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Dynamic Behaviour of Piles in Clay Slopes

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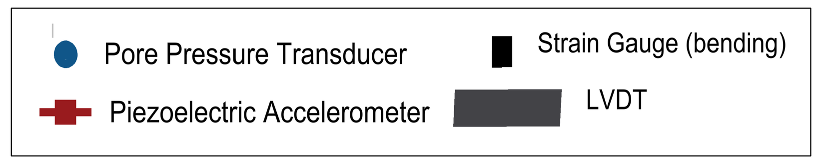
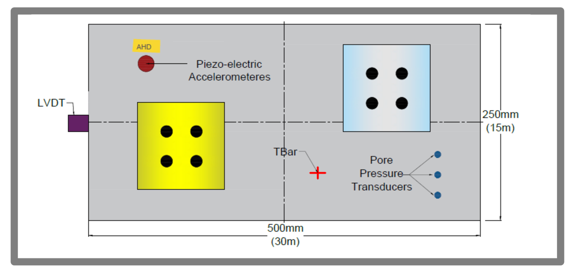
Background and motivation

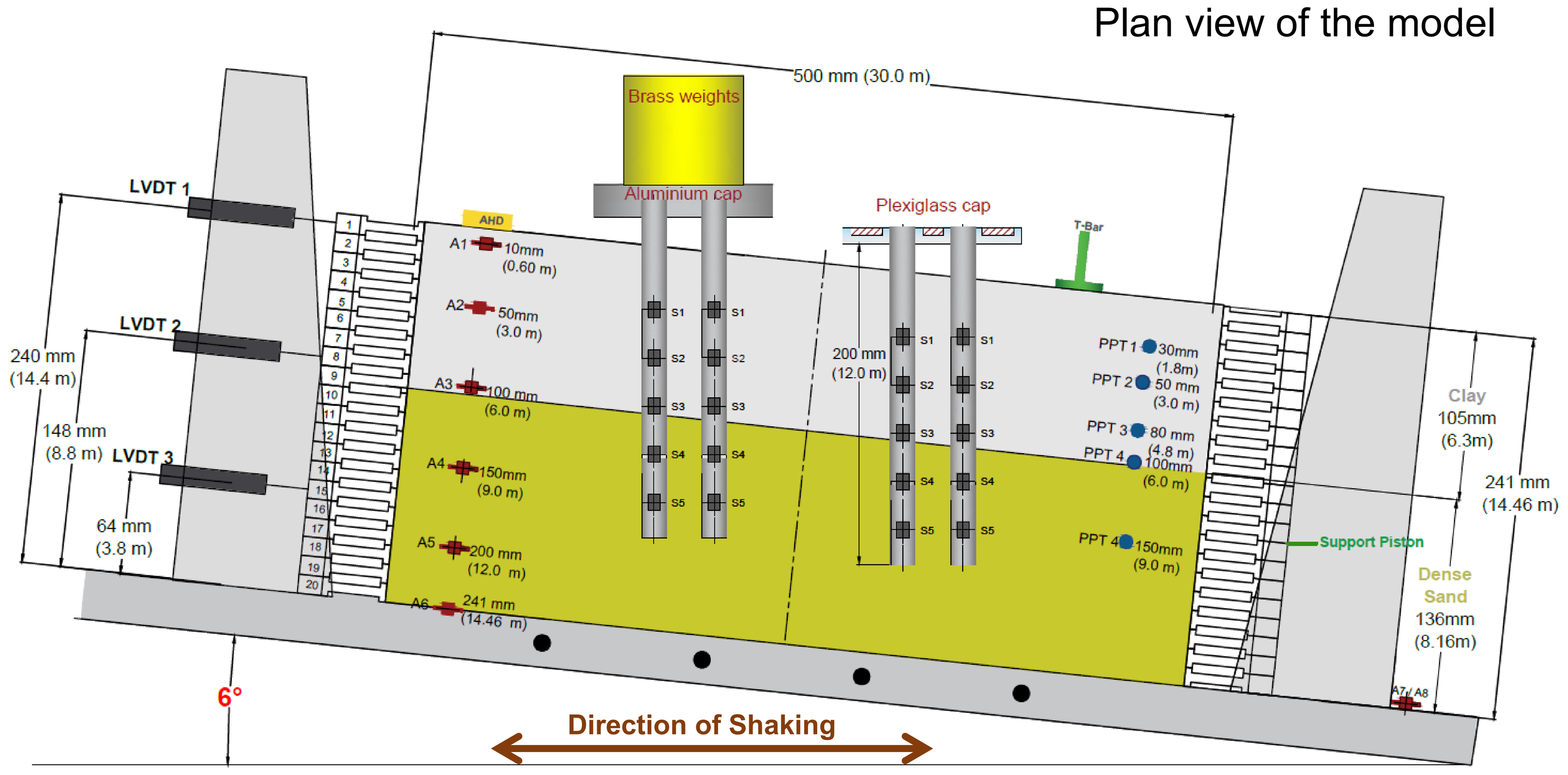
- With the growing global focus on the offshore energy industry, the seismic stability of structures constructed on gentle submarine slopes has become a major concern.
- **Submarine slopes** are composed of soft cohesive soils and generally have gentle inclinations. Similar **low-gradient clay slopes** are also common along **riverbanks**, where bridge abutments are often located.
- **During an earthquake**, as the **soil moves** downslope, **additional pressures** are exerted on pile foundations built in such slopes **(kinematic interaction / KI).**
- Oscillation of the **superstructural mass** atop the pile generates **extra inertial forces** and overturning moments **(inertial interaction / II).**
- The **simultaneous interaction** of **KI + II** is **complex and sparsely researched.**
- Understanding the dynamic behavior of piles in clay slopes is key to **optimising pile design**, especially for seismically active regions.

