Design and measurement on full-scale behavior of reinforced structure

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Full-scale model test and numerical analysis of reinforced soil retaining wall

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ABSTRACT: This paper reports the results of field observation and numerical analysis of full-scale model test for a new reinforced soil retaining wall system, having a vertical layer which absorbs the deformation between facing concrete brocks and reinforced backfill. The field observations and FE-analysis show that little earth pressure acts on the facing blocks and that the structure system is stable. A dynamic elastic-plastic FE-analysis which investigates the interaction behavior between the facing blocks and reinforced backfill, shows that the structure system is stable on the condition of earthquake.

1 INTRODUCTION

Many types of reinforced soil retaining wall have been proposed and have been built worldwide. However, because earth pressure acts directly on facing material, there is the possibility of deformation of facing and lack of soil compaction near the facing. We developed a new reinforced soil retaining wall system, having a vertical layer which absorbs the deformation between facing concrete brocks and reinforced backfill. The layer prevents the earth pressure from exerting directly on the facing brocks. We call the system “double wall structure”. Subjected to an actual structure of this system, we performed field observations in order to evaluate the performance of system. In the observations, we monitored the horizontal earth pressure against facing blocks, deformations of facing blocks, strains on reinforcement geogrids, vertical earth pressure at the base of backfill, and so on. At first, we carry out an elastic-plastic FE-analysis which employs Mohr-Coulomb yield criterion, a simple non-associated flow rule and the initial stress method, and which represents failure mode more realistically. The results of field observations and FE-analysis show that little earth pressure acts on the facing blocks and that the structure system is stable. Secondly we perform a dynamic elastic-plastic FE-analysis in order to investigate the interaction behavior between the facing blocks and reinforced backfill. The result shows that the structure system is stable also on the condition of earthquake.

2 STRUCTURE

The structure of the reinforced soil retaining wall is shown in Figure 1 (Yoshida, K. et al., 2006). It has a vertical layer which absorbs the deformation between facing concrete brocks and reinforced backfill. The reinforcement geogrid in which aramid fibers are inserted in polyethelene net, is shown in Figure 2. The wall system has two facing walls such as an outer wall and an inner wall. The facing block exists as the outer wall, and the inner wall consisting a non-woven fabric and L-form wire net exists in the inside. Reinforced backfill is stable state by the inner wall and geogrid. In order to reduce the earth pressure acting from backfill to facing concrete block, facing concrete block and backfill separate perfectly. Between the facing concrete block and backfill, an absorption layer for deformation consisting single sized crushed stone is set. Facing concrete block is not connected with geogrid laying in backfill. In addition, the facing concrete block and reinforced backfill are connected by fiber belt made in non-corrosive polyester (below called the connection belt). Characteristics of this system are as follows: 1) The facing concrete block and reinforced backfill separate perfectly so that it can compact backfill near the inner wall surface sufficiently. 2) It can reduce the earth pressure acting on the facing concrete block, with reducing the external stress with the deformation of compression of backfill after construction by the absorption layer for deformation. 3) Since material of the connection belt is

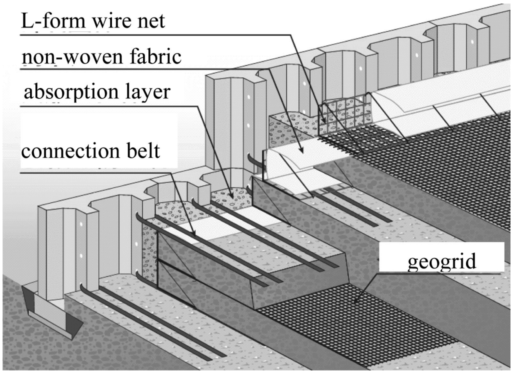

Figure 1. Structure of reinforced soil retaining wall.

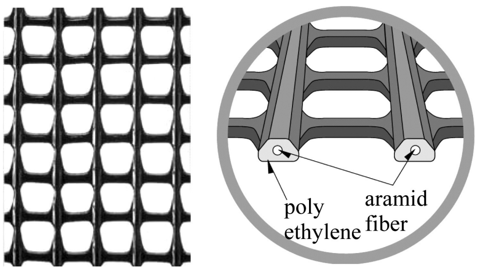

Figure 2. Geogrid reinforcement.

flexible, it can respond to the deformation due to the consolidation of reinforced backfill and the stress concentration in the connection part of facing concrete block is prevented.

