# Simplified PBEE Procedures for Estimating Seismic Slope Displacements

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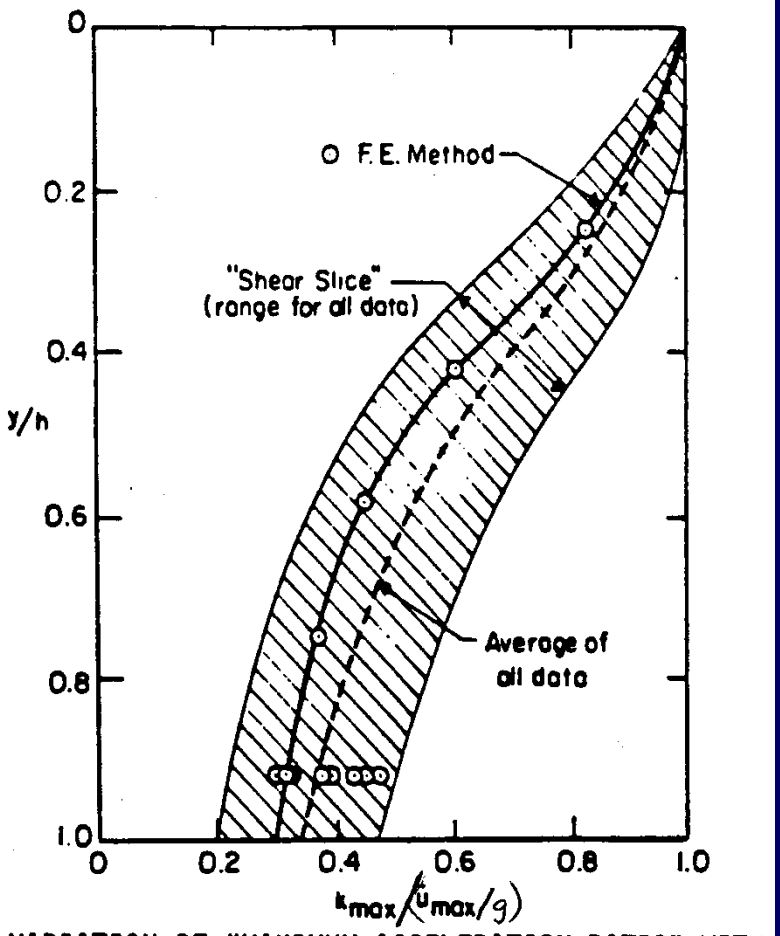
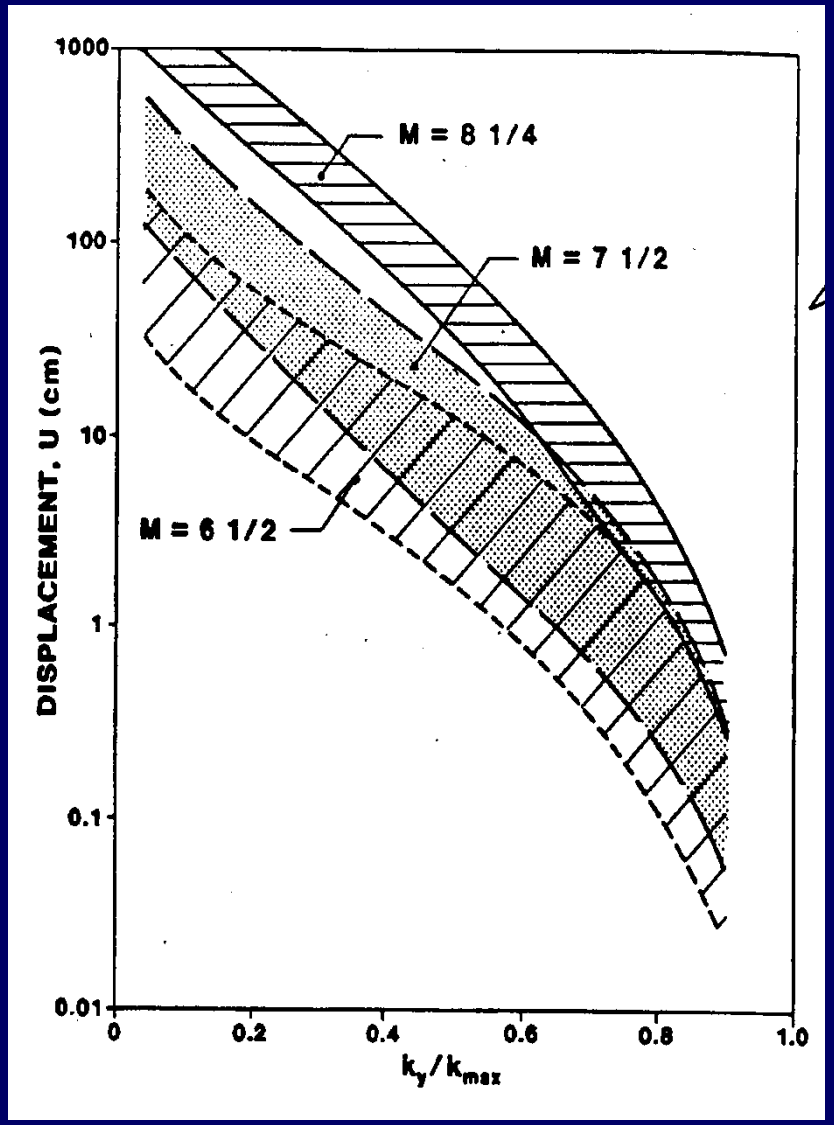
*Thanks to Dr. Thaleia Travasarou, Christian Ledezma, & others, with support from PEER*

