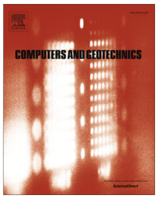
Computers and Geotechnics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo



Research Paper

Dynamic assessment of saturated reinforced-soil retaining wall

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ARTICLE INFO

Article history:
Received 16 January 2017
Received in revised form 27 July 2017
Accepted 25 August 2017
Available online xxxx

Keywords:
Saturated reinforced-soil retaining wall
Dynamic behavior
Centrifuge shaking table test
Dynamic FEM
Constitutive model

ABSTRACT

The dynamic assessment of a saturated reinforced-soil retaining wall (SRS-RW) has drawn considerable interest as several partial or full collapses of retaining walls due to earthquakes occurring during or immediately after heavy rains have been reported. In this study, a centrifuge shaking table test of the dynamic performance of a SRS-RW, in which five shaking waves were sequentially applied in the horizontal direction, was simulated using a dynamic finite element program. In the analysis, a cyclic mobility model was employed to simulate backfilled soil. This model can account for the complicated mechanical behavior of the saturated backfilled soil and described the influences of the stress-induced anisotropy, the density and the structure of the soil in a unified way. The plastic joint elements that transfer only shearing and compressive forces were inserted between the backfilled soil and the reinforcements. By comparing the calculated results with those of the centrifuge shaking table test, the dynamic behavior of the SRS-RW was thoroughly studied and the accuracy of the numerical analysis was proven to be quite satisfactory. Based on these results, numerical tests were also conducted to investigate the dynamic performance of a SRS-RW under realistic ground conditions. Parametric analyses with three different reinforcement patterns were carried out to develop an effective measure for improving the stability and controlling the deformation of SRS-RWs. The main purpose of this study is to establish an effective assessment method for the dynamic behavior of SRS-RWs.

1. Introduction

In the past two decades, the popularity of reinforced-soil retaining walls has grown throughout the world due to their distinctive advantages over conventional retaining walls [1,2]. A reinforced-soil retaining wall commonly consists of three elements, namely a facing panel, reinforcement and backfill, as shown in Fig. 1. The friction between the backfilled soil and the reinforcement enhances the stability of the wall.

With the increasing application of the reinforced-soil retaining wall, several incidents of partial or complete wall collapses due to recent earthquakes (such as 1995 Kobe earthquake and 1999 JiJi earthquake) have been reported [3]. In these incidents, many reinforced-soil retaining walls collapsed or dramatically deformed in almost saturated conditions. In the Niigata-ken Chuetsu earthquake, in 2004, the water content of the collapsed reinforced-soil retaining walls was much higher than usual due to the heavy rains a few days prior to the earthquake. Therefore, increased attention has been paid to the seismic evaluation of saturated reinforced-soil retaining walls. The deformation and failure characteristics of saturated reinforced-soil retaining walls (SRS-RWs) subjected to dynamic loading have been investigated by laboratory tests, classical limit equilibrium methods, and sophisticated elastoplastic numerical analyses. For instance, to investigate the dynamic behavior of SRS-RWs, researchers conducted 1-g/N-g (gravitational acceleration) shaking table model experiments on a SRS-RW [4,5]. Izawa and Kuwano [5] conducted centrifuge shaking table tests on a SRS-RW using five sequential sine waves, in which the horizontal displacement, time histories of settlement and pore water pressure at some selected points were carefully measured by means of optical targets, displacement transducers and pore pressure transducers, respectively. With respect to the classical limit equilibrium method, a well-known pseudo-static approach for the seismic design of retaining walls was proposed by Mononobe [6] and Okabe [7]. This approach was later called the Mononobe-Okabe

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https://doi.org/10.1016/j.compgeo.2017.08.020

Please cite this article in press as: Ren F et al. Dynamic assessment of saturated reinforced-soil retaining wall. Comput Geotech (2017), https://doi.org/10.1016/j.compgeo.2017.08.020

