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PHYSICAL MODELLING OF PILED FOUNDATION UNDER COMBINED LOADING: INSIGHTS ON THE PILES-RAFT-SOIL COUPLING

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ABSTRACT: Many European infrastructures are reaching their design lifespan, requiring adjustments for accommodating new societal demands such as increased traffic loads. For the case of aging viaducts, it is crucial to reassess their piled foundations in accordance with current design standards, also accounting for seismic actions. Common design practice still relies on oversimplified assumptions, including disregarding the piles-raft-soil coupling. A recent numerical study carried out by the authors has proven that verifying piled foundations under generic actions at ultimate limit states could result in non-optimal design choices. These could ultimately lead to excessive consumption of raw materials during retrofitting, especially in cases where the length of the piles is similar to the major raft dimension.

This contribution presents an experimental campaign conducted at TU Delft geotechnical centrifuge, aimed at validating and completing the aforementioned numerical study. The campaign consists of a series of small-scale centrifuge tests carried out at an effective acceleration of 50g and 100g, on a prototype foundation model embedded in Geba sand. The foundation model consists of a raft rigidly connected to eight piles. The system is subjected to wide range of pseudo-static loading paths, as well as to a series of cyclic loading conducted at progressively increasing loading.

1 INTRODUCTION

The 2030 Agenda for Sustainable Development, individuated in the resilience of Critical Infrastructure (CIs), is one of the strategic targets that should guide the management and planning in the transport sector (Sustainable Development Goal 9 - SDG9). In particular, bridges, embankments, tunnels and dykes are the backbone of transport CIs and are vital for public safety, economic prosperity and societal well-being.

In Europe, most of the transport networks were designed and built after World War II, and many CIs are nowadays used well beyond their intended lifespan. Despite being crucial lifelines, these structures were originally designed disregarding seismic loads, a requirement only recently included in some design codes. At the same time, traffic loads and vehicle dimensions have significantly increased with respect to the original design. This implies that reassessing the level of safety of the existing network according to present conditions is crucial, as well as the implementation of suitable retro-fitting strategies where necessary. The main challenge of current civil engineering practice is to develop new strategies to futureproof CIs while limiting costs, raw material consumption, and carbon footprint (SDG12).

Among all structural elements, the foundation is arguably the most critical and challenging to be reassessed. Compared to other elements, the foundation remains hidden underground with a limited possibility of direct inspection, making it difficult to ascertain its construction quality and current conditions. Moreover, retro-fitting foundation systems can be both expensive and resource-intensive. These challenges introduce the need to limit interventions to only truly required cases and avoid unnecessary and costly refurbishments. From this perspective, caution is necessary when applying current design approaches for foundation systems based on oversimplified and over-conservative assumptions.

The present contribution focuses on the discussion of preliminary centrifuge test results conducted in the framework of a project aimed at introducing an innovative approach for the ultimate limit state (ULS) verification of bridge piled foundations under seismic actions [1]. The experimental campaign is an ongoing research by

Politecnico di Milano (Polimi) and Technische Universiteit Delft (TUD).

2 MOTIVATION

The experimental campaign aims to collect experimental data for benchmarking numerical models performed considering advanced constitutive models [6], which can be used to estimate the foundation response even in the case of cyclic loads. The numerical results highlighted the non-negligible role of the soil-pile-raft in the global cyclic stiffness and damping. Such effect of the raft on the response of piled foundations is disregarded in the standard geotechnical design practice, which (i) assumes the raft to be detached from the foundation soil, (ii) ignores plastic redistribution among piles, (iii) treats the pile connection to the raft as a hinge, and (iv) decouples horizontal capacity verification from vertical and moment capacity [2], [3]. These assumptions lead to the underestimation of the capacity of the foundation, as indicated in Figure 1. In this figure, the bending moment, M, and the shear force, V, are presented from conventional (solid line) and analytical (dashed black line) methods, and the interaction domain is compared to numerical results [4], [5] (blue line interaction domain). Further inaccuracies occur when the pile length is comparable to the raft's major dimension and when ignoring the bending moment induced in the piles due to the pile-raft clamp.

