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Seismic performance of reinforced soil wall with untreated and cement-treated soils as backfill using a 1-g shaking table

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Abstract

Reinforced soil walls were only slightly damaged in the recent earthquake disasters in Japan. However, because sandy soils are generally used as backfill in steel-strip reinforced soil walls, these walls may deform during or immediately after an earthquake. Therefore, it is important to clarify the resistance of this type of wall to seismic shocks and to improve the wall's seismic performance for stabilisation through such methods as cement treatment. For this purpose, we developed a reinforced soil wall model to simulate the stress and deformation around an embedded reinforcement. The reinforcement used here was a steel strip with ribs. First, a series of conventional pullout tests was performed to examine the pullout resistance of the strip with its ribs embedded in the soil layer. Next, shaking table tests were performed using a reinforced soil wall model with different initial pullout loads applied to the strip. The conditions of the horizontal shaking table tests briefly consisted of a maximum acceleration of 1000 Gal and a frequency of 3 Hz. The initial pullout load before the shaking tests was set at 75% of the maximum load obtained from the pullout tests. Sand, clay, and cement-treated sand and clay were used for the soil samples. The clay had a fine fraction content of over 25%. This paper discusses the seismic behaviour of a reinforced soil wall composed of sand, clay, and cement-treated clay based on the results of pullout and shaking table tests. The primary conclusions can be summarised as follows: 1) When no overburden pressure was applied, shaking caused the strip in the untreated sand layer to slip within a couple of seconds. Conversely, when the overburden pressure was above 50 kPa, the strip did not slip at all during 3 min of shaking. When the initial pullout load was decreased by 5%, the facing wall moved forward by only 0.2% of its height. Therefore, no large deformations affecting the instability of the wall were recognised during the shaking tests. 2) Furthermore, in the case of untreated clay with or without overburden pressure, the resistance between the strip and the soil was negligible, and the strip was simultaneously made to slip from the shaking table tests to the same extent as the untreated sand without overburden pressure. 3) After the cement treatment was applied to the clay, the strip did not slip during 3 min of shaking, the initial pullout load did not decrease, and the facing wall did not move during the shaking period. 4) When the strip was connected to the facing wall, the strip slipped more slowly than when it was not connected. 5) The stability and seismic performance of the reinforced soil wall were not affected by the ratio of the initial pullout load to the maximum pullout load within the tested range. 6) Conversely, when the acceleration was set to 1500 Gal, the initial pullout load decreased by only a maximum of 5%. Therefore, the use of cement-treated soil can crucially improve the stability of a reinforced soil wall, even if a large acceleration occurs during an earthquake.

Keywords: Reinforced soil wall; Steel strip; Retaining wall; Seismic performance; Shaking table; Stabilisation; Pullout resistance

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1. Introduction

It is well known that reinforced soil walls generally showed high levels of anti-earthquake capability in the aftermath of both the South Hyogo Prefecture Earthquake of 1995 and the Noto Hanto Earthquake of 2007 (Koseki et al., 2006, 2007). After the 2011 Great East Japan Earthquake (off the Pacific Coast of Tohoku), it was reported that whole foundations below reinforced soil walls slipped due to the strong motion and that crests settled and retaining walls tilted. Inherent factors, such as poor drainage or frost heaving, may have contributed to these failures (Sahara, 2012). Such damage can lead to the instability of reinforced soil walls (Sato et al., 2006). However, the established theory suggests that reinforced soil walls still exhibit strong earthquake resistance. The seismic performance of reinforced soil walls using geosynthetics, such as geogrids, has been examined through experiments and numerical analyses of construction materials conducted under various conditions (Richardson and Lee, 1975; Richardson et al., 1977; Matsuo et al., 1998; Ling et al., 1997; Watanabe et al., 2003; Koseki et al., 2006, 2007). Provided that a reinforced soil wall is designed and constructed under appropriate standards, it will exhibit excellent seismic resistance compared with other soil structures. However, the seismic performance of a retaining wall with a steel strip reinforcement has been examined in only a few studies (Uezawa et al., 1974; Richardson et al., 1977; Yogendrakumar et al., 1992; Futaki et al., 1996). Additionally, the behaviour of a reinforced soil wall over a long duration of strong ground motion, as occurred in the recent great earthquakes, remains unclear.

