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Seismic response of a sheet-pile wall with anchoring frame beam by numerical simulation and shaking table test

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ABSTRACT

The sheet-pile wall is widely combined with anchoring frame beam to support high slope in Geotechnical Engineering. However, the dynamic characteristics of the sheet-pile wall with anchoring frame beam subjected to seismic excitation are not clear, and the seismic design for such combined structure is still performed based on pseudo-static method or experience. The combination effect will probably induce an interaction between the sheet-pile wall and the anchoring frame beam, which subsequently makes the seismic behavior of such combined structure more complex. In this study, numerical simulation and shaking table test were carried out to investigate the seismic response of the sheet-pile wall with anchoring frame beam by applying Wenchuan ground motion with different amplitudes. The acceleration response, the earth pressure response and the axial stress of anchor were studied in time domain, and the failure mode of structure was obtained by analyzing the element state at different excitation moment. The influence of the excitation amplitudes on the seismic response of sheet-pile wall with anchoring frame beam was also studied regarding the acceleration amplification, the residual earth pressure, the peak earth pressure response, the distribution of anchor stress and the element state of structure. The results show that the acceleration response of sheet-pile wall with anchoring frame beam is less intense while experiencing another equal seismic excitation. The acceleration amplification of anchoring frame beam is greater than that of sheet-pile wall. The residual earth pressure behind sheet-pile wall increases with an increase in excitation amplitude, especially at the top of sheet-pile wall. The peak earth pressure response at the back of sheet-pile wall increases along the wall height, while it presents a decreasing trend behind anchoring frame beam. The anchor is more likely to fail at the beginning of earthquake. The axial stress of anchor increases nonlinearly with an increase in excitation amplitude, and the increasing ratio increases for a larger value of input acceleration. The outer surface of soil deposit experiences repeated tension and shear failures. The element state of structure changes greatly during the intense periods of seismic excitation.

1. Introduction

A sheet-pile wall is one of typical retaining structures in Geotechnical Engineering. The sheet-pile wall consists of a series of piles which are embedded in foundation to produce sliding resistance force, and the sheets are set behind the piles to support soil mass and to transfer the lateral earth pressure onto piles. According to engineering experience, when the cantilever length of pile is larger than 15 m, the pile is likely to deform greatly or to be damaged during engineering construction [1]. Consequently, in high slope engineering, the sheet-pile wall is generally combined with anchoring frame beam to improve its mechanical behavior. Meanwhile, it is possible to make an eco-friendly structure by planting among the grids of anchoring frame beam. Presently, the seismic design for sheet-pile wall with anchoring frame beam is still performed based on experience or pseudo-static method although it is widely used in engineering practice.

The seismic behavior and calculation model on retaining structures have been concerned by many scholars, such as gravity wall [2–5], cantilever wall [6–9], sheet-pile wall [10–12], anchor-reinforced structure [13–15] and gabion retaining wall [16,17]. Zhang et al. [18] investigated the mechanism of the earth structure damage along 41 roads in seismic hazard areas after the 2008 Wenchuan earthquake with

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a finding that the sheet-pile wall presented a well seismic performance in earthquakes. Qu et al. [19] established a numerical model of sheet pile wall by FLAC3D to investigate its deformation and stress nephogram in different values of peak ground motion acceleration, and estimated the interaction force between the structure and the soil. Rasouli et al. [20] conducted a 1 g shaking table test to evaluate the performance of a mitigation on the settlement of surface structures by installing the sheet-pile walls around the foundation, and the result showed that the installing sheet-pile walls in relatively low ground water level stopped the settlement of structures completely. Dong et al. [21] proposed a dynamic calculation model for the frame supporting structures with prestressed anchors by treating the frame as an elastic foundation beam and simplifying the influence of prestressed anchors as linear spring and damped system, and the equations of vibration response were used to determine the analytical solutions under simple harmonic vibration. Lin et al. [22] investigated the horizontal and vertical acceleration responses, the displacement response and the anchor stress response of anchoring frame beam by applying Wenchuan ground motion with different amplitudes in shaking table test and dynamical numerical simulation.

