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Combined reinforcement by means of EPS blocks and geogrids for retaining wall structures

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ABSTRACT: This study illustrates that a compressible layer such as EPS blocks installed immediately behind a rigid wall combined with geogrid reinforcement proves to be a good solution to reduce earth pressures on earth retaining wall structures. A series of large-scale model tests were conducted with medium loose sand reinforced as follows; one test with EPS blocks only, another test with layers of geogrid reinforcement only, and the other test with layers of geogrid reinforcement fixed to EPS blocks behind the rigid wall. The roles of controlled yielding due to the inclusion of the EPS blocks and the fixity provided by the EPS blocks to the layers of geogrid reinforcement are discussed with respect to the earth pressures at rest and at active states and the geogrid tensile strains.

1 INTRODUCTION

It has become known that the use of a compressible geosynthetic layer behind the rigid wall allows lateral expansion of soil in retaining wall structures, and therefore leads to a reduction in the lateral earth pressure, which enables the retaining wall structures to gain more stability. This technique was successfully employed in the fields and reported by Partos & Kazaniwsky (1987), who used a prefabricated expanded polystyrene bead drainage board for a 10 metres high basement wall. Karpurapu & Bathurst (1992) supported the effectiveness of this technique by employing a FEM analysis, and introduced a controlled yielding concept as follows. A compressible geosynthetic layer behind the rigid wall is subjected to lateral compression due to the action of the earth pressure. The soil behind the wall is on the other hand subjected to lateral expansion, and therefore caused to deform plastically towards an active state in proportion to the lateral compression of the geosynthetic layer, while the rigid wall is kept stationary. This phenomenon is characterized by the trade-off between lateral compression of the geosynthetic layer and lateral expansion of soil, in other words, the increase in the compressive stress on the geosynthetic layer and the reduction in the lateral earth pressure exerted by soil. As a result, the earth pressure at rest in effect reduces.

In this study, the use of compressive expanded polystyrol (EPS) blocks for the controlled yielding of granular materials in retaining wall structures is examined by employing large-scale model tests. The use of geogrid reinforcement together with EPS blocks installed behind the rigid wall is also examined.

2 EXPERIMENTAL DETAILS

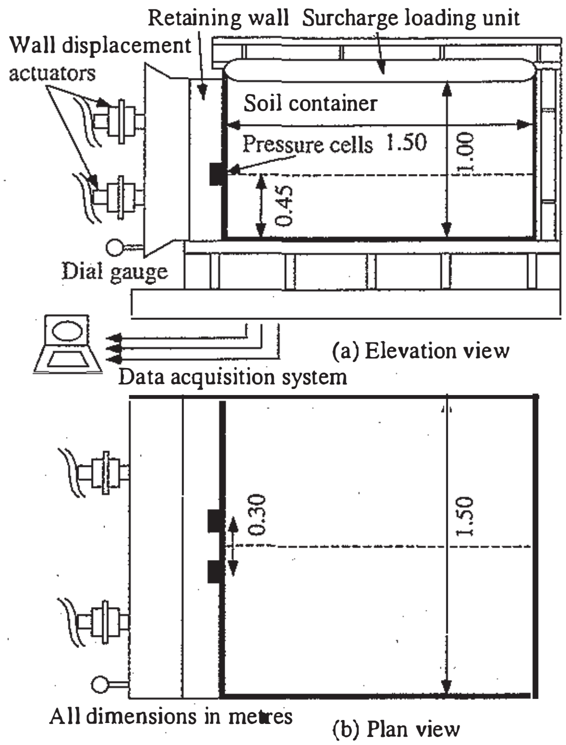
2.1 *Test apparatus*

Figure 1 shows the large-scale model test apparatus used in this study, which is described in more detail by Tsukamoto et al. (1999). The model soil container is 1.5 m wide, 1.5 m long and 1.05 m high, in which one of the wall with 1.5 m in width and 1.0 m in height is a motor-driven mobile rigid model retaining wall and produces a translational mode of wall displacement. The earth pressures are measured with the pressure cells installed at the mobile rigid model retaining wall, and the displacement of the model retaining wall is measured with dial gauges attached to the model retaining wall. The surcharge loading unit is located at the top surface of the model soil specimen. All the voltage outputs from the pressure cells, dial gauges and electrical resistance strain gauges instrumented along layers of geogrid reinforcement embedded in the model soil specimen, where necessary, are stored in the data acquisition system.

