Royal HaskoningDHV
Enhancing Society Together

PILED WHARF – SEISMIC DESIGN EXAMPLE

DISPLACEMENT –BASED SEICMIC DESIGN [PUSHOVER ANALYSIS]

Duyet Nguyen
Dimitrios Pachakis
Helge Frandsen
8 February 2016

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?

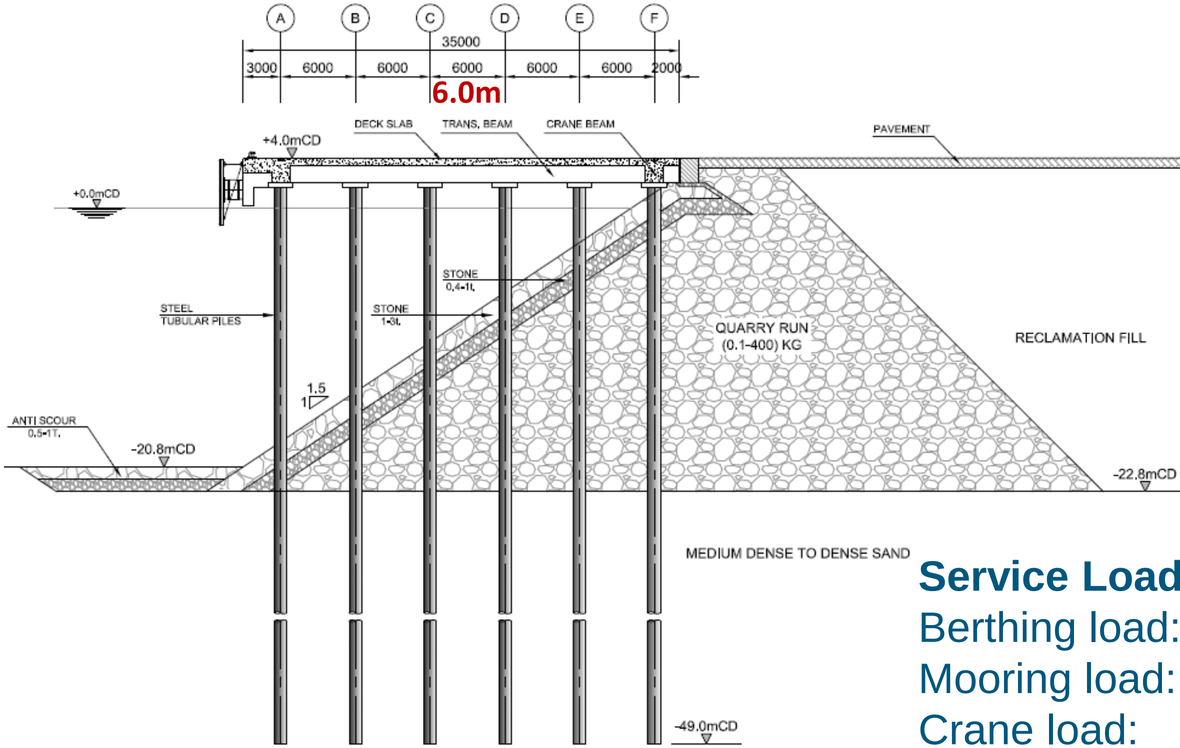
Royal HaskoningDHV

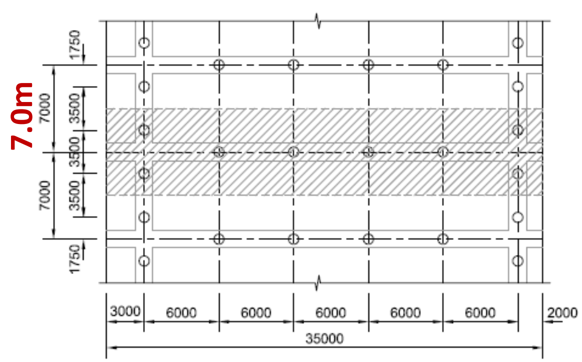
CONTENTS

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

Royal HaskoningDHV

