BEHAVIOR OF A LARGE-SCALE MODULAR-BLOCK REINFORCED SOIL RETAINING WALL SUBJECT TO KOBE EARTHQUAKE SHAKING

Hoe I. LING [1], Dov LESHCHINSKY[2], Yoshiyuki MOHRI[3]

ABSTRACT

This paper describes the behavior of a full-scale reinforced soil retaining wall subject to Kobe earthquake shaking. The test was conducted to investigate the behavior of reinforced soil retaining walls having a modular block (Allan Block) facing and polymeric geogrids (Fortrac geogrid from Huesker). The blocks were connected to the geogrid layers through frictional interaction. The wall was 2.8 m high, tallest of this kind of modular block walls for dynamic loading. It was fully instrumented with transducers through a high-speed data acquisition system. Kobe earthquake motions were used to excite the wall horizontally at a maximum acceleration of 0.4g followed by 0.8g. The wall was able to withstand the shaking with minimal deformation and acceleration amplification. Quantities that are relevant for examining the wall performance are presented and discussed.

Keywords: reinforced soil, retaining wall, modular block, geosynthetics, geogrids, Kobe earthquake.

INTRODUCTION

Several reduced scale model tests of reinforced soil retaining walls have been reported in the literature. Most of the studies were associated with metallic reinforcements (Ricahrdson and Lee, 1975; Richardson et al., 1977) and some with geosynthetic reinforcements (e.g., Murata et al., 1994; Matsuo et al., 1998). Although modular block walls have gained wide popularity in North America, failures have been reported during the 1999 Ji-Ji of Taiwan (Ling et al., 2001) and the 2001 Nisqually earthquakes of Seattle area. The failure generated concerns about their seismic stability under strong earthquake shaking.

Reduced scale shaking table tests of height 1 m have been conducted in Canada (Bathurst et al., 1997, 2002), but no full scale tests are available to examine the seismic behavior. In the tests of Bathurst et al. (1997, 2002), models of modular blocks were used and the wall facing was propped during construction. A sinusoidal wave up to 0.35g was used to excite the models. These tests could possibly be subject to scale and stress-level effects. In addition, field case histories (e.g., Ling et al., 1997; Ling and Leshchinsky 1998, Tatsuoka et al., 1997), because of limited data, are irrelevant for validation of numerical procedures. In the field, the actual ground acceleration at the site, wall configuration and material properties of soils and geosynthetics are not known. Thus, large-scale shaking table tests must be conducted as benchmark for validating analytical procedures. This paper reports one of the three walls that have been conducted in a series of studies on reinforced soil retaining walls that was backfilled with sand. The readers are referred to Ling et al. (2005) for additional information.

[1] Associate Professor, Department of Civil Engineering and Engineering Mechanics, Columbia University, New York, NY 10027, USA, Email: Ling@civil.columbia.edu
[2] Professor, Department of Civil and Environmental Engineering, University of Delaware, Newark, DE, USA.
[3] The Director, Geotechnical Laboratory, National Research Institute of Rural Engineering, Tsukuba, Japan.

LARGE SCALE SHAKE TABLE TESTS

Three shaking table tests were conducted at the National Research Institute of Rural Engineering (formerly National Research Institute of Agriculture Engineering), Japan. Walls 2.8 m high, 2 m wide and 4 m long were constructed incrementally inside a steel container installed on the shaking table. Provision was made to avoid reflection wave from the ends of the wall, and also to minimize the friction between the side walls and backfill. This paper is concerned with the first wall.

Sand - A fine sand of mean diameter 0.27 mm and having an angle of internal friction of 38^o was used. It was prepared at a moisture content of 9.5% to give an in-situ unit weight of about 14.3 kN/m^3.

Geogrid (Fortrac geogrid from Huesker) - The geogrid used was manufactured from polyester and had an ultimate strength of 35 kN/m. Large deformation strain gages, which allowed axial strain larger than conventional strain gages, were attached to the geogrid in measuring the tensile load. This geogrid gave a frictional angle of 34^o with the sand.

