Soil–Structure–Interaction in Liquefied Grounds and Countermeasures: Lessons from Numerical Studies

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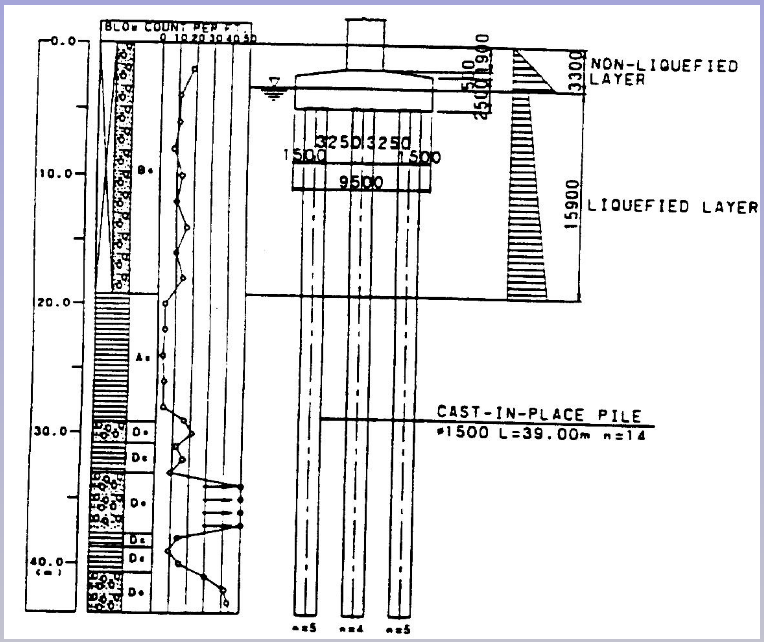
Introduction

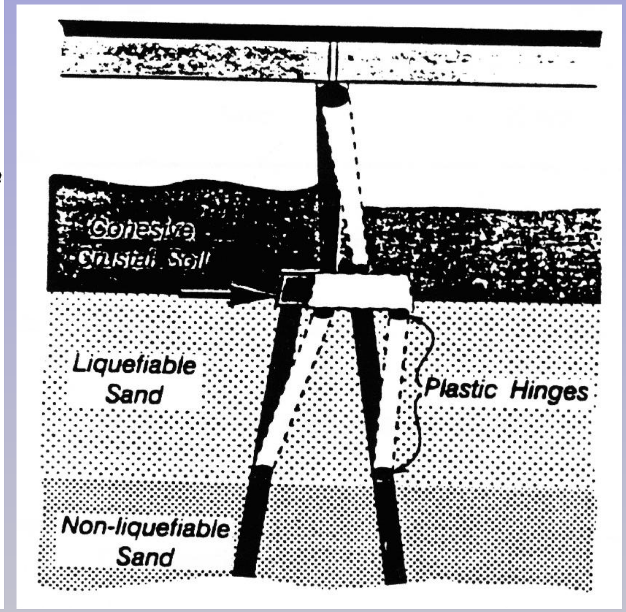
- Dynamic effects (shaking)

- Kinematic effects (lateral spreading)

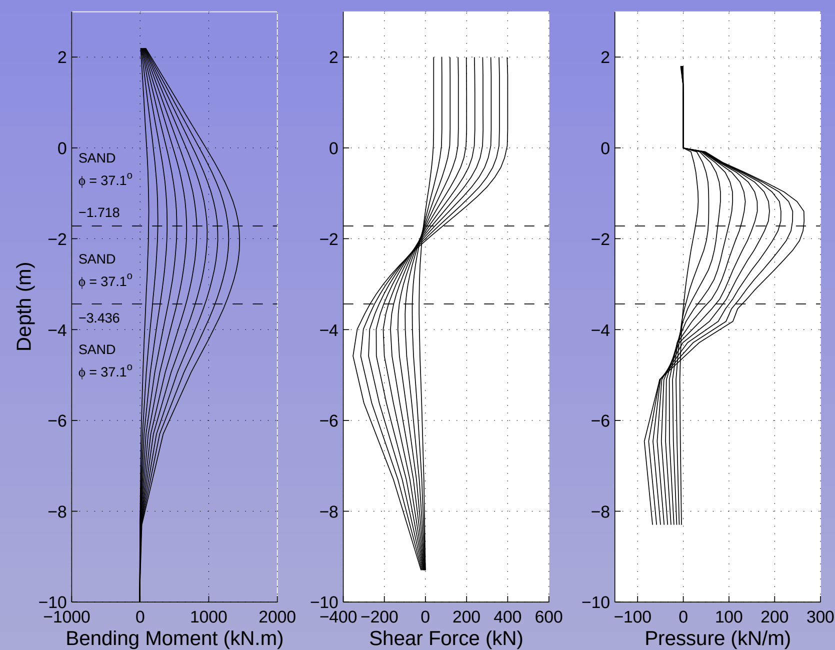
State of Practice (Art)

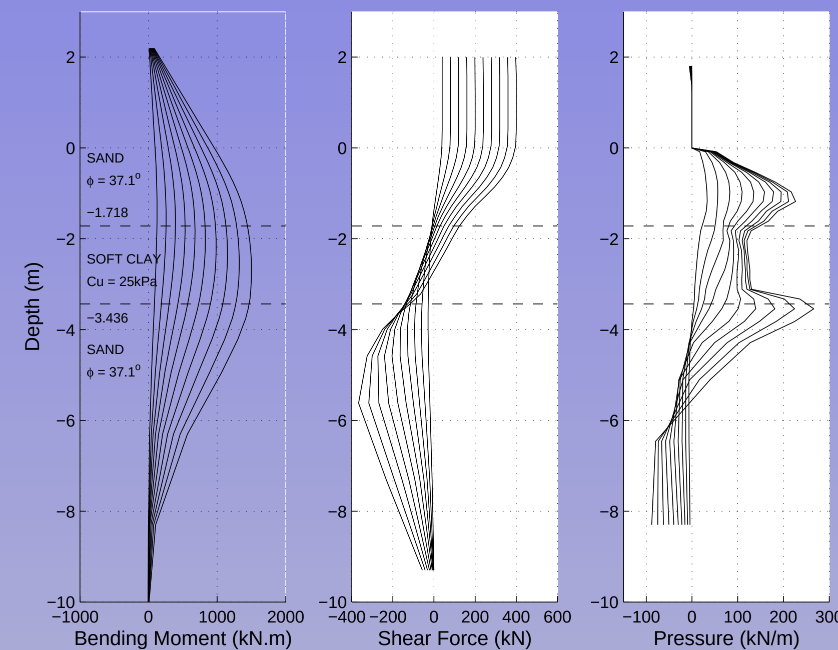
- **Scaled p–y spring approach**. (Suggested by old Japanese specifications for highway bridges (Japanese Road Association [3]), by the Architectural Institute of Japan [1], by Liu and Dobry [5], by Caltrans (Boulanger et al. [2] and Wilson et al. [8]), Wang et al. [7] and Lok and Pestana [6]: OK if for non–liquefying problems and gives consistent results using a range of computer platforms provided that: (a) appropriate p–y curves are used; (b) consistent radiational damping is implemented; and (c) appropriate gaping mechanics is used. **However, for liquefied grounds this approach does not provide consistent results**.)
- **Limit equilibrium**.This approach is adopted by the latest Japanese specifications for highway bridges (Japanese Road Association [4]). For example, Shin–Shukugawa Bridge was was designed using this methodology and (eg. Yokoyama et al. [9]). Land Road Bridge, (1987 Edgecumbe earthquake, New Zealand), barely made it. **Need to assume actual failure kinematics a–priori?**