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/m^2

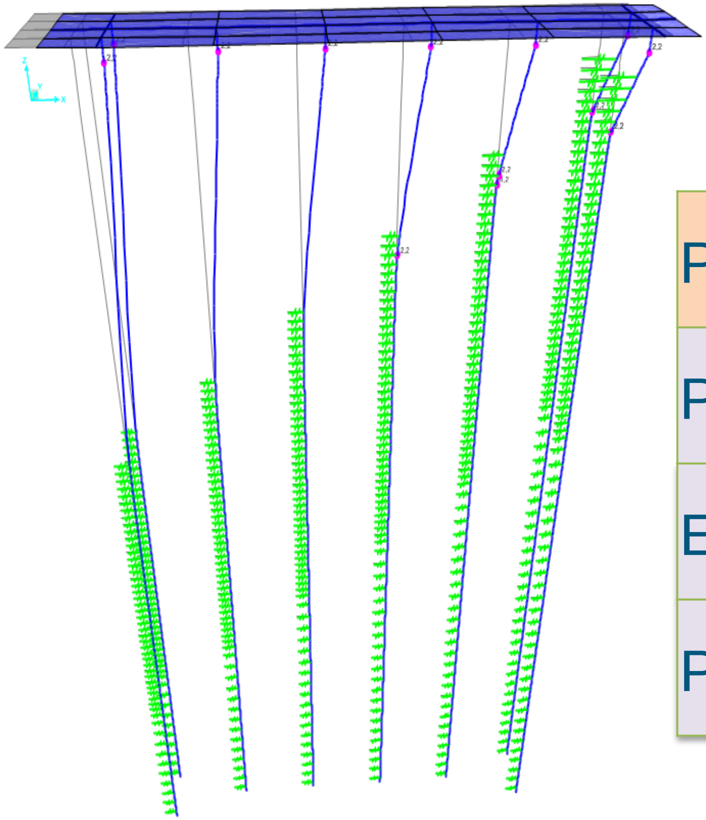
Geotechnical parameters:

Soil layers	γ [kN/m³]	K [kN/m³]	Φ [Degree]
Quarry Run	20.0	44,000	40
Sand	19.0	25,500	36

Royal HaskoningDHV

Seismic design considerations

- Structure is located in moderate to high seismic area



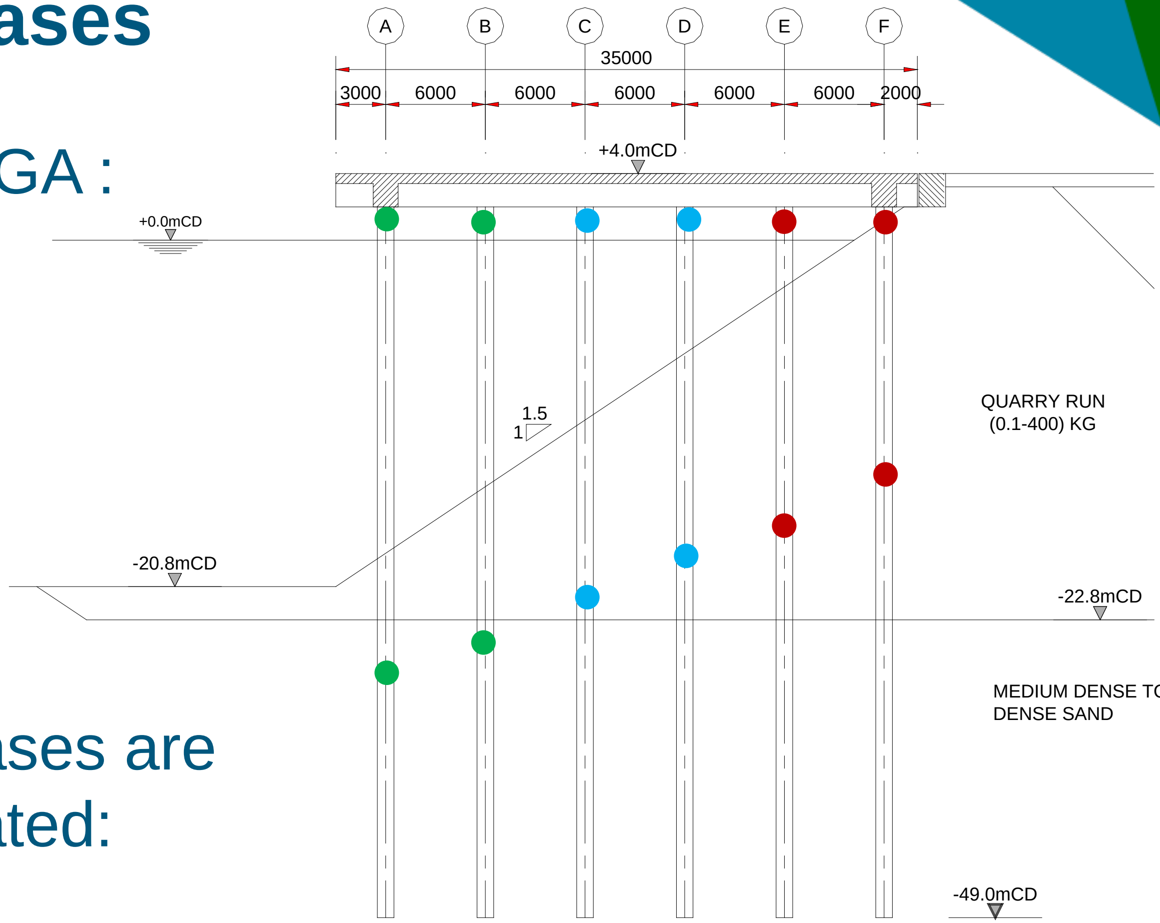
Pile behavior	Class	In-ground hinge?
Plastic [ductile]	1/2	All piles
Elastic	3/4	No piles
Plastic &Elastic	2&4	Landward piles