# Makdisi & Seed (1978) Seismic Displacement




VARIATION OF "MAXIMUM ACCELERATION RATIO" WITH DEPTH OF SLIDING MASS



# Limitations

"*… the design curves presented are based on averages of a range of results that exhibit some degree of scatter and are derived from a limited number of cases. These curves should be updated …*"

Makdisi & Seed (1978)

Limited number of earthquake ground motions used.

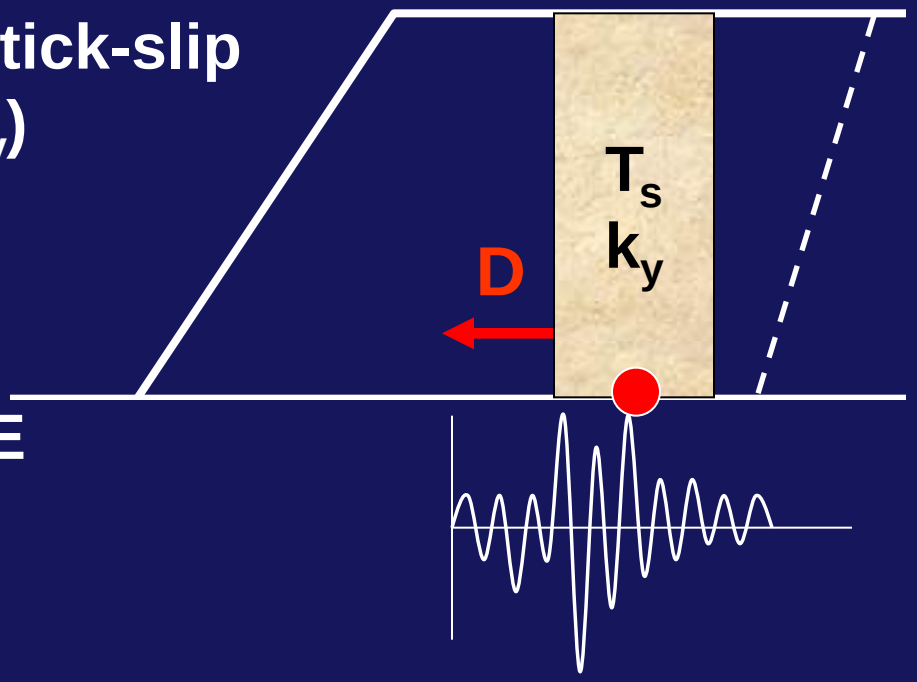
Simple decoupled shear slice analysis employed.

Upper and lower bounds are not true upper and lower bounds.

No estimate of uncertainty.

