2-D Soil-Structure Interaction Analysis and Its Application for 3-D Structural Designs

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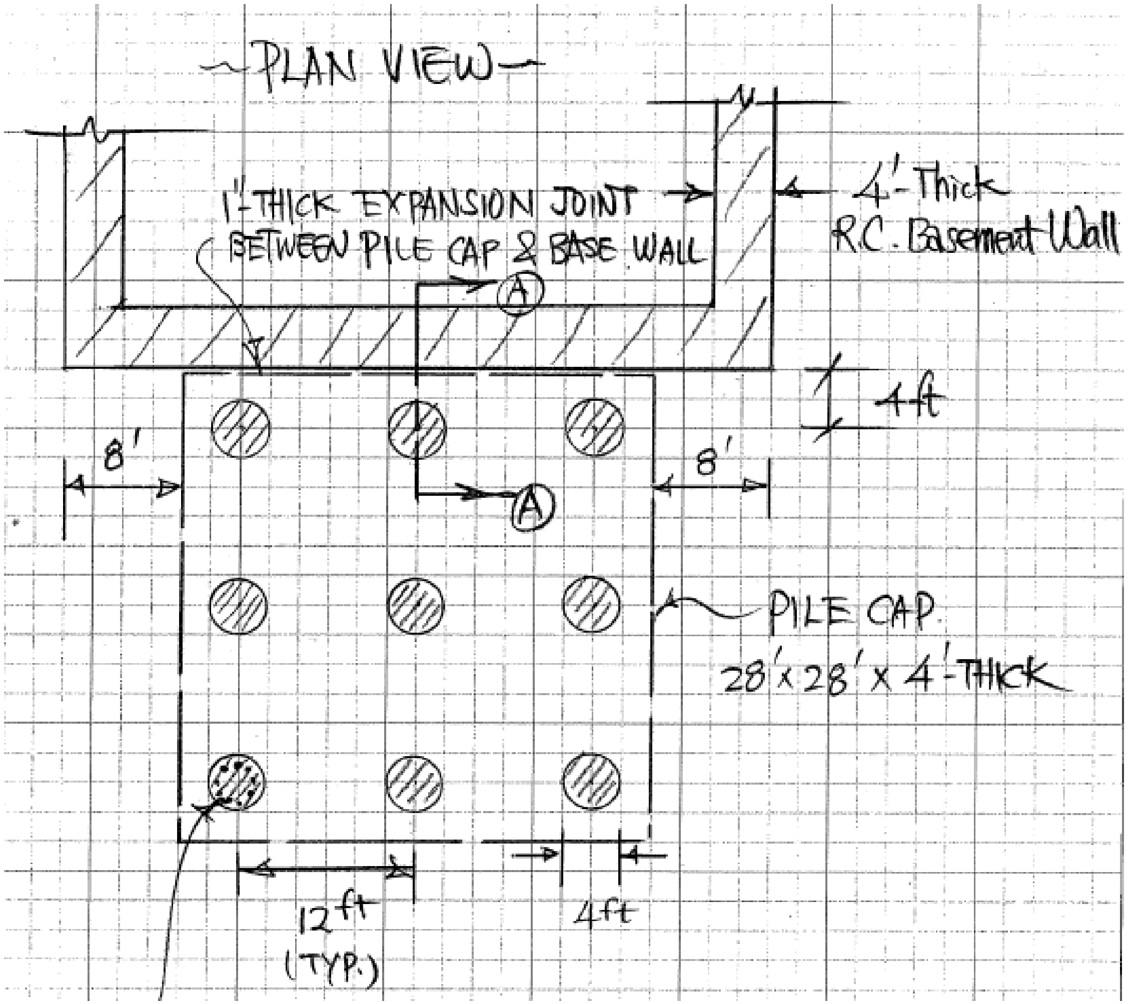
Presentation Outline