- Nonlinear static pushover analysis is used

Royal HaskoningDHV

Design cases

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



- Three cases are investigated:

Case 1:

All pile class: 1/2

Case 2:

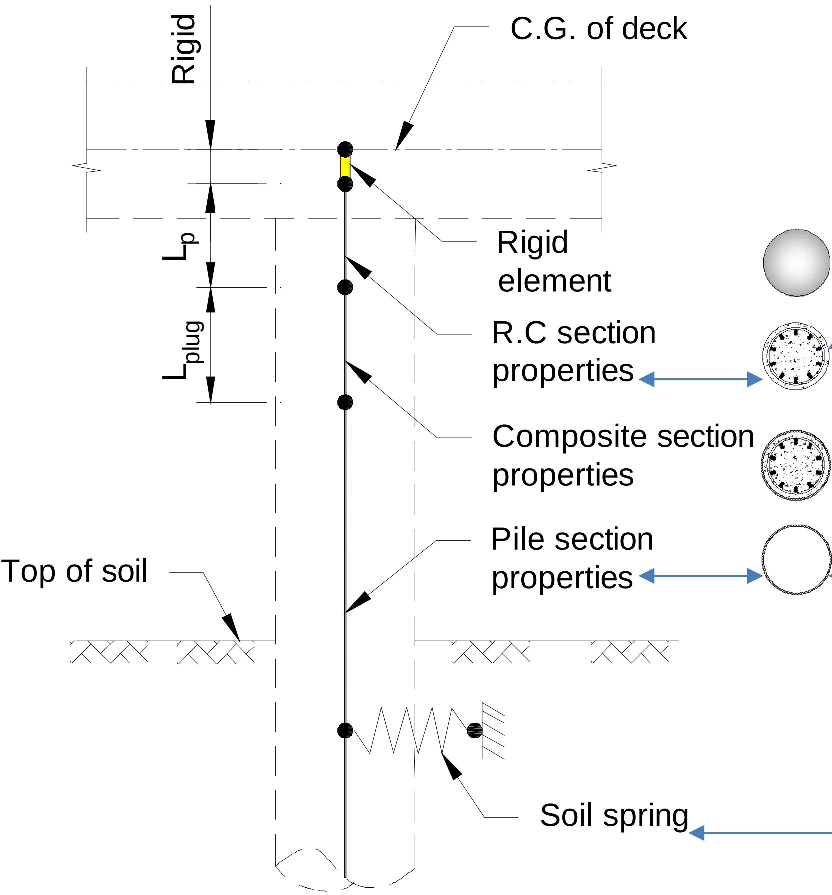
All pile class: 3/4

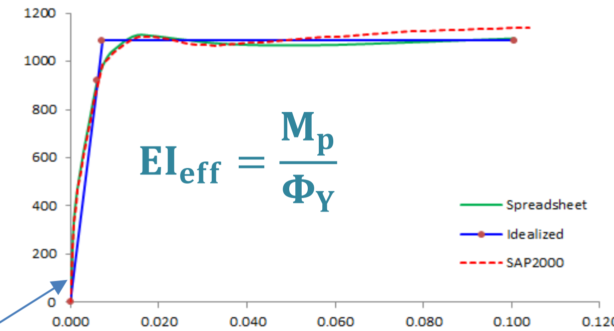
Case 3:

Mixed class: 1/2 + 3/4

Royal HaskoningDHV

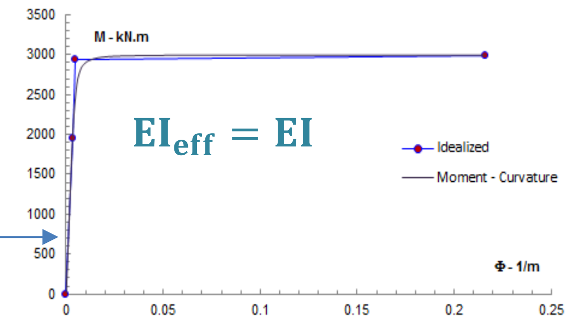
Modelling





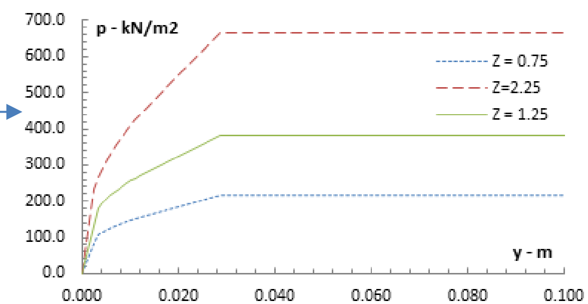
$$EI_{eff} = \frac{M_p}{\Phi_Y}$$

Pile plug



$$EI_{eff} = EI$$

Pile structural

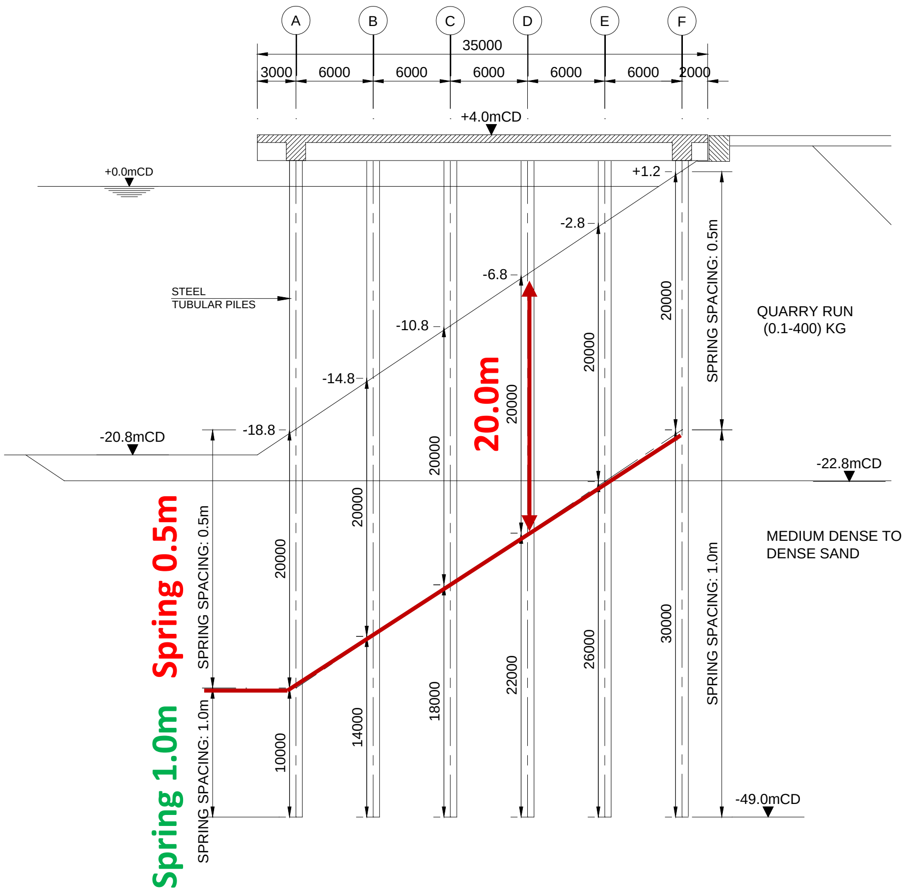


$$K_i = \frac{P_i}{Y_i}$$

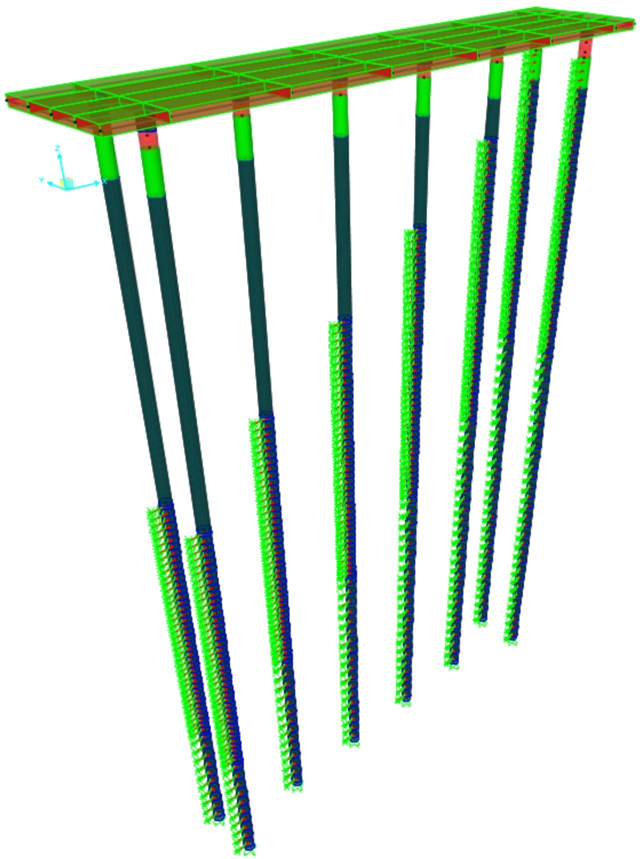
Soil – [p-y curves by Reese et al.]

