Design practice for pile foundations in laterally spreading ground

Scott A. Ashford, Oregon State University
Ross W. Boulanger, UC Davis
Scott J. Brandenberg, UCLA

2012 PEER Annual Meeting

Acknowledgments

- Funding provided by PEER Lifelines Program
  - Caltrans
  - California Energy Commission
  - Pacific Gas & Electric
- Thanks to Reviewers
  - Steve Kramer/UW
  - Lelia Mejia/URS
- Special Thanks to Tom Shantz/Caltrans
  - Report used as basis for new Caltrans guidelines
  - Being developed for ODOT and WashDOT

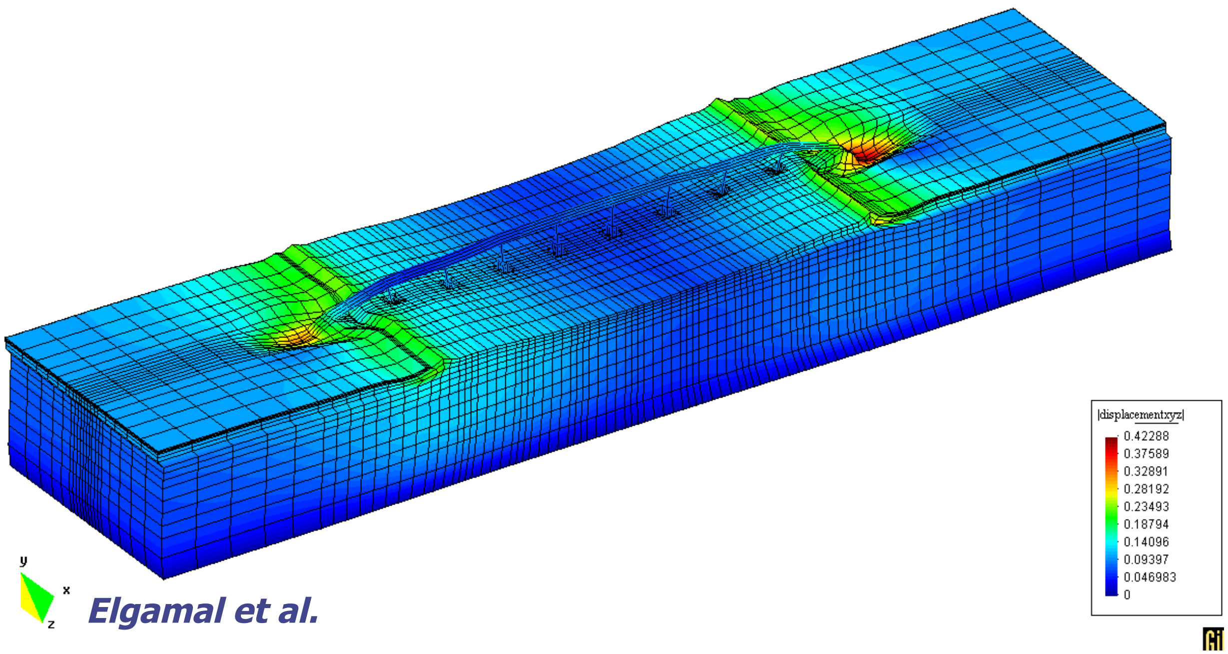
PEER

Research developments

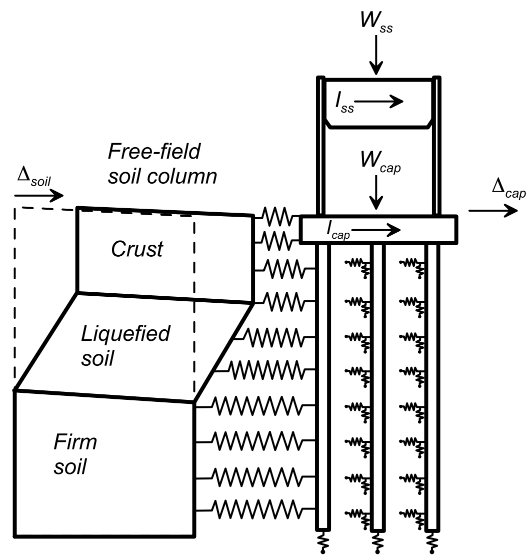
- Last 20 years have seen considerable progress in understanding, analyzing, and designing for lateral spreading effects.

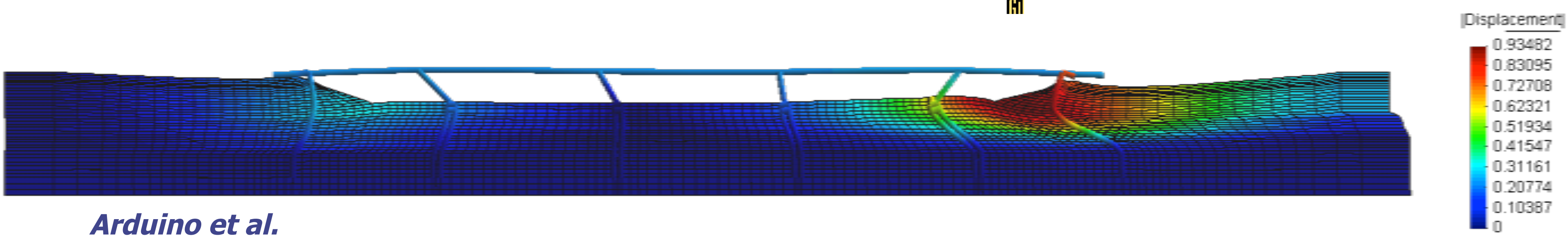
Simulation

- Hierarchy of 2-D and 3-D modeling capabilities developed; proprietary, commercial, and open source.



Elgamal et al.

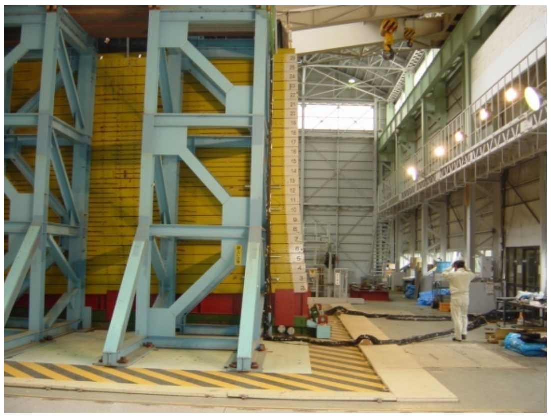


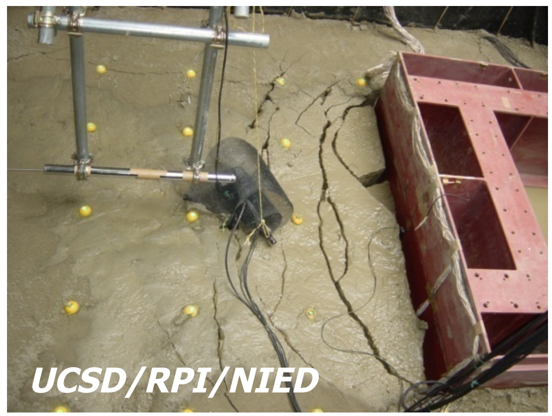


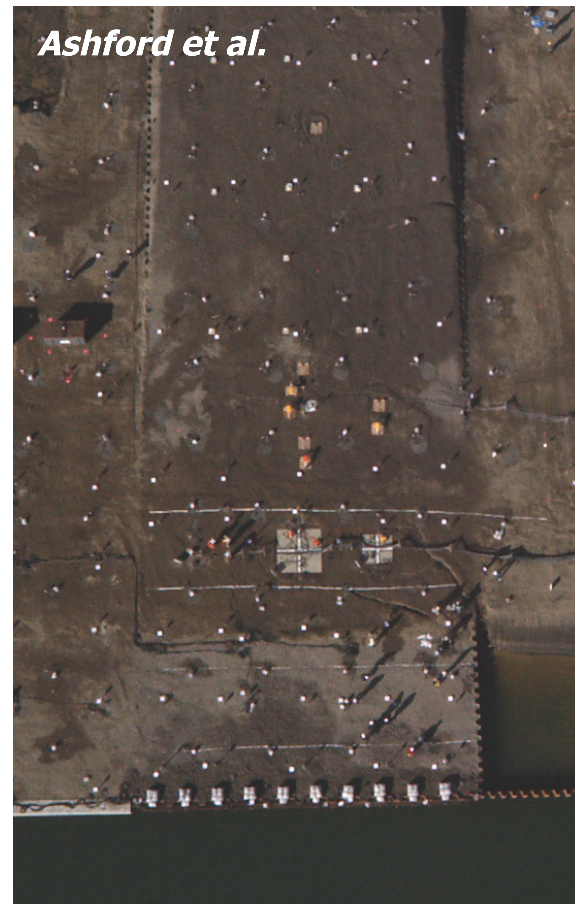
Arduino et al.

