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# Centrifuge Modelling of seismically loaded monopiles: DONISIS – System Response

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**ABSTRACT:** The demand for renewable offshore wind energy is driving an expansion of the global market, including earthquake prone regions. Understanding earthquake effects on large-diameter monopile (MP) used to support these OWTs is increasingly critical and requires targeted research. Physical modelling in a geotechnical centrifuge provides an appropriate platform to study these structures, providing key insights into dynamic SSI. This work presents some key results from centrifuge tests of a large diameter monopile with scaled superstructure and extensive instrumentation. The model OWT is founded on Hostun HN31 sand, saturated with water. The seismic performance of the MP is monitored by embedded accelerometers; the soil is also densely instrumented with multiple arrays of accelerometers. The system is subjected to an earthquake motion from the Kocaeli earthquake, and the recorded response illustrates the interaction between soil, MP and superstructure.

## 1 INTRODUCTION

Offshore wind is increasingly expanding in Asia and North America; regions prone to earthquakes. The effects of repeated wind/wave loading on offshore wind turbine (OWT) monopile (MP) foundations has been well explored (e.g. Wang et al., 2025), less work has focused on seismic loading (e.g. Español-Espinel et al., 2024). Seismic shaking differs from wind/wave loading; broader frequency content mobilises a complex dynamic OWT response, which is expected to affect foundation behaviour and, in turn, design criteria. To investigate dynamic soil-strucuture interaction (SSI) effects, centrifuge tests examining the soil and the soil-structure response are performed at the ETH Zürich Geotechnical Centrifuge Centre. Preliminary results are presented herein.

## 2 PHYSICAL MODELLING

The model soil is created in a laminar box with Hostun HN31 sand. An automated sand raining system is used to create a sand layer with relative density of 95%. The MP of diameter $D = 9m$ is installed during pluviation. An array of accelerometers (ACCs) are installed next to the pile with distance 1$D$ to the pile centre and in the "far-field", at 4$D$. The model is water saturated, the prototype static effective stresses are produced and excess pore-water pressures are quickly dissipated, approximating drained response.

A seismic record from the Kocaeli earthquake is produced with the earthquake shaker. Two models are tested at 100g. The first targets soil response (SRA), having only the soil and instrumentation. The second (DSR) includes soil, monopile and superstructure (Panagoulias, et al., 2026), aiming to investigate system response and dynamic SSI.

## 3 PRELIMINARY RESULTS

Figure 1 illustrates the experimental setup and accelerometer positions, acceleration-time histories

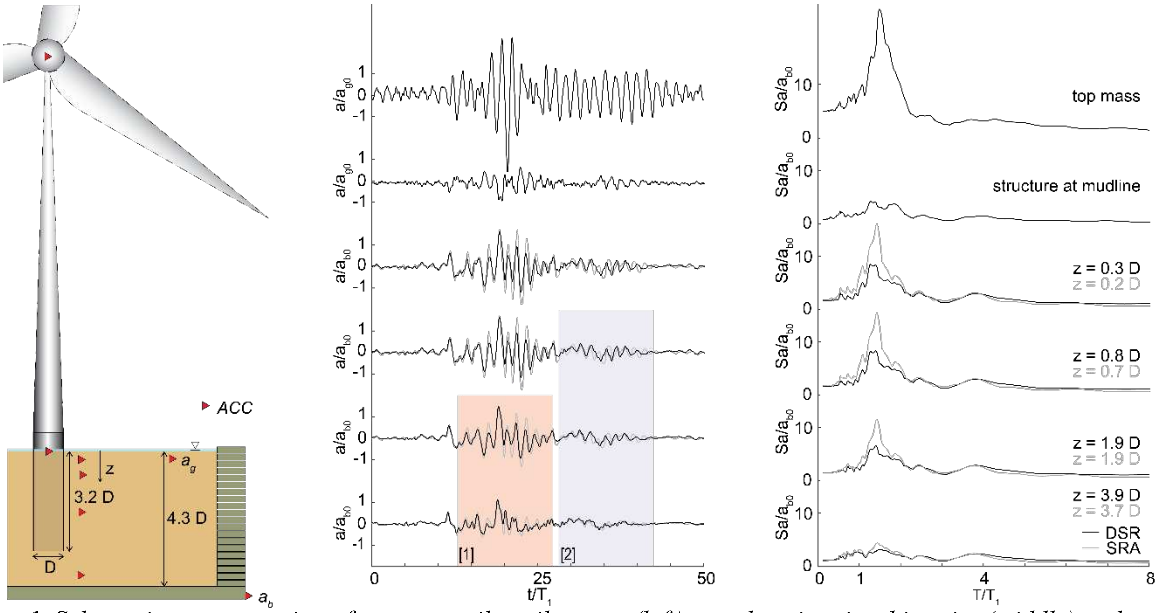


*Figure 1. Schematic representation of structure-pile-soil system (left), acceleration time histories (middle) and response spectra (right), measured on the structure at the top and at mudline, and at various depths in the soil for the DSR (black line) and the SRA (grey line) tests.*

and corresponding response spectra. The acceleration time histories, normalised with the peak bedrock acceleration ($a_b$), show that at larger depths large cycles are significantly amplified (time window [1] in Fig. 1). At shallower depths the same cycles are not strongly amplified. Smaller amplitudes (time window [2]) are amplified throughout the model. Amplification is less strong at shallow depths (~1$D$) indicating highly non-linear behaviour. Comparing SRA and DSR tests; amplification is everywhere reduced in the DSR test, suggesting significant SSI. The response spectra show an increasing peak through the soil layer. These peaks show increasing energy concentration slightly above the soil elastic natural period, indicating soil nonlinearity and reduced stiffness. In contrast to the DSR test, the peaks in the SRA test are more pronounced and concentrated around a single period.

The accelerations measured on the structure at mudline and in the top mass, normalised by the peak far-field ground motion ($a_g$), show a large amplification around the first mode of the soil with the top mass continuing to oscillate strongly after the peak. This energy concentration is replicated in the huge peak in the response spectra of the top mass.

## 4 CONCLUSION

The acceleration measurements in the SRA and the DSR tests highlight the nonlinearity of soil and soil-structure response. The comparison between the SRA and the DSR test indicates that the MP kinematically interacts with the soil, affecting the propagation of seismic shear waves.

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