# Bray & Travasarou (2007)

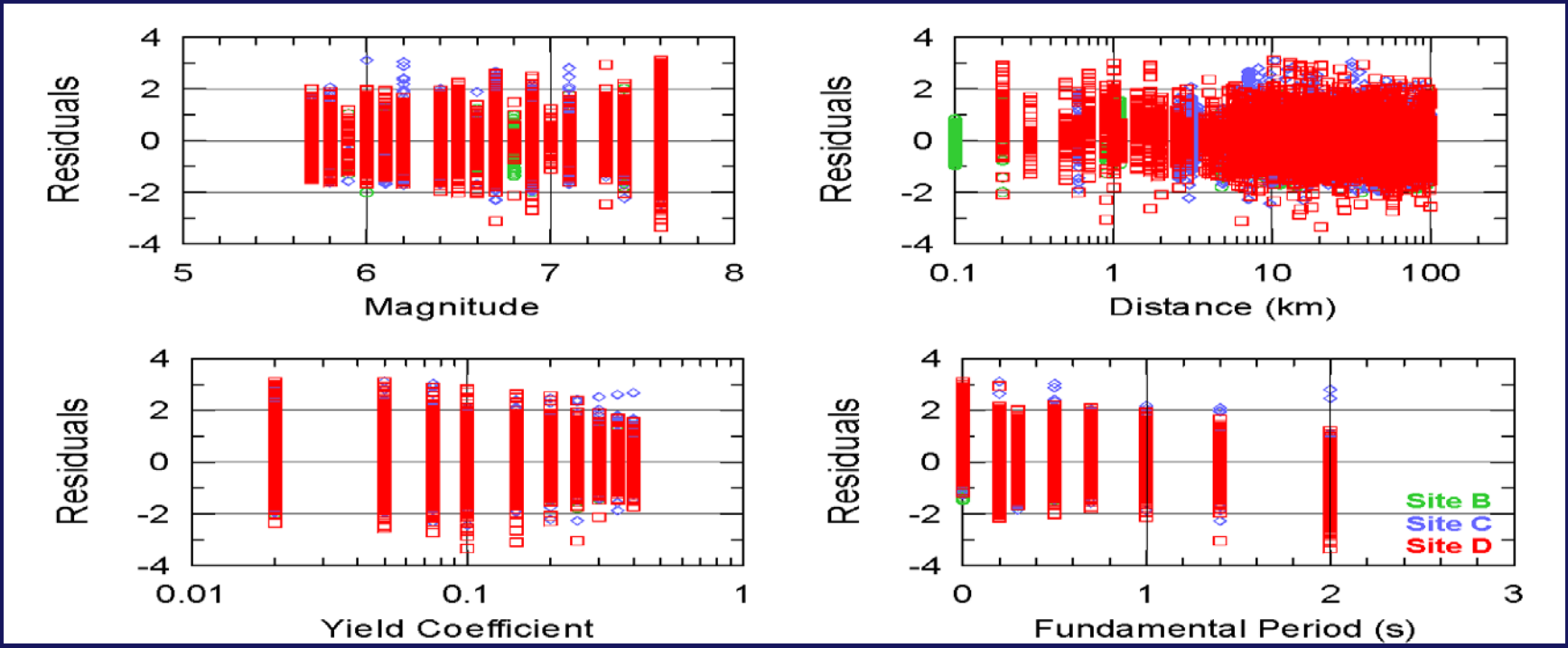
1. **SLOPE MODEL**
   **nonlinear soil response**
   **fully coupled deformable stick-slip**
   **stiffness ($T_s$) & strength ($k_y$)**
   **8 $T_s$ values & 10 $k_y$ values**