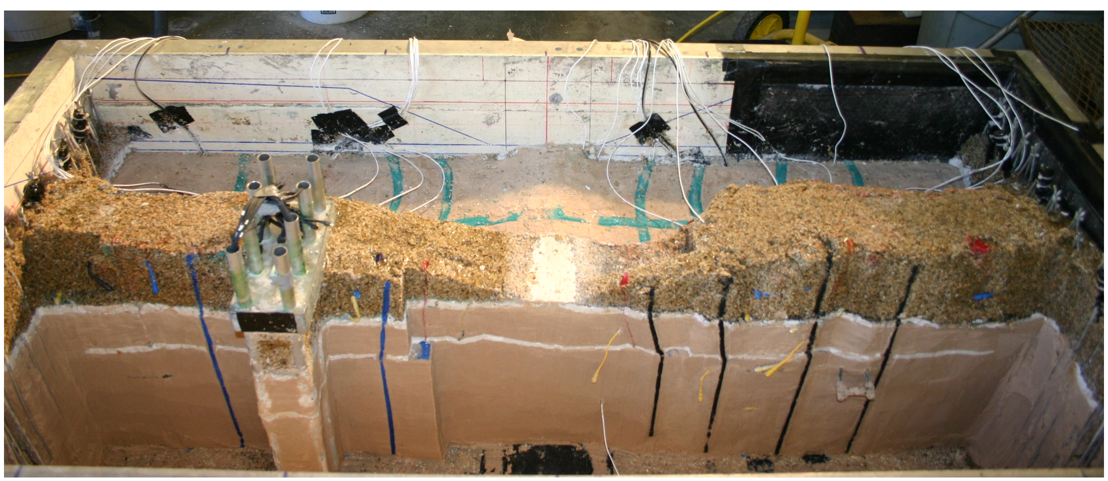
Validation

- Dynamic centrifuge, shake table, and field tests addressed knowledge gaps for deep foundations.



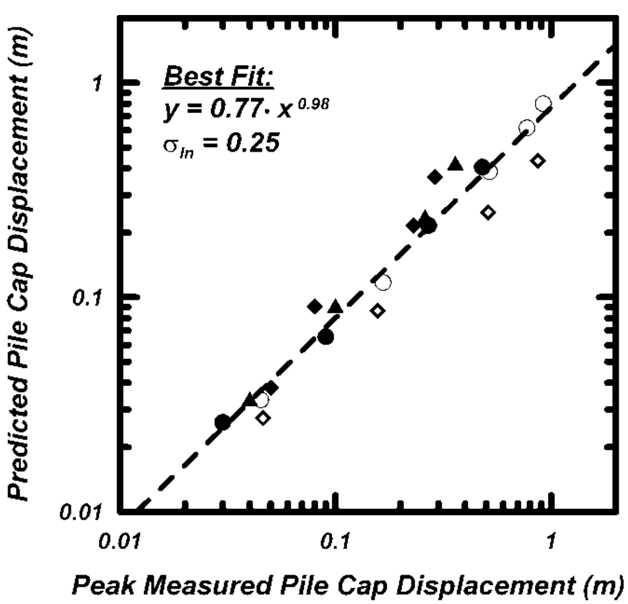


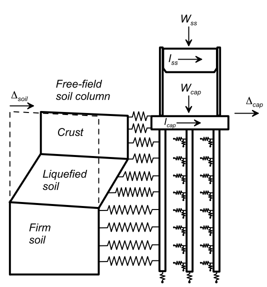




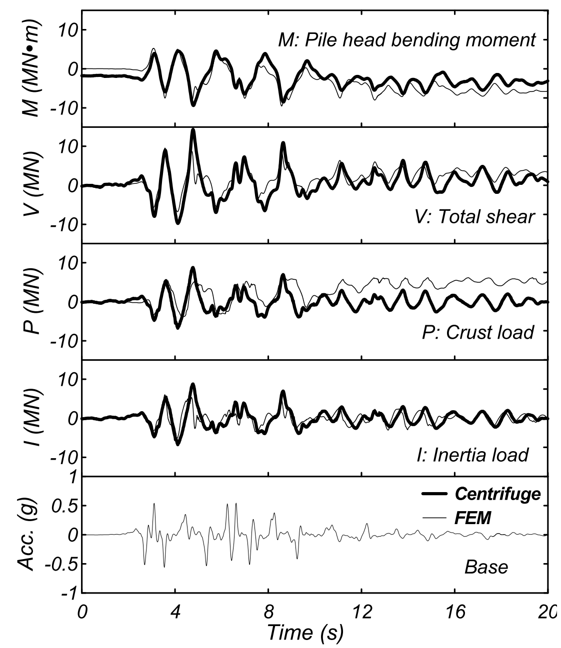
Development of design guidance

- Parametric studies to evaluate ESA methods against case histories, physical modeling data, and nonlinear dynamic analyses.

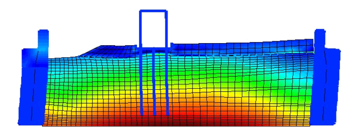




Brandenberg et al.



DDC01 in Large Kobe Motion



Chang et al.