- 2-D LPILE Soil-Pile Interaction Analysis

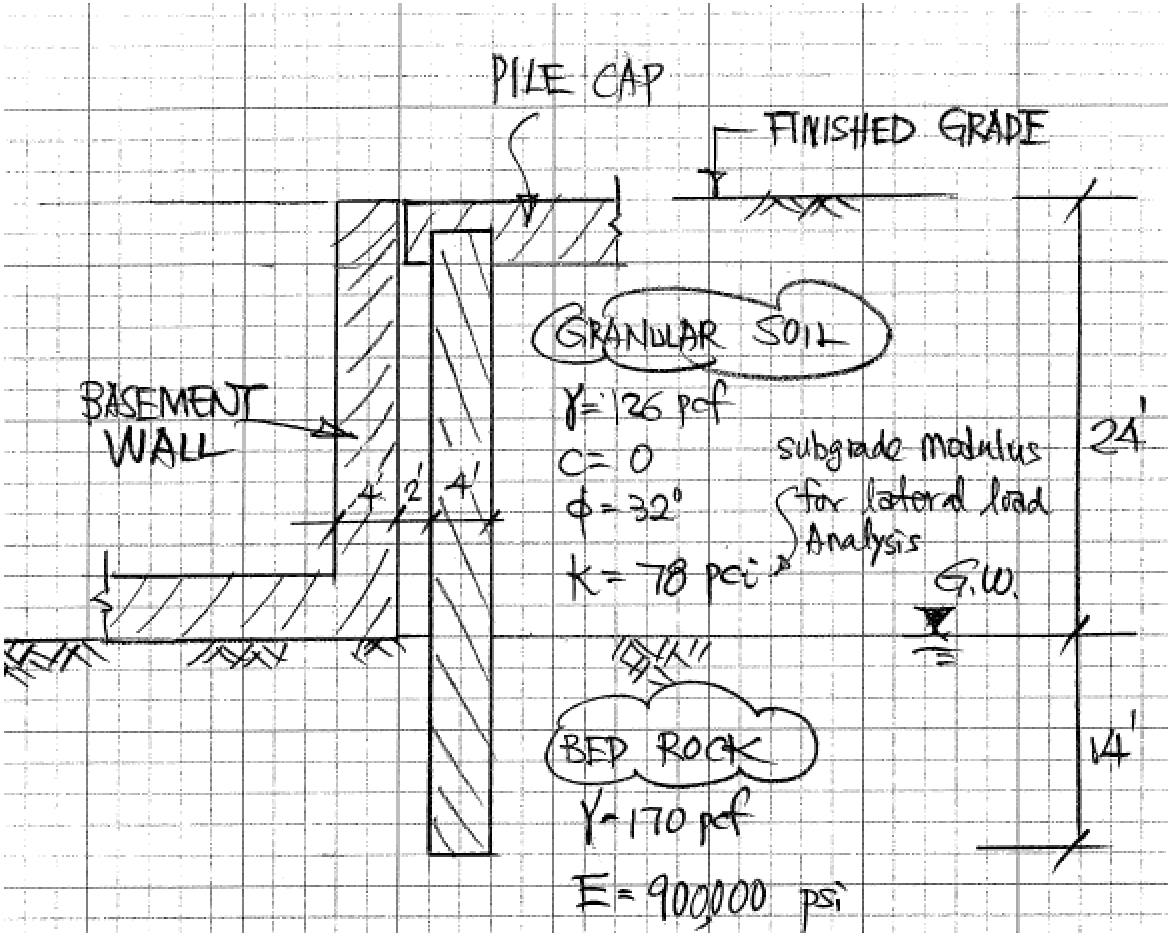
  - Evaluation of group effects;
  - Evaluation of boundary conditions due to close proximity of the drilled shafts to adjacent existing subsurface structures (boundary effects)

- Application of 2-D LPILE Results for 3-D Structural Modeling

Example of Site Configurations



Example of Site Configurations



Pile Group Effects
Subject to Lateral Loading

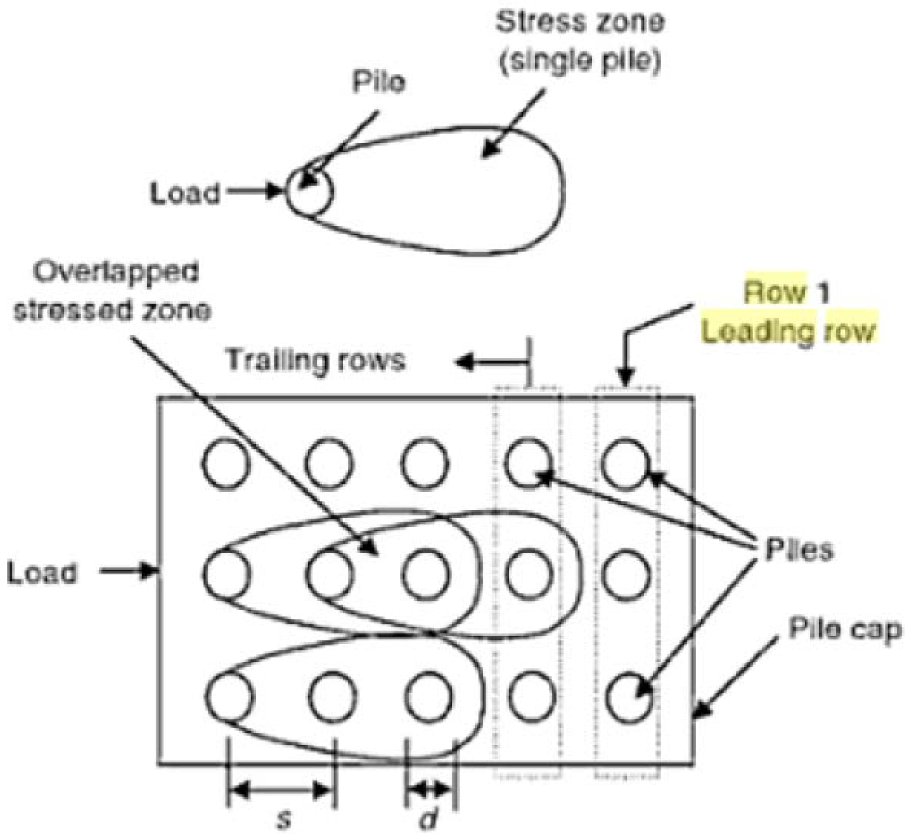
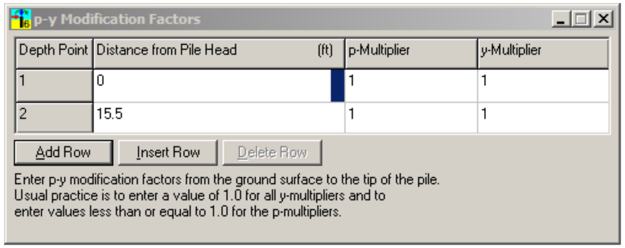


