MITIGATION OF LATERAL SPREADING EFFECTS ON BRIDGES

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Title: Mitigation of Lateral Spreading Effects on Bridges

Consider an existing ordinary bridge:

1. Assess the potential of liquefaction and lateral spreading
2. If needs to fix:
   I. Add more piles
   II. Use large diameter extended pile shafts - Arash’s work
   III. Use ground improvement techniques, like DSM shear box wall - Thang’s work
   IV. Decision making
Inelastic Response of Large Diameter Extended Pile Shafts in Laterally Spreading Ground during Earthquakes
Statement of Problem

• Large diameter extended pile shafts (2 to 3 m) can be an effective choice in areas of potential lateral spreading.

• How to design for effects of shaking and lateral spreading?
Research Approach

1. Nonlinear Dynamic FE Analyses (NDA)
3. Evaluate Current Caltrans Equivalent Static Analysis (ESA)
4. Develop an Improved Guidance
Nonlinear Dynamic FE

1. OpenSees FE framework
2. Soil elements (far field)
   - Constitutive models (MYPD and MYPI)
   - 2Dim “Up” elements
3. Pile elements
   - Fiber sections
   - Flexibility based nonlinear beam column elements
4. Soil springs
   - PY and PYLiq
   - TZ and TZLiq
   - QZ
Ground Motions

40 ground motions from Professor J. Baker

They were selected so that their response spectra match the median and log standard deviations predicted from Boore and Atkinson (2008) model: (from J. Baker, Stanford U.)

- Magnitude = 7 earthquake
- Source-to-site distance = 10 km
- Site Vs30 = 760 m/s
- Earthquake mechanism = strike slip
Results

- Max deck displacement (m)
- Combination of inertia and lateral spreading

(a) Lateral spreading alone
(b) Inertia alone
Results
Conclusions:

- Dynamic FE analyses show that:
  - coupling of inertial and kinematic demands during lateral spreading can be the governing load case, and
  - that is not enveloped by analyzing the inertial and kinematic loading cases separately.

- Caltrans DRAFT ESA criteria:
  - The ESA underestimate the peak displacement and ductility demands,
  - The criterion for $M_{LS}$ being less than 20% $M_p$ did not correlate well with either good or poor performance.
Conclusions (Cont’d)

• Draft proposed ESA includes:

1. Analyze the non-liquefaction case.

2. Analyze the liquefaction case by:
   i. Removing p-y springs from liquefied and crust layers,
   ii. Applying full passive earth pressure from the crust,
   iii. Imposing an additional superstructure displacement $\Delta_2 = C_{\Delta L} \Delta_{NL}$, where $\Delta_{NL}$ is the demand predicted in the absence of liquefaction. Currently, we use $C_{\Delta L}=1.0$ based on the NDA results.
   iv. Adjusting the predicted deck displacement if significant shear strains are estimated to occur in the underlying dense/stiff soils.

• The proposed ESA appears to work equally well for structures that do not yield ($\mu_\phi \leq 1$) and do yield ($1 \leq \mu_\phi \leq 3.5$). We are currently performing a broader set of parametric analyses, which may lead to revisions in the ESA procedures.
Results

(a) Max deck displacement (m) vs. Ground surface PGA (g)

- NDA results
- Caltrans ESA for nonliquefied case
- Caltrans ESA for liquefied case
- Proposed ESA
- $P-\Delta$ criterion
- 1% drift
Ground Improvement Methods:

Cement-mix shear box
Figure 2.1: OpenSeesPL main window.
Next Tasks:

1. 3D vs. 2D simulation using OpenSeesPL
   - How much do the results change?
   - Do the findings change?
   - What are the important factors/parameters?

2. Decision Making
   Compare the efficiency and cost of different mitigation techniques
   - Extended pile shaft vs. pile group
   - Extended pile shaft vs. ground improvement
Animation
Nonlinear Dynamic Analysis (NDA)
Thank you
Any question ?
**Graph Legend:***
- **NDA results**
- **Caltrans ESA for nonliquefied case**
- **Caltrans ESA for liquefied case**
- **Capacity limit**
- **Allowable ductility of 3.5**
- **Yield limit**
- **Proposed ESA**
Equivalent Static Analysis (ESA): Caltrans Draft Guidance
Steps include:

1. **Pushover analysis without liquefaction**
   - Use non-liquefied p-y and t-z springs

2. **Pushover analysis with liquefaction (no LS)**
   - Use liquefied springs (p-multipliers)