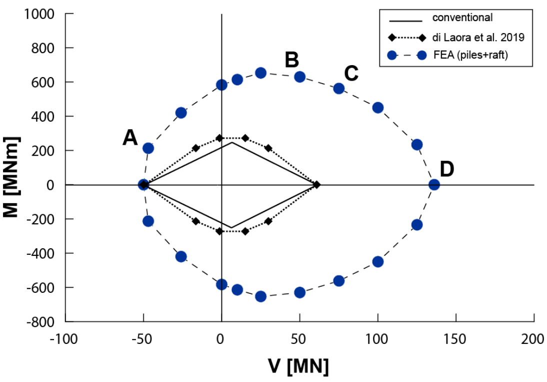

Figure 1 - M-V Interaction domain. Blue dot are numerical data considering pile-raft interactions. Conventional and di Laora (2019) approach are plotted for comparison

The experiments presented in this study introduce several innovative features focusing on the raft's role in the response of a piled foundation under inclined, eccentric loads. This effect has been investigated in the past only with reference to vertical loads [8]-[11] and for "small pile rafts" [12], for which the pile's length is significantly larger than the raft's width. Other authors analysed the case of piled foundations under complex load distributions and with the raft detached from the soil [13]-[15]. Only recently, a few authors have begun to deeper explore the effect of eccentric, inclined loads on piled foundations [16]–[18].

3 DESCRIPTION OF THE EXPERIMENTAL CAMPAIGN

The experiments modelled a representative case study of the most common typology of viaduct pier foundation in Italy [7], as depicted in Figure 2. The foundation scaled model consisted of a rectangular raft with a width of 38 mm and a length of 88 mm. The raft is connected to four aluminium, hollow piles with an outer diameter of 8 mm, a wall thickness of 1 mm, and a length of 80 mm. It is noted that the foundation scaled model was designed with a geometry scale factor of 100.

Figure 2 – Small-scale foundation model

The foundation model was installed in a sand bed composed of uniform, fine-grained Geba sand prepared inside a prismatic strong box with inner length, height, and width of 41 cm, 16.5 cm, and 15 cm, respectively. Further details of the strong box are shown in Figure 3. The sand bed was prepared by dry pluviation using the special setup shown in Figure 4, which was designed and developed for the experimental campaign. This setup is capable of guaranteeing repeatability of relative density with an error lower than 5%. The sand beds used as foundation soil in this study were prepared to a relative density of nearly 70%.

The experiments in this study were performed at centrifuge accelerations of 50g and 100g to study different prototype geometries, while the load is transferred to the raft by means of a bidirectional actuator. All the tests are carried out under a displacement control condition imposed by the actuator, and two additional laser sensors were used to check the vertical displacement and rotation. The connection between the actuator and the foundation has been 3D printed with a carbon fibre reinforced PLA filament with improved stiffness and strength. Displacement measurements have been depurated accounting for its deformability. Figure 5 shows the setup assembled and installed in the centrifuge prior starting a test.

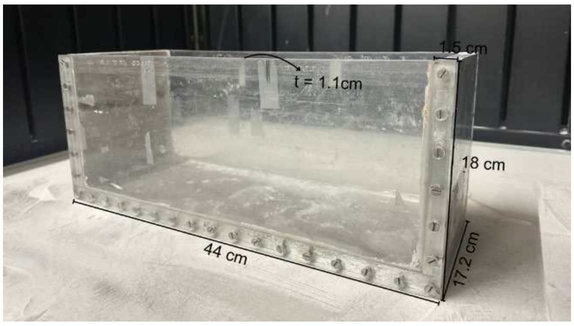

Figure 3 – Strong box

Figure 4 – Pluviometer and sample preparation

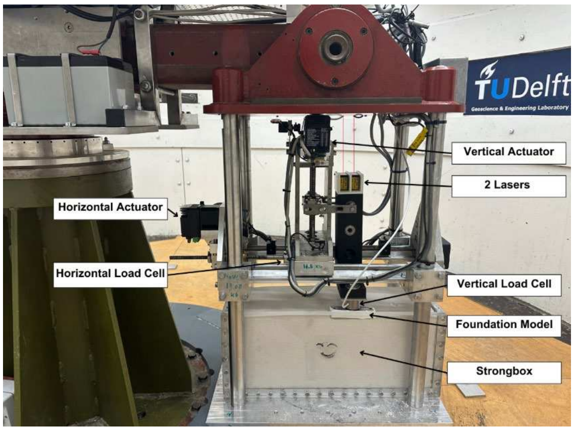

Figure 5 – Picture of the experimental setup with installed specimen.

