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Shaking table test and numerical simulation on a combined retaining structure response to earthquake loading

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ABSTRACT

The combined retaining structure is widely used in high slope supporting engineering. In this paper, shaking table test and numerical simulation are carried out on the seismic response of a combined retaining structure where a gravity wall and an anchoring frame beam are used as a lower structure and an upper structure, respectively. The shaking events of Wenchuan, Da-Rui and Kobe ground motions with different amplitudes are applied in both horizontal and vertical directions. The horizontal and vertical acceleration responses are studied in time domain and frequency domain based on shaking table test, and the results are compared with those obtained from numerical simulation. The axial stress response of anchor and the element state of combined retaining structure subjected to earthquake loading are supplemented and studied by using numerical simulation. Both horizontal and vertical acceleration responses near the bottom of frame beam are significantly magnified, which results in a dramatic increment in acceleration amplification. The acceleration response behind the frame beam is more intensive than that at the back of the gravity wall. The high-frequency component of seismic ground motion is weakened by the combined retaining structure, and the vertical acceleration response presents a wider frequency band. The axial stress of anchor is greatly increased by seismic excitation, and the increment is mainly induced within the excitation period of great acceleration amplitude. Shear failure, tension failure, or both are observed at different positions of combined retaining structure during seismic excitation.

1. Introduction

Combined retaining structure is widely used in high slope supporting engineering. As for the combined retaining structure, a flexible supporting structure, such as an anchoring frame beam, is commonly used as an upper structure, and a rigid structure, such as a gravity wall, is used as a lower structure to bear a large horizontal load. This combination is regarded as a reasonable structure in seismic zone because the flexible structure at upper part can consume a large amount of seismic energy in earthquakes. However, currently, the seismic design for such combined retaining structure is mainly conducted based on experience, and the real seismic behavior of the combined retaining structure is not clear yet.

Dynamic model tests and numerical simulations are powerful techniques to assess the real seismic behavior of retaining structures. Kloukinas et al. [1] conducted a shaking table test on cantilever retaining walls with different retaining wall geometries and soil configurations to investigate earthquake responses, and the experimental investigations were used to verify the theoretical results derived from limit analysis and wave-propagation method. Watanabe et al. [2] investigated the seismic earth pressure exerted on retaining wall using shaking table test, by which a practical method of seismic earth pressure for a practical design under large seismic load was suggested. Al Atik and Sitar [3] investigated the seismically induced lateral earth pressure on cantilever retaining structure using dynamic centrifuge experiment and finite-element analysis, and the experimental results showed that the dynamic earth pressure and the inertia force did not simultaneously act on cantilever retaining wall. Lin et al. [4,5] deduced a nonlinear distribution solution for the seismically active and passive earth pressures of cohesive-frictional soil behind a gravity retaining wall based on a slice analysis method while considering most of possible parameters. Mojallal and Ghanbari [6] proposed a procedure to calculate the seismic permanent displacement of retaining wall under sliding and sliding-rotational modes by applying limit analysis method

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and upper bound theorem, and the effect of main parameters on the magnitude of seismic displacement was investigated. Hwang and Chen [7] proposed a model to explain the failure mechanism in large lateral displacement of gravity quay walls during earthquakes based on the data derived from a scaled-down shaking table test. Ling et al. [8] investigated the behavior of several reinforced soil structures after Ji-Ji (Chi-Chi) earthquake in Taiwan in 1999, and the post-earthquake investigation showed that the reinforced structures performed better than the unreinforced soil retaining walls. Wang et al. [9] studied the seismic internal force of geogrid in reinforced soil retaining wall structures using nonlinear finite difference method and shaking table test, and drew some conclusions about the seismic strain of geogrid, the distribution of seismic residual deformation, and so on. Masini et al. [10] interpreted the seismic performance of geosynthetic-reinforced earth retaining structure in view of the energy dissipation using numerical pseudo-static analysis and limit analysis methods. Lin et al. [11] performed a shaking table test and a numerical simulation on the seismic responses of anchoring frame beam supporting structure regarding the acceleration amplification, the displacement response and the axial stress of anchor.

Our previous work has conducted a shaking table test on a gravity retaining wall with anchoring frame beam supporting a steep rock slope [12]. Apart from that, another group of research work was conducted on a combined retaining structure supporting covering soil on gently inclined rock slope. An aim of this work is to compare the influence of different seismic ground motions on the seismic behavior of combined retaining structure, and to analyze the acceleration response in frequency domain. Consequently, three different seismic ground motions were applied in shaking table test and numerical simulation to study the seismic behaviors of combined retaining wall in terms of the horizontal and vertical acceleration responses, the axial stress response of anchor and the element state of combined retaining structure during seismic excitation. The acceleration responses were analyzed in both time domain and frequency domain. A clear seismic response of combined retaining structure subjected to earthquake loading was discussed, which was helpful for creating a more reasonable seismic design.