The fine fraction content and maximum grain size of backfill soil are regulated according to the Geosynthetic Reinforced Soil Wall (GRSW), the Reinforced Railroad/Road with Rigid Facing (RRR), Terre Armée, and Multi-Anchored Retaining Wall (MARW) methods (Miyata et al., 2001). In a reinforced soil wall, such as that by Terre Armée, frictional resistance is expected to be well mobilised upon contact between the backfill soil and the steel strip. Backfill soil with a fine fraction content of no more than 25% is suitable for a reinforced soil wall (PWRC, 2003). A recent problem is that the supply of suitable backfill soil has been nearly exhausted, making it difficult to procure sufficient amounts. Accordingly, there is an increasing demand to make better use of on-site soil with high fine fraction content. Even construction-generated soil, such as fine-particle soil, has been occasionally used in chemical stabilisation techniques (JGS, 2006). The application of cement or lime treatment to the backfill material of a reinforced soil wall has been conducted in a practical manner. However, the strength characteristics of cement-treated soil, whose cohesion gradually increases, have not been sufficiently considered in the design code for reinforced soil walls. The authors previously clarified the pullout resistance characteristics of a steel strip embedded in a cement-treated soil layer (Tasaka et al., 2010). Consequently, it remains unknown how much the seismic performance of a reinforced soil wall is improved when using cement-treated soil as a backfill material. With this as our background and using a shaking table, the aim of the present study is to clarify the seismic resistance of retaining walls reinforced with cement-treated soil. This paper describes the results of pullout and shaking table tests. The pullout tests were performed under conditions of monotonic loading and stage loading to determine the maximum pullout load of the strip. The shaking tests were performed using a reinforced soil wall model that was designed based on an earlier pullout test apparatus (Suzuki et al., 2007) and was set up on a shaking table. While carrying out the shaking table tests, we assumed that the reinforced soil wall generally exerted its retaining effect by retaining the pretension with respect to the strip. Thus, the shaking table tests were performed using pretension based on the results of the pullout tests. The effects of the overburden pressure, the cement treatment, the pretension load, and the acceleration on the shaking behaviour of the reinforced soil wall were examined separately through a series of tests. Based on the test results, we mainly discuss the characteristics of the shaking pullout behaviour of the strip and the simultaneous displacement of the retaining wall.

2. Reinforced soil wall model on shaking table

Fig. 1(a)–(c) show our newly developed reinforced soil wall model. The sketch in Fig. 1(a) indicates how the model

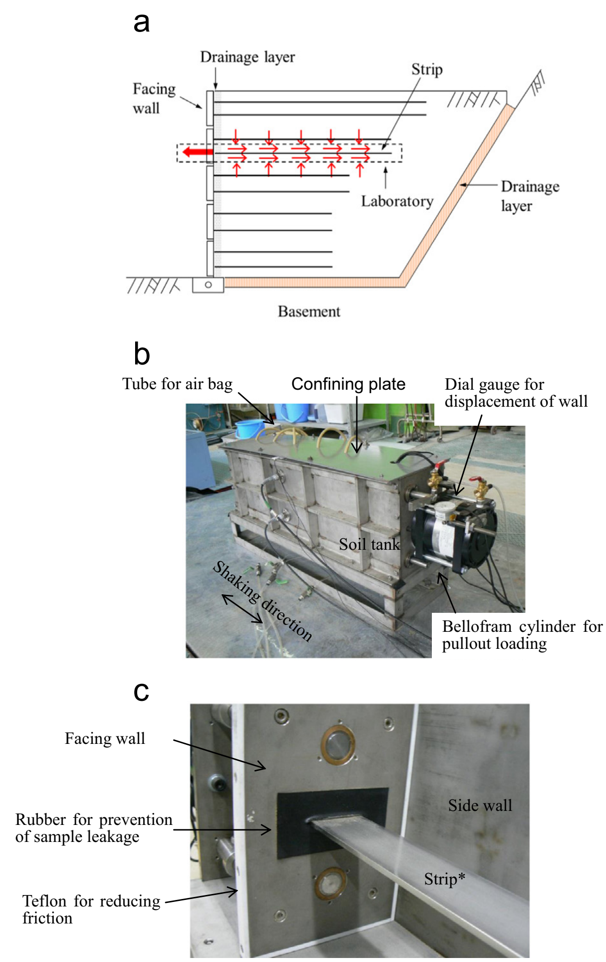

Fig. 1. Reinforced soil wall model on shaking table., (a) Field and laboratory conditions, (b) Overview of reinforced retaining wall model, and (c) Close up of internal structure. *: Smooth-type strip (not used in the experiments).