Pile modelling

Modelling



Pile bent modelling



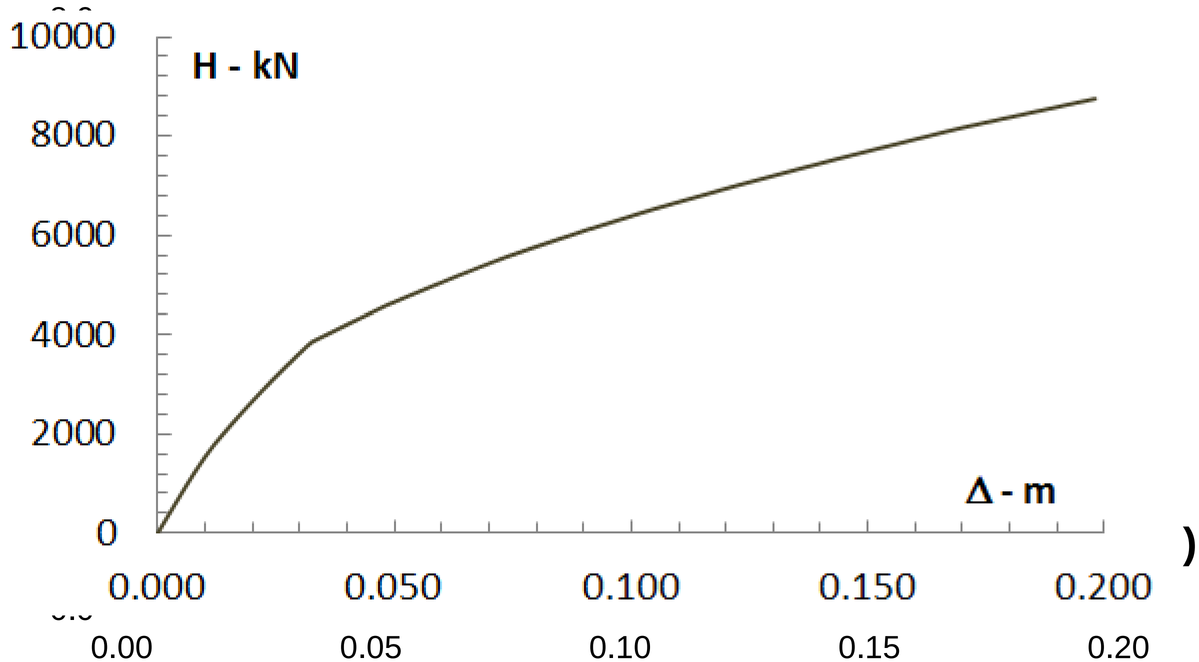
Model in SAP2000

Royal HaskoningDHV

Analysis steps

S1. Run static pushover analysis & display pushover curve

S2. Determine displacement demand [capacity spectrum]