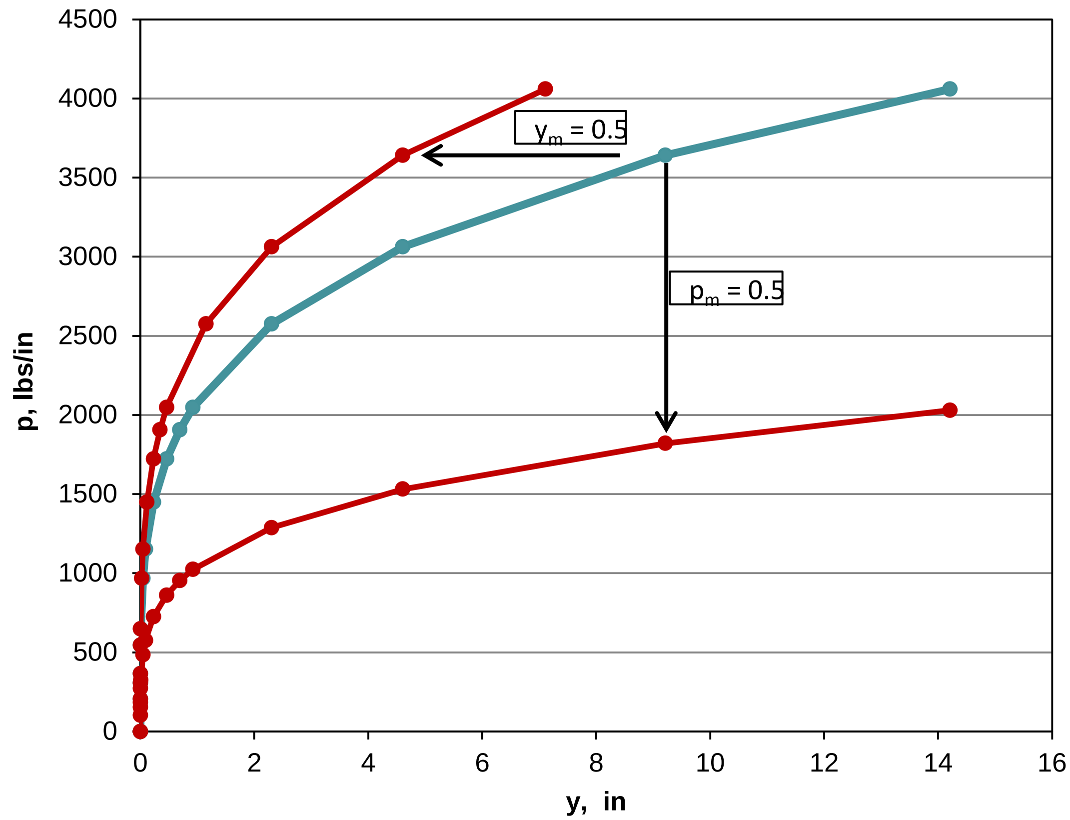
FIGURE 5.50 Typical stress zones for pile foundations under lateral load.