3 FIELD OBSERVATIONS

The reinforced soil retaining wall used in the full-scale test is shown in Figure 3. The wall was constructed to have a vertical height of 9 m by piling up 0.9 m high facing concrete blocks in ten rows. The construction procedures are follows: 1) grading the foundation ground to enable the facing concrete blocks to be horizontally installed, spreading crushed stones for the foundation, and building concrete foundation, 2) installing the facing concrete blocks on the foundation concrete, 3) installing the connection belt, installing a form for crushed stones on the inner wall, 4) installing the geogrid reinforcement, backfilling and compacting soil, and 5) filling the layer for absorbing deformation with single sized crushed stones. A front view and a cross section of the reinforced soil retaining wall are shown in Figure 4. The earth pressure acting on the back of the facing concrete blocks was measured by using an earth pressure meter. For monitoring the displacement of the wall, several targets were installed on the concrete blocks. The displacement of the wall during and after the construction was monitored using an electro-optical distance meter. An earth pressure meter was also installed on the bottom of the reinforced soil retaining wall to monitor the ground reaction at the bottom of the wall. Strain gauges were attached to geogrid reinforcement to monitor the strain of the geogrid.

Figure 3. Overall view.

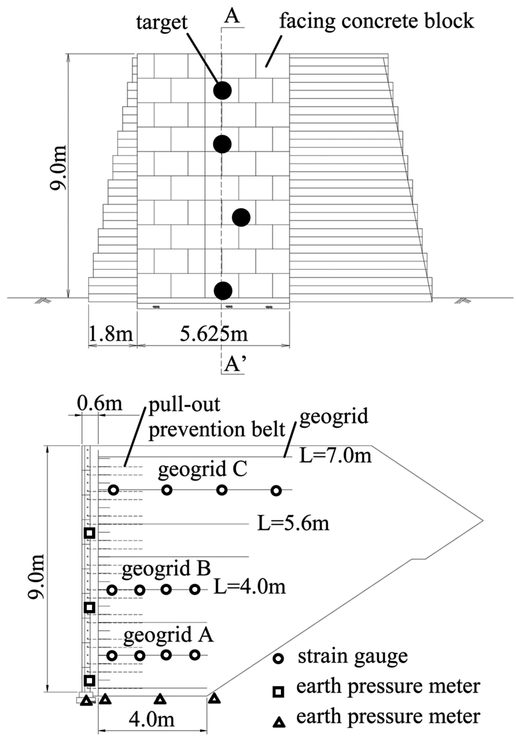

Figure 4. Front view and cross section.

4 NUMERICAL ANALYSIS

The ground is expressed as a plane strain element, and the shift between the ground and the wall blocks

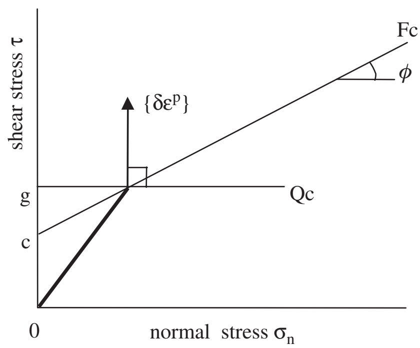

Figure 5. Yield surface and flow rule (Coulomb).

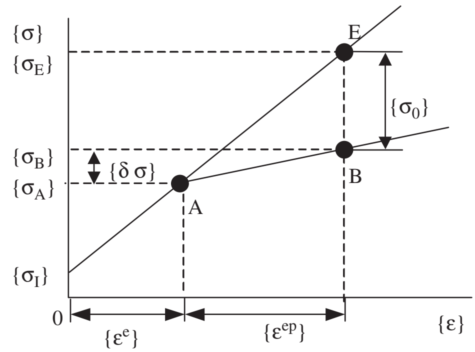

Figure 6. Initial stress method.

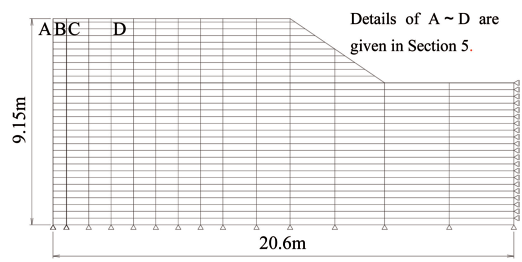

Figure 7. FE meshing.

is expressed in an interface element. Mohr-Coulomb failure criterion is applied to the ground, and Coulomb failure criterion is applied to the interface element (Desai, C. S. et al. 1984).