2.2 *Soil material, geogrid and EPS*

Toyoura sand is used as a model granular backfill in this study, which is a poorly graded clean fine sand with no fines. The physical properties of this material are as follows ; G_s=2.65, D_{50}=0.19mm, U_c=1.70, F_c=0%, e_{max}=0.988 and e_{min}=0.616.

One type of the geogrid reinforcement is used in this study. The polymer type is vinylon, and the physical properties are as follows; mass/unit area = 200g/m^2, aperture size (L×W) = 19mm×16mm, rup-



Figue1. Test apparatus.

ture strength = 29.4kN/m, secant stiffness at 0.5% strain = 560kN/m and strain at rupture = 10%.

The physical properties of the EPS used in this study are as follows; mass/unit volume = 25kg/m^2, allowable compressive strength = 70kPa, Young's modulus under triaxial compression at a confining pressure of 10kPa = 2.5×10^4kPa and Poisson's ratio = 0.13. A large block of the EPS material was provided and cut into pieces to produce a dozen of small blocks with 15cm in height, 20cm in length and 100 cm in width, which are used in the model tests described below.

2.3 *Test series*

Figure 2 shows the test series carried out in this study. In all the tests, the dry soil specimens are prepared with a relative density D_r of 75%. The soil specimen is air-pluviated to a designed height and the top surface is tamped equally. A layer of geogrid reinforcement is placed where necessary, and this procedure is repeated until the entire soil specimen is ready. Then, the surcharge loading unit is set up on the final top surface of the soil specimen. In test A, there is neither geogrid reinforcement nor EPS blocks in the model soil specimen. In tests B-1 and B-2, 4 EPS blocks of 20 cm long and 30 cm long are installed immediately behind the retaining wall, respectively. In test C, 3 layers of geogrid reinforcement are embedded in the model soil specimen and are not fixed to any wall of the model container. In test D, 4 EPS blocks and 3 layers of geogrid reinforcement are introduced and each layer of geogrid reinforcement is fixed between the adjacent EPS blocks.

2.4 *Test procedure*

It is more comprehensive and informative to see the test procedure in the p - q plot of the loading history, where $p = (\sigma_v+\sigma_h)/2$, $q=(\sigma_v-\sigma_h)/2$, σ_v is the overburden pressure at the location of the pressure cells, and σ_h is the lateral earth pressure measured by the pressure cells. Figure 3 shows the p – q plot for test B-1. First, the surcharge pressure of q_o = 100kPa was applied to the top surface of the soil specimen. The mobile model retaining wall was then moved way

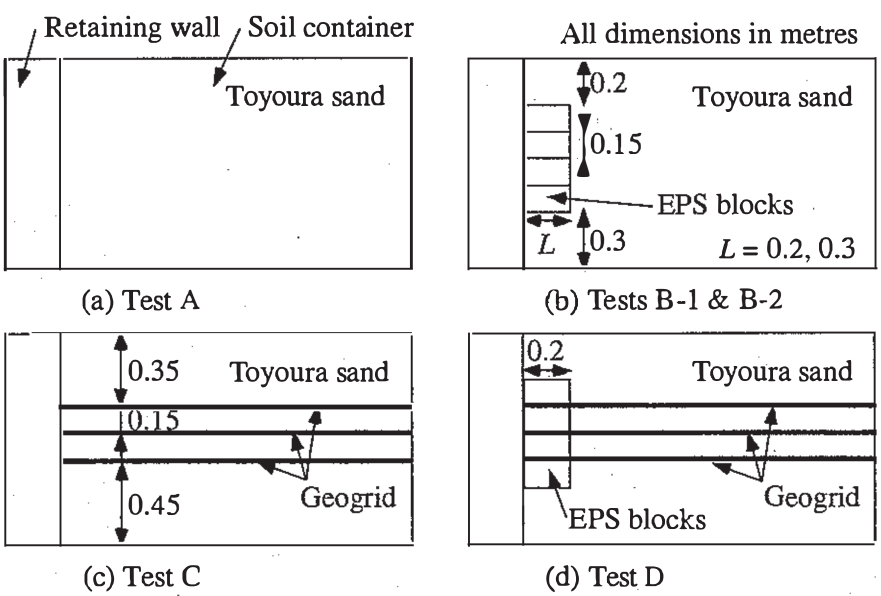


Figure 2. Test series.