Modular Block (Allan Block) - The concrete blocks, 20 cm high, 30 cm wide and 45 cm deep were used. This type of block is characterized by a lip at the front part to provide alignment during construction such that the finished wall face was 12^o. To increase the shear resistance, the hollow portion of the blocks was filled with gravels and compacted.

Figure 1 shows the front end of the wall during construction, where the blocks were filled with gravels and compacted. Part of the gogrid is attached with the strain gages and protected with silicon and rubber sheets.

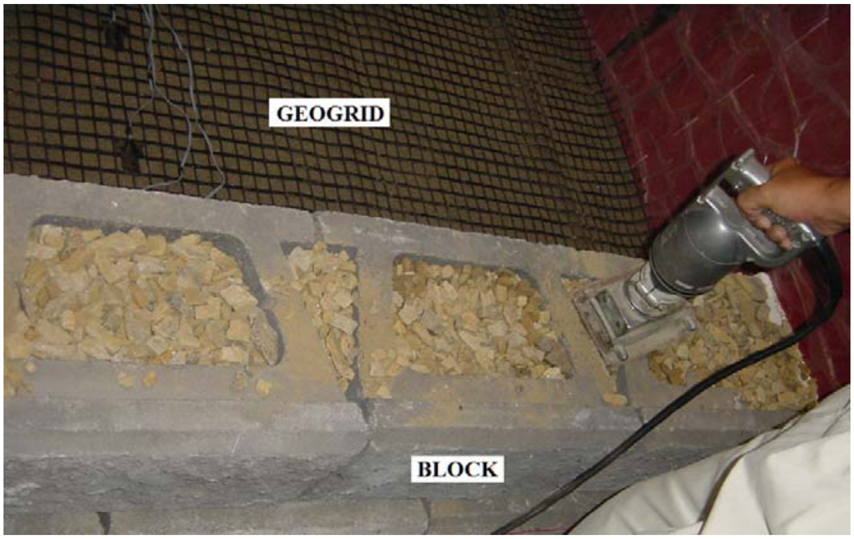

Figure 1. Modular Block and Geogrid

The layout of the wall and instrumentation is shown in Figure 2. The reinforcement layers were 205 cm long (73% wall height) and the vertical spacing was 60 cm (3 blocks). The instrumentation consisted of 20 accelerometers, 8 laser displacement transducers (wall face), 4 linear variable transducers (backfill surface), 20 force transducers (to measure the lateral force acting at the blocks and vertical force under the backfill) and 40 strain gages.