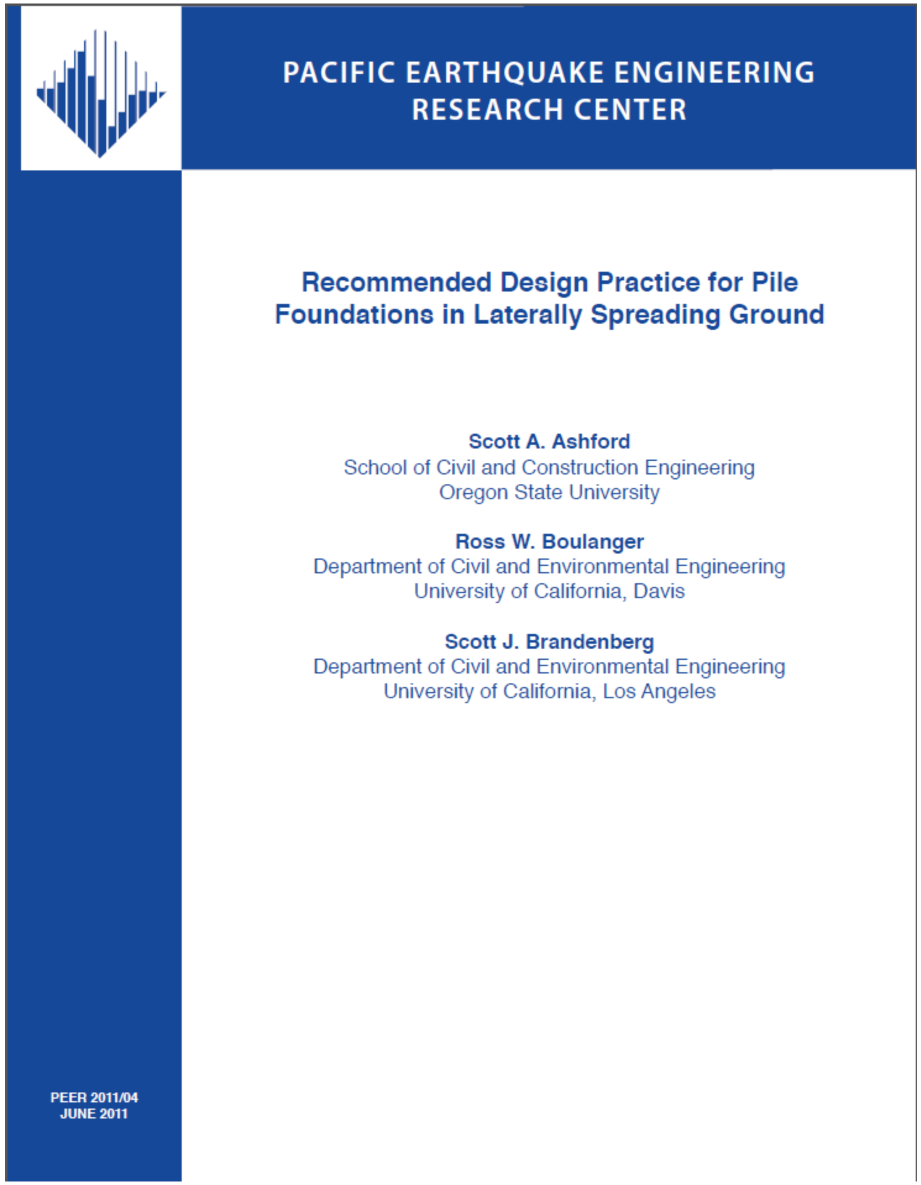
PEER

Exchanges

- ASCE Geotechnical Special Publication No. 145, 2006.

PEER

Recommended Design Practice



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Recommended Design Practice for Pile Foundations in Laterally Spreading Ground

Scott A. Ashford
School of Civil and Construction Engineering
Oregon State University

Ross W. Boulanger
Department of Civil and Environmental Engineering
University of California, Davis

Scott J. Brandenberg
Department of Civil and Environmental Engineering
University of California, Los Angeles

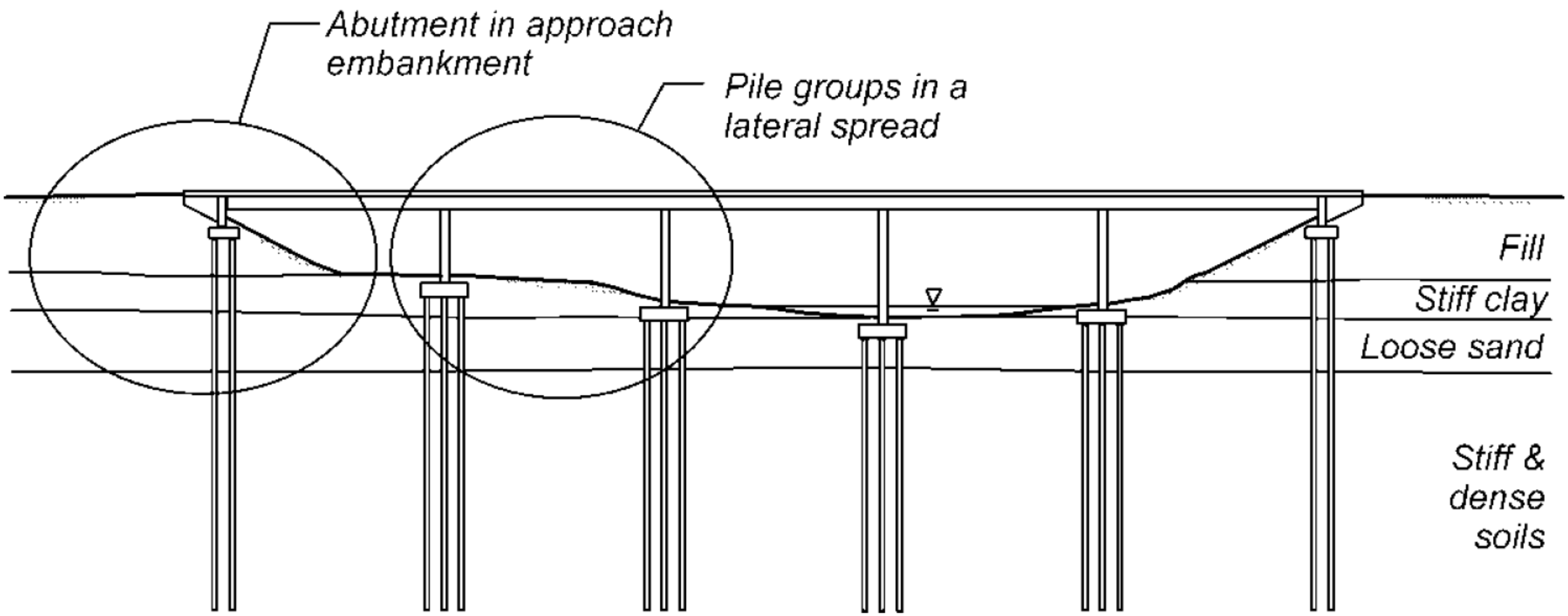
PEER 2011/04
JUNE 2011

Design practice for lateral spreading

- Steps for design or performance evaluation of a bridge include:
  - Design/evaluate for inertia loading that would occur in the absence of liquefaction.
  - Evaluate the potential for liquefaction and associated ground displacements.
  - Design/evaluate for the lateral spreading and inertia demands that would occur if liquefaction is triggered.

Local and global analyses

- Bridge pinning effects on ground displacements can be modeled using different approaches for different local or global analysis methods.



Estimating lateral spreading displacements

- Three key evaluation steps
  - Site characterization
  - Liquefaction triggering
  - Ground deformations

- Site characterization and evaluation of liquefaction susceptibility
  - Use appropriate mix of SPT and CPT
  - Detailed cross-section showing *in situ* data
  - Key factor: spatial extent and continuity

Liquefaction Triggering

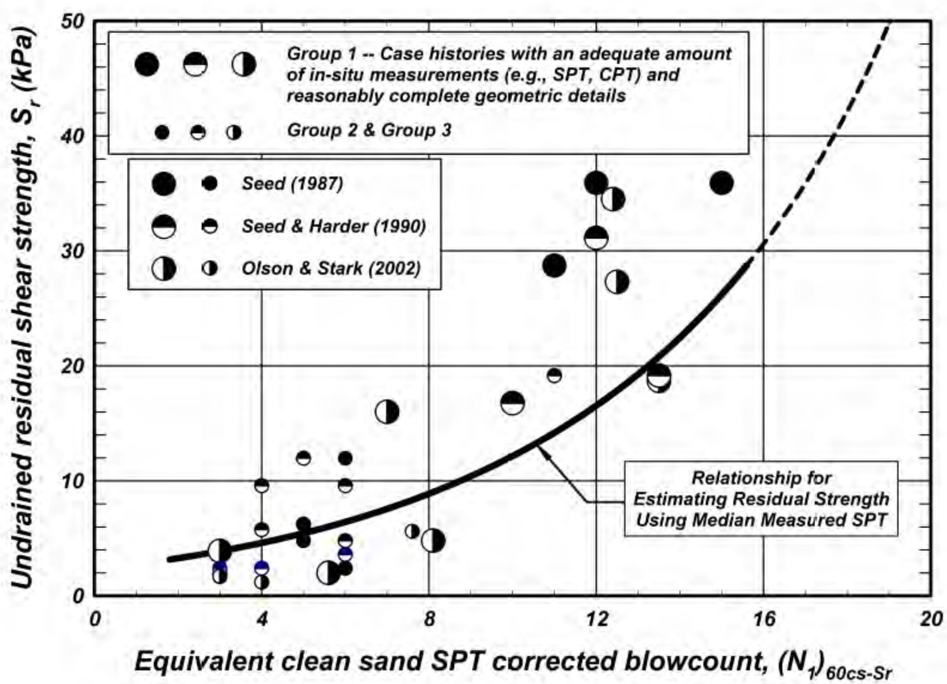
- Potential for liquefaction triggering in susceptible soils
  - Comparison of CSR (Seed & Idriss 1971) and CRR
  - For CRR, use Youd et al (2001) for now
    - Until consensus is reached in profession
    - Cetin et al ('04), Idriss & Boulanger ('06), Moss et al ('06)
  - Fines consideration
    - Boulanger and Idriss (2006)
      - Silts and clays with PI≥7, treat as cohesive soil
      - For PI<7, evaluate using SPT/CPT procedures
        - Or do lab testing
    - Bray and Sancio (2006)
      - For 7≤PI≤20, do lab testing

