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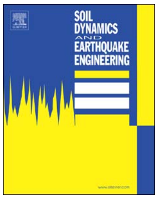

Zhejiang University benchmark centrifuge test for LEAP-GWU-2015 and liquefaction responses of a sloping ground

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ABSTRACT

A dynamic centrifuge model test of mildly sloping ground was conducted at Zhejiang University according to the LEAP-GWU-2015 experiment specifications. A 5-degree slope consisting of a saturated medium dense Ottawa F-65 sand was prepared by air pluviation method in rigid container, which simulated a prototype with a 20 m length and 4 m depth under 26 g centrifugal acceleration. The model was subjected to three smaller and two destructive motions. Test data and preliminary analyses of model responses during multiple shakings are presented. In-flight measurement of shear wave velocity by bender elements was used to characterize the evolution of soil state. Acceleration response spectra were presented and site amplification effects were observed. Shear stress-strain loops were calculated from acceleration records, and asymmetric dilatancy in the sloping ground was observed during liquefaction. Generation and dissipation of excess pore pressure were depicted. Large liquefaction-induced ground displacements were measured and analyzed. This study provides valuable data and delivers some important observations of liquefaction responses of a sloping ground.

1. Introduction

The Liquefaction Experiments and Analysis Project (LEAP) is an international collaboration to evaluate and validate the capabilities of numerical models (e.g., Boulanger et al. [1]) and constitutive models (e.g., Manzari and Dafalias [2], Yao et al. [3], Huang et al. [4]) for liquefaction problems, using centrifuge model tests (e.g., Iai et al. [5], Abdoun et al. [6]). The results of LEAP-Kyoto-2013 and -2014 showed some inconsistency between different centrifuge tests due to the different laminar containers used, which introduces challenges for numerical predictions [7]. Thus in LEAP-GWU-2015, a simpler boundary condition (i.e., rigid container) was proposed to obtain more consistent results [8–10]. Kutter et al. [11] describes the specifications for the experiment and compares the experimental results from the involved six LEAP centrifuge facilities.

The large geotechnical centrifuge ZJU-400 was developed in Zhejiang University (ZJU) in 2010 [12]. It was jointly designed by ZJU and China Academy of Engineering Physics. The centrifuge incorporates a high performance uniaxial hydraulic shaker for seismic/dynamic excitation, which was designed by ZJU and Solution Co., Ltd. in Japan. Advanced in-flight testing system including bender element and a two-dimensional (i.e., moving horizontally and penetrate vertically) miniature cone penetration were also developed [13,14]. Recent research at ZJU has included seismic induced liquefaction, site response and soil-structure interaction (i.e., tunnel, pipeline, retaining wall, etc.) [15,16]. This paper provides details of the benchmark centrifuge model test for LEAP-GWU-2015, including centrifuge facilities, model preparation, test procedure, results and preliminary analyses of the tested sloping ground during liquefaction.

2. Test facilities

2.1. ZJU-400 geotechnical centrifuge and hydraulic shaker

The LEAP test was conducted using the ZJU-400 centrifuge (Fig. 1) at Zhejiang University. It has a payload capacity of 400*g*-tons and a radius of 4.5 m to the base of the swinging platform. The maximum centrifugal acceleration is 150*g* and 100*g* for static and dynamic tests, respectively. The platform has overall dimensions of 1.5 m (L) ×1.2 m (W) with an usable height of 1.5 m.

The uni-axial hydraulic shaker (Fig. 2) of ZJU-400 centrifuge can generate up to 40*g* excitation under a maximum centrifugal g-level of