2. Shaking table test

Shaking table test was carried out using the shaking table facility at China Merchants Chongqing Communications Technology Research and Design Institute Co. Ltd whose table dimension was 6.0 m × 3.0 m. The shaking table facility could perform three-dimensional and six-degree-of-freedom ground motions. The maximum permitted acceleration was 1.0 *g* in each direction, and the working frequency ranged from 0.1 to 50 Hz. The allowable taking weight of the shaking table was 35 *t*.

Fig. 1 shows a prototype model of combined retaining structure supporting covering soil on an inclined rock slope. The combined retaining structure was composed of a gravity wall and a frame beam which were used as a lower structure and an upper structure respectively. The frame beam was inclined at a ratio of 1:1.25 with the horizontal surface. The frame beam consisted of a series of rectangular lattice, and the dimension for each lattice was 4.0 m × 4.8 m. There was a horizontal platform with 2 m in width at the interface of the gravity wall and the frame beam, and no other direct connection was set between them. The gravity wall was embedded in rock slope with an embedded depth of 1.2 m, and the frame beam was linked with rock slope by two rows of anchor with an anchoring length of 4.0 m. These two rows of anchor were inclined at an angle of 30° with the horizontal surface, and they were upwards named as Anchors 1 and 2 respectively. The rock slope was shaped with a flat surface inclined at 20° with the horizontal surface. A 0.4-m thick weathered rock layer laid on the surface of rock slope, and the soil deposit was covering on the weathered rock layer.

Generally, the shaking take test is performed by a reduced-scale model in Geotechnical Engineering due to a large size of geotechnical structure. Consequently, a similarity relation is required between the prototype and the model. Due to the difficulty in developing a complete similarity, a similar design is basically developed by taking several main factors as control variables. In this study, the geometric size,

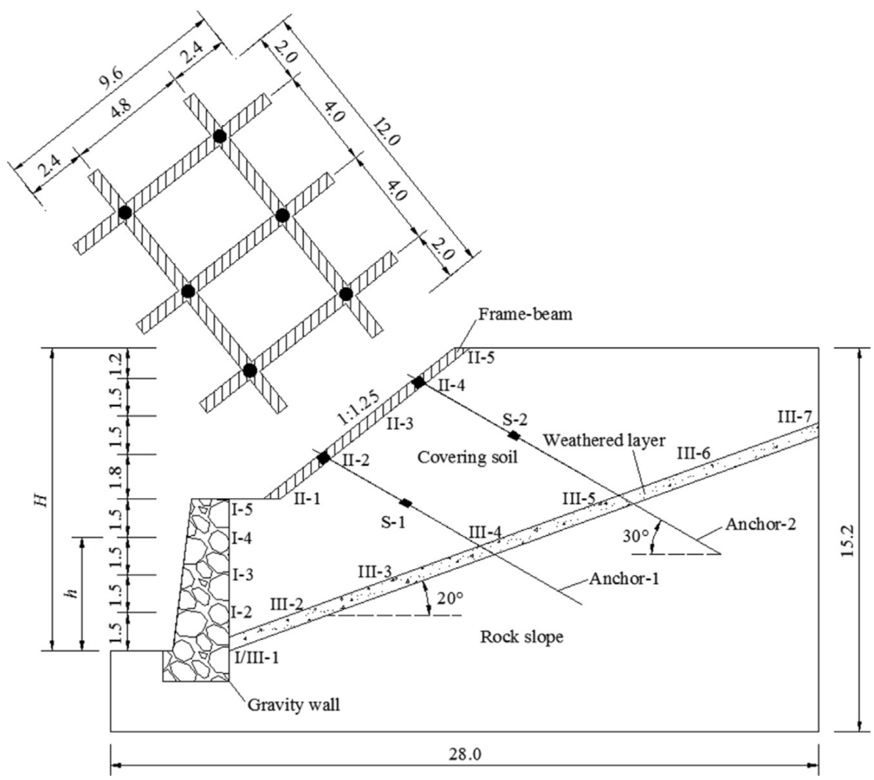

Fig. 1. The prototype of the combined retaining structure consisting of a gravity wall and a frame beam in Da-Rui railway line (Unit: m).