Mohr-Coulomb:

$$F_M = \left\{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}{}^2\right\}^{1/2} - \left\{(\sigma_x + \sigma_y)\sin\phi + 2c\cos\phi\right\} = 0 \tag{1}$$

$$\text{Coulomb}: \quad F_C = |\tau| - c - \sigma_n \tan\phi = 0 \tag{2}$$

Where, $\sigma_x, \sigma_y, \tau_{xy}$: the stress components in the entire coordinates, $\sigma_{n,4}$ τ: the stress components on the slip surface and c, ϕ: Mohr-Coulomb strength parameters.

When the confining pressure σ_3 or the vertical stress σ_n of the shear surface continues increasing by the load of banking, the curve is likely to move on the yield line after yielding. As shown in Figure 5, the increment of plastic strain, when the curve moves on the yield line, was assumed to follow the non-associate flow rule with a dilatancy angle of 0. Plastic potential is

Mohr-Coulomb:

$$Q_M = \left\{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}{}^2\right\}^{1/2} - 2g = 0 \tag{3}$$

$$\text{Coulomb}: \quad Q_C = |\tau| - g = 0 \tag{4}$$

where, g: unnecessary parameter since plastic potential is used in a differential form. As shown in Figure 6, the entire load is applied at a single loading stage. In Figure 6, Point A shows the yield point, and Point B is the final equilibrium point. $\{\varepsilon^e\}$: elastic strain, $\{\varepsilon^{ep}\}$: elastic-plastic strain. $\{\sigma_I\}$: actual initial stress and $\{\sigma_0\}$: initial stress in the initial stress method which is determined by an iteration loop (Arai, K. et al., 1996).

The FE meshing is shown in Figure 7. The facing concrete block is represented by beam elements, the geogrid reinforcement is expressed using truss elements, and the backfill and the layer for absorbing deformation are represented by plane strain elements. Interface elements are put between the facing concrete blocks and the deformation absorbing layer and between the deformation absorbing layer and reinforced backfill. The geogrid is assumed to not bear the compression stress. Soil parameters used for numerical analysis are shown in Table 1, in which E: elastic modulus, ν: Poisson's ratio, G: shear modulus at the interface, γ: unit weight, A: cross sectional area, and I: moment of inertia. The joints between two vertically adjacent facing concrete blocks were assumed to have a moment of inertia of 1/100 of that of facing blocks to reproduce the drops in bending stiffness. Note that the elastic modulus of backfill gives little effect to earth pressure and wall displacement.

The calculated and measured horizontal earth pressures acting on the facing concrete blocks are

Table 1. Soil parameters.

	E(kN/m^2)	ν	c(kN/m^2)	ϕ (degree)
Embankment	1.0×10^4	0.3	0.0	36.0
Absorption layer	1.0×10^4	0.3	0.0	30.0
Interface	1.0×10^4 (G = 100kN/m^2)	0.3	0.0	20.0

	E(kN/m^2)	A(m^2)	I(m^4)
Facing concrete block	1.4×10^6	0.14	2.3×10^{-4}
Geogrid	4.1×10^6	5.0×10^{-4}	–
Connection belt	2.0×10^5	4.8×10^{-4}	–

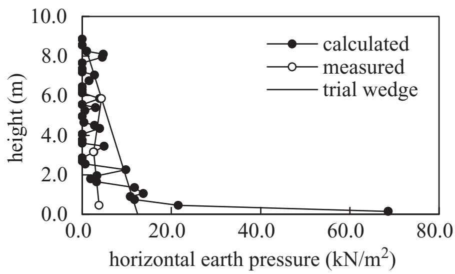

Figure 8. Horizontal earth pressure.