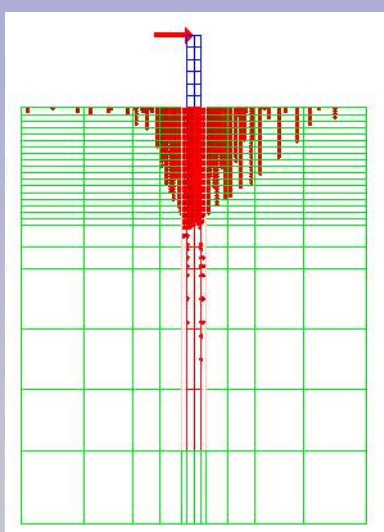


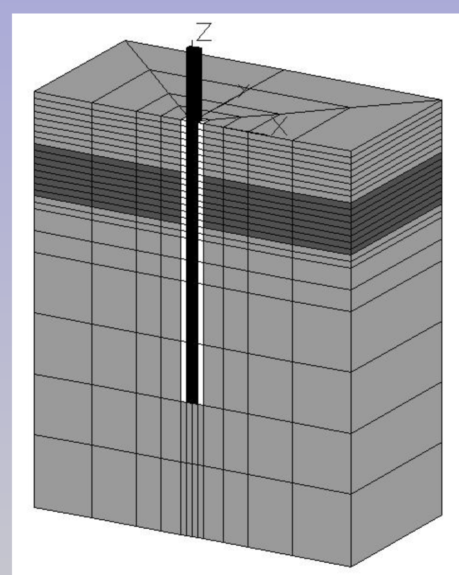


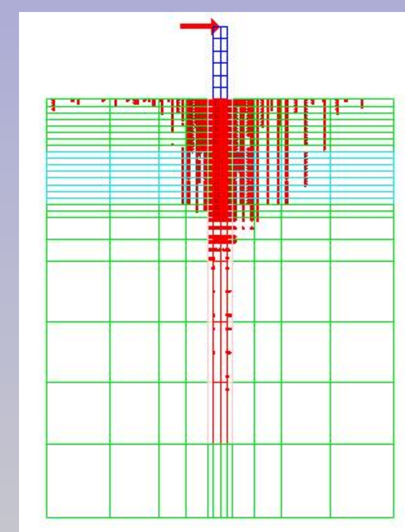
Single Pile in Layered Soils



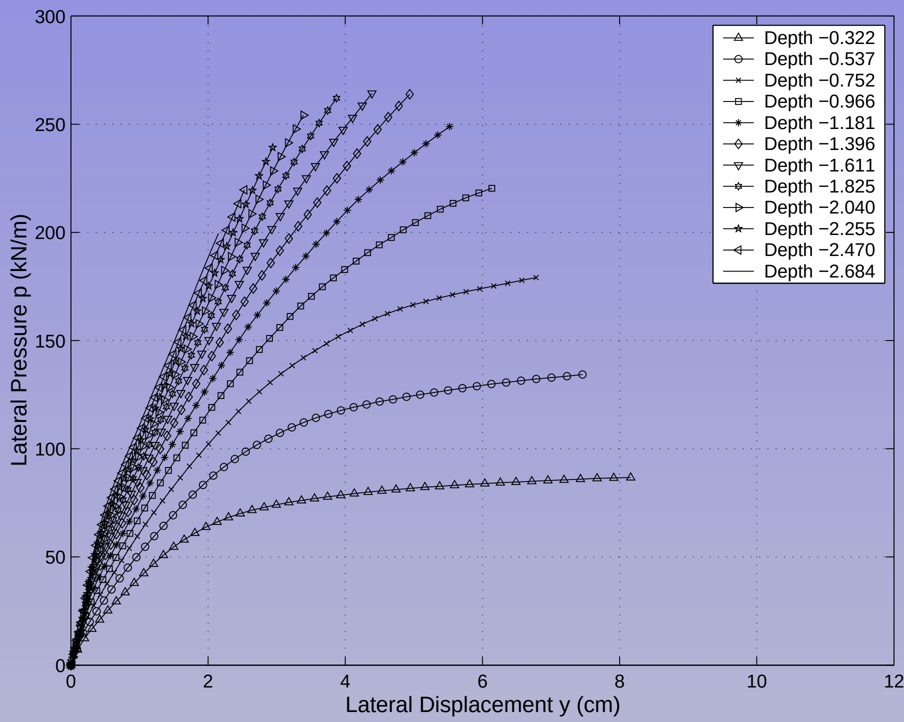


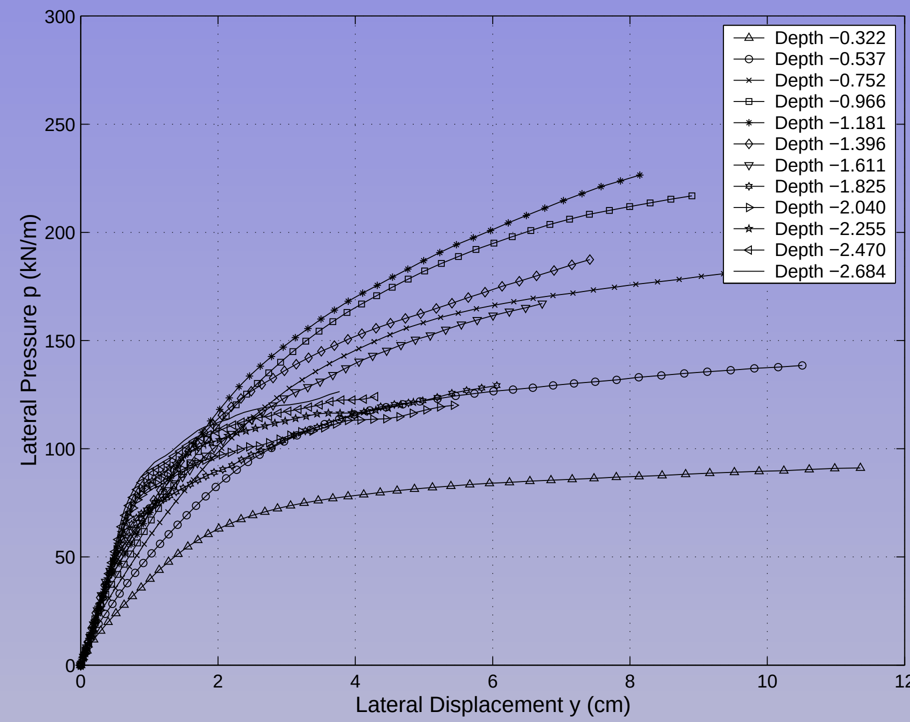