2. **EARTHQUAKE DATABASE**
   **41 EQ - 688 records**

**> 55,000 analyses**

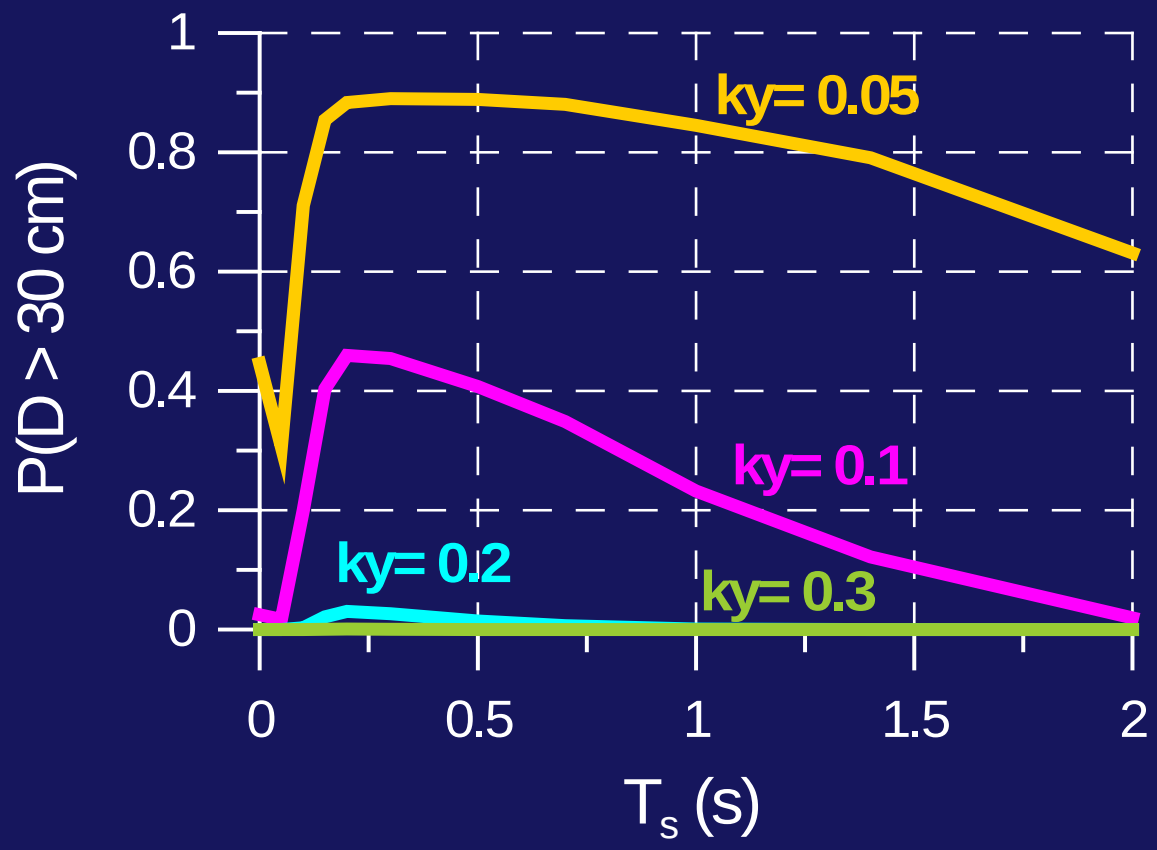
# Bray & Travasarou (2007)




**"Nonzero" Seismic Displacement Estimate:**

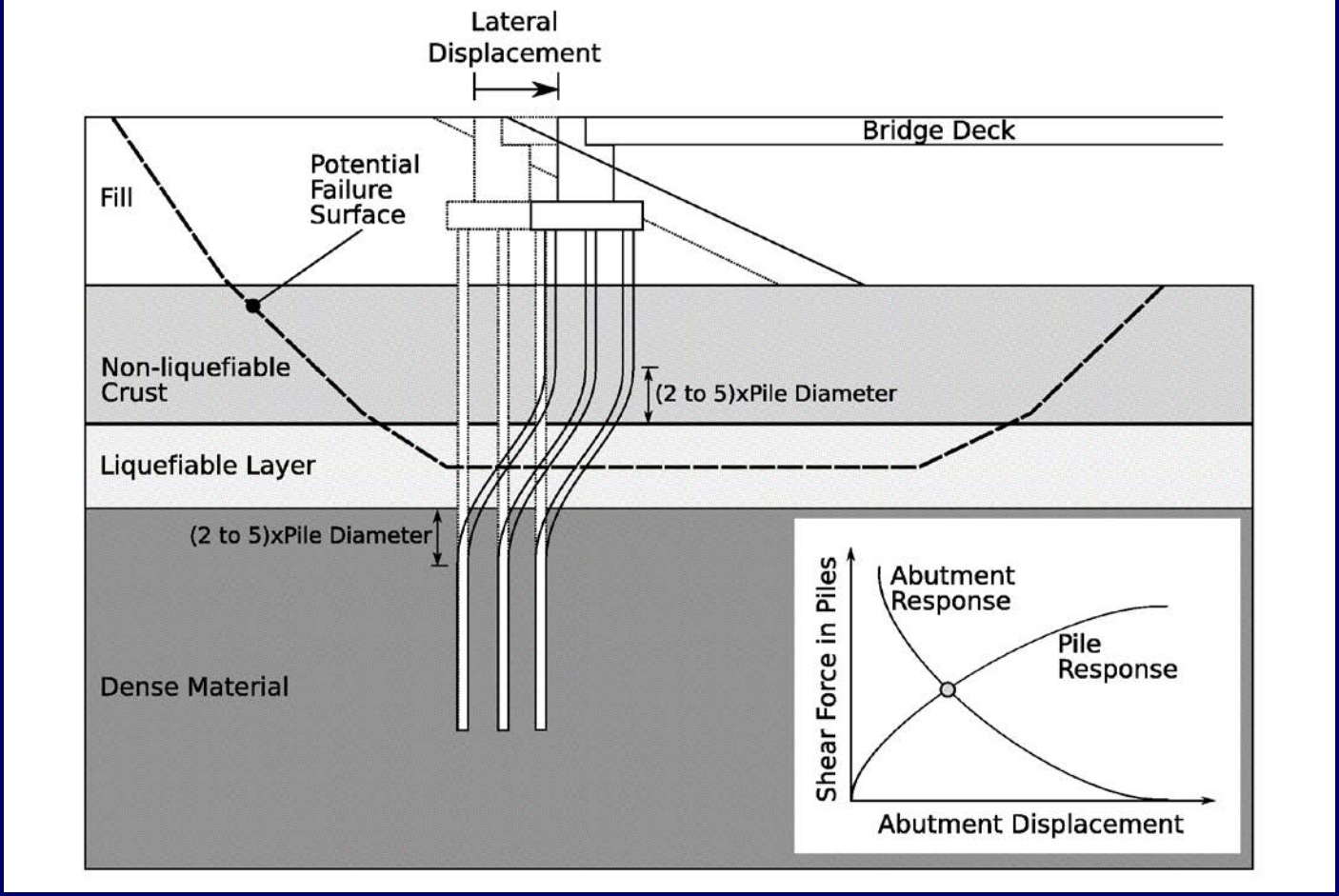
$$\ln(D) = -1.10 - 2.83\ln(k_y) - 0.333\left(\ln(k_y)\right)^2 + 0.566\ln(k_y)\ln(S_a(1.5T_s)) +$$
$$3.04\ln(S_a(1.5T_s)) - 0.244\left(\ln(S_a(1.5T_s))\right)^2 + 1.50T_s + 0.278(M-7) \pm \varepsilon$$

