SEISMIC PERFORMANCE OF PILED WHARVES

- Seismic design and BS 6349?
- Part 1-2 will have guidance on seismic loading
- Design example using displacement based design [Eurocode 8, ASCE 61-14]
- Concrete deck on steel piles
SEISMIC PERFORMANCE OF PILED WHARVES

- How does the choice of pile section affect the seismic performance?
- When can we allow plastic hinges form in-ground?
- How can we refine the pile selection using Nonlinear Static Pushover Analysis?
CONTENTS

- Sample structure considered [typical container quay]
- Steel pile sections and seismic loading considered
- Nonlinear static pushover analysis steps
- Comparison of results
Sample structure

Service Loads:
Berthing load: 1200 kN / bent (7.0m)
Mooring load: 500 kN / bent (7.0m)
Crane load: 4000 kN WL at crane rail pos.
UDL: 40 kN/m²

Geotechnical parameters:

<table>
<thead>
<tr>
<th>Soil layers</th>
<th>$\gamma$ [kN/m³]</th>
<th>$K$ [kN/m³]</th>
<th>$\Phi$ [Degree]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarry Run</td>
<td>20.0</td>
<td>44,000</td>
<td>40</td>
</tr>
<tr>
<td>Sand</td>
<td>19.0</td>
<td>25,500</td>
<td>36</td>
</tr>
</tbody>
</table>
Seismic design considerations

- Structure is located in moderate to high seismic area

<table>
<thead>
<tr>
<th>Pile behavior</th>
<th>Class</th>
<th>In-ground hinge?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic [ductile]</td>
<td>1/2</td>
<td>All piles</td>
</tr>
<tr>
<td>Elastic</td>
<td>3/4</td>
<td>No piles</td>
</tr>
<tr>
<td>Plastic &amp; Elastic</td>
<td>2&amp;4</td>
<td>Landward piles</td>
</tr>
</tbody>
</table>

- Nonlinear static pushover analysis is used
Design cases

- Design PGA:
  - 0.25g
  - 0.40g
  - 0.60g

- Three cases are investigated:

**Case 1:**
All pile class: 1/2

**Case 2:**
All pile class: 3/4

**Case 3:**
Mixed class: 1/2 + 3/4
Modelling

Top of soil

Rigid element

R.C section properties

Composite section properties

Pile section properties

C.G. of deck

Pile plug

Soil spring

Rigid element

Pile section properties

Modelling

\[ EI_{\text{eff}} = \frac{M_p}{\phi_Y} \]

\[ EI_{\text{eff}} = EI \]

\[ K_i = \frac{P_i}{Y_i} \]

Soil – [p-y curves by Reese et al.]
Modelling

Pile bent modelling

Model in SAP2000
Analysis steps

S1. Run static pushover analysis & display pushover curve

S2. Determine displacement demand [capacity spectrum]

S3. Applied DMF factor => $\Delta_D = \text{DMF} \times \Delta_0$
Analysis steps

S4. Re-push model to $\Delta_D$ & save hinge output
S5. Checking the plastic curvature by interaction diagram

\[ \frac{\theta_p}{L_p} = \Phi_p \]
Results

- PGA = 0.25g

**Case 1:** Class 1/2
- D813-14.2mm

**Case 2:** Class 3/4
- D1220-(12.5-20.6)mm

**Case 3:** Mixed class 1/2 + 3/4
- D1016 – (12.5-17.5)mm

**Limited ductile (EC8-2)**
- D1220-(16.0-23.8)mm
Results

Pile weight per bent & Displacement

- Case 1-D813: 79.5 Class 1/2
- Case 2-D1220: 93.6 Class 3/4
- Case 3-D1016: 78.3 Mixed
- LD-1220: 115.3 EC8-2

PGA=0.25g

W - t/bent

Case 1-D813
Case 2-D1220
Case 3-D1016

PGA/g

△ - mm

Case 1-D813
Case 2-D1220
Case 3-D1016

PGA/g

D1220-20.6mm => D1520-25mm
12.5 => 16.0mm
Results

Bending moment in crossheads

Class 1/2 – D813

Class 3/4 – D1220

Mixed – D1016

Class 3/4 – D1220/1620
Conclusions

- Pile design with in-ground plastic hinges is an economical option, especially for high PGA.

- Using a non-ductile pile section preventing plastic hinges in the ground, usually leads to the uneconomical design.

- Limiting criteria is typically shear demand in landward pile / deck connections.

- Using pushover analysis enables specifying ductile sections for some piles and class 4 for others.