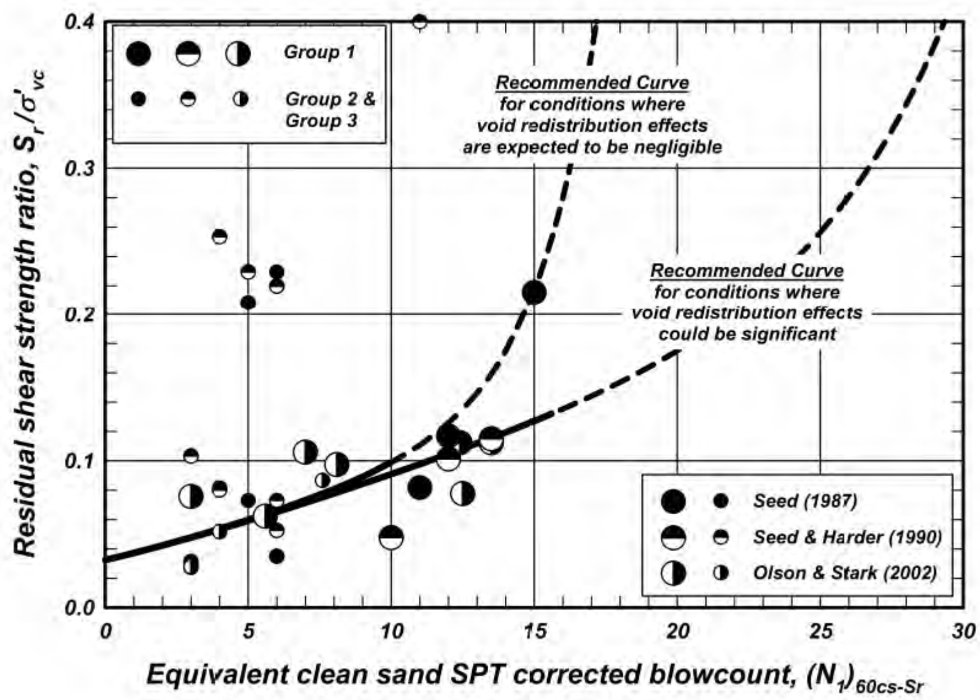
Consequences of Liquefaction

- Residual strength
  - Instability of a slope or embankment due to loss of shear strength in liquefied zones.
- Strains
  - Lateral spreading of level or sloping ground
- Displacements
  - Settlement due to one-dimensional reconsolidation of liquefiable soil

Residual strength estimation

- Estimation of residual shear strength of a liquefied soil for slope/embankment instability investigation





(Idriss and Boulanger 2007)

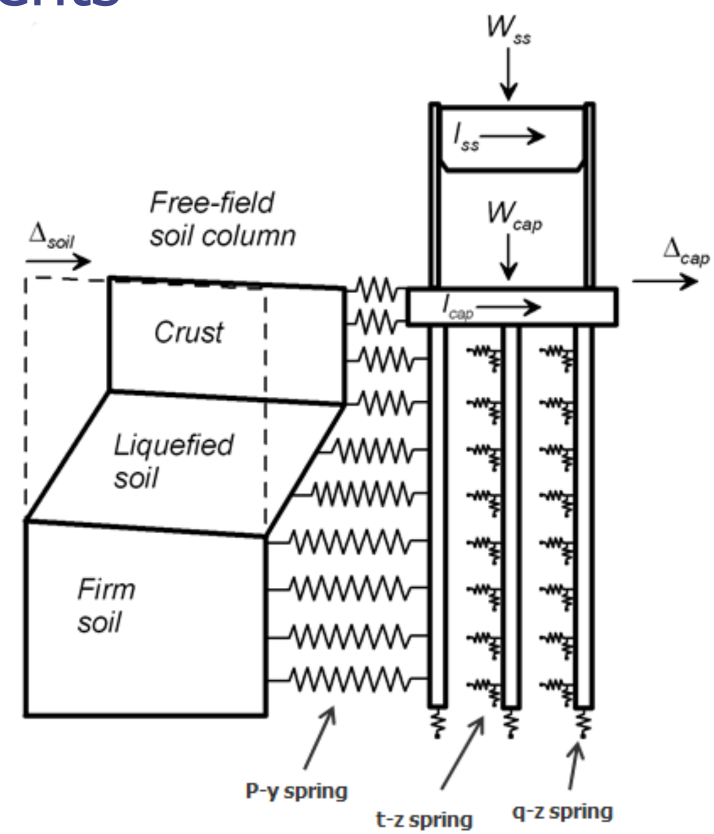
PEER

Liquefaction-induced ground displacements

- Free-field lateral spreading displacement can be estimated using different approaches
  - Empirical relationships
    - Specific to the cases that relationships were developed
    - Youd et al. 2002, Bardet et al. 2002, Rauch & Martin 2000
  - Integration of shear strain profiles with depth
    - Estimated in conjunction with SPT- and CPT- based liquefaction analysis (Zhang et al. 2004)
  - Newmark sliding block analyses
    - Can depend heavily on the residual strength
  - Nonlinear dynamic analyses

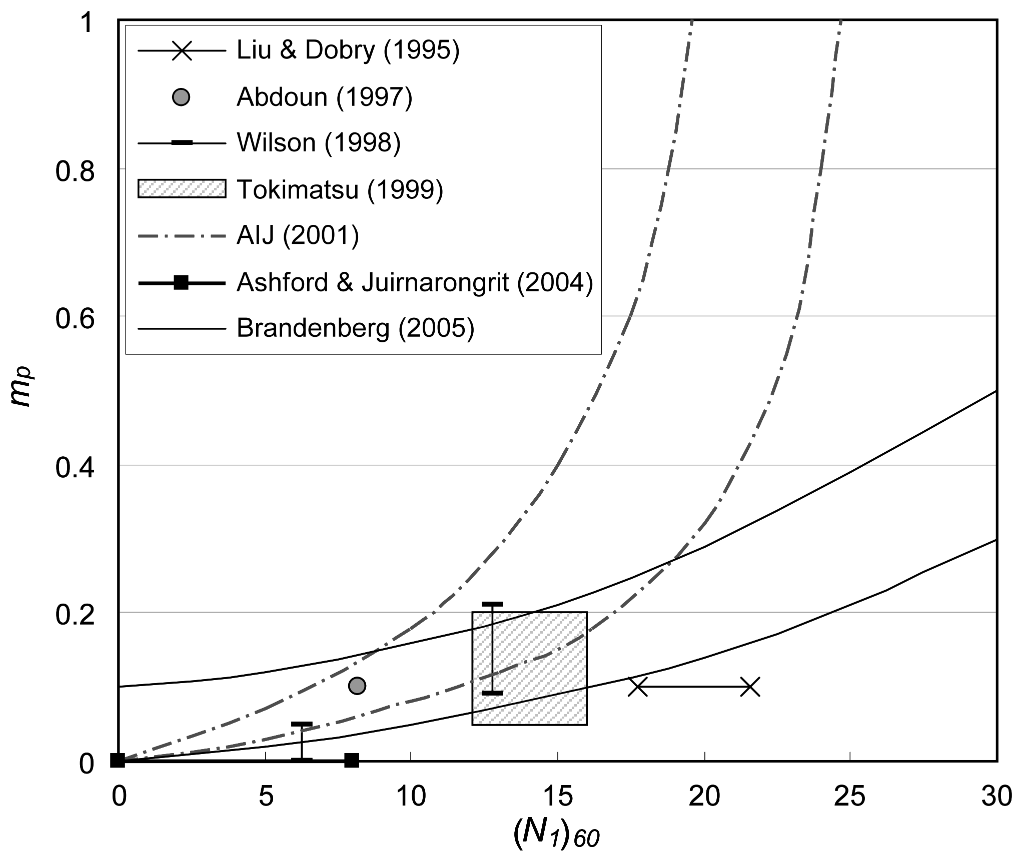
Pile analysis for lateral spreading case