2D LPILE Analysis – p-y Curve Modification

p-y modification factors:

- p-multiplier (p_m)
- y-multiplier (y_m)

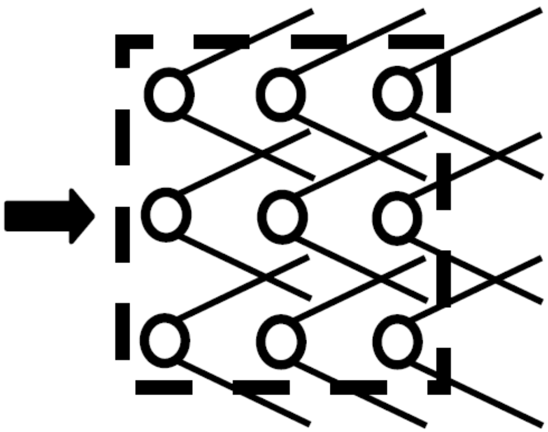




p-Multipliers
for Pile Group w/ Constant Spacing

Reference	Group Size	Pile Sp.	*p*-multipliers (by row) 1	2	3	4
Meimon (1986)	3x2	3d	0.9	0.5	-	-
Brown (1987)	3x3	3d	0.7	0.6	0.5	-
Brown (1988)	3x3	3d	0.8	0.4	0.3	-
Townsend (1997)	4x4	3d	0.8	0.7	0.3	0.3
Rollins (1998)	3x3	3d	0.6	0.4	0.4	-

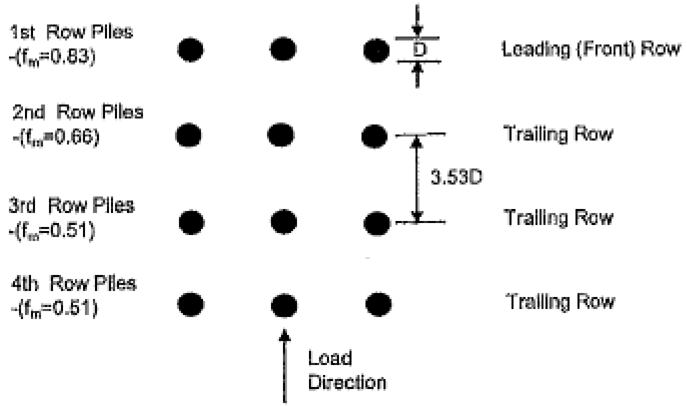
Table 1: Summary of *p*-multipliers based on previous full-scale lateral pile group tests. (Modified from Rollins et al., 2002)



Ref.	Grp Size	Pile Sp.	*p*-multipliers (by row) 1	2	3	4	5	6
McVay (1995)	3x3	3d	.65	.45	.35	-	-	-
	3x3	3d	.80	.45	.30	-	-	-
	3x3	5d	1.0	.85	.70	-	-	-
McVay (1995)	3x3	3d	.80	.40	.30	-	-	-
	3x4	3d	.80	.40	.30	.30		
	3x5	3d	.80	.40	.30	.20	.30	
	3x6	3d	.80	.40	.30	.20	.20	.30
	3x7	3d	.80	.40	.30	.20	.20	.20
Garnier (1998)	1x2	2d	-	.52	-	-	-	-
	1x2	4d	-	.82	-	-	-	-
	1x2	6d	-	.93	-	-	-	-

Table 2: Summary of *p*-multipliers based on previous centrifuge tests. (Modified from Rollins, et al., 2002)