# PROBABILITY OF EXCEEDANCE of Seismic Displacement




**Scenario EQ: M 7 at 10 km on soil site**

# Liquefaction-Induced Lateral Displacement of Bridges with the Pile-Pinning Effect




Ledezma & Bray (2008)

# PEER Methodology

- The problem is divided into pieces that, although related, can be analyzed independently from each other:
  - – Intensity of ground motions?
  - – Response for a given intensity?

~✓

  - – Damage for given response?
  - – Consequences for a given damage state?

?

# Retrofit Options Before Earthquake Event

## (Ledezma & Bray with input from Caltrans Engineers)

| Engineering Demand Parameter | Seismic Displ. (in) | Damage State | Retrofit Decision | Repair Cost Ratio | Down-Time (days) |
|---|---|---|---|---|---|
| **Fill settlement** | 0 – 1” | Negligible | Do nothing | 0% | 0 |
| | 1” – 8” | Small | Repave | 2% | 1 |
| | 8” – 40” | Moderate | Reshape embankment some and repave | 10% | 5 |
| | 40” – 120” | Large | Reshape embankment much and repave | 50% | 20 |
| | > 120” | Collapse | Tear down and rebuild | 100% | 120 |
| **Pile head displacement** | 0 – 1” | Negligible | Do nothing | 0% | 0 |
| | 1” – 4” | Small | Do nothing | 0% | 0 |
| | 4” – 20” | Moderate | Thicken the displaced bridge pier; add a few more piles | 10% | 15 |
| | 20” – 80” | Large | Add many more piles | 50% | 30 |
| | > 80” | Collapse | Tear down and rebuild | 100% | 120 |

# INSIGHTS

- Methodology can be used to identify likely damage state and repairs required
- Methodology can be used to evaluate the relative importance of key parameters:
  - Intensity of the ground motion, $S_a(1.5T_s)$
  - Error term in estimating seismic displacement, $\varepsilon$
  - Residual undrained shear strength of liquefied material, $S_{ur}$
- Identify what matters most to impact on death, dollars, and downtime.

# Limitations

- Key limitation in PEER methodology is relating death, dollars, and downtime to damage and then relating damage to seismic displacement.
- Uncertainty in the evaluation will always depend significantly on the seismic and geotechnical characterization.