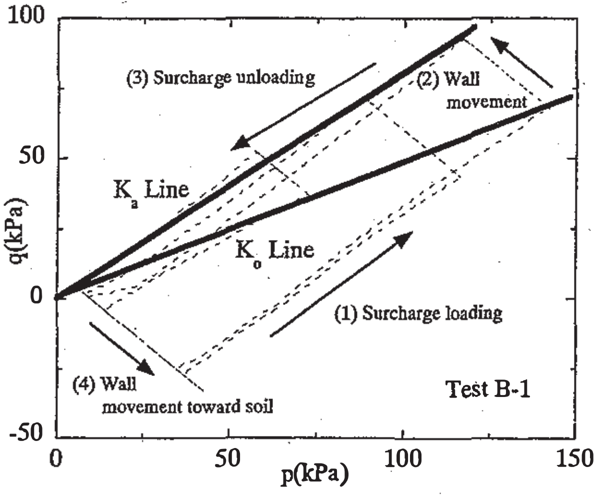


Figure 3. Test procedure in p - q plot.

from the soil specimen until the active stress state was achieved, while the surcharge pressure was maintained constant. The surcharge pressure was gradually released. Finally the model wall was moved back to the original position. This procedure was repeated under the different surcharge pressures of q_o = 100, 150 and 200kPa. The K_o and K_a values can be inferred from the p - q plot by interpolating three data points corresponding to the test conditions under the three different surcharge pressures, as shown in Figure 3, where $K_o = (1-\alpha)/(1+\alpha)$, $K_a = (1-\beta)/(1+\beta)$, α and β are the inclinations of the K_o and K_a lines, respectively.

3 TEST RESULTS

3.1 *Earth pressure coefficients, K_o and K_a*

Table 1 summarizes the earth pressure coefficients inferred from the test results, as described above in Section 2. It is seen that in comparison to test A where no reinforcement is introduced, the K_o value greatly reduces with the EPS blocks inclusion, but the K_a value appears to be the same, as seen in tests B-1 and B-2. On the other hand, the K_a value reduces with the geogrid reinforcement, but the K_o value appears to be the same, as seen in test C. In test D where the layers of geogrid reinforcement fixed to the EPS blocks are introduced, the K_o as well as K_a values are found to reduce. In this case, the K_a value is even less than that for test C. The physical interpretations of these findings are given below.

Table 1. Summary of K_o and K_a values.

Test	Test conditions	K_o value	K_a value
A	no reinforcement	0.395	0.114
B-1	EPS(L=0.2m)	0.354	0.112
B-2	EPS(L=0.3m)	0.120	0.105
C	geogrid	0.403	0.076
D	EPS+geogrid	0.292	0.042

3.2. *Influence of EPS blocks*

Figure 4 shows the earth pressure K - wall displacement d curves for tests A, B-1 and B-2, in which the K values move from at rest to active state conditions. It is seen that although the comparison of the curves for tests A and B-1 gives erroneous results, in which these curves cross over each other, the K_o value for test B-1 is found to be lower than that for test A, but the K_a values are similar to each other. This reduction of the K_o value due to the EPS blocks inclusion may be interpreted with a controlled yielding concept. Figure 5 shows the interpretation of the controlled yielding concept as follows. K_{oi} denotes the earth pressure coefficient at rest against a rigid wall. When a compressible layer such as EPS blocks is introduced behind a rigid wall, the backfill material is caused to expand laterally in relation to the amount of the compression of the EPS blocks, $\Delta L = \varepsilon_h \times L$, where ε_h and L are the compressive strain and length of the EPS blocks, respectively. Subsequently the earth pressure reduces down to K_{oa}. By assuming a plane strain condition, the following formula may be used for the initial estimates of ΔL ;

$$\Delta L = \varepsilon_h \times L, \ \varepsilon_h = \frac{1+\nu}{E}\{(1-\nu)\sigma_h - \nu\sigma_v\}, \qquad (1)$$