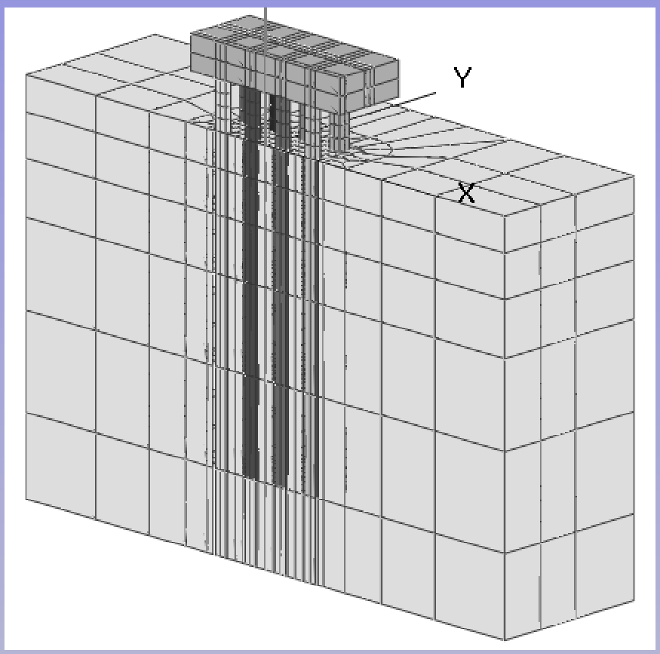
$p-y$ Response for Single Pile in Layered Soils

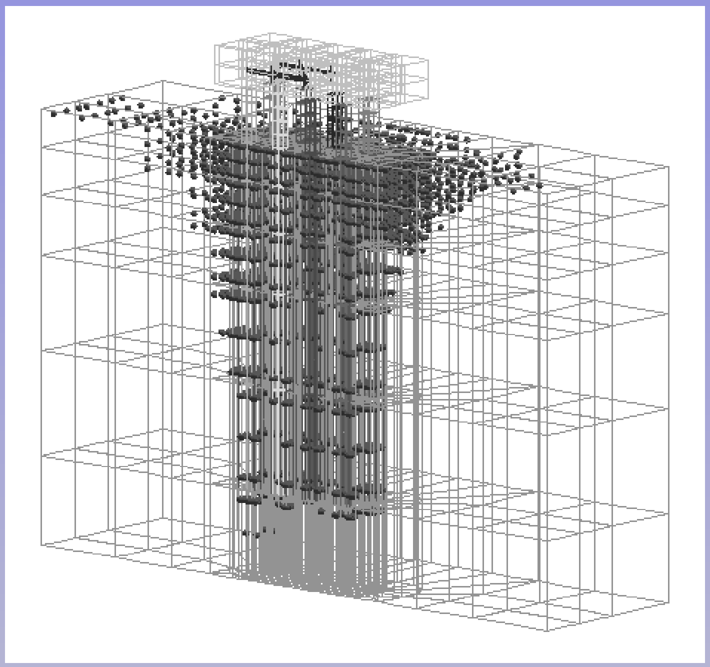




- Influence of soft layers propagates to stiff layers and vice versa
- Can have significant effects in soils with many layers

