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Rocking response of a reinforced concrete pile group: Insights from monotonic pushover loading centrifuge tests

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ABSTRACT: The study presents insights from centrifuge tests of a reinforced concrete 2x2 pile group subjected to monotonic pushover loading. The piles are 1 m in diameter and 15 m in length, founded on dense dry sand. To accurately reproduce the highly nonlinear and axial load dependent behaviour of reinforced concrete, the model piles (scale 1:50) are produced from micro concrete and additively manufactured steel reinforcement. Custom load cells are developed in-house to measure the axial loads, shear forces and bending moments at each pile head. These load cells allow a close monitoring of the complex pile group failure mechanisms as they enable tracking of shear and moment redistributions between the leading and trailing piles of group. The observed trend is attributed to the stiffness contrast between the axially unloaded trailing piles and the additionally loaded leading ones. Furthermore, a comparison with pushover tests employing simpler to produce epoxy-coated hollow-section aluminium model piles highlights the importance of accurately modelling the complexities of reinforced concrete behaviour.

1 INTRODUCTION & SCOPE OF WORK

Ageing of critical infrastructure is becoming an emerging engineering challenge. When it comes to bridges founded on piles, evaluation of the existing foundations, on whether those meet the capacity or performance criteria set, is a critical element given the complexity of any upgrade operation. Such evaluation is possible employing computationally demanding nonlinear 3D Finite Element analysis, or applying simplified methods of analytical or approximate nature. Regardless of the choice, gaining confidence in each method used, would require validation against experimental results. With respect to typical pile group layouts, large scale testing is practically prohibitive. Centrifuge modelling is the only viable alternative to validate numerical tools or verify the underlying assumptions of simplified methodologies.

Centrifuge modelling of reinforced concrete pile groups needs to reproduce appropriately the structural behaviour of the prototype piles. The axial load dependency of their bending capacity and stiffness is nowadays recognised as a fundamental element of pile group behaviour (Sakellariadis & Anastasopoulos, 2024). However, most of the available tests on pile groups employ model piles made of aluminium or steel (often instrumented), which remain within the elastic range of response. Such model piles typically match a target operational stiffness, overestimating capacity (Sakellariadis & Anastasopoulos, 2024). Knappett et al. (2011) introduced a novel physical modelling technique using gypsum, sand (as scaled aggregates) and small steel bars to construct miniature reinforced concrete components. This technique successfully reproduces important features of RC response under monotonic and seismic loading (Loli et al. 2014). Recently, Del Giudice et al. (2022) proposed an updated preparation method, replacing gypsum with cement and employing additive manufacturing for complete 3D printed steel cages. Cantilever testing showed good matching with the expected RC response under monotonic and cyclic loading.

This work uses such miniature RC piles (guidelines by Del Giudice; 2022) to study the behaviour of a simple 2x2 pile group under pushover loading. Furthermore, the simpler model piles (hollow-section aluminium piles with epoxy-sand coating) matching the bending stiffness at zero axial loading, are used for comparative assessment. Their comparison regarding (a) the macroscopic Load-Displacement pushover curve, (b) failure mode in terms of plastic hinges, and (c) load path at each pile head, monitored via custom load cells, demonstrates the advantages of the miniature RC modelling as opposed to the simple solid section aluminium piles.

2 EXPERIMENTAL SETUP OVERVIEW

An overview of the experimental setup is provided in Figure 1a. A stepper motor actuator (7 kN capacity, 100 mm maximum stroke) is utilised to apply displacement-controlled pushover loading. The actuator is connected to a rigid loading arm through a sliding hinged connection, which allows the foundation to settle or uplift freely. A concentrated mass atop of the column applies the target vertical load. The lateral displacement is measured by three lasers targeting different heights; those are further used to calculate rotation. A fourth laser measures the vertical displacements.

With respect to the model piles, those are all connected to the pile cap through custom load-cells which monitor the vertical and lateral load, and the bending moment at each pile head.

This is a key novel feature of this setup, allowing for the first time (to the best of our knowledge) to document experimentally the load sharing mechanisms between the leading and the trailing piles, resulting from concrete cracking and subsequent stiffness reduction. The custom load cells comprise two pairs of strain-gauges (gauges *B1* and *B2* in Fig. 1b) measuring bending and one pair measuring axial loading (gauges *F* in Fig. 1b). The shear force is calculated using the bending moments and the lever arm between the pairs of strain gauges. The functionality is similar to that of the instrumented loading arm used by Hu et al. (2017).

Figure 1 further presents the deformed shape of the RC pile group in post-testing inspection. The miniature concrete modelling technique allows for a more realistic representation of the failure modes, and thus offers the basis for stricter validation of available design methodologies

(a) (b) (c)

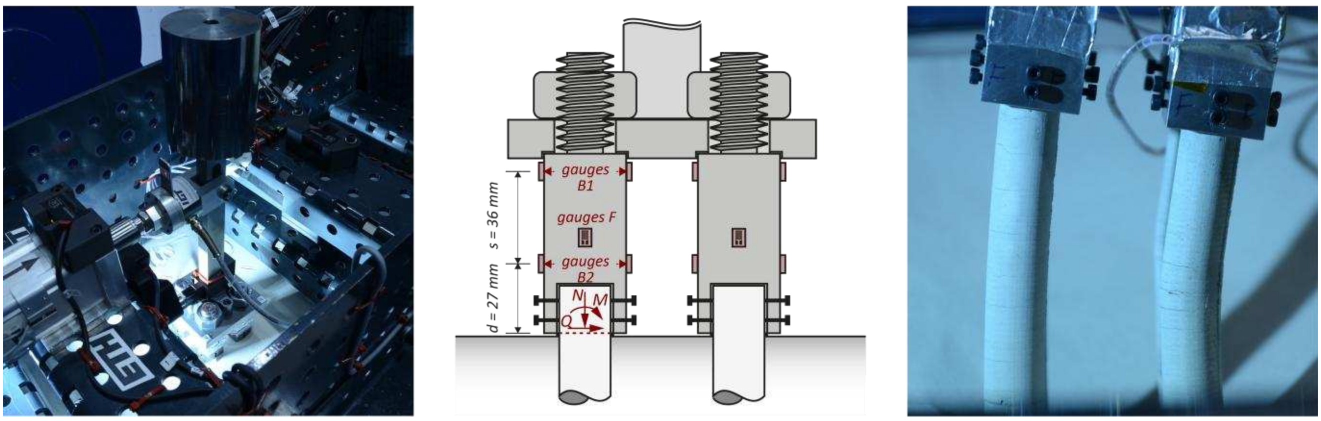

Figure 1. a) Overview of the experimental setup, b) schematic illustration of the custom load cells, and c) post-test deformed piles showing concrete cracking and development of plastic hinges

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