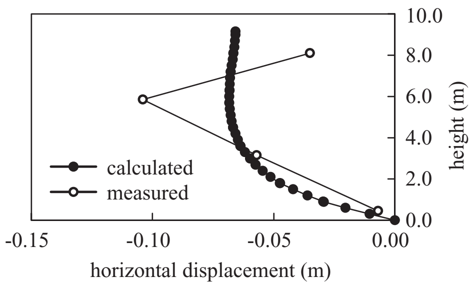

Figure 9. Horizontal displacement.

comparatively shown in Figure 8. The earth pressure values calculated by the trial wedge analysis are also shown in the figure, which were determined by assuming that the inner wall was stable natural ground. Both the measured and calculated values were much smaller than the values determined by the trial wedge analysis, showing that the earth pressure acting on the facing concrete blocks was small. The calculated values well reproduced the measured values although the calculated values were larger than the measurements at the lower part of the wall, because of restricting displacements at the boundary. The calculated and measured horizontal displacements of the facing concrete blocks are shown in Figure 9. The measured horizontal displacement at the completion of the reinforced soil retaining wall was about 10cm the maximum at a height of 6 m and was bulging frontward. The calculations reproduced the measured displacements almost completely. A comparison between the calculated and measured tensile force of the geogrids after the completion of the reinforced soil retaining wall is shown in Figure 10. Large strains were observed near the wall on Geogrid A and at the centers of Geogrids B and C.

5 BEHAVIOR DURING EARTHQUAKE

To simulate the behavior of the reinforced soil retaining wall during an earthquake, a non-linear dynamic analysis is performed (see Owen et al., 1980). The

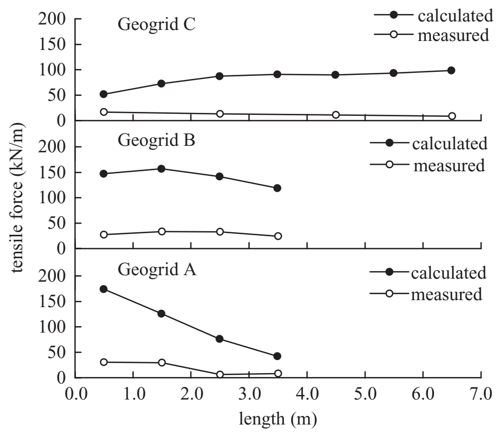

Figure 10. Tensile force of geogrid.

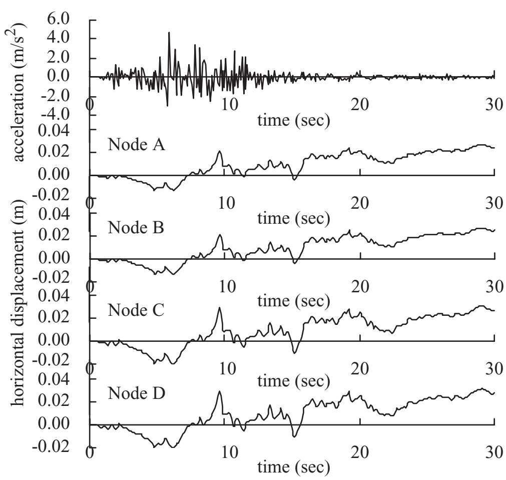

Figure 11. Result of dynamic FE-analysis.

elastic-plastic stress and strain relationship is used for the ground, which is the same as the one employed in the static analysis. The attenuation matrix is derived by the modified Rayleigh attenuation so that the attenuation properties are independent of frequency. For time integration, Newmark's β method is applied. The earthquakes along the north-south direction monitored at 17 km from the epicenter during the Niigata Chuetsu Earthquake in 2004 are given to the FE meshing shown in Figure 7. The attenuation parameters α is 36.7 and β is 0.0021. Displacements are calculated at Nodes A to D shown in Figure 7. Node A is on the facing concrete blocks, Node B is on the front of the deformation absorbing layer, Node C is on the front of the inner wall, and Node D is within the reinforced soil. The calculated horizontal displacement is shown in Figure 11 for the given acceleration waveforms. When an earthquake motion is given, a displacement difference of about 5 mm is observed between the facing concrete blocks and the reinforced soil at the crown of the wall, but there are no phase differences among the facing concrete blocks, the deformation absorbing layer and the reinforced soil, and all behaved as a united structure.

6 CONCLUSIONS

A field observation and a numerical analysis were carried out on a reinforced soil retaining wall that was installed with a layer for absorbing deformation between facing concrete blocks and reinforced soil to mitigate the earth pressure acting on the facing concrete blocks by the deformation of the soil during and after the construction of the wall. The results are: 1) The field observation and numerical analysis showed that the horizontal earth pressure acting on the facing concrete blocks was very small and 2) The dynamic finite element analysis showed that there were no phase differences among the facing concrete blocks, the deformation absorbing layer and the reinforced soil, and all behaved as a united structure.

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