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Seismic evaluation of reinforced-soil segmental retaining walls

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ABSTRACT

In this paper, a shaking table test on the seismic performance of SRW was simulated systematically with dynamic finite element method. In the analysis, a cyclic mobility model, in which the influences of the stress-induced anisotropy, the density and the structure of the soil can be described in a unified way, was adopted to simulate the backfilled ground. By comparing the results between the calculation and the shaking table test, the seismic performance of SRW under earthquake motions was discussed in detail. The accuracy of the calculation was proven to be quite satisfactory. Based on this result, numerical tests were also carried out to investigate the dynamic behavior of SRW in field condition. In the numerical tests, parametric analyses were conducted to obtain an effective method for improving the stability and controlling the deformation of the SRW. It was found that increasing the reinforcement length is more efficient to improve the stability of the SRW than reducing the reinforcement spacing, and that the compaction degree in the resistant zone should be guaranteed for controlling the overall deformation. The main purpose of this paper is to establish an effective evaluation method for the seismic behavior of SRW.

1. Introduction

Over the past several decades, Reinforced-soil Segmental Retaining Wall (SRW) has gained wide popularity for its good mechanical performance, e.g., flexibility of design, drainage face, ease and rapid installation, economics, high durability, ecologic friendly and esthetic appearance since its first appearance in the mid-1980s (Bathurst and Simac, 1994; Bathurst and Cai, 1995; Allen and Bathurst, 2014, 2015). This type of retaining wall is enhanced by layers of geosynthetics that are placed between the stacked concrete blocks at regular vertical spacing as shown in Fig. 1. The integrity of the facing wall is maintained through the interactions among the blocks, the backfill and the confined geosynthetics layers (Portelinha et al., 2014; Miyata et al., 2015).

With an increasing application of SRW, case histories about partial or full wall collapse during recent earthquakes, such as Kobe earthquake and JiJi earthquake, were reported. Therefore, the seismic evaluation of SRW has been well pursued in geotechnical engineering for years. More and more attention has been paid to clarifying the deformation and failure characteristics of SRW under dynamic loading by laboratory tests, numerical calculations with classical limit equilibrium method or sophisticated elastoplastic numerical analyses. For instance, in order to investigate the dynamic behavior of reinforced soil retaining walls, model experiments under seismic loading had been done in the laboratory by some researchers (El-Emam et al., 2001, 2002; Ling et al., 2005, 2010; Sabermahani et al., 2009; Huang et al., 2011; Guler and Selek, 2014; Komak Panah et al., 2015; Latha and Santhanakumar, 2015; Panah et al., 2015; Wang et al., 2015). In the works by Ling et al. (2005, 2010), full-scale shaking table tests were conducted on SRW using Kobe earthquake motions and corresponding numerical analyses were conducted. In the tests, the lateral displacements, the settlement, accelerations, geogrid strains and earth pressure at some selected points were carefully measured by laser displacement transducers, linear variable displacement transducers (LVDTs), accelerometers, strain gauges and force transducers, respectively. As for the classical limit equilibrium method, a well-known pseudo-static approach to the seismic design of the retaining walls was proposed by Mononobe (1924) and Okabe (1924), which was later called the Mononobe-Okabe method.

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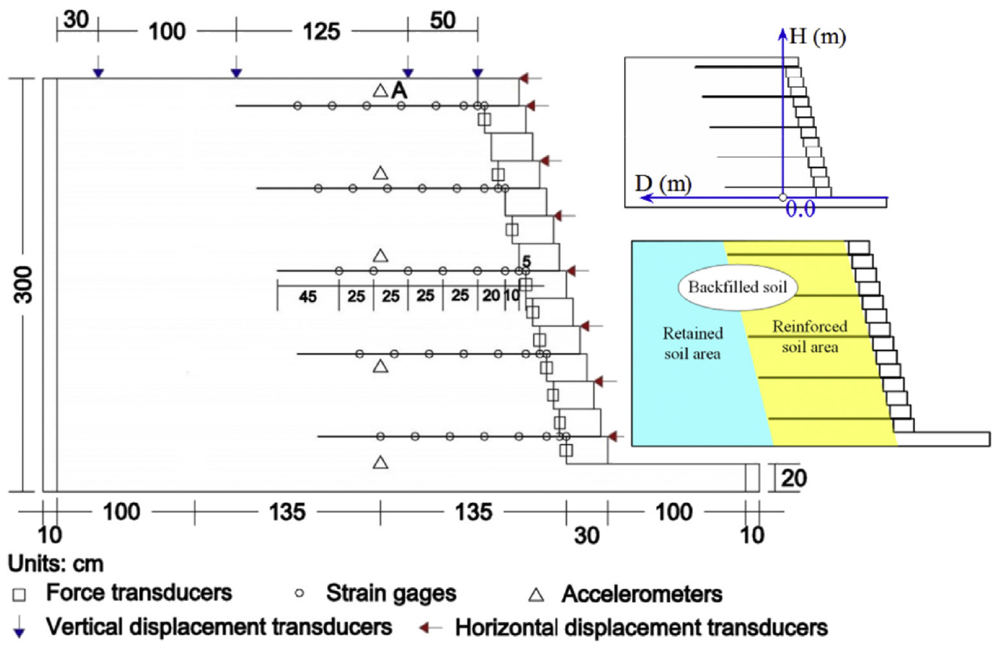

Fig. 1. Layout and instrumentations of the wall.