A sheet-pile wall with anchoring frame beam is regarded as a reasonable retaining structure because the sheet-pile wall, as a lower structure, can provide enough stiffness to bear lateral force, and the anchoring frame beam, as a flexible structure in upper part, can consume a lot of seismic energy in earthquakes. For example, a sheet-pile wall with anchoring frame beam in Partridges Mountain performed quite well in great Wenchuan earthquake of China (Mw 7.9 or Ms 8.0) in May 12, 2008, as shown in Fig. 1. However, the real seismic behavior of the sheet-pile wall with anchoring frame beam is still not clear yet, and a previous research work on such combined retaining structure is rare. In this study, based on a prototype of sheet-pile wall with anchoring frame beam in Da-Rui railway line in Southwest China, dynamic numerical simulation and shaking table test were carried out to investigate the seismic response of the sheet-pile wall with anchoring frame beam by applying a series of shaking cases of Wenchuan ground motion. The structure of this paper is as following: Section 2 interprets the establishment of the numerical model of sheet-pile wall with anchoring frame beam; Section 3 introduces the model of sheet-pile wall with anchoring frame beam in shaking table test. The seismic behaviors of sheet-pile wall with anchoring frame beam are presented and analyzed in Section 4 in terms of the acceleration, the earth press, the anchor stress and the element state. The main conclusions are drawn in Section 5.

Fig. 1. A sheet-pile wall combined with anchoring frame beam performed well in 2008 Wenchuan great earthquake.

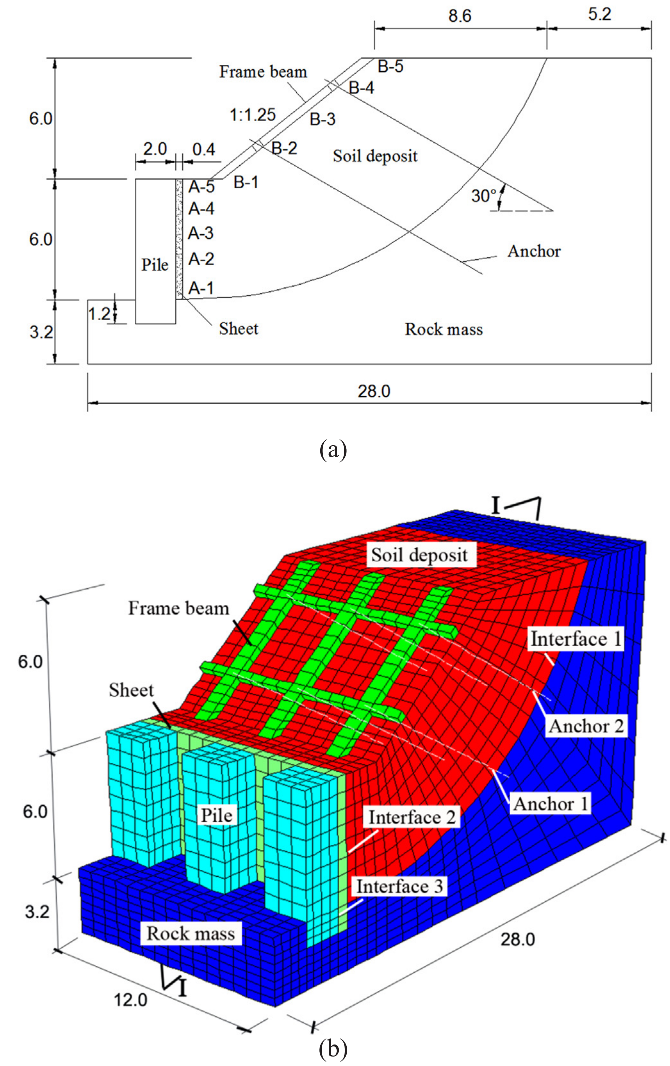

Fig. 2. The prototype of a sheet-pile wall with anchoring frame beam (Unit: m). (a) A cross section of the prototype; (b) A panorama of full-scale numerical model.

2. Numerical model

Fig. 2 shows a cross section of the profile of sheet-pile wall with anchoring frame beam in prototype unit in Da-Rui railway line of Southwest China as well as its full-scale numerical model. In which, the cross section of the prototype shown in Fig. 2(a) is taken from the Section I-I in full-scale numerical model (see Fig. 2(b)). A series of square piles were embedded in rock mass with an adjacent spacing of about 5.2 m. The side length of square pile was 2.0 m, and the cantilever length was 6.0 m. A 0.4 m-thick sheet was set behind the rock-socketed piles to support the soil deposit. The piles were embedded in rock mass with a depth of 1.2 m. The frame beam was composed of a number of lattice grids with a dimension of 4.0 m × 4.8 m. The frame beam was covering on soil deposit with an inclined ratio of 1:1.25, and was linked to rock mass by two rows of anchor. The total vertical height of anchoring frame beam was 6.0 m. There was a 2 m-wide platform between the sheet-pile wall and the anchoring frame beam. Subsequently, the sheet-pile wall and the anchoring frame beam constituted a whole combined retaining structure. To facilitate the analysis below, five points at the back of sheet-pile wall were marked as Points A-1, A-2, A-3, A-4 and A-5; and the other five points were signed as Points B-1, B-2, B-3, B-4 and B-5 behind the anchoring frame beam.

The numerical model of sheet-pile wall with anchoring frame beam