2D LPILE Analysis – p-Multiplier



For the first (leading) row piles

$$f_m = 0.26 \ln(S/D) + 0.5 \leq 1.0$$

For the second row

$$f_m = 0.52 \ln(S/D) \leq 1.0$$

For the third and higher row piles

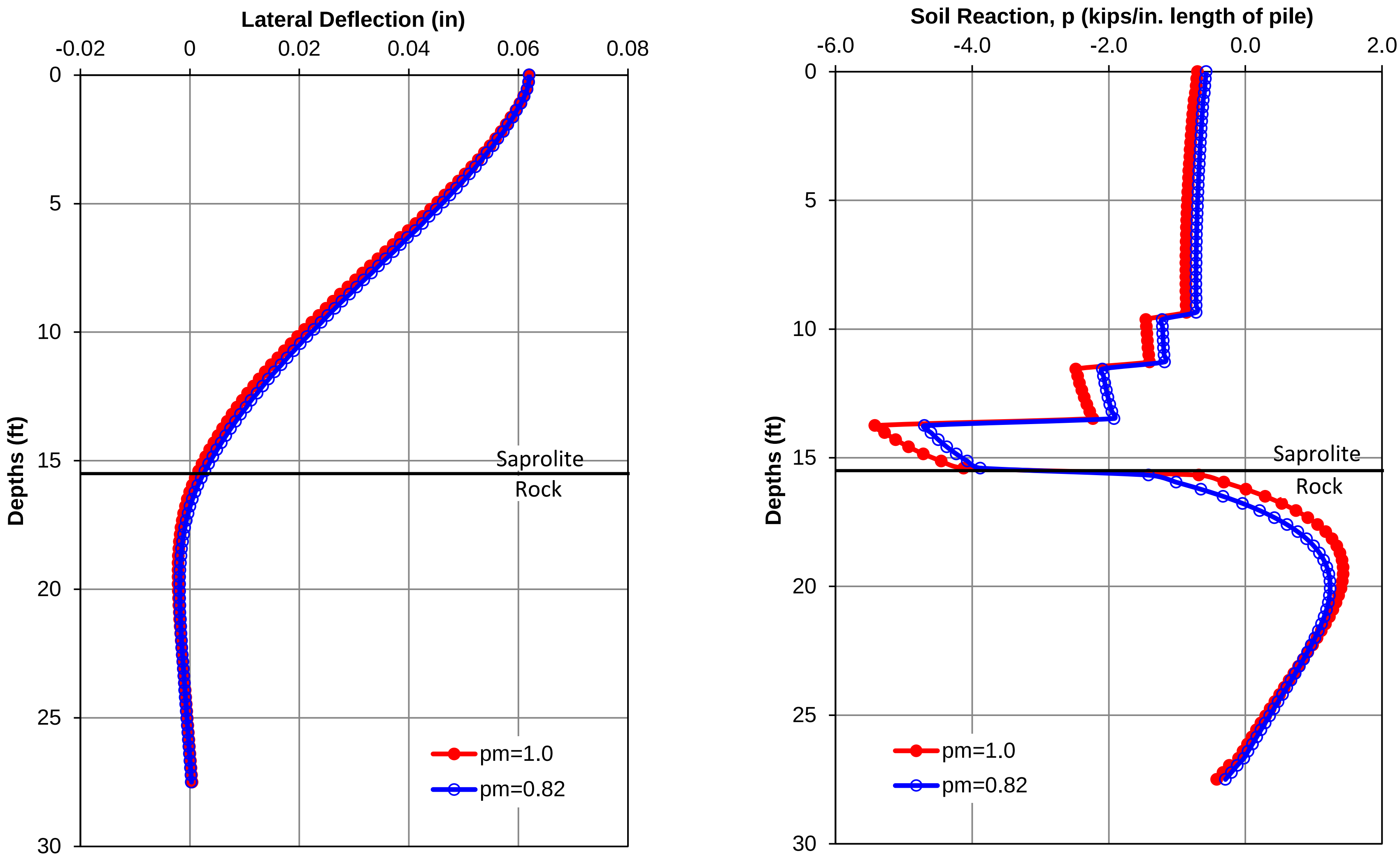
$$f_m = 0.60 \ln(S/D) - 0.25 \leq 1.0$$

In case of caissons spacing non-uniformly, the following rules are adopted in utilizing the above equations:

- For caissons at the first and second rows, the S-value is taken as the distance between these two rows;
- For caissons at the third row, the S-value is taken as the distance to the second row caisson located in front of it.

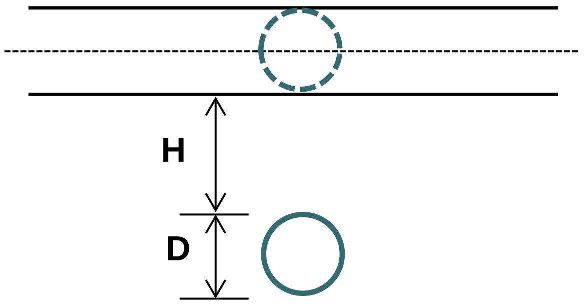
Reference: Rollins, et al. (2006). "Pile Spacing Effects on Lateral Pile Group Behavior: Analysis," Journal of Geotechnical and Geoenvironmental Engineering, Vol. 132, No. 10, October 1, pp. 1272-1283.

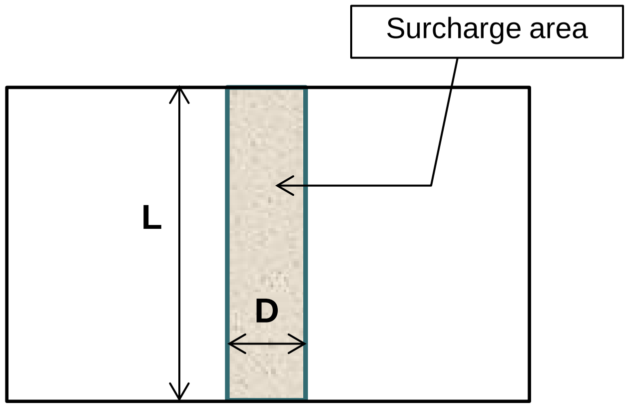
2D LPILE Analysis – p-Multiplier



2D LPILE Analysis – y-Multiplier

- Calculate the far-field caisson movement; with H= (6.8) D
- Calculate the near-field caisson movement; based on actual edge-to-edge clearance between caisson and basement.
- How to calculate the Caisson movement?