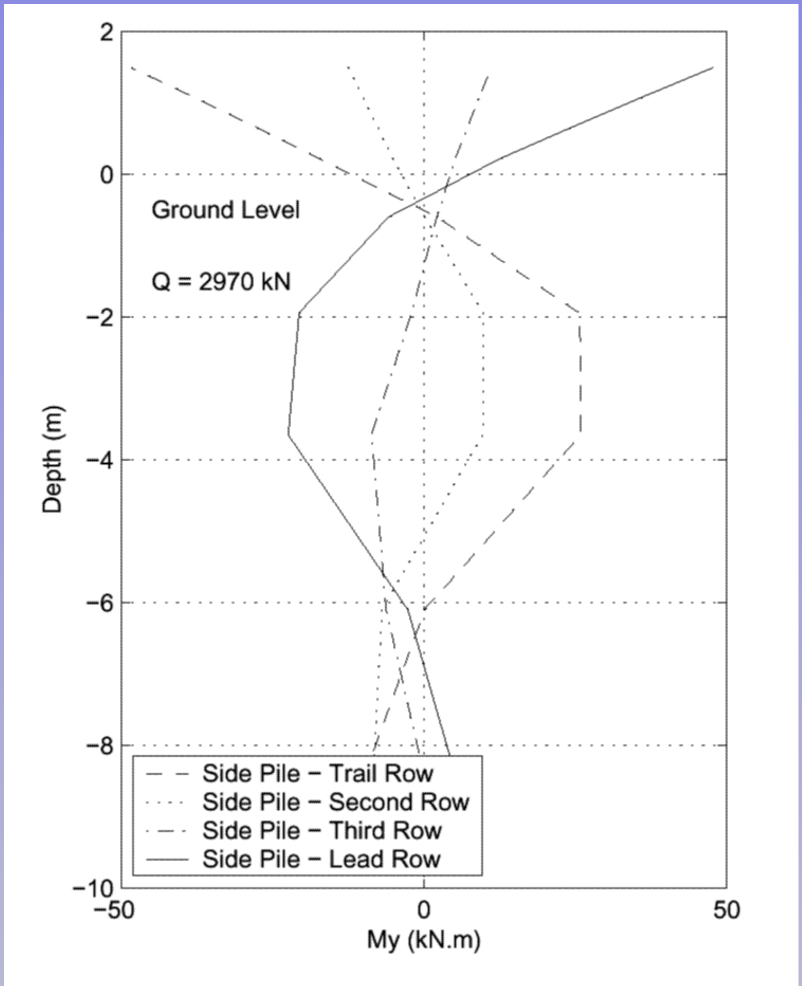
Pile Group Simulations

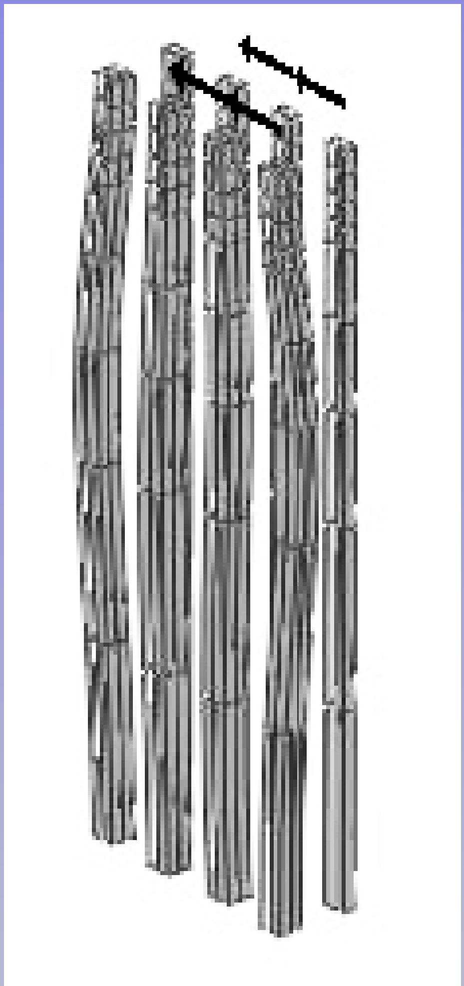




- 4x3 pile group model and plastic zones