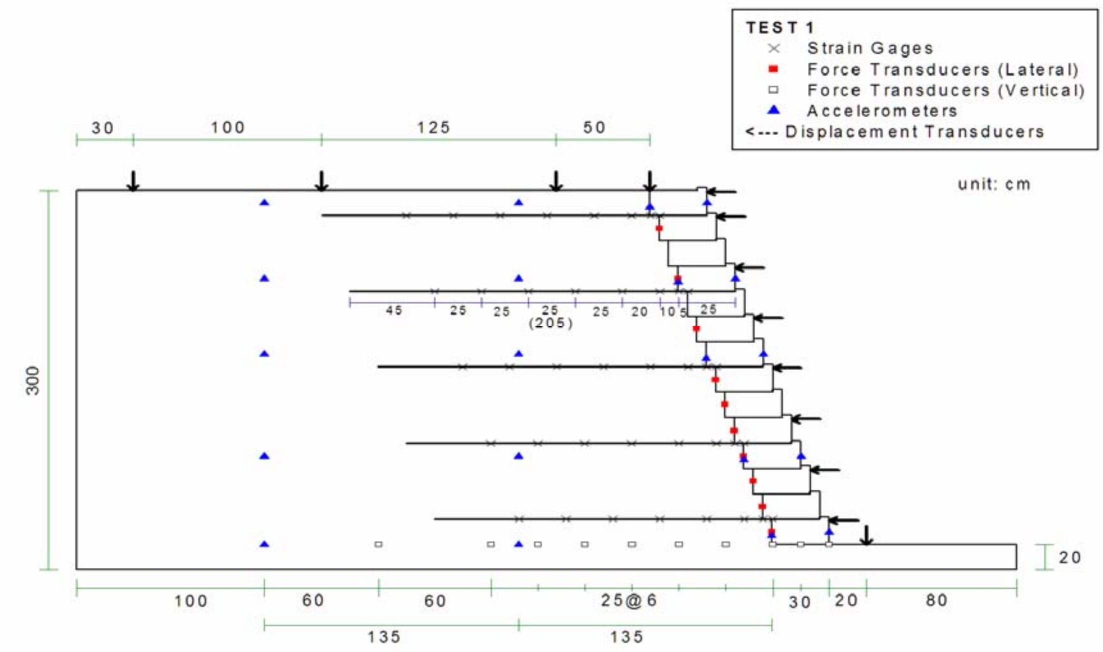

Figure 2. Wall Configuration and Instrumentation

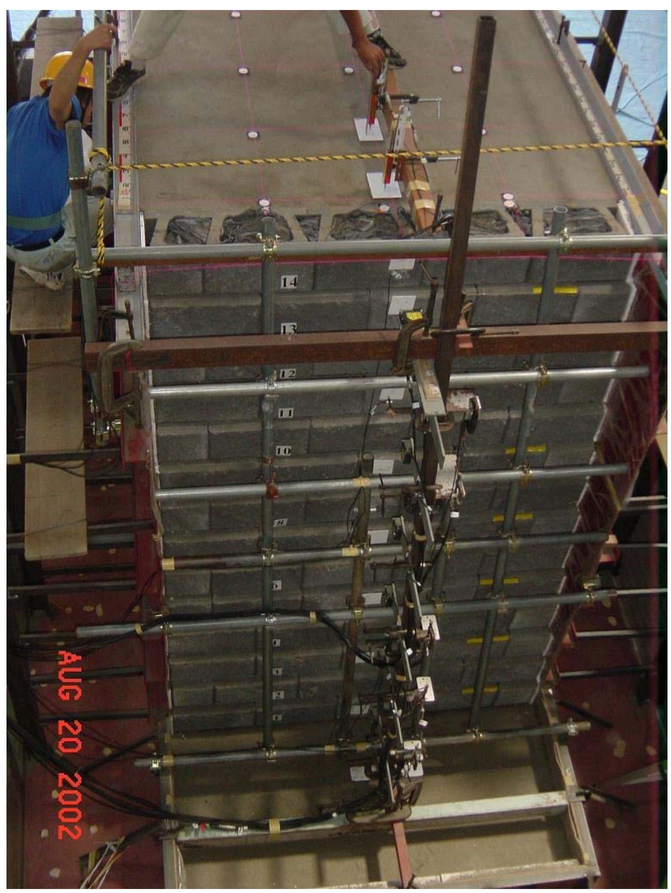

Figure 3. The Wall at End of Construction

TEST RESULTS

After the first shaking, only hair crack was seen behind the reinforced soil zone. With the second shaking, cracks appeared in the backfill behind the reinforced zone, and the front of the backfill settled with relative to the blocks. The wall was very stable as these cracks were at the surface and did not penetrate into the backfill.

Figure 4. Cracks Behind The Blocks (Left) and In The Backfill Behind Reinforced Zone (Right)

Figure 5 shows the displacement of the wall, where the top portion recorded larger deformation of magnitude 1 cm and 10 cm, respectively, in the first and second shakings.

The earth pressure distributions (Figure 6) show that the value increased with shaking. While the peak and residual pressures did not differ much in the first shaking, the residual pressure was smaller than the peak pressure at the second shaking. The shape of pressure distribution is approximately triangular. The vertical pressure distribution, though not presented here, gave a nonuniform distribution close to the block because of eccentricity.