The experimental programme consist in different tests. A first set of tests focuses on pure vertical load, in particular comparing results obtained with the raft attached and detached to the ground surface. Then, pseudo-static push-over tests with a monotonically increasing inclined eccentric load will be considered. Finally, the experimental campaign includes also symmetric cyclic inclined and eccentric loading tests, performed by progressively increasing the load amplitude at each cycle.

4 PRELIMINARY RESULTS

In this paper, two preliminary results, part of the full experimental programme, are presented and discussed, including one 50g and one 100g pure vertical test. To ensure soil deposition homogeneity and repeatability, in-flight mini-CPT tests have been performed. The MiniCPT used consists of a 7.5 mm stell penetrator with a standard 60 degrees cone tip. The cone is inserted by means of a vertical actuator into the soil stratum while the driving force is measured by means of a load cell. In Figure 6, the force profile with penetration depth is plotted for both 100g (blue and red curves) and 50g (yellow line) conditions. The linearity of the plots confirm soil homogeneity over depth.

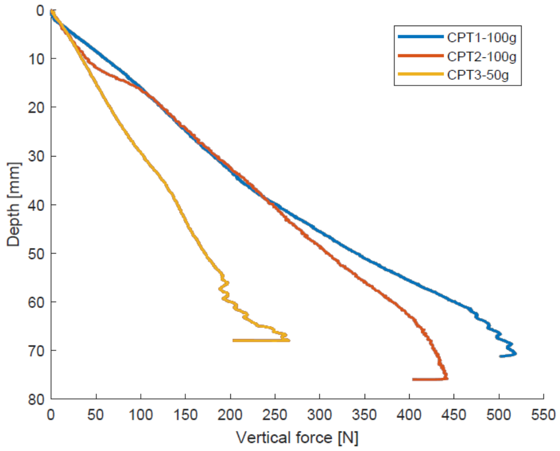

Figure 6 – MiniCPT results

In Figure 7 the load displacements curve are plotted for the two levels of acceleration, referring to different geometries at the prototype scale. The absence of any plateau suggests that, for displacements up to 35% of the pile diameter, the response is far from ultimate conditions, as is expected for piled raft foundations. Although the response seems to be linear, irreversible displacements are evident after the unloading reloading load step. The ratio between the two virgin loading line is close to $ratio = \sqrt{\frac{100g}{50g}} = 1.4$, indicating that the stiffness of load-displacement curve depends of the square root of the soil pressure.

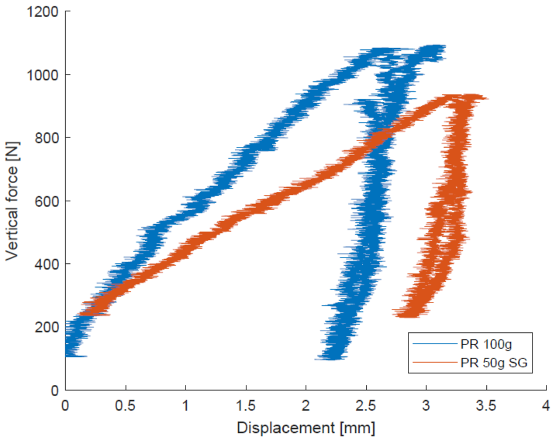

Figure 7 – Load displacement curve for the piled raft

5 CONCLUSIONS

These results will provide interesting information regarding the load settlement response for piled raft and be employed to validate numerical pushover analyses used to derive both the interaction domain and failure mechanisms and highlight the combined action of piles connected with the raft in contact with the ground. Moreover, data will be used to verify the accuracy of numerical models in reproducing both push-over and cyclic loading conditions.

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