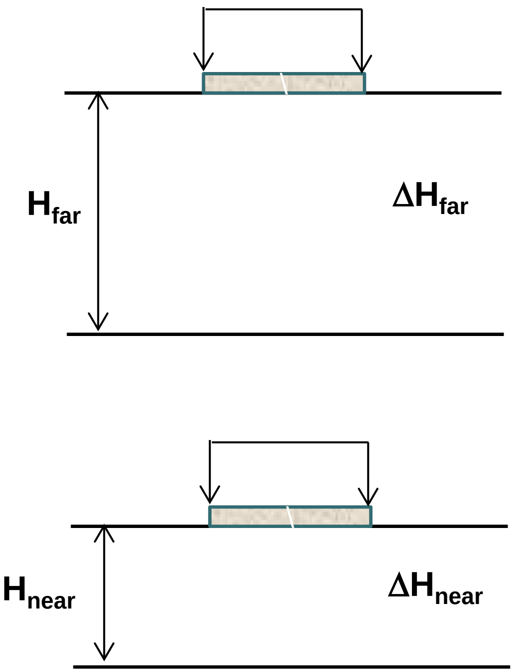
2D LPILE Analysis – y-Multiplier

- The caisson movement is calculated as settlement of the loaded rectangular footing:

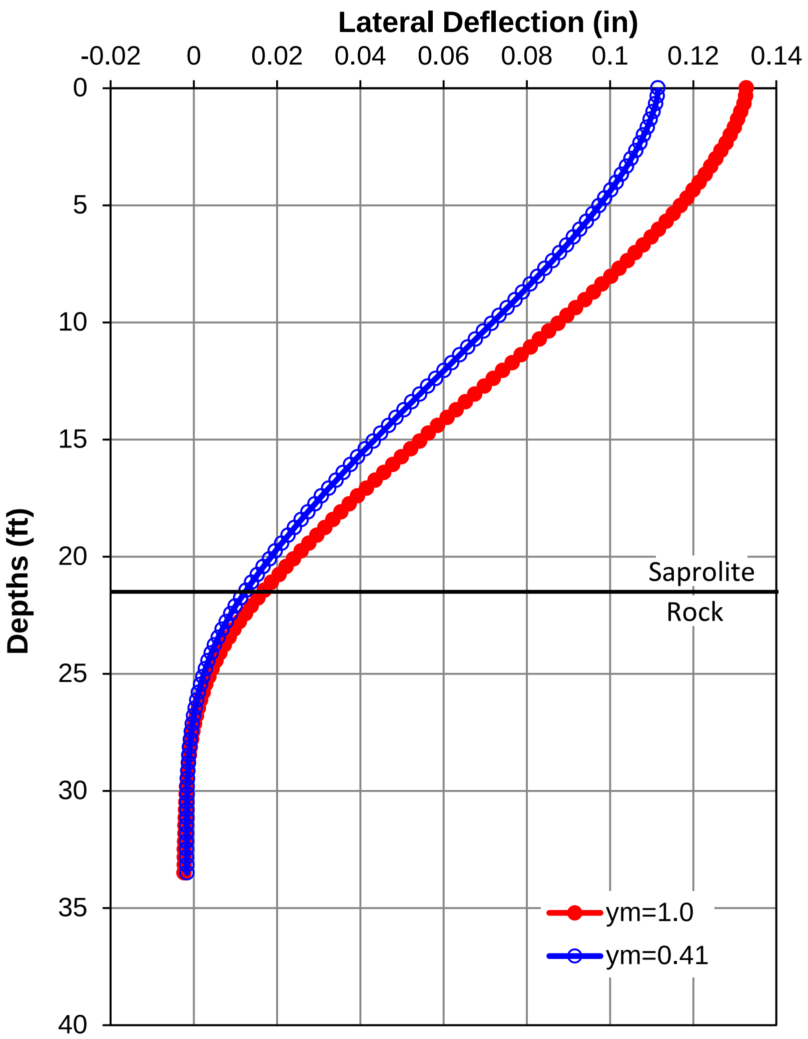
$$\Delta H = q_0 \frac{1-\mu^2}{E_s}\left(I_1 + \frac{1-2\mu}{1-\mu} I_2\right) I_F$$