Bathurst and Cai (1995), Ling et al. (1997), Huang and Wu (2009) also reported their research works on the reinforced soil retaining wall by pseudo-static stability analyses, in which it is assumed that the inertia force due to horizontal acceleration in an earthquake may lead to the failure of soil masses along a prescribed plane. As the structure allowing large amounts of displacement before failure, the seismic performance of reinforced-soil retaining wall both in strength and deformation, however, did not draw much attention until the 1995 Kobe earthquake, and the 1999 JiJi earthquake (Ling et al., 2001), after which numerous examples of SRW failure were reported. Since the 1995 Kobe earthquake, it has been recognized that the pseudo-static analysis for the reinforced soil retaining wall is not applicable for Level-II ground motion (Technical Standards for Port and Harbor Facilities in Japan; Ministry of Transport, Japan, 1999). This is because that the main concern of the pseudo-static analysis is focused on the safety, although it is effective for the design of the reinforced soil structures under Level-I ground motion. For this reason, a new analytical method, which can not only evaluate the strength of soil at critical state but also the deformation quantitatively, is urgently required. Therefore, numerical analysis is increasingly being used on the reinforced soil retaining wall since the late 1990s (Bathurst and Hatami, 1998a, 1998b; Bathurst et al., 2002; El-Emam et al., 2004a, 2004b; Hatami et al., 2005; Guler et al., 2012; Liu et al., 2011, 2014; Abbasi et al., 2014; Akhlaghi and Nikkar, 2014). For instance, Bathurst and Hatami (1998a, 1998b) employed FLAC to investigate the influence of reinforcement stiffness, reinforcement length and base boundary condition on the seismic response of a reinforced soil retaining wall constructed with a very stiff continuous facing panel. Parametric analyses were also carried out to investigate the quantitative influence of the damping ratio magnitude and the effects of distance and type of far-end truncated boundary. Guler et al. (2012) carried out a numerical study to analyze the behavior of SRW under cyclic loads, the effect of cohesive backfill on the seismic behavior of geosynthetics reinforced retaining wall was studied, and the variables of facing type, reinforcement stiffness and the role of the peak ground acceleration were investigated as well. Liu et al. (2014) employed a finite element procedure, in which the soil-geogrid interfaces were modeled with thin-layer solid elements, to study the seismic performance of multi-tiered SRW under seismic loading. Akhlaghi and Nikkar (2014) used FLAC software to investigate the influence of the mechanical and the geometrical properties of the wall, the amplitude and the frequency of input motion, on the dynamic behavior of SRW. It is rather easy to simulate real-scale problems using numerical methods, compared with the model tests that cannot be frequently carried out due to the limitation of costs and time. Therefore, numerical simulation has become a very important way to evaluate the seismic performance of the reinforced soil retaining wall under seismic loading on the condition that the analyses are accurate enough, and the soils should be properly described by sophisticated constitutive model whose parameters are all determined with element tests, not by numerical fitting in boundary value problem. Furthermore, it is known that dynamic soil-structures interaction may greatly influence the seismic behavior of not only the soil, but also the structures. Therefore, it is recommended that a full system, which consists of the soil and structures, be used in the numerical analyses of soil-structures interaction problems (Zhang et al., 2007). This suggestion is also valid for the seismic evaluation of SRW.

In this paper, a shaking table test was simulated by the dynamic finite element analyses, using a program called DBLEAVES (Ye, 2007, 2011). This study aims to propose an accurate numerical method for evaluating the seismic behavior of SRW. It is true that shake table tests and corresponding seismic simulation have been done by many researchers and some related papers has been referenced in the revised manuscript. However, the main concern of this work is not only on the reproduction of the experiment, but also the seismic behavior of SRW walls in the field condition, where the influence of the foundation and the surrounding soil can also be considered by employing the equal-displacement boundaries. On this basis, numerical tests were carried out to investigate the dynamic behavior of SRW in the field condition. This is quite different from other researchers' works and is also the major purpose of our work.

In the shaking table test, earthquake vibration with two stages was applied to the model SRW, the results of the first shaking