Methodology : Centrifuge testing

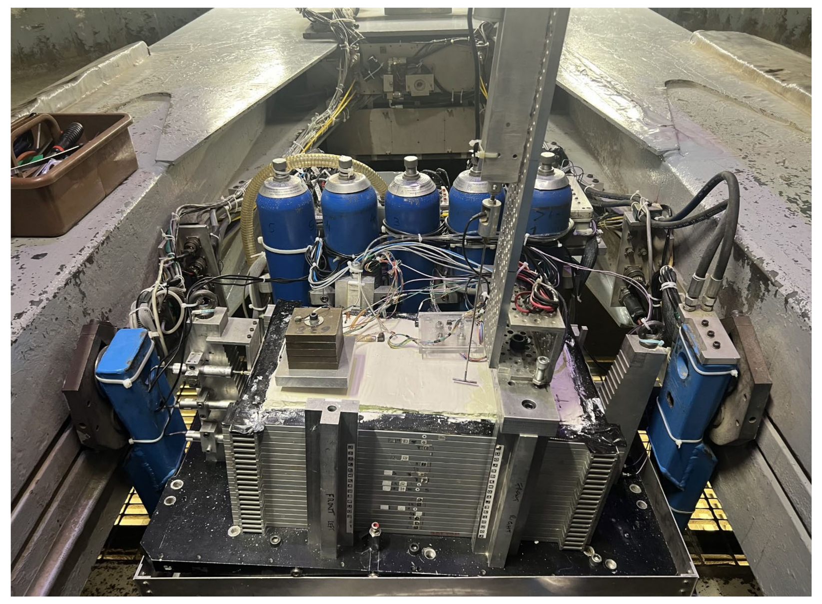
- Four geotechnical centrifuge tests at **60*g*** were conducted on **2x2 pile groups with and without top masses:**
  - SW03: Pile groups of **spacing 2.5D** embedded in a **6˚ slope**
  - SW04: Pile groups of **spacing 5D** embedded in a **6˚ slope**
  - SW05: Pile groups of **spacing 2.5D** embedded in a **3˚ slope**
  - SW06: Pile groups of **spacing 5D** embedded in a **3˚ slope**
- Prototype pile dimensions **0.9m (D) x 12m (L).**
- To simulate **KI** ⟶ used an acrylic plexiglass pile cap of negligible weight.
- To simulate **KI+II** ⟶ brass masses were added on pile cap (*static vertical force at prototype scale = 8.26 MN*).
- The **laminar container** driven solely by soil deformations was utilised to model the sloping ground.
- A saturated dense sand layer prepared with **Hostun sand (I_d=80%)** was overlain by a layer of **Speswhite Kaolin clay (s_u = 20 kPa).**
- Models were subjected to a **range of earthquakes.**
- Pile groups and sensors were placed in separate vertical planes to minimise boundary effects and possible dynamic interactions.