- ESA with imposed soil displacements
  - Soil displacement
    - Magnitude
    - Shape
  - Soil springs
    - Nonliquefied layers
    - Liquefied layers
  - Inertia loads
  - Kinematic loading
    - Loads from a nonliquefied crust
  - Inertial and lateral spreading loading combinations



Pile analysis for lateral spreading case

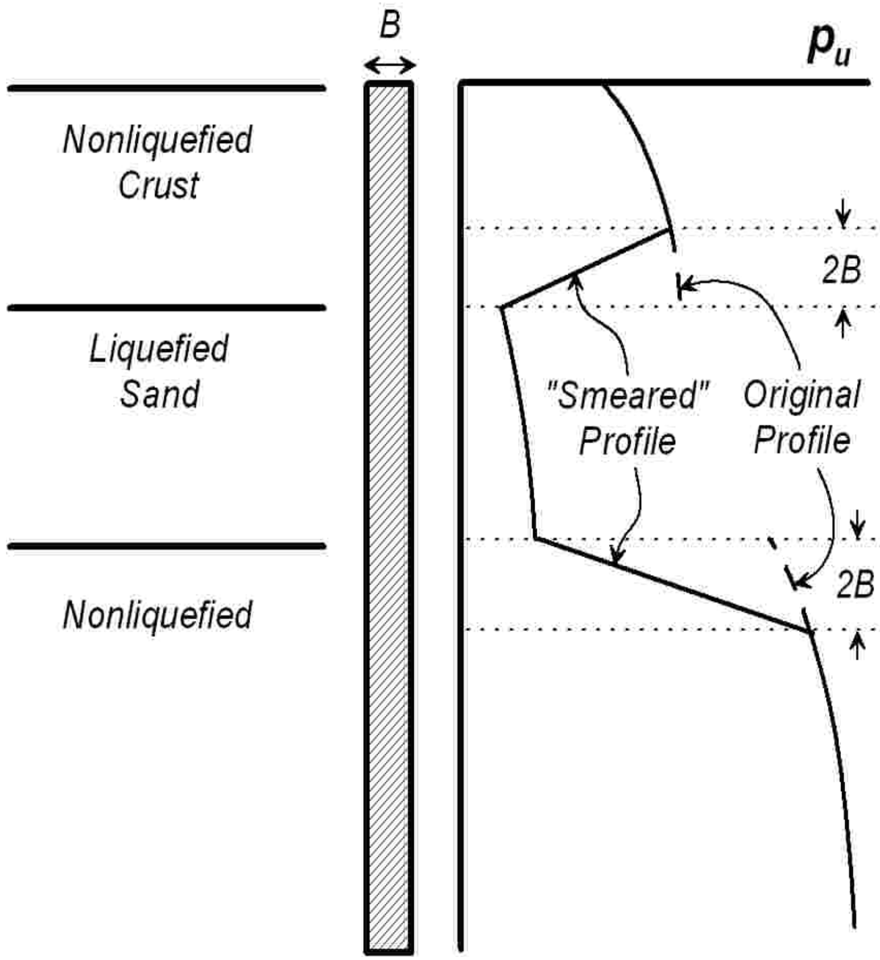
- p-y behavior in liquefied sand
- ESA requires crude approximation of complex behavior



$(N_1)_{60\text{-}CS}$	m_p
<8	0.0 to 0.1
8-16	0.05 to 0.2
16-24	0.1 to 0.3
>24	0.2 to 0.5

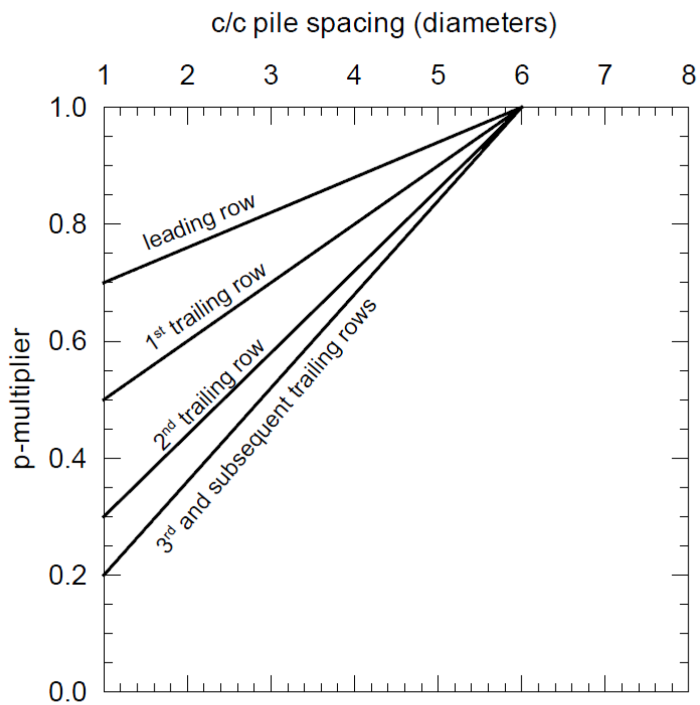
Pile analysis for lateral spreading case

- Reduction of ultimate lateral loads in the overlying or underlying nonliquefied layers



Pile analysis for lateral spreading case

- Pile group interaction effects
  - Apply group p-multipliers underlying nonliquefied layer
  - No p-multiplier for liquefied soil
  - No group effects for nonliquefied crusts

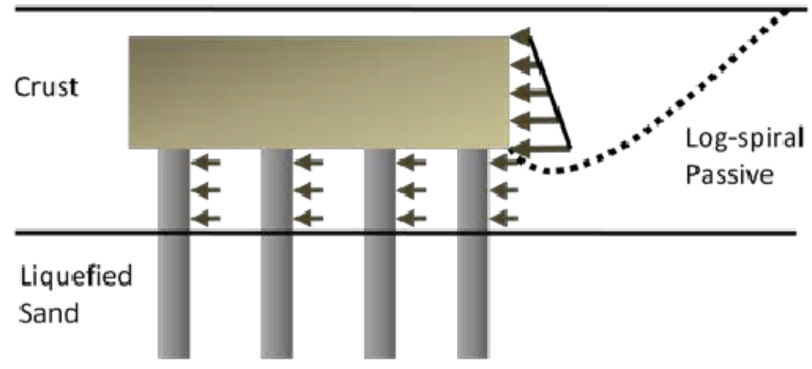


(Mokwa, 2000)