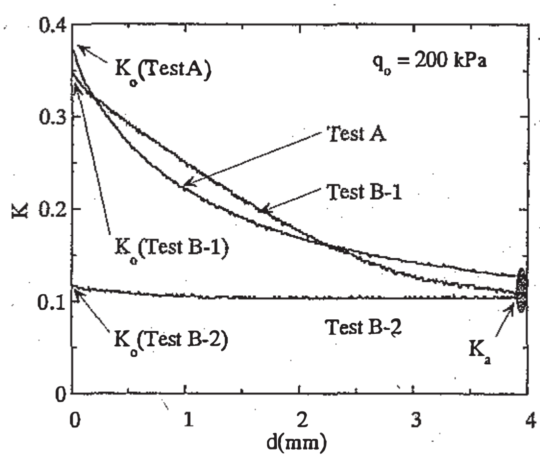


Figure 4. Influence of EPS blocks on K - d curves.

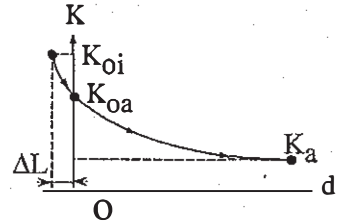


Figure 5. Interpretation of controlled yielding concept.

where E and v may be assumed as described above in Section 2.2. By some manipulation of the test results, the initial estimates of ΔL thus obtained seem to provide a good evaluation of the reduction of the earth pressure due to controlled yielding. The K_o value for test B-2 is extremely lower than those for test A and test B-1. This significant reduction is beyond description from the viewpoint of the controlled yielding concept. This phenomenon might rather be related to the fact that the significant portion of the soil, where plastic flow would be expected to occur due to wall movement if there were no EPS blocks, is replaced by the lightweight EPS blocks in case of test B-2, which in turn greatly reduces the earth pressure at rest.

3.3 *Influence of geogrid*

The K - d curves for tests A and C are included in Figure 6. The layers of geogrid reinforcement embedded in the model backfill have little influence on the earth pressure at rest, where the geogrid tensile stresses are not mobilized enough to counteract against the lateral stress exerted by the model backfill on the retaining wall. It is only when the wall moves and reaches an active state that the geogrid tensile stresses are mobilized, and therefore affect the earth pressure at an active state.

3.4 *Influence of fixity between EPS and geogrid*

Figure 6 also includes the comparison of the K - d curves for tests C and D. It is to note that each layer of geogrid reinforcement is not fixed to any wall of the model container and left free in test C, while in test D each layer of geogrid reinforcement is fixed between the adjacent EPS blocks. The earth pressure at rest for test D is found to be lower than that for test C. This can be explained by the controlled yielding of the EPS blocks, as described in Section 3.2. The earth pressure at an active state for test D is found to be lower than that for test C. This difference is considered to stem from the fixity provided by the EPS blocks to the layers of geogrid reinforcement, which affects the magnitudes of tensile strains induced along the layers of geogrid reinforcement. In tests C and D, the layers of geogrid reinforcement were instrumented with electrical resistance strain gauges to observe the distribution of the geogrid tensile strains. Figure 7 shows the distributions of the geogrid tensile strains ε_g with wall displacement for tests C and D, in which D is the distance from the original position of the model retaining wall. The maximum geogrid tensile strains are observed at around D = 40 cm for both tests C and D. In this diagram, the geogrid tensile strain at D = 0 for test C is theoretically assumed to be zero, because the layers of geogrid reinforcement are left free. However, the geogrid tensile strain at the point of fixity to the EPS blocks for test D develops with

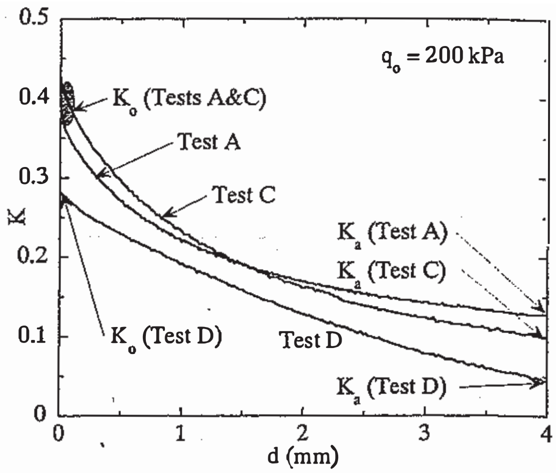


Figure 6. Influence of geogrid alone and geogrid fixed to EPS blocks on K - d curves.