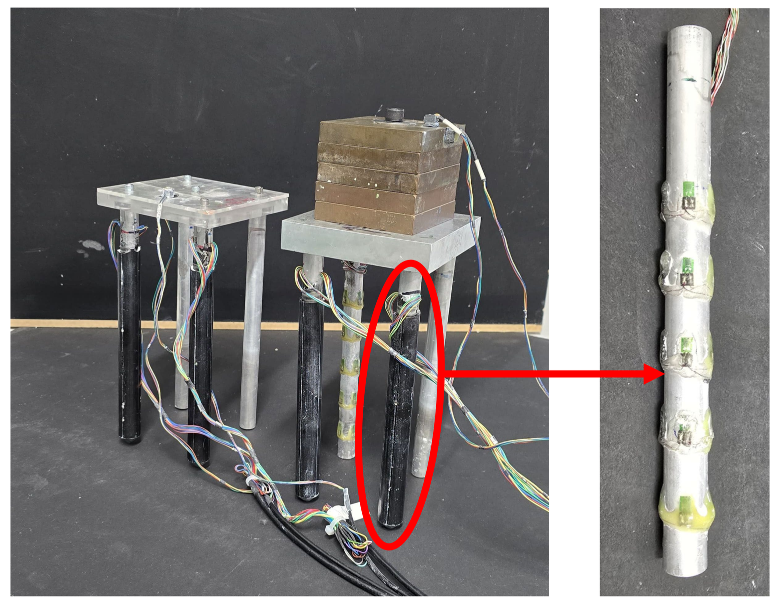


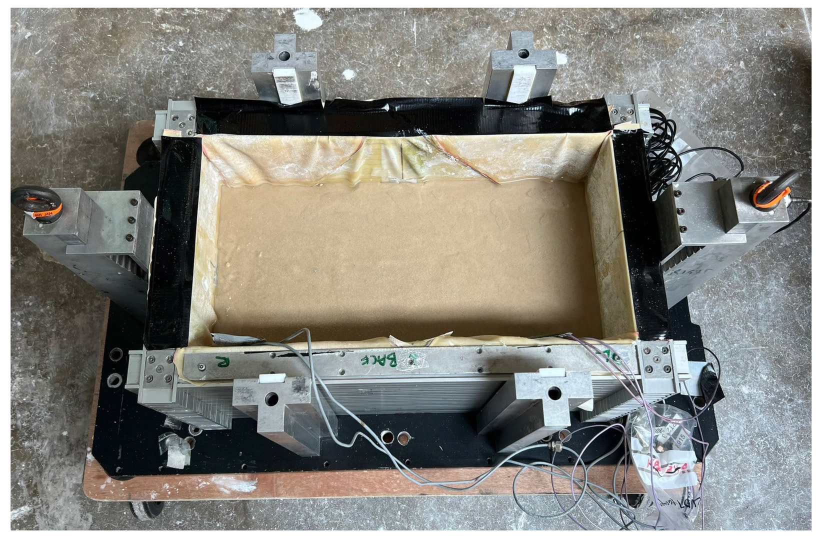

Plan view of the model

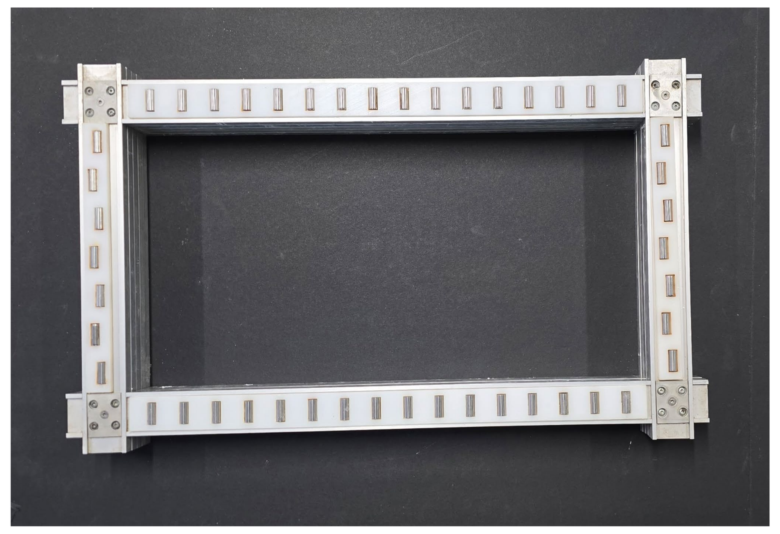


Schematic of centrifuge model (*prototype dimensions within brackets*)


