Effects of negative pore air pressure in backfill soil on seismic behavior of geosynthetic-reinforced soil and conventional type retaining walls

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ABSTRACT: In order to investigate the seismic behavior of geosynthetic-reinforced soil and conventional type retaining walls, a series of model shaking tests was conducted. After preparing a subsoil layer having a thickness of 20 cm in a rigid soil container, model walls having a height of about 50 cm were placed and backfilled with a layer of dense dry Toyoura sand. The models were subjected to several steps of horizontal irregular excitations. As a result of these model tests, generation of negative pore air pressure in the backfill soil layer was observed. The maximum amplitude of the negative pore air pressure during each shaking step increased with the base acceleration. Based on analyses of the measured data, it was inferred that such negative pore air pressure was caused by outward wall displacement relative to the backfill soil, not by dilative behavior of the backfill soil. It would cause a reduction in the seismic earth pressures exerted from the backfill soil. This feature suggests an advantage of the rigid full-height facing for reinforced soil walls over the other types of facing, in addition to the advantages that have been reported in previous studies.

1 INTRODUCTION

Geosynthetic-reinforced soil retaining walls perform well during a seismic event when properly designed, as summarized by Koseki et al. 2006. This has led to many structures remaining in service after major earthquakes while conventional structures have not.

In order to reveal seismic behavior of different types of retaining walls under large earthquake loads, a variety of studies have been conducted (e.g., Watanabe et al. 2003 among others). As far as the authors know, however, no measurement has been made on the possible change of pore air pressure in the backfill soil, which would affect the mobilization of shear resistance in the backfill soil and thus the seismic earth pressures exerted from it.

In view of the above, in the present study, a series of shaking table test was conducted under normal gravity field on models of a geosynthetic-reinforced soil retaining wall and a leaning type retaining wall, focusing on the pore air pressure change in the backfill soil. Its effect on the mobilization of seismic earth pressure was also discussed, together with the advantage of using a rigid full-height facing for the reinforced soil retaining walls.

2 MODEL TEST

2.1 *Procedures*

Relatively small-scale 1-g model shaking tests were conducted on a geosynthetic-reinforced soil retaining wall and a leaning type retaining wall resting on level ground as shown in Fig. 1.

In order to model geogrid reinforcements, a net of polyester (PE) was used in one test, while a grid of phosphor-bronze (PB) was used in another test. They were placed in the backfill soil at a vertical spacing of 5 cm and connected to a model of rigid full-height facing having a thickness of 3 cm. As the conventional type retaining wall, a model of leaning type wall having a base width of 18 cm was used. The facing and wall models were about 50 cm high.

The subsoil and backfill soil layers were modeled by very dense air-dried Toyoura sand (D_{50} =0.16 mm, e_{max} =0.997, e_{min} =0.605) at a relative density of 90 %. In order to measure the pore air pressure during shaking, several pressure transducers were installed in the backfill soil (Fig. 1).

The models were subjected to several steps of horizontal irregular excitations as typically shown in Fig. 2. The maximum amplitude of the base acceleration was initially set at 0.9 G and increased at an increment of about 0.3 G for the two reinforced soil wall models, while it was initially set at 0.1 G and increased at an increment of about 0.1 G for the leaning type wall model.

In order to simulate the dead load of railway ballast and its base, in the two tests on the reinforced soil wall models and one test on the leaning type wall model, a surcharge of 1 kPa was applied to the surface of the backfill layer by placing lead shots that were wrapped in small plastic bags. In the other test on the leaning type wall model, such surcharge was not applied, since the plastic bags may affect the possible change in the pore air pressure by reducing the amount of dissipation of excess pore air pressure through the surface of the backfill layer.

Refer to Watanabe et al. (2003) and Nakajima et al. (2007) for the detailed test conditions.

