity Modulus $E_{oed}$ (ksf)</th>
<th>Elasticity Modulus $E_{50}$ (ksf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mohr Coulomb</td>
<td>110</td>
<td>38</td>
<td>8</td>
<td>648</td>
<td>720</td>
<td>N/A</td>
</tr>
<tr>
<td>Hardening Soil</td>
<td>110</td>
<td>38</td>
<td>8</td>
<td>N/A</td>
<td>720</td>
<td>800</td>
</tr>
</tbody>
</table>

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Mohr-Coulomb Model

- The Mohr-Coulomb yield condition is an extension of Coulomb's friction law to general states of stress.
- The full Mohr-Coulomb yield condition consists of six yield functions when formulated in terms of principal stresses.
- Six plastic potential functions are defined for the Mohr-Coulomb model.
  - Includes dilatancy angle.
Basic MC Model Parameters

- $E$, Young’s Modulus
  - Basic Stiffness modulus in elastic model
- $\nu$, Poisson’s Ratio
- $\phi$, Friction Angle
- $c$, Cohesion
- $\psi$, Dilatancy Angle
- $E_{\text{increment}}$, to account for increase in stiffness with depth
Hardening Soil Model

- Advanced Model which yield surface incorporates shear and compression hardening
  - Yield surface is not fixed in principal
  - Shear Hardening: Used to model irreversible strains due to primary deviatoric loading
  - Compression Hardening: Used to model irreversible plastic strains due to primary compression

- Supersedes hyperbolic model by using plasticity theory, by including soil dilatancy, and by introducing a yield cap
Basic Characteristics of H.S. Model

- **Input Parameter** $m$
  - Stress dependent stiffness according to the power law

- **Input Parameter** $E_{50}^{ref}$
  - Plastic Straining due to primary deviatoric loading

- **Input Parameter** $E_{oed}^{ref}$
  - Plastic straining due to primary compression

- **Input Parameter** $E_{ur}^{ref}, \nu_{ur}$
  - Elastic unloading/reloading

- Failure according to Mohr-Coulomb ($c, \phi$ and $\psi$)
Basic Characteristics of H.S. Model

Yield Surface in p-q Plane

Total Yield Contour in Principal Space
Soil Parameters

Unfortunately, nearly all test had to be abandoned due to presence of large boulders
Soil Parameters (Cont.)

- One Dilatometer and Two Pressure-meters were damaged. Only 1 PMT was performed.

Miscellaneous Uncontrolled Fill
- Composed of shot rock intermixed with brown medium to fine sand with varying amount of silt and gravel. Large boulders were common.
Soil Exploration in Pictures
Soil Exploration in Pictures
Soil Exploration in Pictures

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