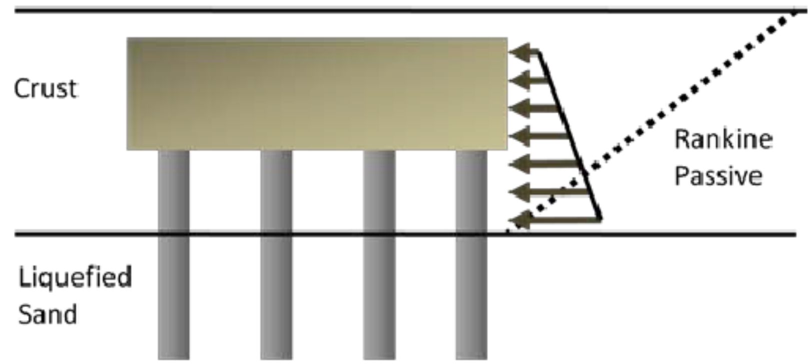
PEER

Pile analysis for lateral spreading case

- Loads from nonliquefied crusts
  - Passive earth pressure
  - Practical problems, case B will result smaller foundation loads.
  - Controlling mechanisms depends on size and number of piles, thickness of crust



Case A



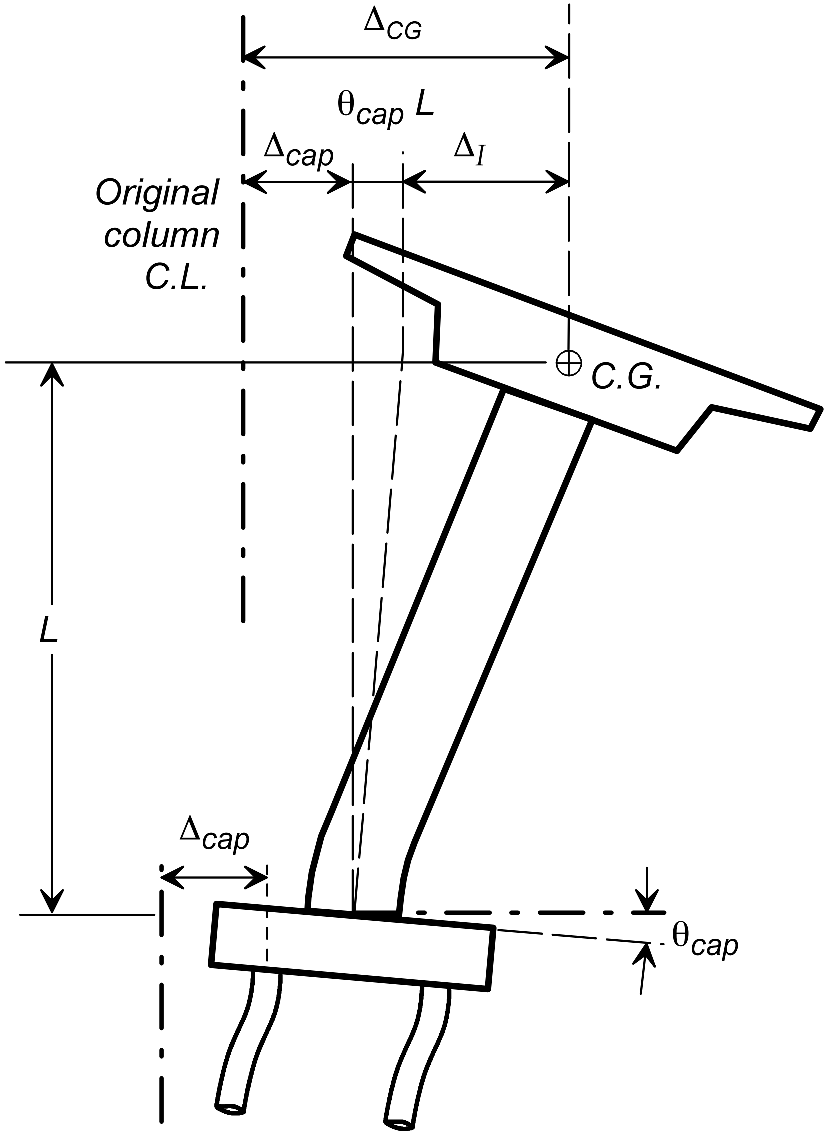
Case B

Ref. Design examples by Tom Shantz

PEER

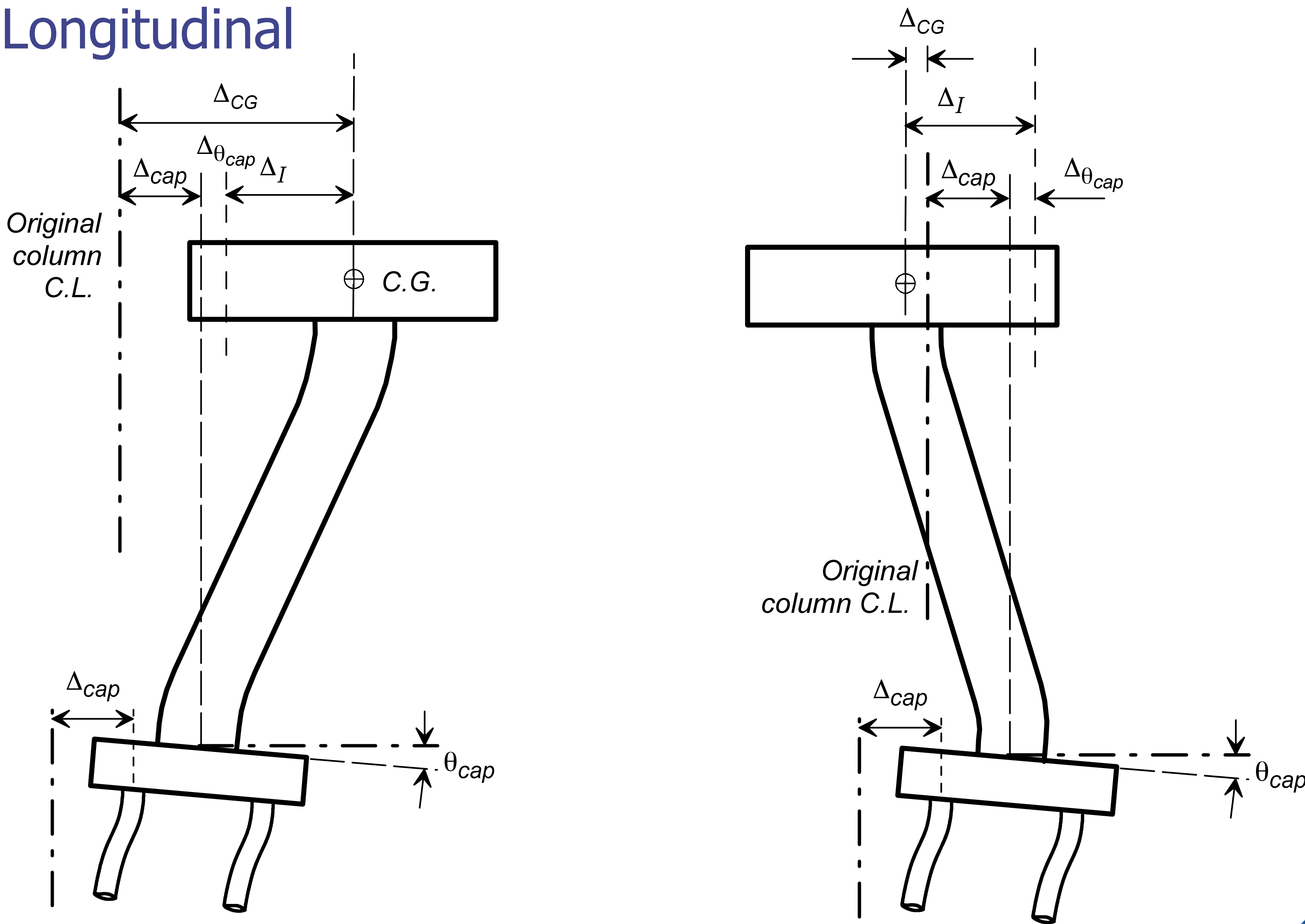
Displacement demands

- Combined lateral spreading & inertia loading: Transverse



