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Centrifuge modelling of flexible retaining walls subjected to dynamic loading

Michele Tricarico [a,b,*,1], Gopal Santana Phani Madabhushi [c,d], Stefano Aversa [a,b]

[a] Dipartimento di Ingegneria, Università degli Studi di Napoli Parthenope, Napoli, Italy
[b] Università degli Studi di Napoli Parthenope, Centro Direzionale isola C4, 80143 Napoli, Italy
[c] Engineering Department, University of Cambridge, UK
[d] Schofield Centre, High Cross Road, Cambridge, Cambs CB3 0EL, UK

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ABSTRACT

This paper outlines the results of an experimental program carried out on centrifuge models of cantilevered and propped retaining walls embedded in saturated sand. The main aim of the paper is to investigate the dynamic response of these structures when the foundation soil is saturated by measuring the accelerations and pore pressures in the soil, displacements and bending moment of the walls. A comparison among tests with different geometrical configurations and relative density of the soil is presented. The centrifuge models were subjected to dynamic loading in the form of sinusoidal accelerations applied at the base of the models. This paper also presents data from pressure sensors used to measure total earth pressure on the walls. Furthermore, these results are compared with previous dynamic centrifuge tests on flexible retaining walls in dry sand.

1. Introduction

The study and the monitoring of earth retaining structures [1–4] and of physical models in centrifuge simulations [5–12] have shown the vulnerability of these structures during seismic events.

The presence of water affects the dynamic response of such structures mainly for three reasons: influence on the effective stresses of pore pressures due to the presence of water in hydrostatic or permanent flow state, secondly hydrodynamic pressures acting directly on the structure and finally modification of earth pressure due to variation of pore water pressure produced by seismic action in undrained conditions. The latter aspect can also determine the occurrence of liquefaction, which, besides the structural failure and the mobilisation of shear strength, is another relevant cause of collapse of retaining structures. While for the first two factors some simplified solutions can be used, like the generalized apparent angle of seismic coefficient [13] and the Westergaard solution [14], the calculation of the pore pressure build up during the shaking is related to the material response to the dynamic cyclic loading and is very difficult to predict [15]. From a theoretical point of view, this problem can be analysed through the implementation of adequately complex constitutive laws, to be used within a software that solves numerically the Biot's coupled two-phase equations that describe the mechanical response of the soil-structure system. From an experimental point of view physical models can certainly represent a tool to help observe the dynamic behaviour of saturated soil in the far-field and in proximity of a structure. In addition, they offer the possibility to verify the capability of prediction of the numerical analyses. This work aims at developing an understanding of the dynamic behaviour of flexible retaining walls embedded in saturated sand. An experimental program consisting of a series of dynamic centrifuge tests has been carried out at the Schofield Centre of the University of Cambridge (UK) with the aim of studying the dynamic response of these structures. The tests have been performed on reduced scale models of pairs of retaining walls, both cantilevered and with one level of props near the top of the wall. The main objective of this work is to investigate the mechanisms affecting the seismic behaviour of these structures in the presence of ground water.

2. Geometries of the models

The experimental campaign consisted of seven tests on embedded walls in saturated sand, with piezometric head at dredge level (see Fig. 1). Four tests have been carried out on pairs of

* Corresponding author at: Dipartimento di Ingegneria, Università degli Studi di Napoli Parthenope, Napoli, Italy.
E-mail addresses: michele.tricarico159@gmail.com (M. Tricarico), mspg1@cam.ac.uk (G.S.P. Madabhushi), aversa@uniparthenope.it (S. Aversa).
[1] Permanent address: via Alessandro Pertini 19, Ruvo di Puglia, 70037 Bari, Italy.

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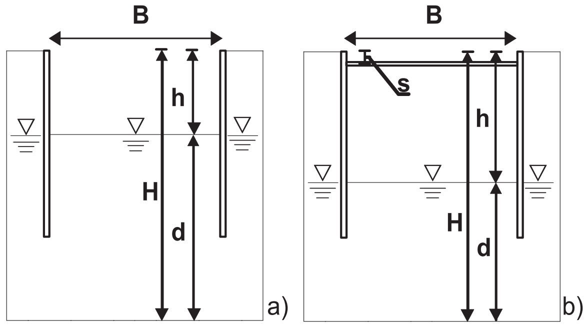

Fig. 1. Reference models and geometrical features: (a) tests CWU on cantilevered walls and (b) tests PWU on propped walls.

Table 1
Geometrical properties at prototype scale (model scale dimensions in mm are shown in brackets).