3. **Apply lateral spreading (LS) force alone**
   - Check that $M_{LS} < 0.20 M_p$
**ESA – Deck Displacement Demand w/o Liquefaction (Example)**

**Elastic period**

\[ T_e \text{ (non-liq)} = 3.2 \text{ sec} \]

For 0.6 g at rock outcrop

\[ \text{PSa} = 0.11 \text{ g} \]

\[ \Delta_e = \frac{\text{PSa}}{\omega^2} = 0.28 \text{ m} \]

Use R-\(\mu\)-T relationships

High \(T_e\) \(\rightarrow\) “equal displacement”

\(\Delta_{e-p} = 0.28 \text{ m} \)
Steps include:

1. Pushover analysis without liquefaction
   - Use non-liquefied p-y and t-z springs

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 ESA-Caltrans vs. FE Nonlinear Dynamic Analysis

ρ_s = 4%, Axial P = 10% A_g f'_c → μ_φ ≤ 1 (low ductility)
ESA-Caltrans vs. FE Nonlinear Dynamic Analysis

\[ \rho_s = 4\%, \text{Axial P} = 10\% A_g f'_c \rightarrow \mu_\phi \leq 1 \text{ (low ductility)} \]
\( \rho_s = 4\%, \text{ Axial P} = 10\% A_g f'_c \rightarrow \mu_\phi \leq 1 \) (low ductility)
EQUIVALENT STATIC ANALYSIS (ESA): DRAFT PROPOSED GUIDANCE
ESA – Draft Proposed Guidance

Steps include:

1. Analyze for non-liquefaction case
   - Use non-liquefied p-y and t-z springs

2. Analyze the liquefaction case
   - removing p-y springs from liquefied and crust layers and applying full passive earth pressure from the crust
   - Imposing an additional superstructure
     displacement $\Delta z = C_{\Delta L} \Delta_{NL}$, where $\Delta_{NL}$ is the demand predicted in the absence of liquefaction. Currently, we use $C_{\Delta L}=1.0$ based on the NDA results.
ESA – Draft Proposed Guidance

Steps include:

1. Analyze for non-liquefaction case
   - Use non-liquefied p-y and t-z springs

2. Analyze the liquefaction case
   - removing p-y springs from liquefied and crust layers and applying full passive earth pressure from the crust
   - Imposing an additional superstructure displacement $\Delta_2 = C_{\Delta L} \Delta_{NL}$, where $\Delta_{NL}$ is the demand predicted in the absence of liquefaction. Currently, we use $C_{\Delta L} = 1.0$ based on the NDA results.
ESA – Draft Proposed Guidance

Steps include:

1. Analyze for non-liquefaction case
   - Use non-liquefied p-y and t-z springs

2. Analyze the liquefaction case
   i. removing p-y springs from liquefied and crust layers and applying full passive earth pressure from the crust
   ii. Imposing an additional superstructure displacement $\Delta_2 = C_{\Delta L} \Delta_{NL}$, where $\Delta_{NL}$ is the demand predicted in the absence of liquefaction. Currently, we use $C_{\Delta L} = 1.0$ based on the NDA results.
i. Applying full passive earth pressure from the crust

(Crust $S_u = 80$ kPa)
ii. **Imposing an additional superstructure displacement**
**Global Disp demand:**

\[ \Delta_1 + \Delta_2 = 0.34 \text{ m} \]

**Additional Disp:**

\[ \Delta_2 = C_{\Delta L} \Delta_{NL} = 1.0(0.28 \text{ m}) = 0.28 \text{ m} \]

**Global Disp demand:**

\[ \Delta_1 + \Delta_2 = 0.34 \text{ m} \]

*From pushover analysis:*

**Local curvature demand** = 0.003 (1/m)
Adjust displacement for dense sand layer shear strain
Adjust displacement for dense sand layer shear strain

For 0.6 g shake:

Avg. $\gamma = 1.2\%$
$L = 30 \text{ m}$
$\gamma \times L = 0.36 \text{ m}$
$\rho_s = 4\%$, Axial $P = 10\%$  
Crust $S_u = 80$ kPa
\( \rho_s = 4\% \),
Axial \( P = 10\% \)
Crust \( S_u = 80 \text{ kPa} \)

\[
\rho_s = 4\%
\]
\[
\text{Axial } P = 10\%
\]
\[
\text{Crust } S_u = 80 \text{ kPa}
\]
**ESA – Draft Proposed results**

ρ_s = 4%, Axial P = 10%
Crust S_u = 80 kPa