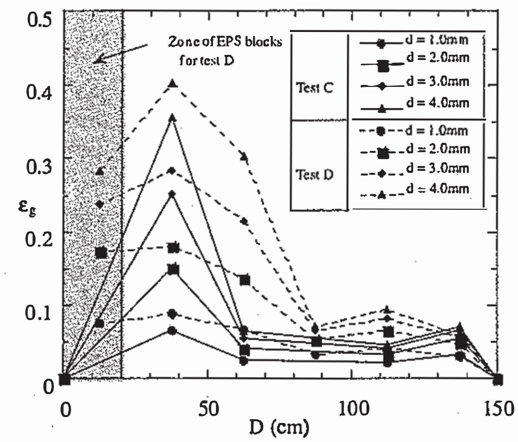


Figure 7. Distribution of geogrid tensile strain with wall displacement.

wall displacement, which most probably allows the maximum geogrid tensile strain for test D to become greater than that for test C, as seen in Figure 7. This increase in the maximum geogrid tensile strain is most likely to contribute to the difference of the lateral earth pressures at active states in tests C and D.

3.5 *Summary of experimental findings*

The experimental findings from the test results can be summarized as follows:

(1) The inclusion of the EPS blocks behind the rigid wall reduces the earth pressure at rest, in comparison to the unreinforced rigid wall, due to what is called controlled yielding.

(2) The layers of geogrid reinforcement embedded in the model backfill reduce the earth pressure at active states, mainly due to the tensile strains induced along the layers of geogrid reinforcement.

(3) The combined reinforcement by means of the EPS blocks and the layers of geogrid reinforcement reduces the earth pressures at rest as well as

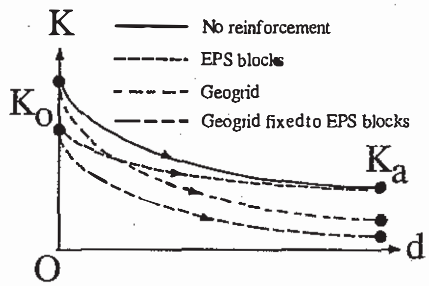


Figure 8. Schematic of K - d curves (nothing, EPS only, geogrid only, EPS+geogrid).

at active states. The reduction in the earth pressure at rest can be demonstrated by the controlled yielding concept. The reduction in the earth pressure at an active state can be related to the fixity provided by the EPS blocks to the layers of geogrid reinforcement.

Based on the above findings, the behaviour of earth pressures with wall displacement under various conditions may be schematically illustrated as shown in Figure 8.

4 IMPLICATION TO FIELDS

This study examined the use of EPS blocks and geogrid reinforcement for retaining wall structures. It needs careful considerations to make this reinforcement technique into practical use. Because of a fragile nature of EPS, a fatigue problem at the fixed positions between EPS blocks and layers of geogrid reinforcement and an installation damage problem need to be addressed. Because of a buoyant nature of EPS, a proper drainage system needs to be designed for this particular structure. A design life time of this structure needs to consider various endurance and degradation characteristics of EPS and geogrid materials used. It is noteworthy that from the viewpoint of the experimental findings, any compressible geosynthetic materials, which guarantee the occurrence of controlled yielding, may be able to replace EPS for this type of structures.

5 CONCLUSIONS

From the viewpoint of the earth pressures on earth retaining wall structures, the roles of a compressible layer such as EPS blocks installed immediately behind a rigid wall and layers of geogrid reinforcement embedded in a granular backfill were clarified in this study. The role of the compressible EPS blocks was examined by a controlled yielding concept, which contributes to the reduction in the earth pressure at rest. The role of layers of geogrid reinforcement was examined by geogrid tensile strains, which contributes to the reduction in the earth pressure at an active state. The combined use of the EPS blocks and layers of geogrid reinforcement enables the fixity to be provided by the EPS blocks to the layers of geogrid reinforcement, which contributes to the even more reduction in the earth pressure at an active state. To make this technique into practical use, several practical problems need to be overcome, such as fatigue occurring at the fixed positions between fragile EPS blocks and layers of geogrid reinforcement, drainage system, installation damage, and various endurance and degradation characteristics of EPS blocks and geogrid among others.

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