		Prototype scale (m) (Model scale) (mm)			
Test	D_R (%)	*h*	*d*	*S*	*B*
CWU1	38	3.6 (90)	4.4 (110)	–	8 (200)
CWU2	80	3.6 (90)	4.4 (110)	–	8 (200)
CWU3	80	3.6 (90)	4.4 (110)	–	8 (200)
CWU4	80	3.6 (90)	4.4 (110)	–	8 (200)
PWU1	38	5.6 (140)	2.4 (60)	0.45 (9)	8 (200)
PWU2	80	5.6 (140)	2.4 (60)	0.45 (9)	8 (200)
PWU3	80	5.6 (140)	2.4 (60)	0.45 (9)	8 (200)

cantilevered walls (CWU1, CWU2, CWU3 and CWU4), and three tests on models of propped walls (PWU1, PWU2 and PWU3). Preliminary results of some of the tests (CWU1, PWU1, CWU2 and PWU2) have been already described by Aversa et al. [5]. A centrifugal acceleration equal to 40g has been selected. Table 1 reports the main geometrical properties at the prototype scale with model scale dimensions in mm shown in brackets. The total height of the walls is 200 mm at the model scale, corresponding to 8 m at the prototype scale. The excavation depths are of 90 mm and 140 mm at the model scale for tests CWU and PWU corresponding to 3.6 m and 5.6 m at the prototype scale. In particular, the total height of the walls, the excavation depth and the embedment depth, d, are similar to those already adopted in a previous experimental work on retaining walls in dry sand [6,7], in order to isolate the effects of the saturation condition on the dynamic behaviour of this type of structures. Two different relative densities (38% and 80%) have been chosen, to study the effect of relative density on the structural response.

The model has been prepared by pouring the sand inside a laminar box container progressively, adding and positioning the instruments and the walls at the chosen depths. The sand has been poured through a sand hopper previously calibrated in order to reach the desired relative density of the sand [16]. The installation procedure of the model wall did not simulate the excavation procedure followed in field scale geotechnical works, in which the walls are installed first and the soil is excavated between the walls. In this research the walls the soil has been pluviated directly behind the walls to form the backfill and in between the two walls to different heights as required, under 1-g laboratory conditions. The centrifuge acceleration has been applied directly on the excavated configuration of the model. In this study the excavation effects are not captured as the model is constructed under 1g conditions. Other researchers, such as Ortiz [17], have modelled staged construction by draining out a heavy fluid from the excavated spaced between the walls gradually to simulate staged excavation at high gravity. This procedure is not adopted in this study as the primary focus of this research was to compare the differences in response between cantilevered and propped wall systems. Different kinds of instruments have been used in order to monitor the following physical quantities: i) acceleration of the soil and of the walls, ii) displacements of the soil surface and of the walls, iii) pore water pressures, iv) bending moment generated in the walls, v) axial forces in the props using load cells. The instruments used for the measurements of these physical quantities are respectively: piezoelectric and MEMS-based accelerometers, linear variable displacements transformers (LVDTs), pore pressure transducers (PPTs), strain gauges and load cells (SG). Figs. 2 and 3 show respectively the cross section of model CWU1 and model PWU1. In test CWU1 8 miniature piezoelectric accelerometers (Acc), 4 LVDTs for horizontal displacements, 2 LVDTs for surface settlements, 8 (or 10) strain gauges for bending moments (SG), and 8 pore pressure transducers (PPT) have been included. Basically, the same set of instruments were used in the layouts of all the tests. The performance of the Cambridge laminar box was specifically studied by Brennan et al. [18]. The instrumentation array used in the tests was dictated by the number of channels that can be logged at a sufficiently high sampling rate. This geometrical configuration has been chosen because it is very common in underground constructions.

3. Seismic actuator and model container

Seismic excitations during centrifuge tests are generated by a Stored Angular Momentum (SAM) actuator developed at Cambridge University [19]. The SAM actuator can apply waves with frequencies in the range 30–50 Hz. Therefore, at the centrifugal acceleration of 40g, the predominant frequency at prototype scale would be in the range 0.75–1.25 Hz, which can be considered to be

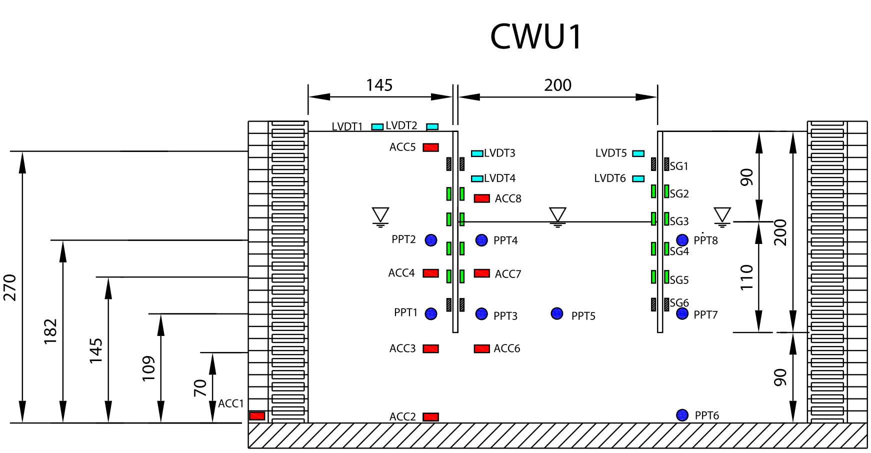

Fig. 2. Layout of instrumentation of test CWU1.