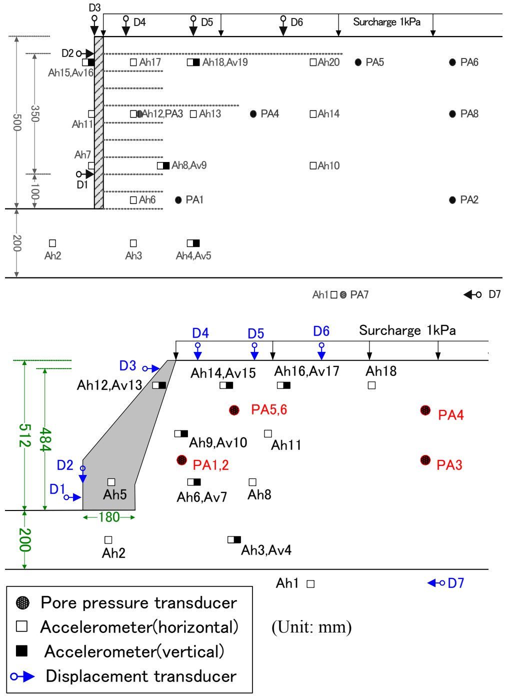

Figure 1. Retaining wall models

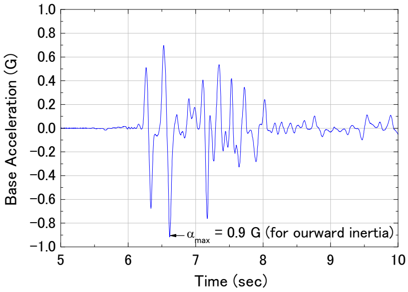

Figure 2. Typical time history of base acceleration

2.2 *Test results*

Figure 3 shows the relationship between the cumulative horizontal wall displacements that were measured near the top of the model wall and the maximum base acceleration α_{max}. In the case of reinforced soil wall models, the wall displacements were relatively small even under significantly high excitation levels. In the case of leaning type wall models, on the other hand, the residual wall displacements accumulated rapidly after exceeding α_{max} of about 0.6 G when a first failure plane was formed in the backfill layer.

Figure 4 shows typical time histories of pore air pressures that were measured in the backfill layer during a shaking step of α_{max}=0.9 G (Fig. 2). With all the models, the pore air pressure changed to both positive and negative values as compared to the zero value set at the atmospheric pressure.

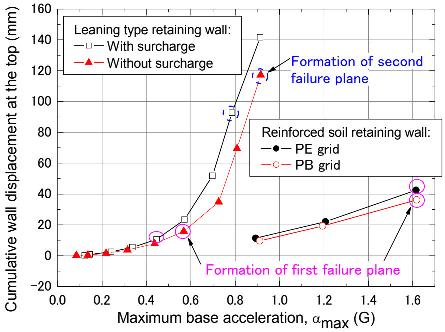

Figure 3. Relationships between cumulative wall top displacement and base acceleration

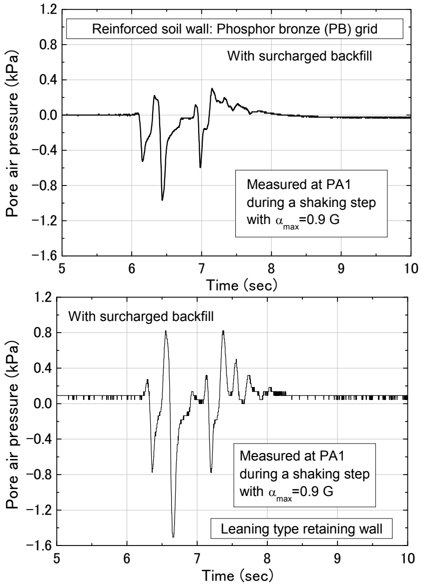

Figure 4. Typical time histories of pore air pressure (refer to Figure 1 for location of pore pressure transducer)

Figure 5 shows typical relationships between the above pore air pressures and the wall top displacement, both of which were normalized by the vertical overburden stress and the wall height, respectively. The wall displacement was defined as positive for the outward movement. With the both types of retaining walls, the negative pore air pressure was generated when the wall displacement accumulated to the outward direction (denoted as active state herein). In contrast, the positive pore air pressure was generated when the wall displacement was recovered partly to the opposite direction (passive state).

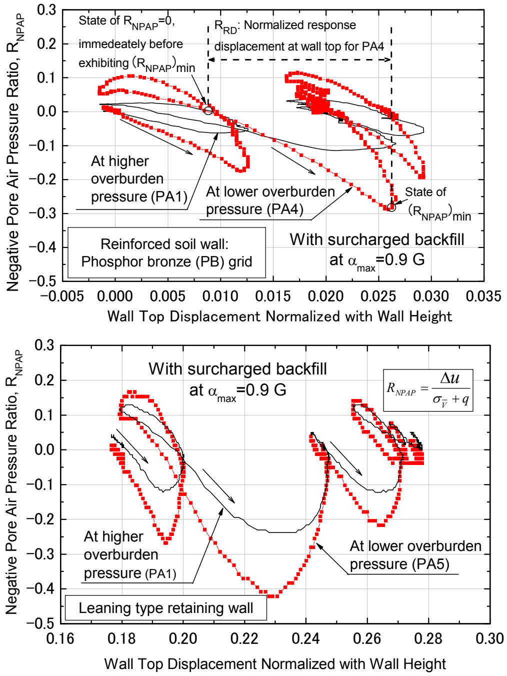

Figure 5. Relationships between normalized pore air pressure and wall top displacement

2.3 *Discussion*

The negative pore air pressure under the active state would have been possibly caused by a) significant dilation of dense sand that is mobilized along the failure plane (or shear band) during its formation and/or b) outward movement of the wall that would cause tentative increase of the pore volume in the adjacent backfill layer (Hong, 2008 and Koseki et al., 2008). The latter factor would in turn cause tentative decrease of the pore volume under the passive state, resulting into generation of positive pore air pressure, as was the case with the present model test results (Fig. 5).

Regarding the possible contribution of the above factor a), Figure 6 was prepared, which shows the relationship between the minimum value of the normalized negative pore air pressure during each shaking step, $(R_{NPAP})_{min}$ (denoted as peak negative pore air pressure ratio herein) and the normalized response displacement at the wall top, R_{RD}, which was induced between the state of $(R_{NPAP})_{min}$ and the preceding state of $R_{NPAP}=0$ (refer to Fig. 5 for typical definition). The shaking steps during which the failure plane was formed in the backfill layer were also indicated in the figure. Formation of failure plane did not affect the trend of increase in the peak negative pore air pressure ratio during the subsequent shaking steps, suggesting that the above factor a) was not relevant.