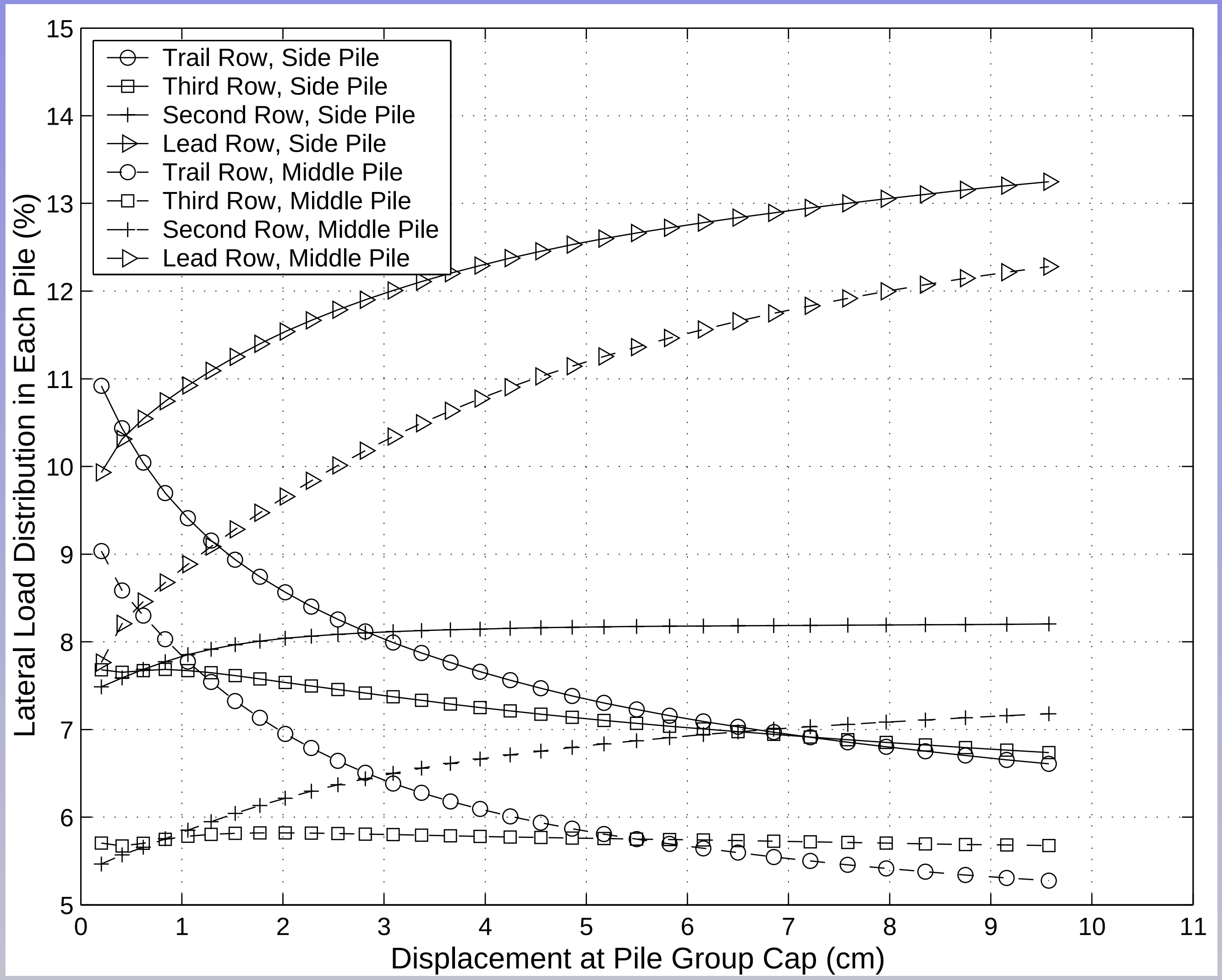
Out of Plane Effects



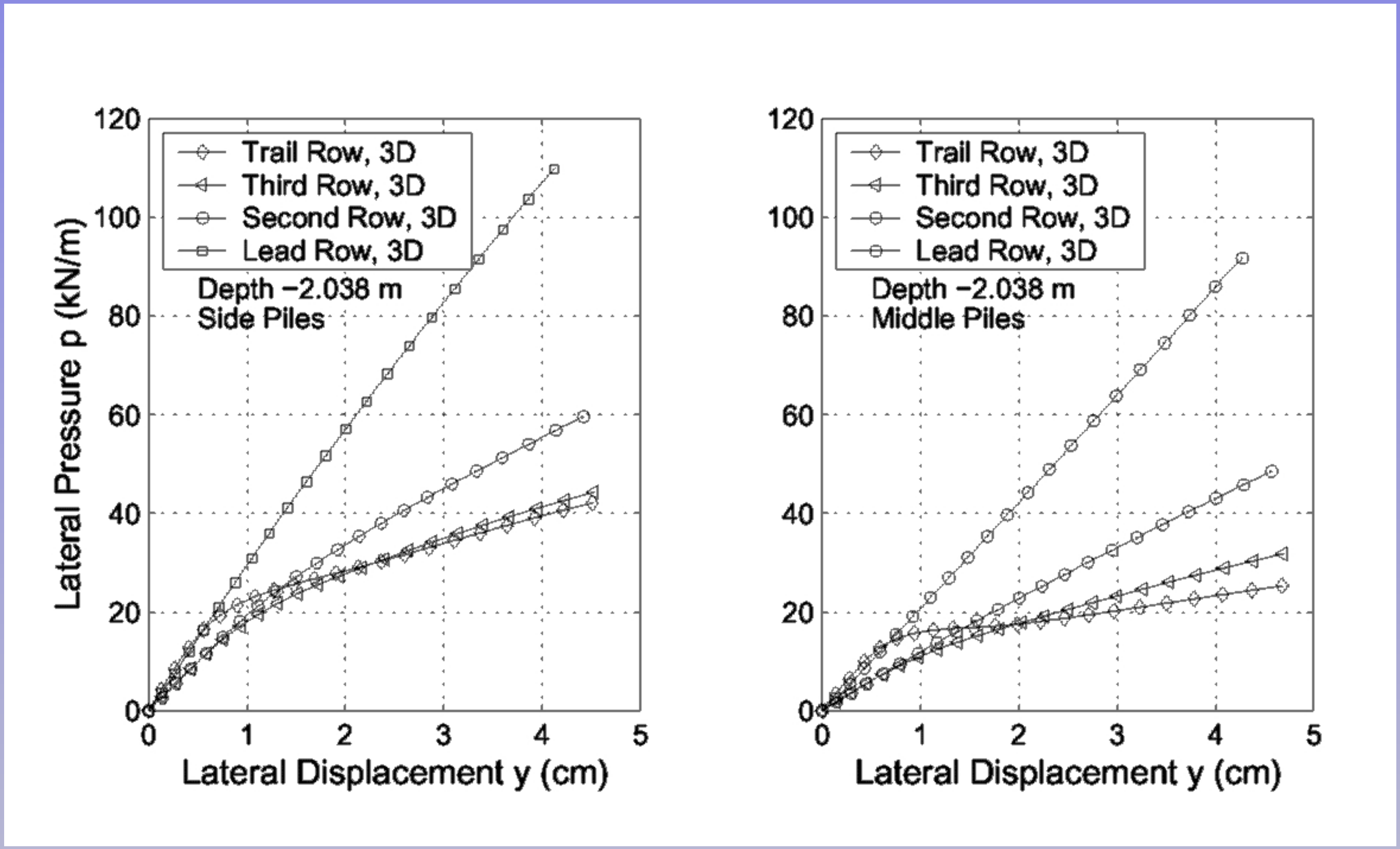


- Out-of-loading-plane bending moment diagram,
- Out-of-loading-plane deformation.