The backfill settlement was negligibly small at the first shaking, but the second shaking resulted in about 9 cm settlement at the front (Figure 7). Figure 8 shows the tensile load distribution in the geogrid layers. The location of maximum load differed in each geogrid layer. The largest load was recorded at the bottom geogrid layer that was about 8.5% the ultimate strength. The peak load recorded during second shaking was partially recoverable.

The accelerations in the blocks, in the soil located close to the block, and in the reinforced and unreinforced soil zones are shown in Figure 9. The amplification of acceleration was less than 1.35 during second shaking.

CONCLUSIONS

A large scale shaking table test was conducted that generated valuable results from over 100 channels of measurements. Under moderate earthquake of 0.4g, the wall deformations, settlement and acceleration amplification were negligibly small. Slightly larger deformations were observed during second shaking with a peak acceleration of 0.8g, but the wall performed very well and remained stable.

The modular block system having a front lip and its interaction with the particular geogrid reinforcement was able to render a stable wall system subject to very strong earthquake loading. This was confirmed with additional testings as reported in Ling et al. (2005).

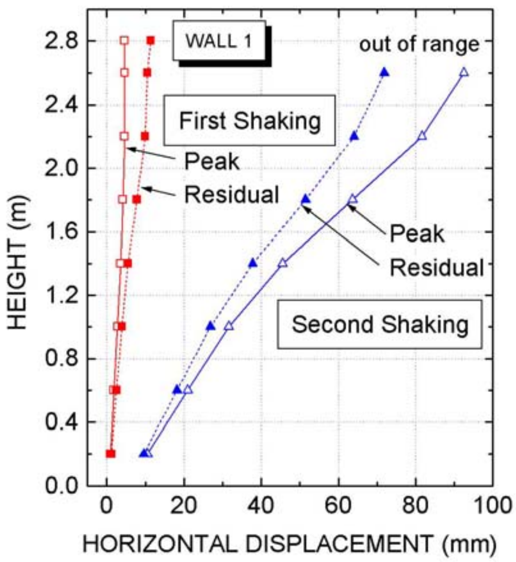

Figure 5. Horizontal Displacement

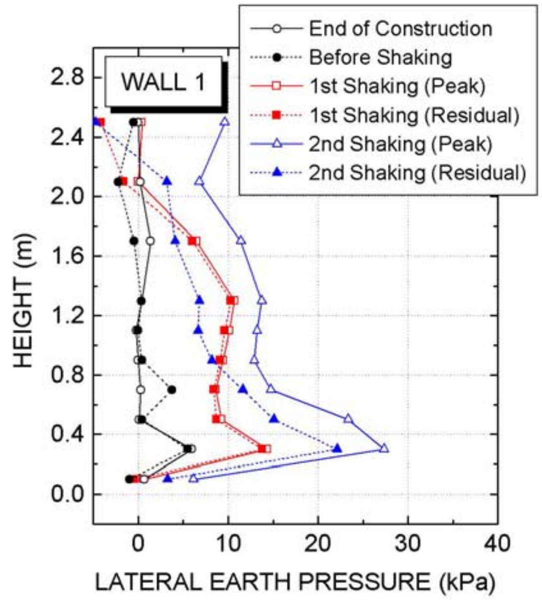

Figure 6. Lateral Earth Pressure

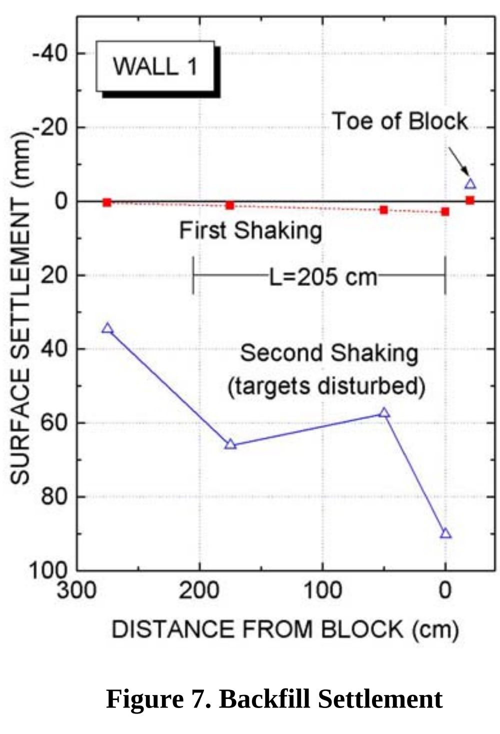

Figure 7. Backfill Settlement

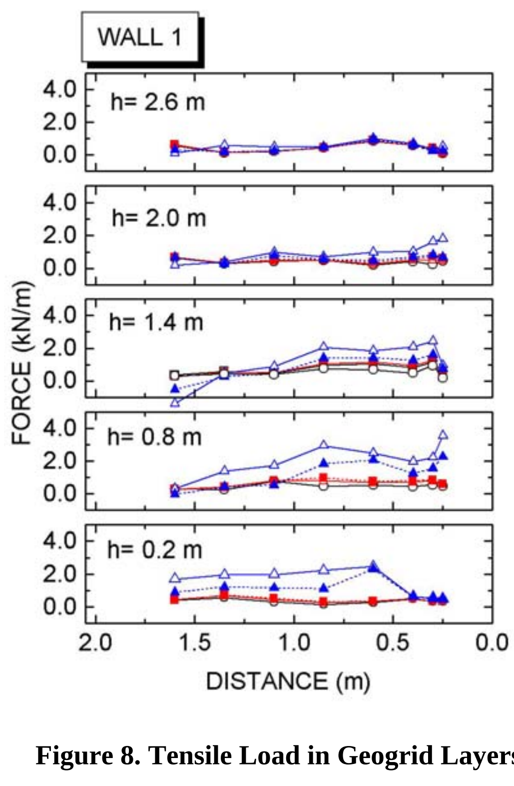

Figure 8. Tensile Load in Geogrid Layers

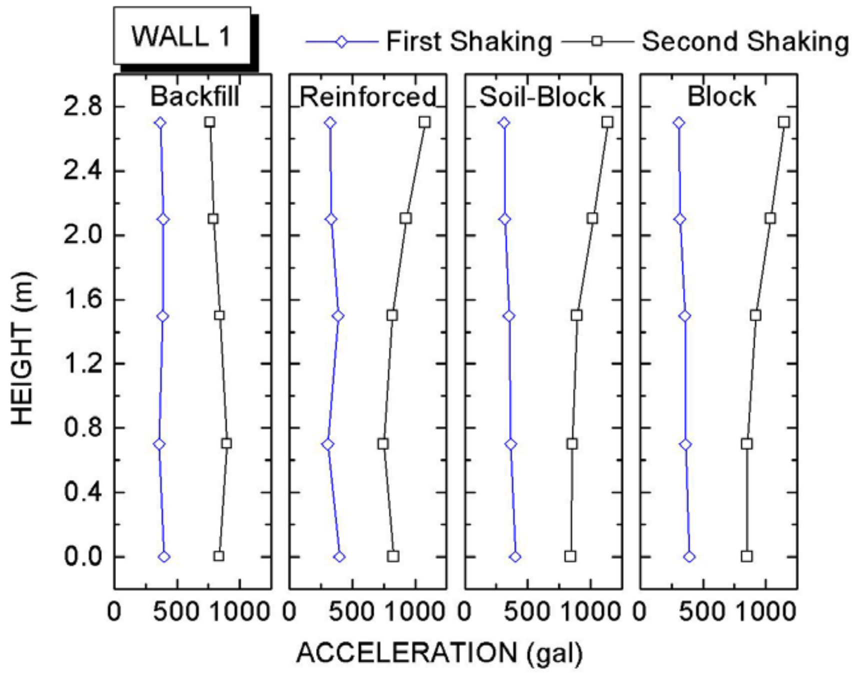

Figure 9. Accelerations in the Blocks and Backfill

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