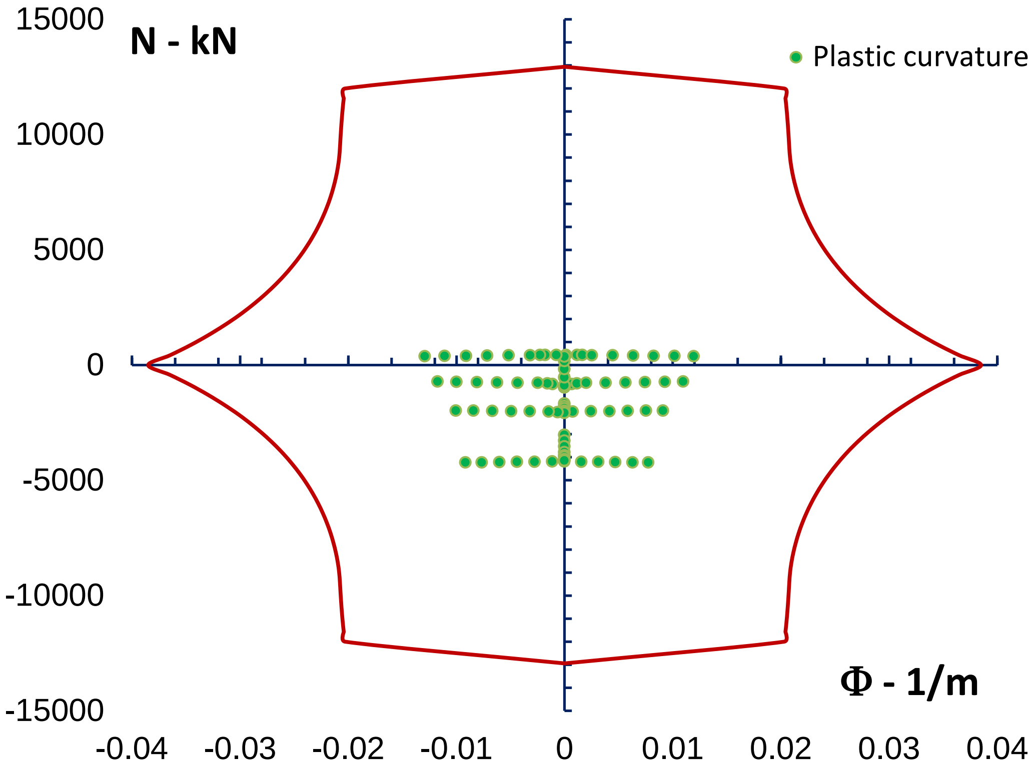


S3. Applied DMF factor => Δ_D = DMF x Δ_0

Analysis steps

S4. Re-push model to Δ_D & save hinge output

S5. Checking the plastic curvature by interaction diagram



$\theta_p / L_p = \Phi_p$

Royal HaskoningDHV

Results

- PGA =0.25g

Case 1: Class 1/2

D813-14.2mm

Case 2: Class 3/4

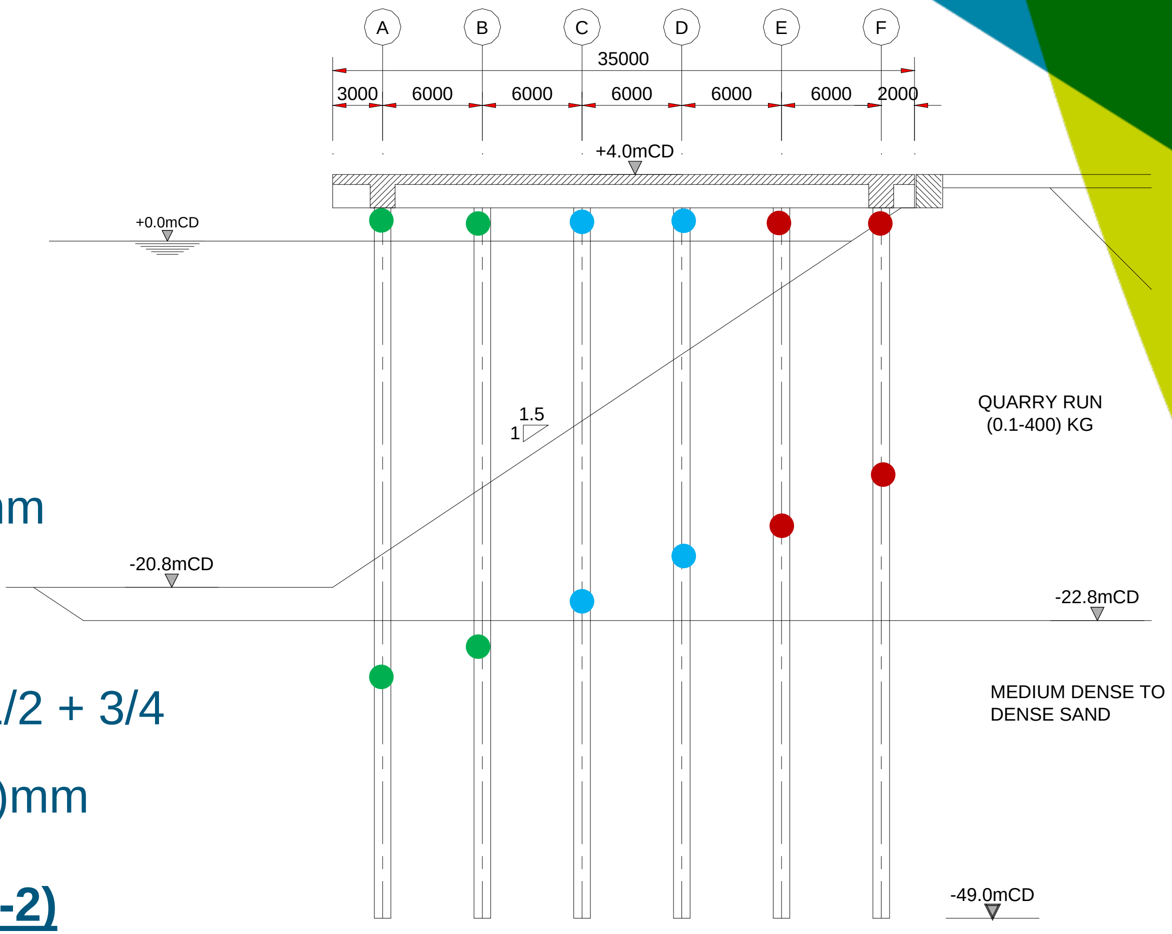
D1220-(12.5-20.6)mm

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

D1016 – (12.5-17.5)mm

Limited ductile (EC8-2)