Load Distribution per Pile

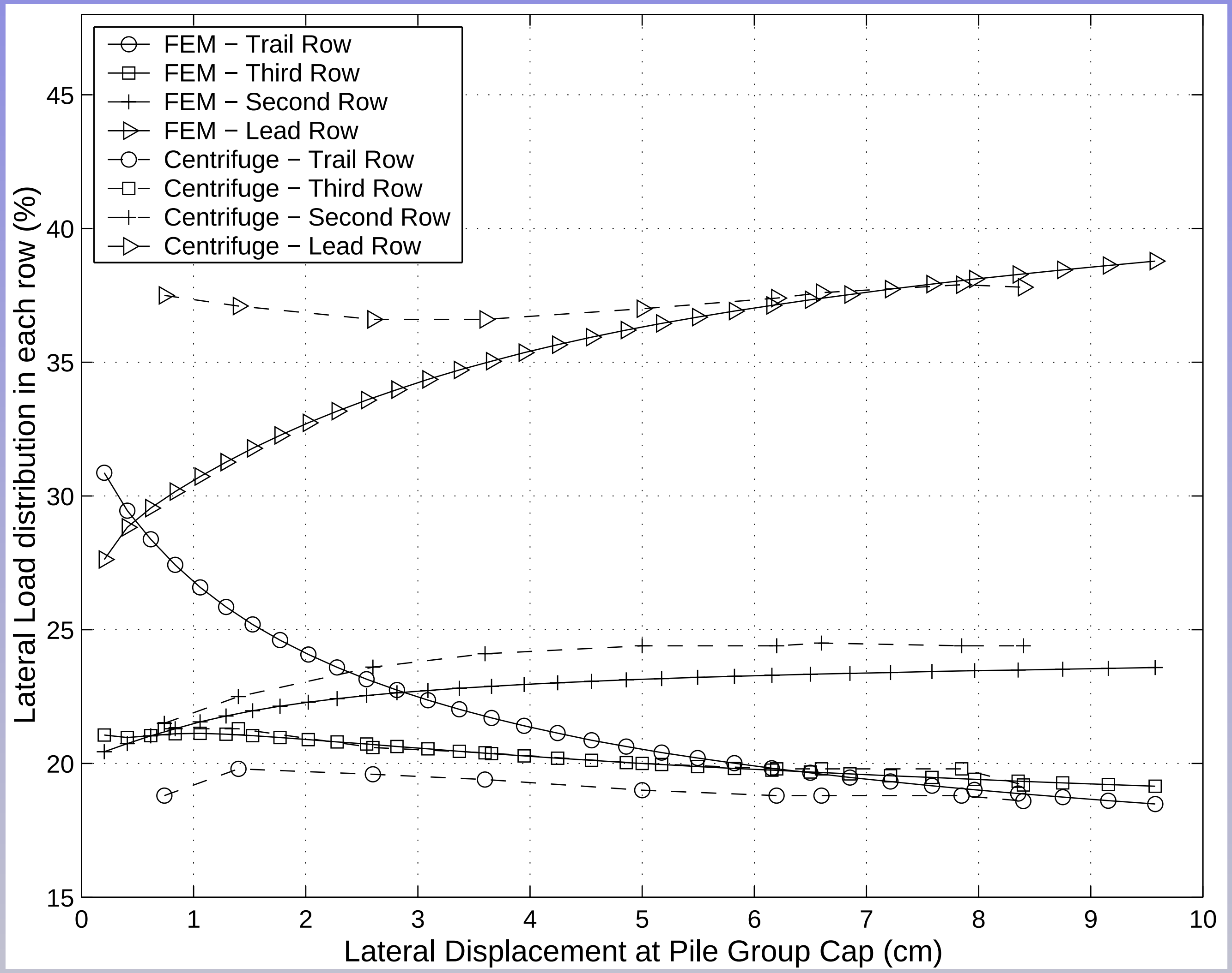


Piles Interaction at -2.0m

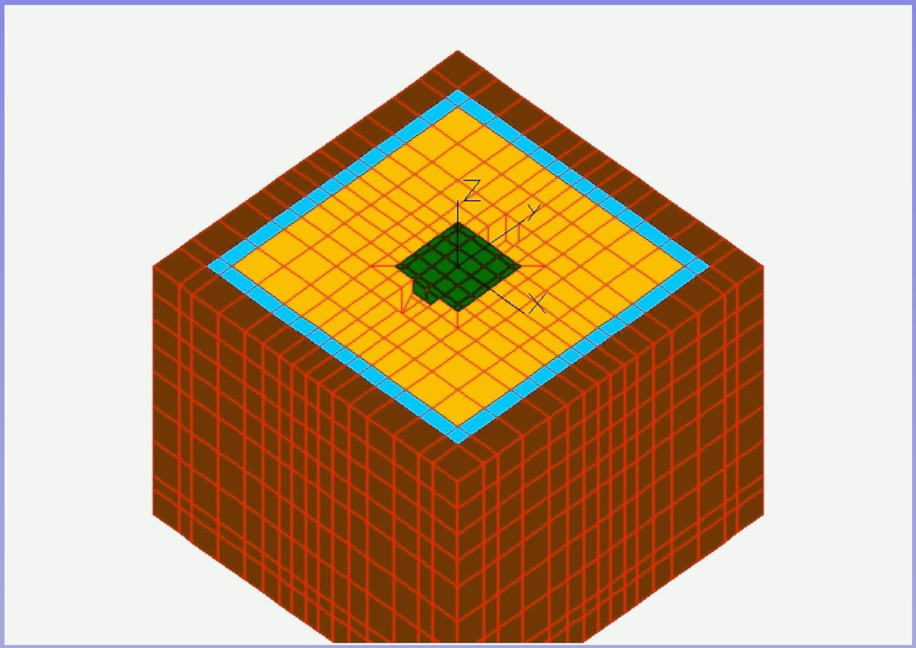


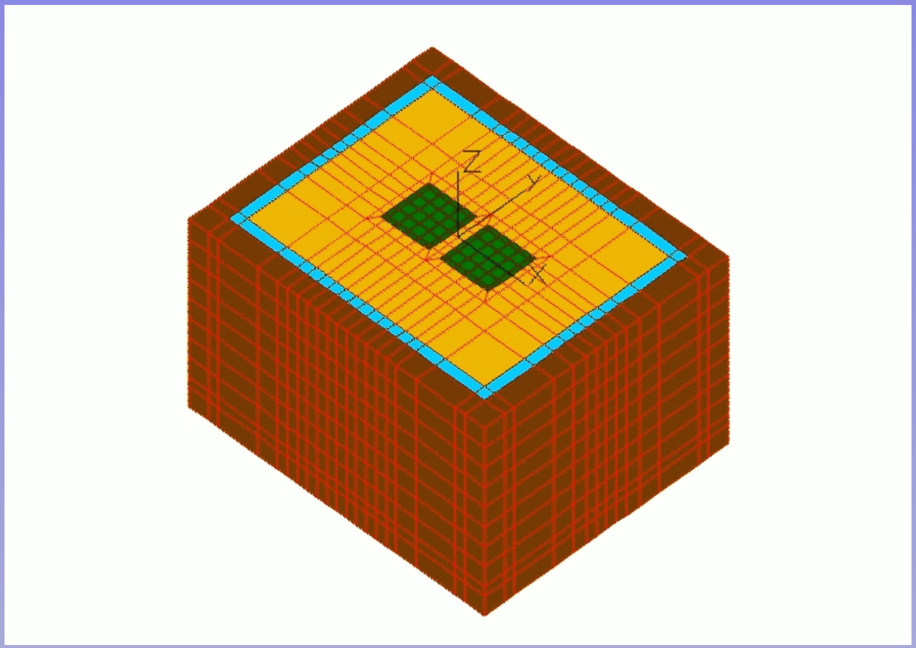
- Note the difference in response curves (cannot scale single pile response for multiple piles)