Displacement demands

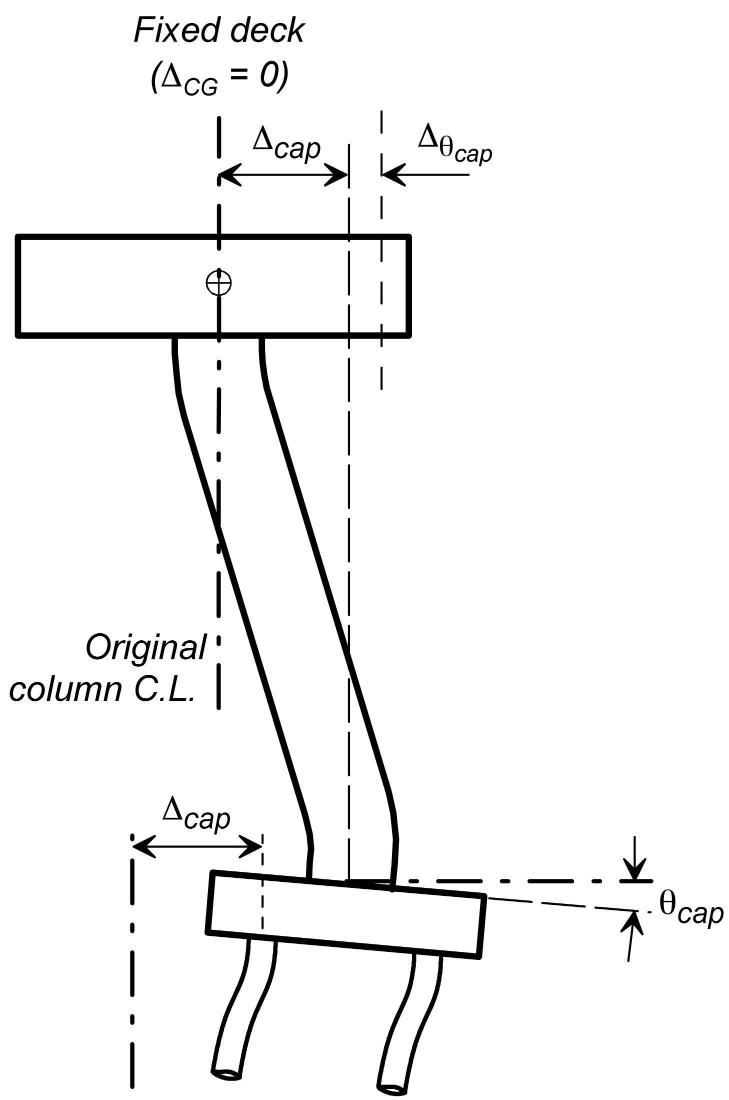
- Combined lateral spreading & inertia loading: Longitudinal



PEER

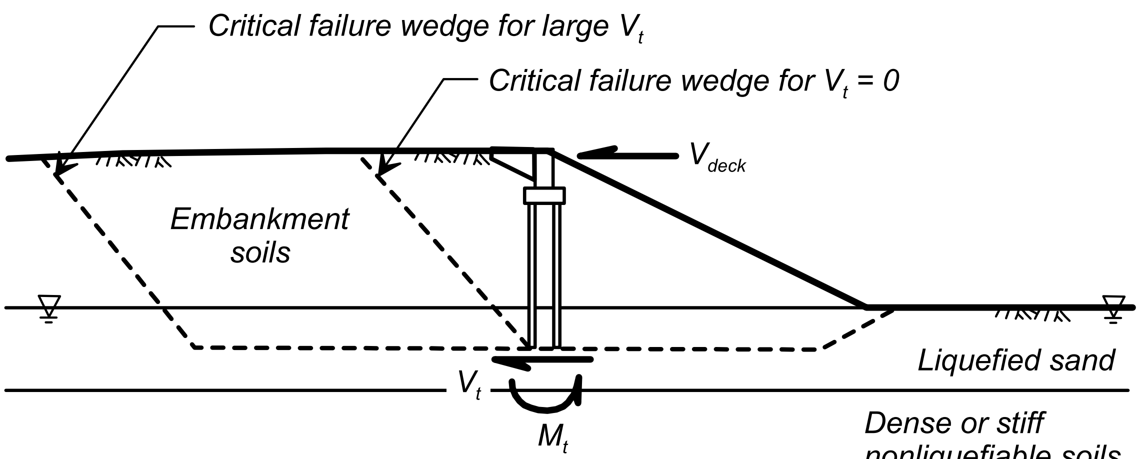
Displacement demands

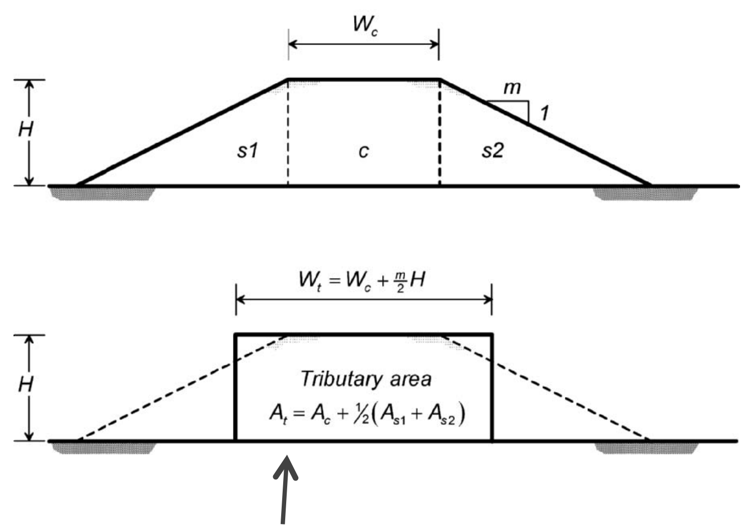
- Lateral spreading with deck restrained



Design of piles in Approach Embankments

- Pile pinning analyses
  - Slope stability analyses of the embankment for a range of restraining forces
  - Consider range of failure surfaces



