Modeling Embankment Induced Lateral Loads on Deep Foundations

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Problem

- Problem based on Failure of East Bound Patapsco Avenue Bridge – Baltimore, MD 1990
- Bridge approximately 50 ft from a 70-90 ft Landfill Construction
- Landfill Construction Caused Excessive Lateral Movement in 12” Concrete Piles and Piles and Bridge Deck Separated at the Top
Approximate Sketch

Patapsco Avenue Bridge
Baltimore, MD

LAND fill
Unit Wt 100 pcf

Sand fill
Unit Wt 120 pcf

Soft Silt/Clay
Unit Wt 100 pcf (dry) 125 pcf (wet)

Hard Clay
Unit Wt 135 pcf

Bridge supported on .12" square concrete piles
Solutions

• Classical Approach
  – Linear Elastic Stress Distribution
  – “Plastic Flow”

• Finite Element Method
  – Simulations with FEM Program
    HOPDYNE  (Anandarajah, 1990)
Classical Approach

• Elastic Stresses on Piles

\[ v = I \cdot w \cdot H \]

- \( w \) - unit weight = 100 pcf
- \( H \) - Height of embankment
- \( I \) - Horizontal stress influence factor = 0.004 \( z \) (at 50 ft)
- \( z \) - Depth
- \( v \) - Horizontal Stress

\( v = 1.9 \text{ ksf} \) @ 60 ft

triangular distribution

\[ \rightarrow \text{Not Realistic} \]

\[ \rightarrow \text{Not Enough Stresses to Cause Pile Failure} \]
Classical Approach

• Plastic Flow of Soft Soil

\[ c \text{ - Shear Strength (Cohesion)} \]

Use Residual Shear strength of 220 to 400 psf on both sides of the pile.

Shear stress on concrete due to this loading 1.2 ksf or more

\[ \Rightarrow \text{Enough to Cause Pile Failure} \]
Failure of Pile

100'

80'

70'

Industrial Waste

See Table

Sand seams (p=0)

WT

Silty Sand

Soft Clay

Stiff Clay

Loading: Construct the landfill in one year

Consolidate for another year
Simulations Using

HOPDYNE (Anandarajah, 1990)

Fully-Coupled Analysis with $k = 1.0 \times 10^{-12}$ ft/s for clays and $k = 1.0 \times 10^{2}$ ft/s for sands
What Constitutive Models to Choose?

Nonhardening, Zero dilation: $E, \nu, \phi, c$

Nonhardening, Controlled dilation: $E, \nu, \phi, c, d$

Hardening, Controlled dilation: $E, \nu, \phi, c, d, \gamma_1, \gamma_2$

$\lambda, \kappa, M, OCR$

$\lambda, \kappa, M, h, OCR$

$\lambda, \kappa, M, h, OCR, A_{init}$
Failure of Pile

DP: Drucker-Prager
ABS: Anisotropic Bounding Surface Clay Model
(Anandarajah and Dafalias, 1986)
CC: Modified Cam-Clay
EE: Linear Elastic

See Table 100'

<table>
<thead>
<tr>
<th>Analysis Types</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td></td>
<td>All elastic</td>
<td>CC with M=0.6</td>
<td>ABS with M=0.6</td>
<td>CC with M=1.2</td>
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<tr>
<td></td>
<td>OCR=1</td>
<td>OCR=1, A=1.3</td>
<td>OCR=10</td>
<td>OCR=10</td>
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Horizontal Stresses in Soil Near the Pile

- **Initial**
- **Elastic**

- Depth
- Horizontal Effective Stress
Horizontal Stresses in Soil Near the Pile

- Depth
- Horizontal Effective Stress

Lines:
- CC
- Elastic
- Initial
Horizontal Stresses in Soil Near the Pile

- **Initial**
- **Elastic**
- **All Stiff**
- **ABS**
- **CC**
M003-1: \( z = 10 \) to 60’ ABS with \( M=0.6 \) and \( OCR=1 \):  Deformation

(Click on the picture)
M003-1: $z = 10$ to $60'$ ABS with $M=0.6$ and $OCR=1$: Pore Pressure
M003-1: \( z = 10 \) to \( 60' \) ABS with \( M=0.6 \) and OCR=1: Shear Strain
Soil Failure: Remove Sand Seams Increase Construction Rate

DP: Drucker-Prager
ABS: Anisotropic Bounding Surface Clay Model
(CC: Modified Cam-Clay
EE: Linear Elastic

Analysis Types

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Sand seams (p=0)
M003-1: $z = 10$ to $60'$ ABS with $M=0.6$ and $OCR=1$: Deformation

M003-1: z = 10 to 60’ ABS with M=0.6 and OCR=1: Pore Pressure

(click on the picture)
M003-1: $z = 10$ to $60'$ ABS with $M=0.6$ and $OCR=1$: Shear Strain

(click on the picture)
Horizontal Stresses in Soil Near the Pile

- **Slow Loading with Sand Seams**
- **No Sand Seams**
- **Fast Loading**

**Depth**

**Horizontal Effective Stress**

3
Comparison of Deformation

Slow Loading with Sand Seams

Fast Loading with no Sand Seams
On a Laptop? Forget it!
What happens to forces on piles when DP is used for the middle soft layer?

Horizontal Stresses in Soil Near the Pile

![Graph showing horizontal stresses in soil near the pile, comparing Initial, ABS with M=0.6, and DP with M=0.6 conditions. The graph plots depth against horizontal effective stress.]
What happens to forces on piles when WT is lowered to the bottom of soft layer?

Horizontal Stresses in Soil Near the Pile

![Graph showing horizontal stresses in soil near the pile.](image_url)
While the difference is not too significant in this case, the results suggest that, in general, quantitative prediction may depend on the choice of the constitutive model. The availability of a model to simulate a certain effect (e.g., anisotropy) allows that effect to be at least parametrically investigated.
USE OF AN MSE WALL TO SUPPORT A LANDFILL

Industrial Waste

MSE Wall

Soft Clay

(step 10: Display Vectors of displacements, |displacements| factor 5.8554. Deformation (\times 0.04424): displacements of TIME ANALYSIS, step 10.)
Advanced Numerical Modeling
Finite Element Method

• Tremendous Potential in Understanding the Problem

• Revolutionize Geotechnical Design and Analysis

• Verification is needed before using them for Quantitative Predictive Purposes
Final Deformed Configuration

Final Deformed Configuration (without displacement vectors)

Deformation (x6.04424): displacements of TIME ANALYSIS, step 140.

(click on the picture)
Pore Pressure Response

(step 20)
Contour Fill of porepressures.
Shear Strain Distribution

(click on the picture)
Fast Construction

Slow Construction

Fast Construction
Horizontal displacement of A

Fast Construction

Slow Construction