Comparison with Centrifuge Tests



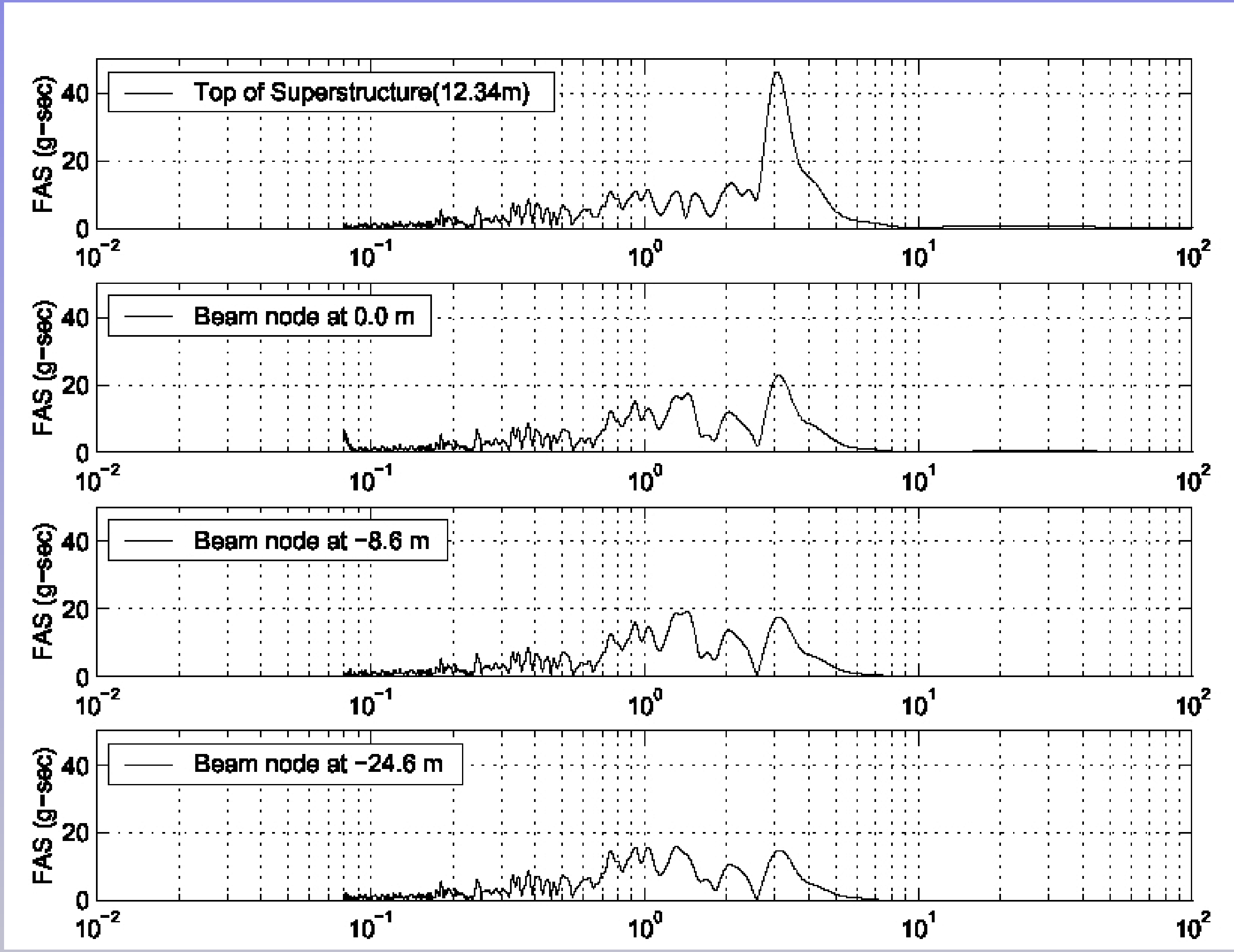
Seismic Behavior of Piles



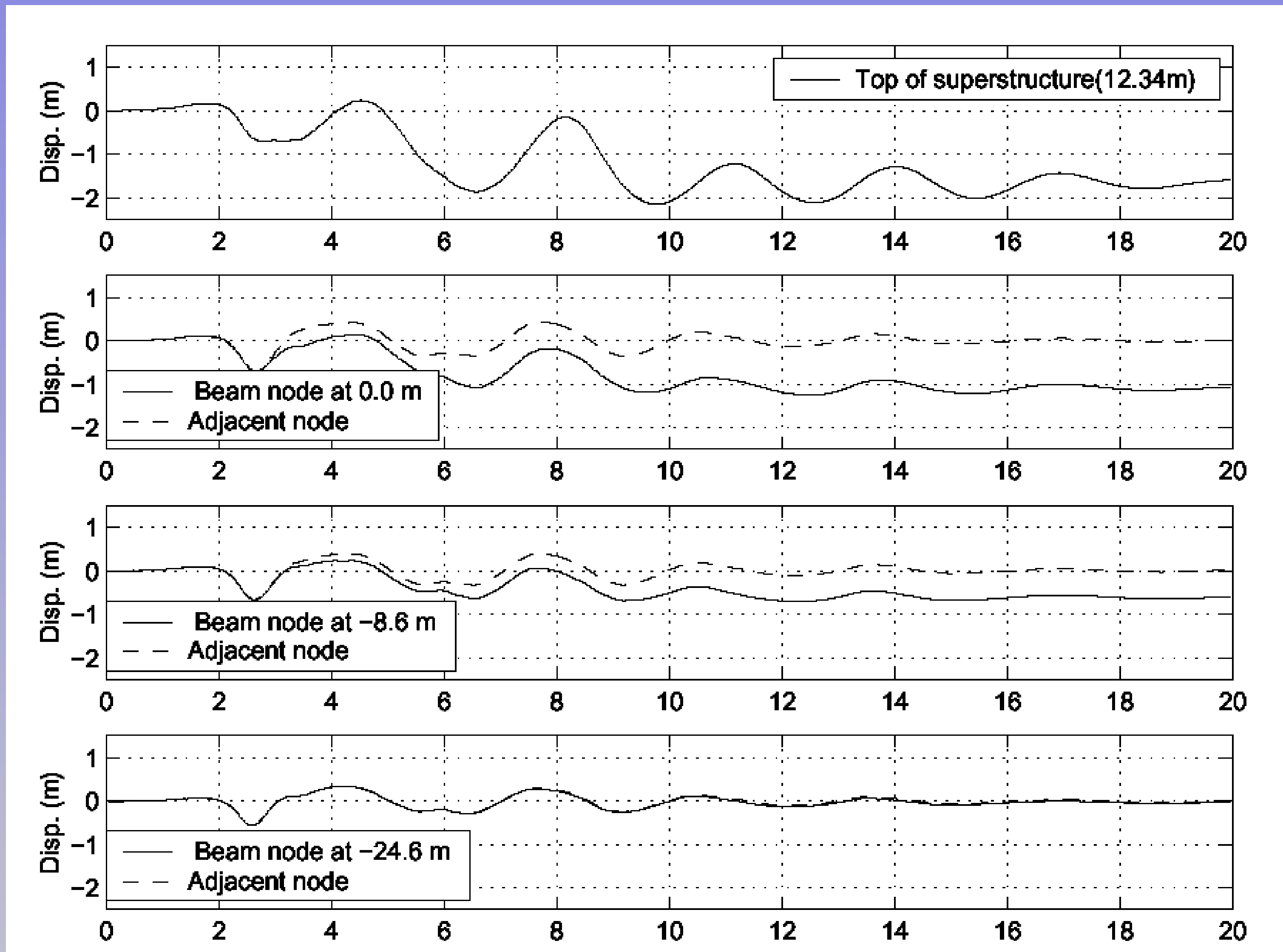


- Example run for a single pile:
- $T_n^{FixedBase} = 1.3s$.
- $T_n^{SFSI} \approx 3.0s$,