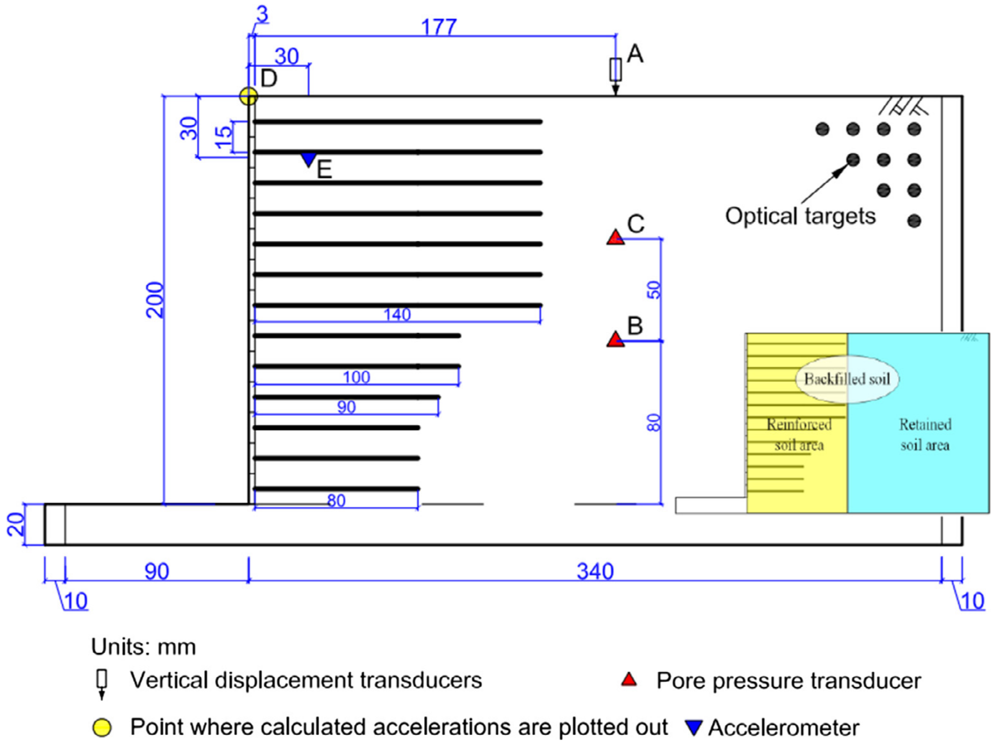

Fig. 1. Layout and instrumentations of the reinforced-soil retaining wall.

method. Based on this method, a considerable amount of research conducted pseudo-static stability analyses on reinforced-soil walls [8–10]. These studies assumed that the inertia force due to horizontal acceleration from an earthquake could lead to the failure of soil masses along a prescribed sliding plane. However, as the soil structure allowed large amounts of displacement before failure, the seismic performance of the reinforced-soil retaining wall, in terms of both strength and deformation, did not draw much attention until the Kobe and JiJi earthquakes [3]. Since the Kobe earthquake, it has been recognized that the pseudo-static analysis for the reinforced-soil retaining wall is no longer applicable for Level-II ground motion (Technical Standards for Port and Harbor Facilities in Japan; Ministry of Transport, Japan, 1999), whose main concern 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, the numerical analysis that can treat the case beyond the limit of force-balance and can evaluate the strength and deformation at critical state simultaneously, has being employed increasingly in evaluating the dynamic behavior of the reinforced-soil retaining wall. For instance, Wang et al. [11] conducted a numerical study of the dynamic responses of reinforced-soil retaining wall by FLAC (Fast Lagrangian Analysis of Continua), and the effects of persisting time of seismic acceleration, seismic wave and peak seismic accelerations were considered. Liu et al. [12] 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 reinforced-soil retaining wall under seismic loading. Akhlaghi and Nikkar [13] investigated the influence of the mechanical and geometrical properties of a wall, as well as the amplitude and frequency of input motion, on the dynamic behavior of a reinforced-soil retaining wall by FLAC. However, most studies have focused on the behavior of the wall in dry conditions. There are very few numerical studies on the dynamic behavior of the reinforced-soil retaining walls in saturated conditions. Moreover, it is known that dynamic soil-structures interaction may not only greatly influence the seismic behavior of the soil, but also the structures. Therefore, it is suggested that a full system, consisting of the soil and structures, should be adopted in the numerical calculation of soil-structure interaction problems [14]. This recommendation is also applicable to the seismic evaluation of SRS-RW [15].

In this study, a centrifuge shaking table test was simulated with dynamic analysis using a program called DBLEAVES [16,17], which is used to conduct soil-water coupling FD-FE analyses. In the analysis, finite element method (FEM) is used for spatial discretization of solid, liquid and gas phases, while finite difference method (FDM) is used for discretization of time domain, a typical hybrid method of FD-FE. For simplicity, hereafter the numerical method is called as dynamic analysis with FEM. In the centrifuge shaking table test, five sequential vibration waves were applied to a model retaining wall in horizontal direction. The final state of each vibration step was taken as the initial state of the next vibration step during all five sequential vibration steps. Therefore, the nonlinear behavior of the soil should be properly and precisely described in the numerical simulation. Hence, a kinematic hardening elastoplastic model, named as cyclic mobility model (CM model) proposed by Zhang et al. [18], was employed in the dynamic analyses with FEM. The CM model is an effective stress model that can automatically satisfies undrained and drained conditions. Meanwhile, this constitutive model has a feature that enabled the unified description of the influence of stress-induced anisotropy, the influence of density and the structure of the soil under different loading conditions (monotonic or cyclic) and different drained conditions (drained or undrained). Besides, the model has a distinct feature that the eight model parameters have the same values for all loading and hydraulic condition once they are calibrated by laboratory tests.

It should be pointed out that the verification of a constitutive model is not a boundary value problem, but an element problem, that is, its validity should be benchmarked using experimental data with well defined (and controlled) stress paths, and it should be noted that Element level validation (especially on the integration

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