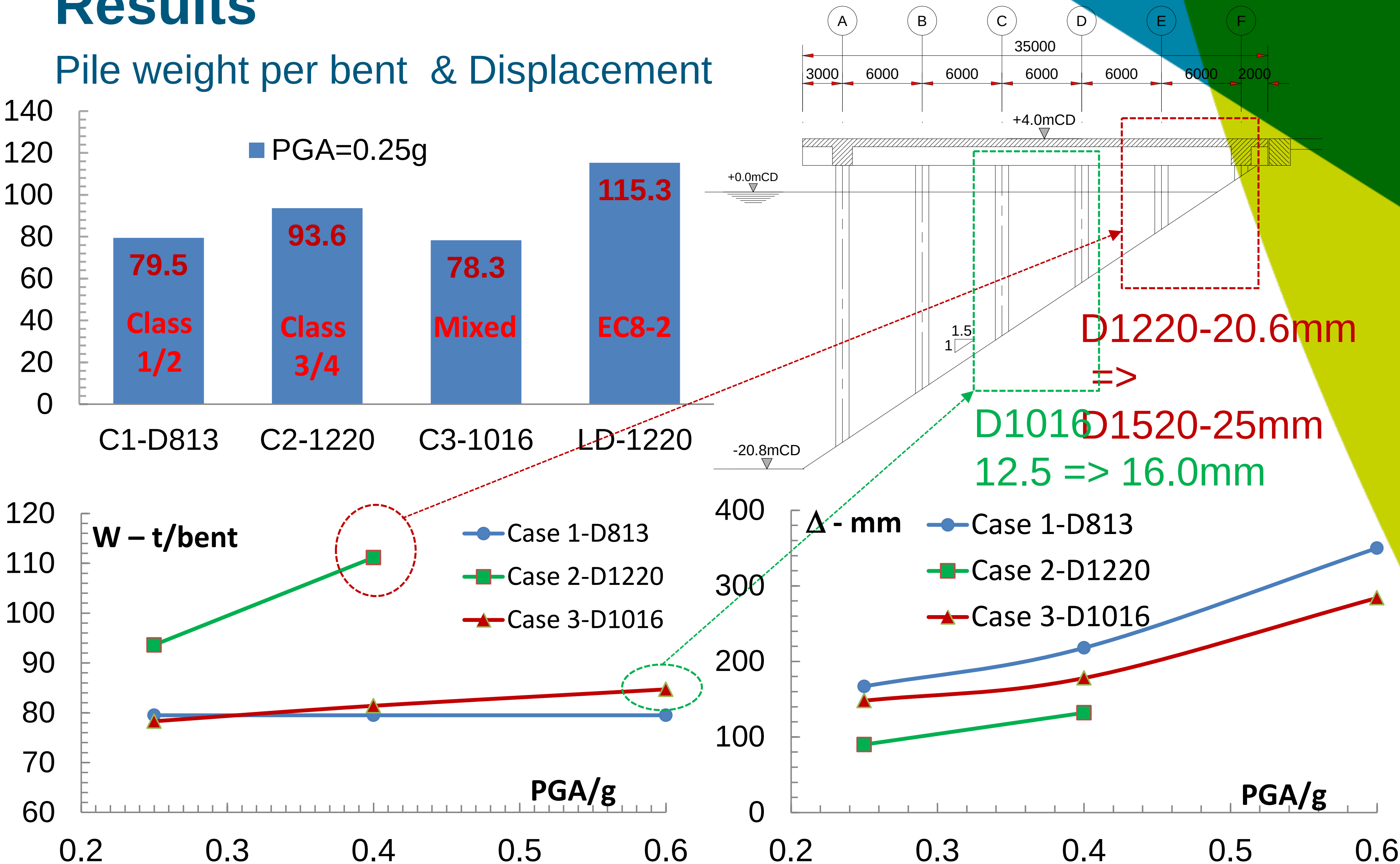
D1220-(16.0-23.8)mm



Royal HaskoningDHV

Results

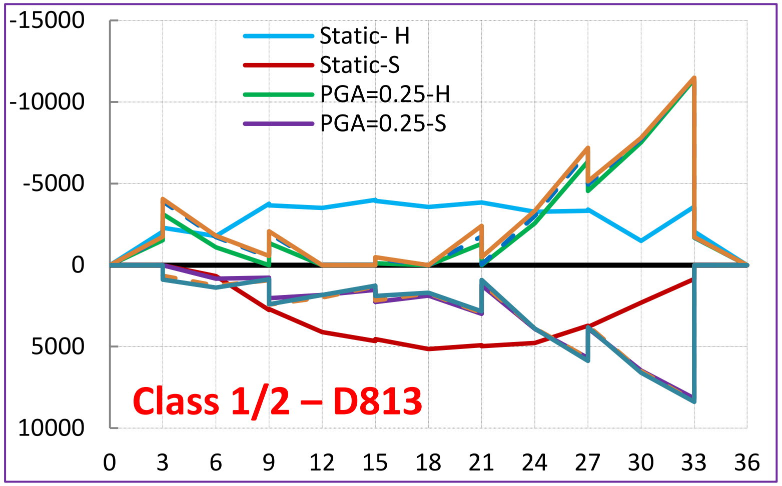
Pile weight per bent & Displacement

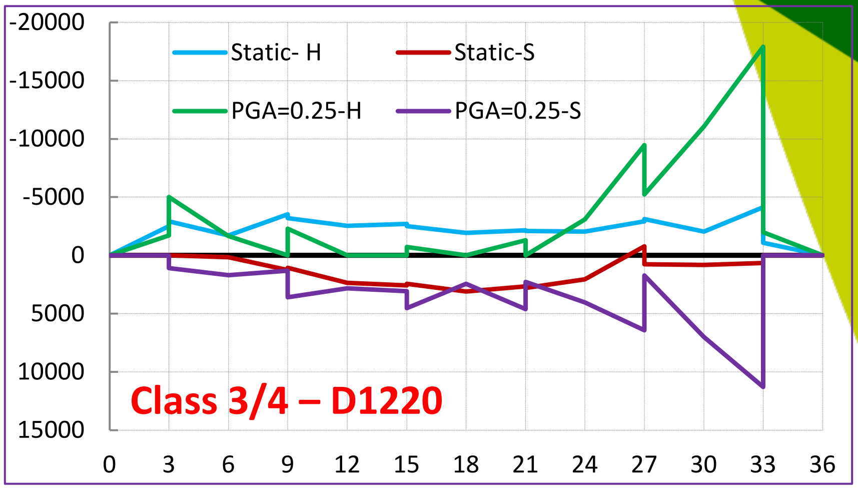


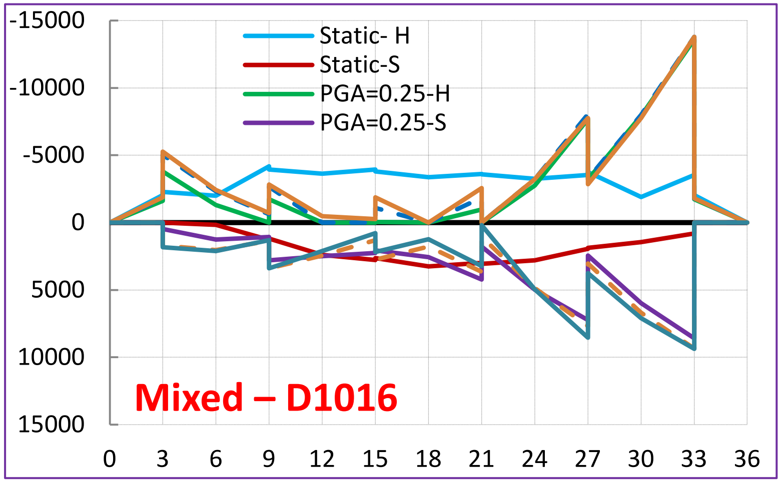