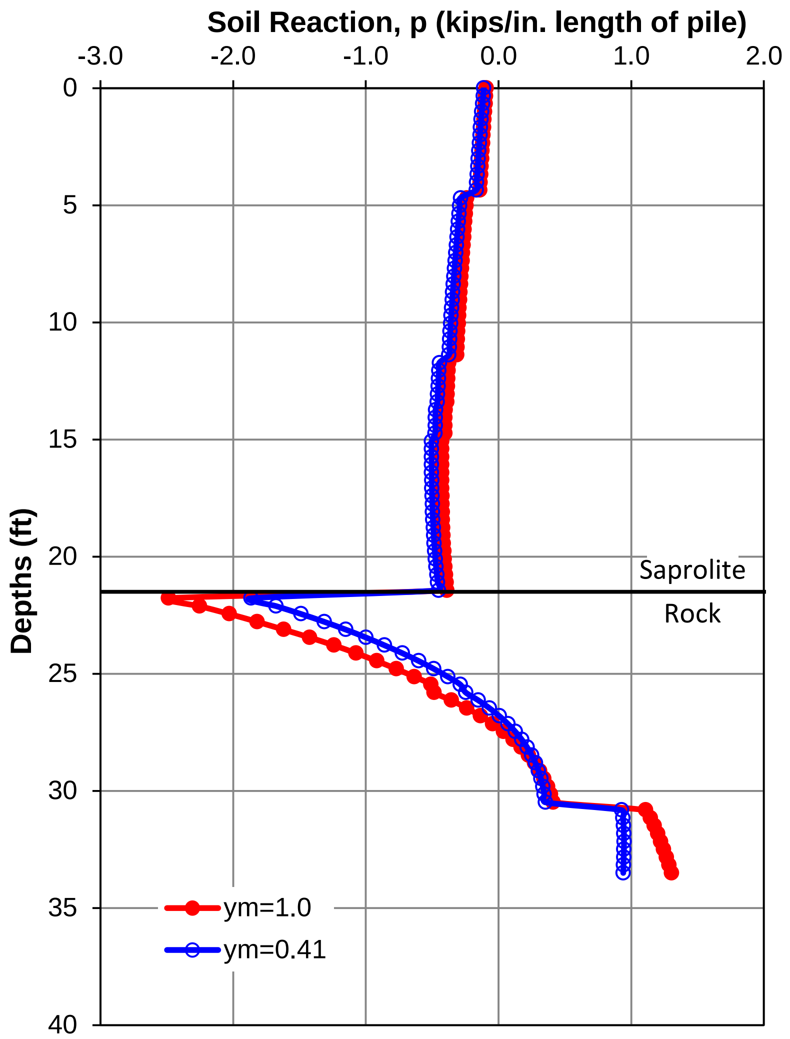
The influence factors I_1 and I_2 can be computed using the Steinbrenner equations.

- **The ratio of the near-field to the far-field movement is applied as a "<u>y-multiplier</u>".**



2D LPILE Analysis – y-Multiplier





3-D Soil-Pile Interaction

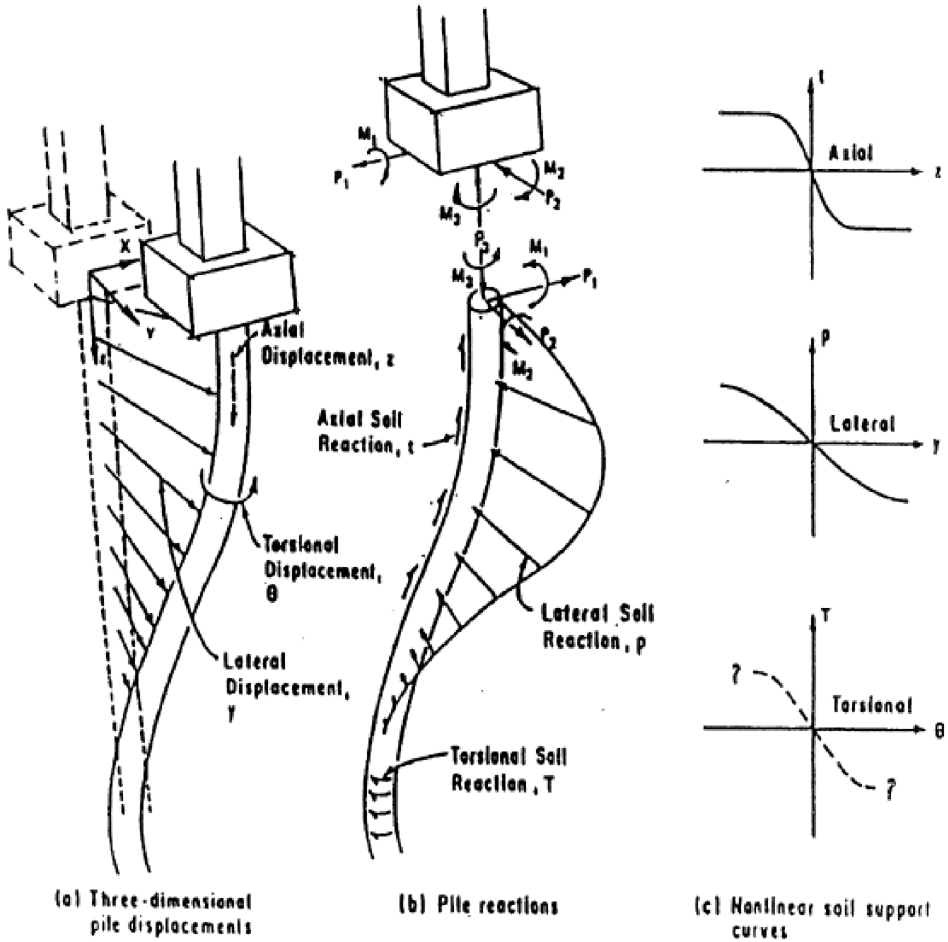
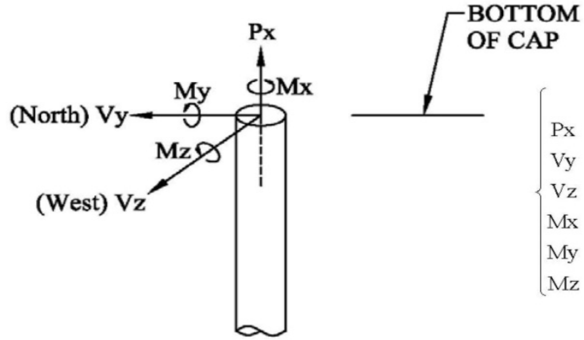