Pre-test model

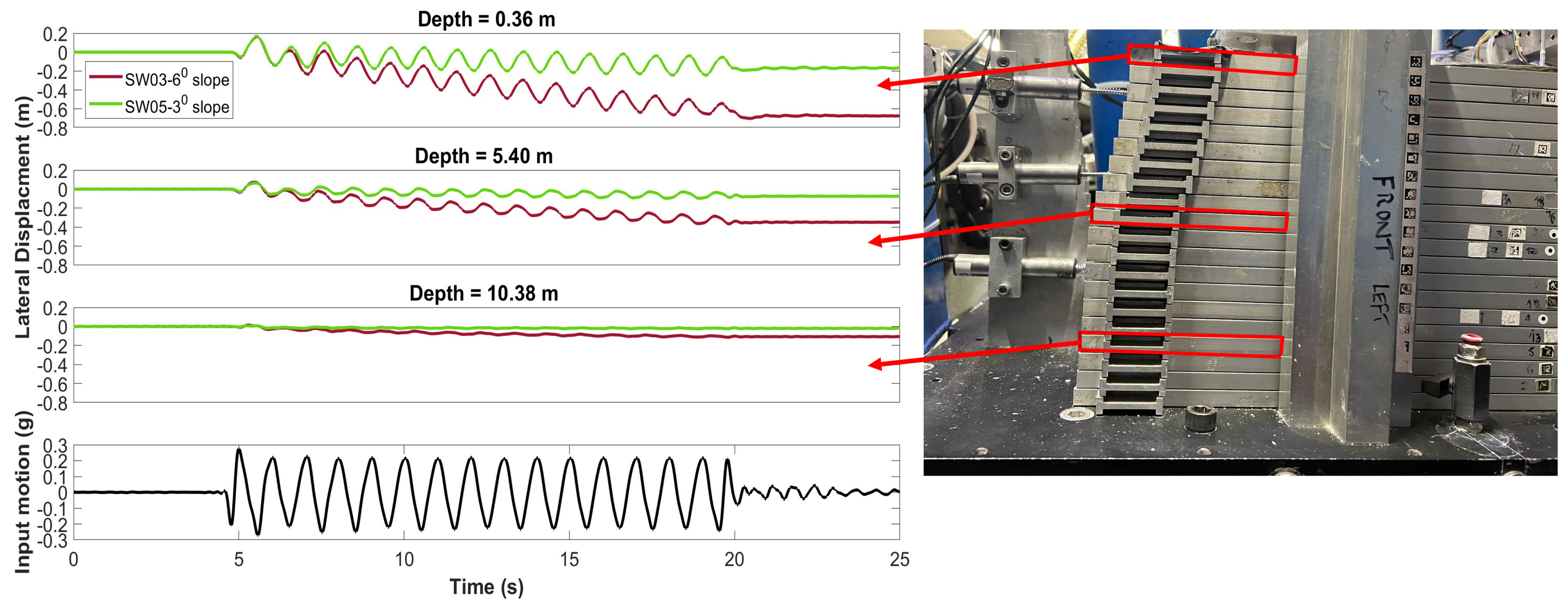

Model pile groups, strain gauges


Laminar container


Laminations with cylindrical bearings

Experimental results

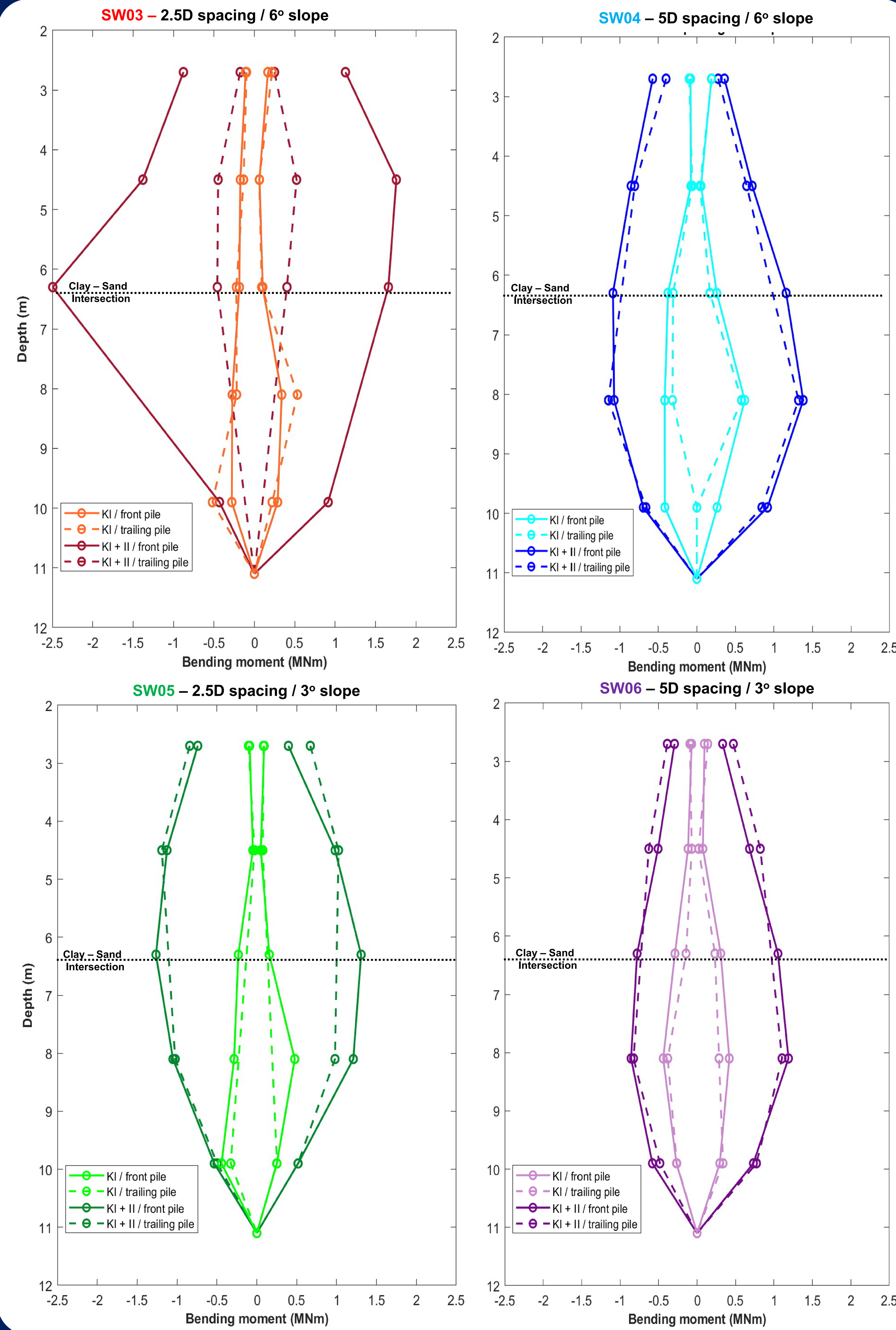
- ***Lateral soil displacements***



Significant lateral displacement was observed in SW03 compared to SW05, as anticipated. Displacement of the 6˚ slope was approximately 4 times that of the 3˚ slope.

- ***Bending moments***

- In general, front piles (downslope) experienced greater bending moments than trailing piles (upslope) as they were pushing into undisturbed soil (*solid vs dashed lines*).
- Piles with top mass exhibited significantly higher bending moments, owing to the extra inertial forces generated by the oscillating top mass (*dark vs light shades*).
- Pile groups of 2.5D spacing have seen larger bending moments compared to those of 5D spacing.
- Steeper slopes beset larger bending moments on piles.
- The front and trailing piles in both pile groups with 5D spacing exhibited similar bending moments, regardless of the top mass condition, indicating minimal group effects at this spacing.



Conclusions and future work

- Steeper slopes generate larger bending moments owing to additional kinematic interaction from slope movement.
- Kinematic interaction has little effect on pile bending moments compared to inertial interaction.
- Pile spacing of a pile group influences the kinematic interaction (i.e shadowing effects) irrespective of top mass conditions.
- Shadowing effects, which are significant at a 2.5D spacing, diminish when the group is more widely spaced at 5D.
- Future work: new design guidelines for more effective pile group design.
  - Quantify the individual kinematic and inertial demands posed on the pile foundations under dynamic and sloping clay ground conditions.
  - Quantify the influence of pile spacing in the dynamic response of pile groups.