Royal HaskoningDHV

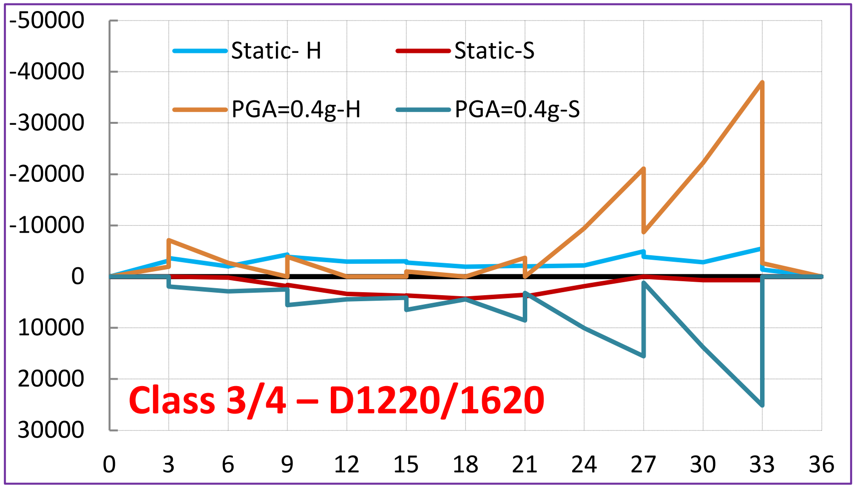
Results

Bending moment in crossheads









Royal HaskoningDHV

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

Q&A

helge.frandsen@rhdhv.com

Royal HaskoningDHV