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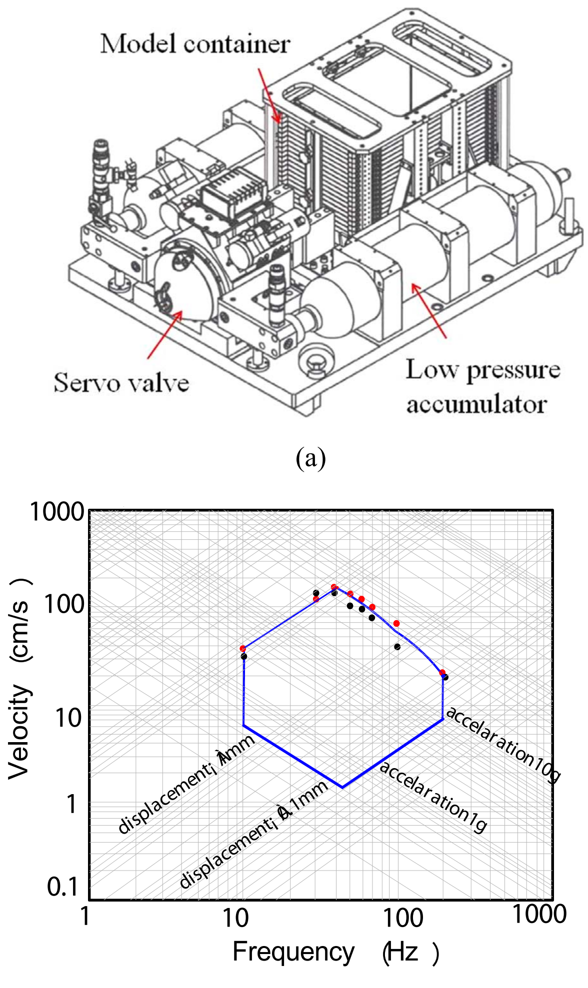
Fig. 1. ZJU-400 centrifuge at Zhejiang University.



(a)

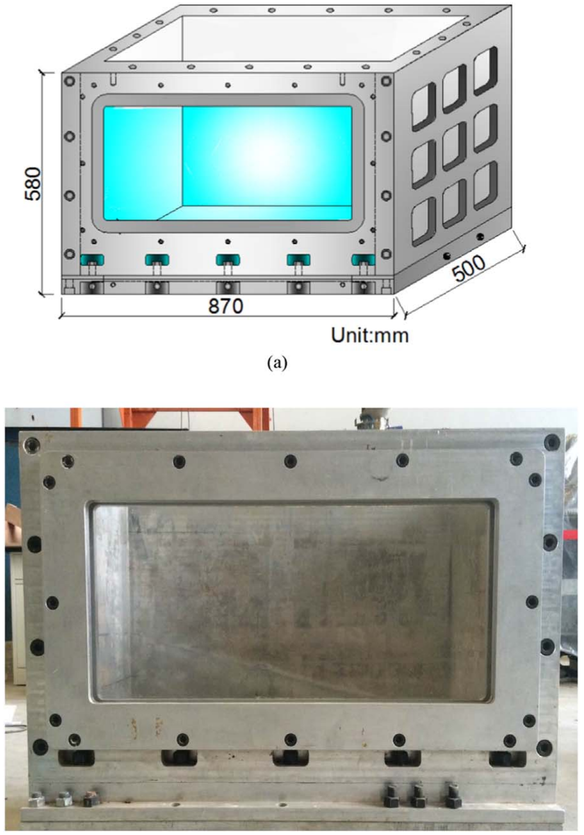
(b)

Fig. 2. In-flight hydraulic shaker: (a) design schematic; (b) performance diagram.

100*g*. Table 1 summarizes the specifications of the shaker. The shaker uses a hydraulic actuator to vibrate the slip table, and is displacement controlled so that the recorded accelerations at the base of the shaker match the target motion.

Table 1
Technical specifications of the shaker.

Key term	Specification
Mass	4.5 t
Payload capacity	500 kg
Max. shaking acceleration	40*g*
Max. shaking velocity	± 150 cm/s
Max. shaking displacement	± 6 mm
Max. shaking force	360 kN
Shaking frequency range	0–200 Hz
Payload mounting area	759.5 mm×600 mm



(a)

(b)

Fig. 3. Rigid container used in the test: (a) structure diagram; (b) photo.

The inner dimension of the rigid model container (Fig. 3) used in this test are 770 mm long, 400 mm wide and 530 mm deep. The end walls are made of 4 aluminum plates, and are connected by high-strength bolts. A porous stone in the base plate is used for model saturation. A transparent side window (650 mm long and 300 mm high) in the front enables cameras to record model response during the test.

2.2. *In-flight bender element system*

Bender elements (BE) have been used to monitor the variation of shear wave velocity (V_s) and shear stiffness of soil model in centrifuge tests [17,18]. The used benders (ZJU-BE) were produced by Piezo Systems, Inc., and parallel-type (T215-A4-303Y) was used as source and series-type (T215-A4-303X) was used as receiver. A cantilever length of 10 mm was chosen to consider the resonant frequency f_r and energy of shear waves at different g-levels [19]. BEs were electrically shielded and grounded to avoid undesired electromagnetic interference in centrifuge environment (Fig. 4). Fig. 5 shows an improvement of receiver signals with electrical shielding and grounding. To avoid near field effect and secure a clear arrival of shear wave, the tip-to-tip