Fourier Amplitude Spectra

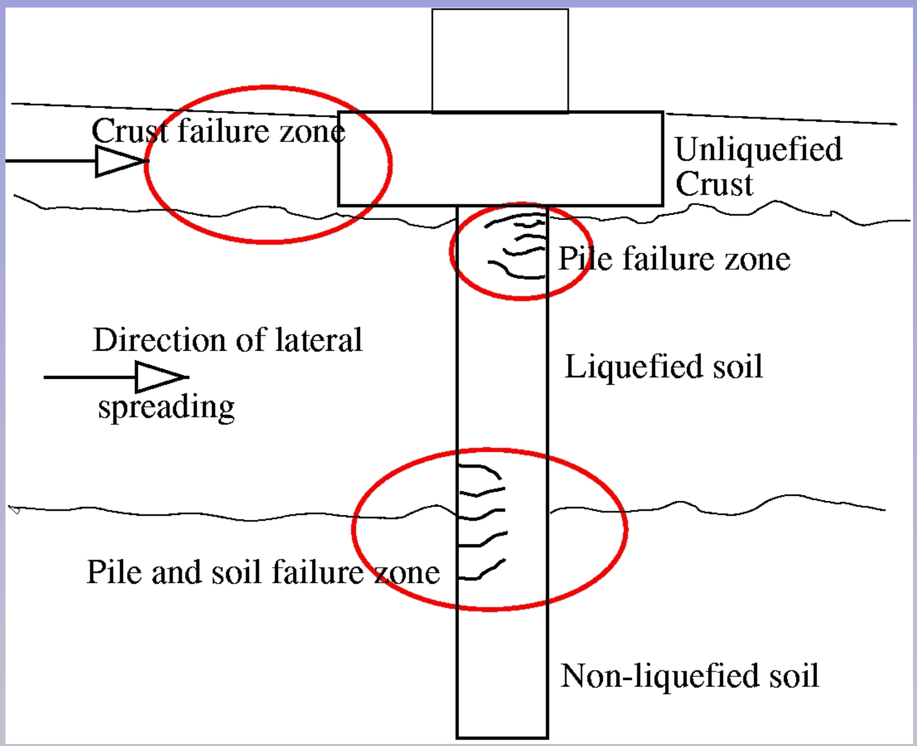


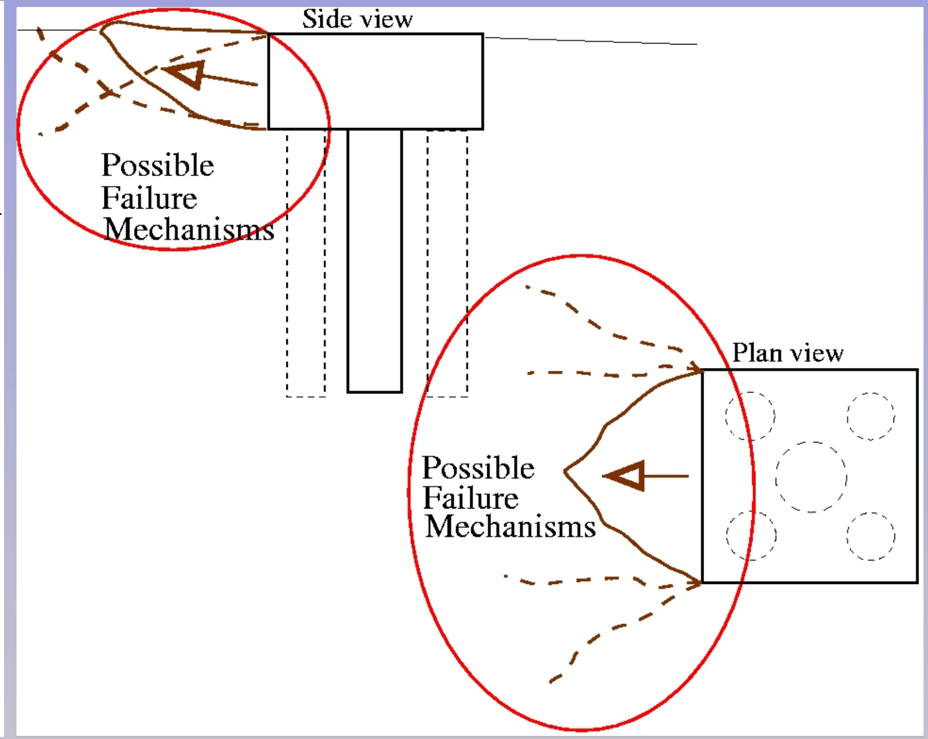
Displacements of a Single Pile



Detailed FEM Analysis

1. Laterally spreading grounds: influence of the type of top nonliquefied soil (loose sand, dense sand, soft clays, hard clays), size and shape of piles and pile cap (single piles, pile group, small cap, large cap), ground surface slope on the forces applied to the foundation system by the laterally spreading ground.
2. Passive failure of the nonliquefied crust – unloads piles
3. If soil in the nonliquefied crust does not fail – increase lateral pressure on pile foundations
4. The pile foundation might significantly reduce the lateral spreading.





Counter Measures

- Soil fails, relieves the structure (weaken the soil around so that it actually fails!)

- Soil liquefies, changes input motions (reduction, active control by controlled liquefaction!)

References

References

[1] Architectural Institutive of Japan. *Recomendation for design of building foundations*, 1988.

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[3] Japanese Road Association. *Specification for highway bridges*, 1980.

[4] Japanese Road Association. *Specification for highway bridges: Part V Seismic Design*, 1996.

[5] Liu, L., and Dobry, R. Effect of liquefaction on lateral response of piles by centrifuge model tests. In *NCEER Bulletin*, vol. 9:1. National Center for Earthquake Engineering Research, January 1995, pp. 7–11.

[6] Lok, T. M., and Pestana, J. M. Numericla modeling of the seismic response of single piles in soft clay deposits. In *Proceedings of the Fourth Caltrans Seismic Research Workshop* (Sacramento, CA., July 9-11 1996), Caltrans Engineering Service Center.

[7] Wang, S., Kutter, B. L., Chacko, J., Wilson, D. W., Boulanger, R. W., and Abghari, A. Nonlinear seismic soil–pile-structure interaction. *Earthquake Spectra 14*, 2 (1998). Earthquake Engineering Research Institute.

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[9] Yokoyama, K., Tamura, K., and Matsuo, O. Design methods of bridge foundations against soil liquefaction and liquefaction induced ground flow. In *2nd Italy–Japan Workshop on Seismic Design and Retrofit of Bridges* (Rome, Italy, 27-28 Feb. 1997), p. 23 pages.