Based on cyclic torsional shear tests on hollow cylindrical specimens with local measurement of pore air pressures conducted inside the specimen, it was also confirmed that the formation of failure plane did not cause significant generation of negative pore air pressures (Hong, 2008).

Rather, the amplitude of the peak negative pore air pressure ratio increased smoothly but in a non-linear manner with the increase in the normalized response displacement at the wall top. With both types of the wall models, the amplitude of the peak negative pore air pressure ratio was larger under lower overburden pressures (i.e., at shallower depths), due possibly to the difference in the wall response displacement at respective locations.

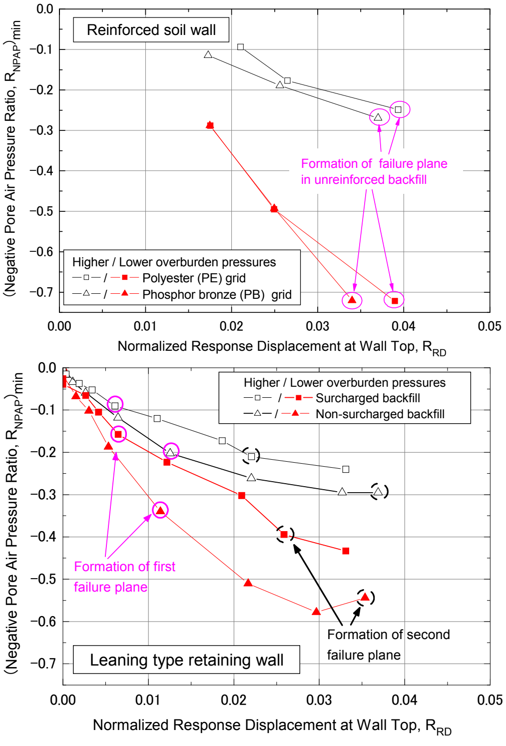

Figure 6. Relationship between peak negative pore air pressure ratio and normalized displacement at wall top

Under the testing conditions employed in the present study, the test results on the reinforced soil wall models were not largely affected by the type of the model reinforcement (Figs. 3 and 6). It was also the case with the leaning type retaining wall models regarding the existence of the surcharge.

On the other hand, a significant difference could be observed between the test results on the two different types of retaining wall models. The difference in the amounts of the peak negative pore air pressure as typically seen in Figs. 4 and 5 is possibly affected by the one in the wall top displacement; i.e., both values with the leaning type retaining wall models were much larger than those with the reinforced soil wall models. Such trend would also confirm that the above factor b) for the cause of the negative pore air pressure generation was relevant.

It should be noted that, as investigated in detail by Hong et al. (2008) and Koseki et al. (2008), the negative pore air pressure generation on the active state would cause a reduction in the seismic active earth pressure exerted from the backfill soil to the retaining wall or facing. This is because the negative pore air pressure would increase isotropically the effective normal stresses, resulting into an apparent increase in the shear strength and thus a reduction in the value of the active earth pressure or the lateral stress in terms of the total stress under the active failure state, as schematically shown in Fig. 7.

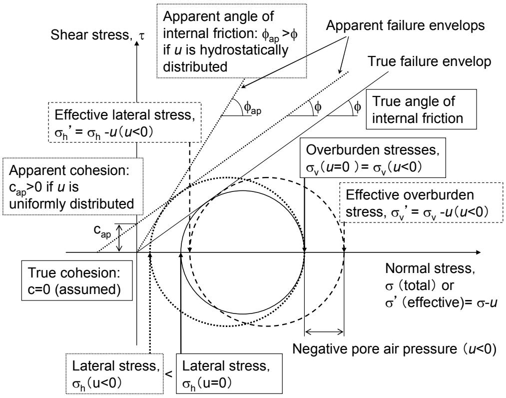

Figure 7. Mohr's circles of stresses with/without negative pore air pressure under active failure state

Note also that, as compared to other types of facing such as the segmental ones for the reinforced soil walls, the rigid full-height facing that has better air-tightness would generate more easily the negative air pressure in the backfill soil. This feature suggests another advantage of the rigid full-height facing, in addition to those that have been reported in previous studies (e.g. Tatsuoka et al., 1997 among others).

3 CONCLUSIONS

Results from the present study can be summarized as follows:

1) Generation of negative excess pore air pressure on the active state was observed during model shaking tests on geosynthetic-reinforced soil and leaning type retaining walls. It was not largely affected by the type of the model reinforcement or the existence of the surcharge.

2) The generation of negative pore air pressure is likely to depend on the outward movement of the wall, rather than the dilatancy behavior of the dense backfill soil. It would cause a reduction in the seismic earth pressures exerted from the backfill soil.

3) The above behavior suggests an advantage of the rigid full-height facing for reinforced soil walls over the other types of facing.

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