Fig. 1.2 Three dimensional soil-pile interaction (after Bryant, 1977)

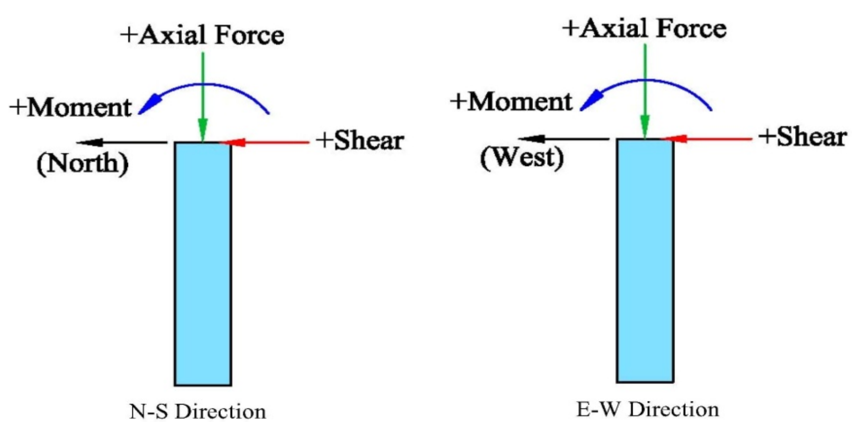
Springs Coordinates & Stiffness Matrix

- GTSTRUDL uses a 3-dimensional <u>global</u> coordinate system
- Spring outputs from LPILE are based on 2-dimensional <u>local</u> coordinate system



$$\begin{array}{c|cccccc} & Px & Vy & Vz & Mx & My & Mz \\ \hline Px & K22 & 0 & 0 & 0 & 0 & 0 \\ Vy & 0 & K11 & 0 & 0 & 0 & K16 \\ Vz & 0 & 0 & K33 & 0 & K34 & 0 \\ Mx & 0 & 0 & 0 & K55 & 0 & 0 \\ My & 0 & 0 & K43 & 0 & K44 & 0 \\ Mz & 0 & K61 & 0 & 0 & 0 & K66 \end{array} \times \begin{Bmatrix} \text{Disp.} \\ \Delta x \\ \Delta y \\ \Delta z \\ \theta x \\ \theta y \\ \theta z \end{Bmatrix} = \begin{Bmatrix} \text{Force} \\ Px \\ Vy \\ Vz \\ Mx \\ My \\ Mz \end{Bmatrix}$$

(a) For GTStrudl Structural Modeling



$$\begin{bmatrix} K22 & K23 \\ K32 & K33 \end{bmatrix}$$

(b) For LPILE Analyses with Horizontal Loading in N-S & E-W Directions

Springs Coordinates & Stiffness Matrix

- Conversion for using LPILE stiffness values for GTSTRUDL analyses.

Stiffness Parameters			
L-Pile Outputs	**GTStrudl Inputs**	**Description**	**Notes**
K22 (south-north)	K11	Longitudinal lateral loading stiffness, (lb/in)	
K33 (south-north)	K66	Longitudinal moment stiffness, (lb-in/rad)	
K32 (south-north)	K61	Longitudinal moment cross-couple term, (lb-in/in)	
K23 (south-north)	K16	Longitudinal lateral loading cross-couple term, (lb/rad)	
K22 (east-west)	K33	Transverse lateral loading stiffness, (lb/in)	
K33 (east-west)	K44	Transverse moment stiffness, (lb-in/rad)	
K32 (east-west)	K43	Transverse moment cross-couple term, (lb-in/in)	
K23 (east-west)	K34	Transverse lateral loading cross-couple term, (lb/rad)	
-	K22	Axial loading stiffness, (lb/in)	Not given by L-Pile.
-	K55	Torsional stiffness, (lb-in/rad)	Not given by L-Pile.

Conclusion

- In 2-D LPILE soil-pile interaction analysis, group effects and boundary effects can be considered by using p-y modification factors (p-multiplier or y-multiplier);
- Spring values from 2-D LPILE analysis can be used for the 3-D structural model, which greatly saves the computational time and cost for the project.

Questions & Discussion