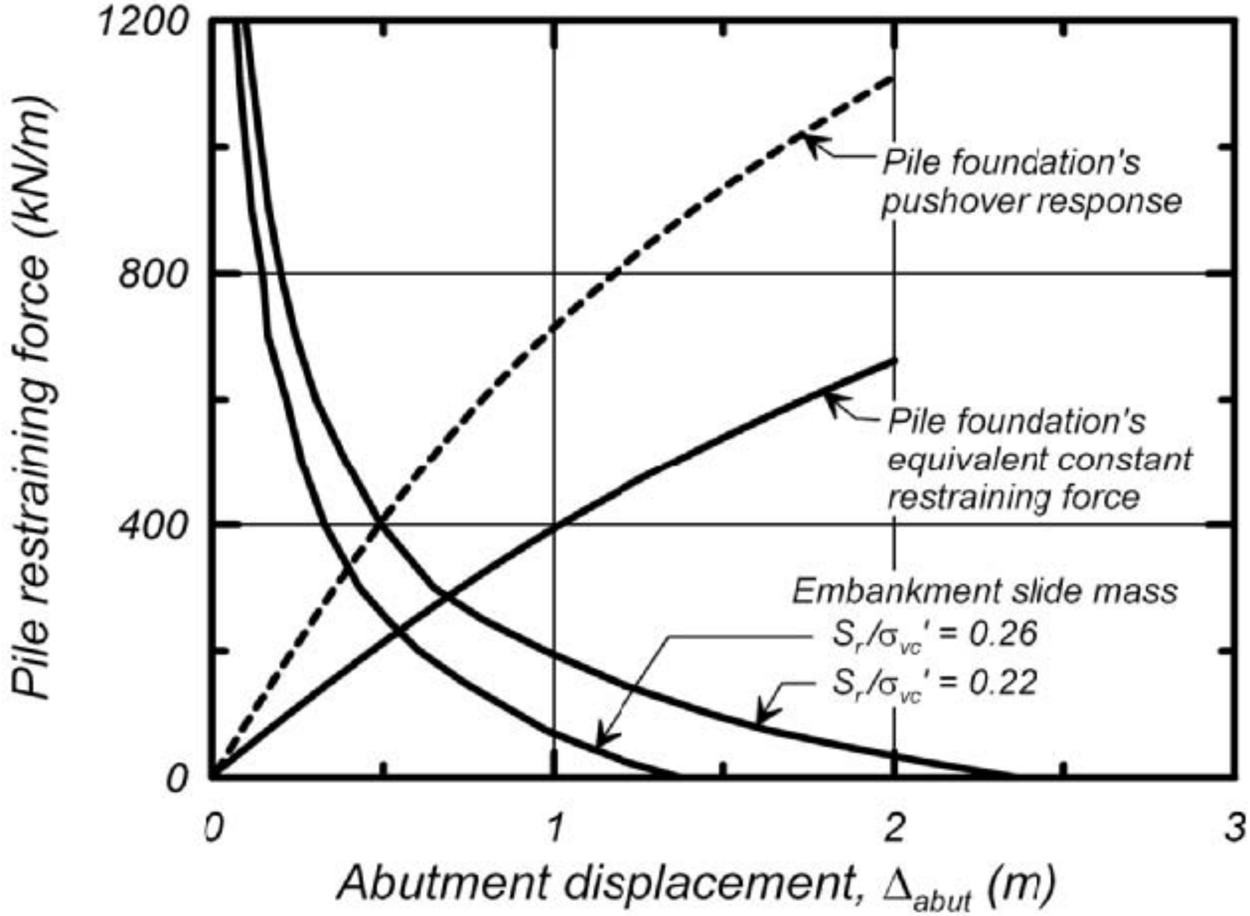


Tributary(transverse) width for the embankment mass which interact with restraining forces from the pile foundation and bridge superstructures

PEER

Design of piles in Approach Embankments

- Compatibility of embankment and pile displacement

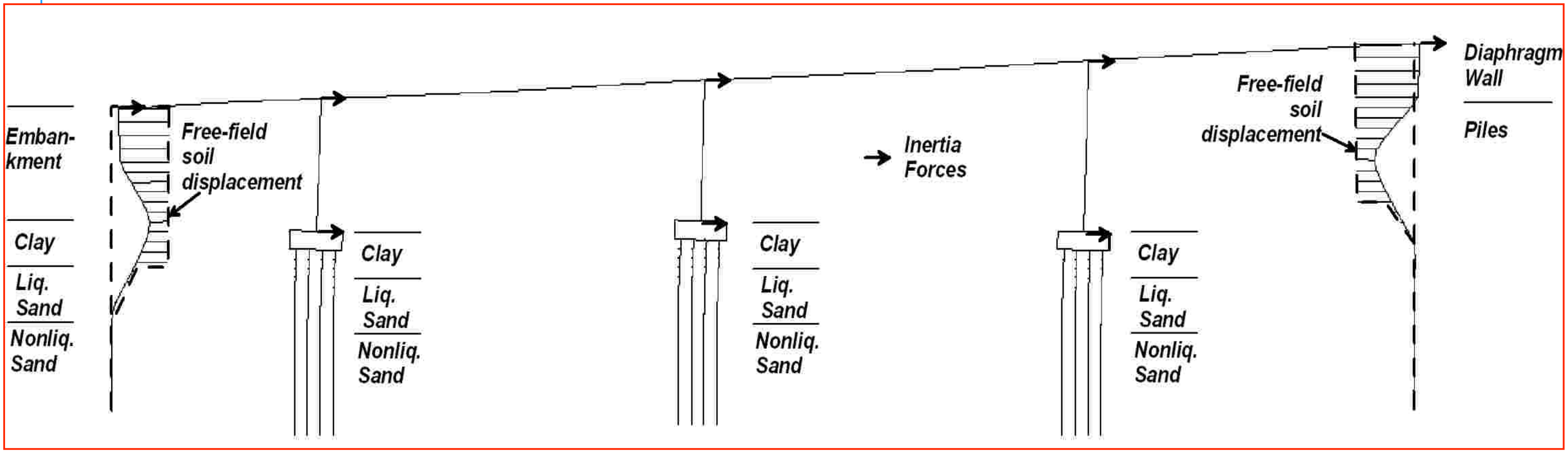


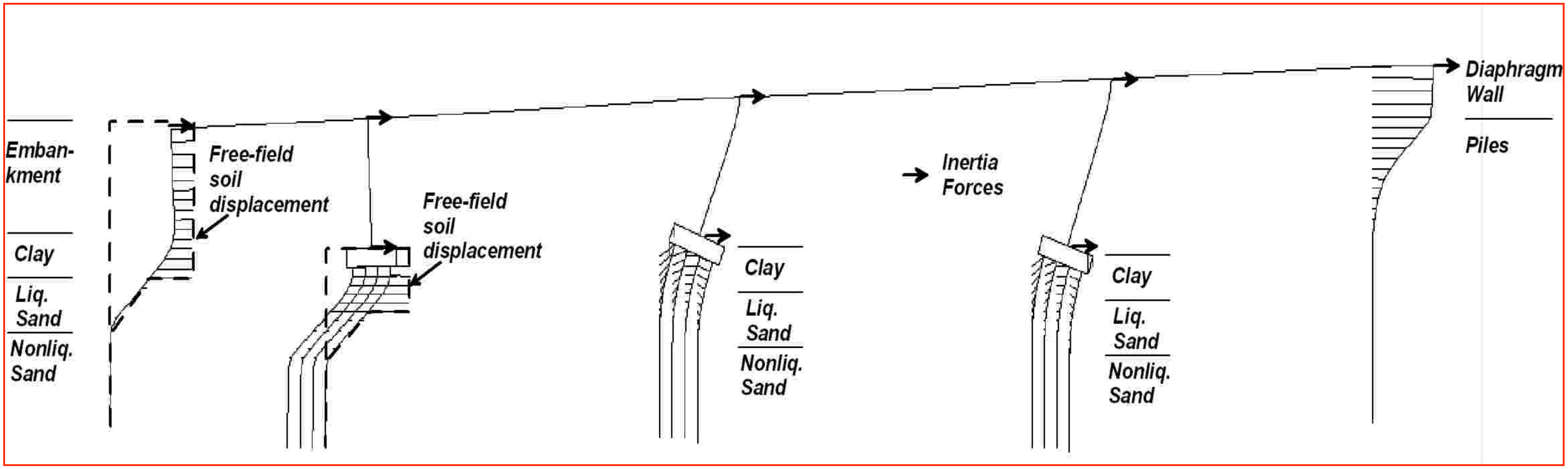
Global bridge response

- Provide more realistic evaluation of the distribution of force and displacement demands than from local analyses of individual bent or frames
- Ordinary bridge without liquefaction effect
  - Linear elastic- ESA
  - Linear elastic dynamic analysis for complicated case
- Global analyses for the effect of liquefaction are warranted when the subsurface conditions and expected liquefaction-induced ground displacement vary substantially along the bridge alignment

Global bridge response

- For example






2010 Chile Earthquake

2010-11 New Zealand Earthquakes

2011 Japan Earthquake
(LA Times Photo)

Thank You…