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Active earth pressures on walls retaining geogrid-reinforced soil

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ABSTRACT : Large-scale model tests are carried out to study the behaviour of the lateral earth pressures on a rigid wall retaining reinforced granular backfill. Three series of experiments are reported, which have different geogrid reinforcement and granular backfill configurations. The earth pressure coefficients K_a at active states are particularly studied. The discussion is made on the distribution of the earth pressures generated at the side wall and also at the back wall of the model backfill, in relation to the collapse states of the reinforced and non-reinforced soil mass.

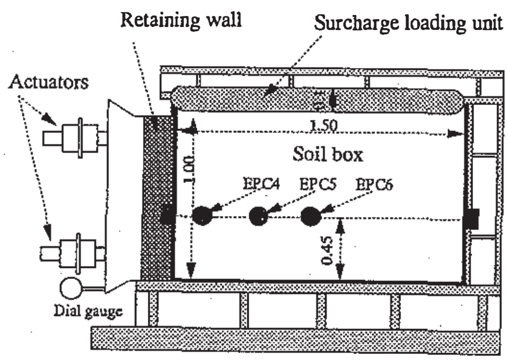
1 INTRODUCTION

One of the major benefits that comes from the use of geogrid reinforcement for retaining wall structures is the reduction of the thrust force on the wall due to soil backfill. Large-scale model tests were carried out to explore the lateral earth pressure behaviour of a rigid wall retaining reinforced granular backfill. The earth pressure coefficient K_a at active states is particularly studied. The discussion is extended to the distribution of the earth pressures generated at the side wall and also at the back wall of the model backfill, which may allow us to examine whether the reinforced backfill at active states really corresponds to collapse states.

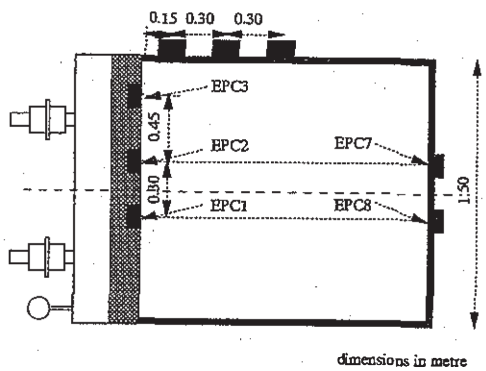
2 EXPERIMENTAL SETUP

2.1 Experimental apparatus

The model retaining wall apparatus used in this study is shown in Fig.1. This experimental apparatus consists of five parts ; soil box, movable retaining wall, wall movement actuators, surcharge loading units, and data acquisition system. The dimensions of the soil box are 1.5 metre in width, 1.05 metre in height and 1.5 metre in length. The rigid model retaining wall is located at one side of the soil box and has dimensions of 1.5 metre in width and 1.0 metre in height. This model retaining wall is activated by four units of motor and actuator fixed to the model retaining wall. The model retaining wall produces a smooth horizontal movement on the backfill. The measurements of the lateral earth pressures of the backfill are made at several locations on the walls of the soil box. All of the earth pressure cells (EPCs) are installed at the same height of 0.45 metre from the basement. EPC1, 2 and 3 are located on the movable retaining wall. EPC4, 5 and 6 are located on the side wall at different distances from the movable retaining wall. EPC7 and 8 are located at the back wall. Therefore, this experimental apparatus allows us to measure lateral earth pressures not only at the movable retaining wall, but also at the side wall and at the back wall. The horizontal displacement of the model retaining wall was measured by a dial gauge. The voltage signals from the earth pressure cells and the dial gauge are gathered at the data acquisition system and stored in data files. Some lubricant and vinyl sheets are put on all of the walls to reduce friction between backfill and the walls. When the preparation of the model backfill is complete, the surcharge load is applied on the top surface of the model backfill via a rubber mattress, as shown in Fig.1.



(a) Elevation view



(b) Plan view

Fig.1 Experimental apparatus

2.2 Material properties

Toyoura standard sand is used as a backfill. The mechanical properties of this sand are well explored in literature and shown in Table 1. The same type of geogrid is used in all of the test series reported in this paper. The properties of the geogrid are shown in Table 2.

Table 1 Material properties of Toyoura sand

Specific gravity G_s	2.65
Mean diameter D_{50} (mm)	0.19
Uniformity coefficient U_c	1.70
Maximum void ratio e_{max}	0.988
Minimum void ratio e_{min}	0.616

Table 2 Material properties of geogrid

Material	polyarylate
Tensile strength (kN/m)	77.3
Rupture tensile strain (%)	7.12
Secant Young's modulus (kPa) at rupture tensile strain	4.89×10^6
Secant tensile stiffness (kN/m)	
at 1 % strain	4.41×10^2
at 2 % strain	5.29×10^2
at rupture tensile strain	1.08×10^3

2.3 Test series and experimental procedures

Three series of experiments, Test A, B and C, are reported in this paper. Different geogrid reinforcement and backfill configurations are adopted in the three test series. The sand specimens of approximately D_r = 90 % are prepared in all of the tests.

In Test A, geogrid reinforcement is not used. All of the layers are uniformly compacted by rod tamping. In Test B, five geogrid sheets are used in the sand specimen. The geogrid sheets are not connected to the model wall. Due to the placement of the geogrid sheets, the sand specimen is divided into six layers of 0.15, 0.2, 0.2, 0.2, 0.2 and 0.1 metre in thickness from the bottom. In Test C, the same configuration of reinforcement and backfill as Test B is adopted, except that geogrid sheets are folded back into adjacent upper soil layers by 0.5 metre at the boundary of the retaining wall.

The same surcharge loading and wall movement history applied for all of the test series is described below. First, the surcharge pressure q_o of 49 kPa is applied on the model reinforced sand specimen. Then, with the surcharge pressure kept constant, the model retaining wall is moved away by 2 ~6 mm from the backfill until it reaches an active stress condition. Then the surcharge pressure is gradually released. Finally, the model wall is moved back to the original position. The same sequence followed successively with increasing surcharge pressures of 98, 196 and 294 kPa.

3 EARTH PRESSURE COEFFICIENTS K_a

Figs.2, 3 and 4 show behaviour of earth pressure coefficients K subjected to the translational displacement h of the model retaining wall away from the backfill, for Test A, B and C, respectively. Here, K is defined as follows,

$$K = \frac{\sigma_h}{\sigma_v}, \qquad (1)$$

where σ_v and σ_h denote the stresses acting on the model retaining wall at the depth d of the earth pressure cells, i.e. $\sigma_v = q_o + \gamma d$, σ_h is the average reading of EPC1 and 2, q_o is the surcharge pressure, γ is the unit weight of the soil.

It can be seen in Fig.2 that the K values of non-reinforced backfill reduce and approach approximately $K_a = 0.1$ for all of the tests at different surcharge pressures. In turn, it can be seen in Figs.3 and 4 that the K values of reinforced backfill reduce down to almost zero for all surcharge pressures. Therefore, the model reinforced backfill is subjected to the axial pressure (surcharge pressure) of 300 kPa without any confining pressure on one side of the walls. In terms of the influence of the overburden stress (surcharge pressure) on the active states, the horizontal displacement necessary to achieve active states becomes larger as the overburden stress becomes greater.

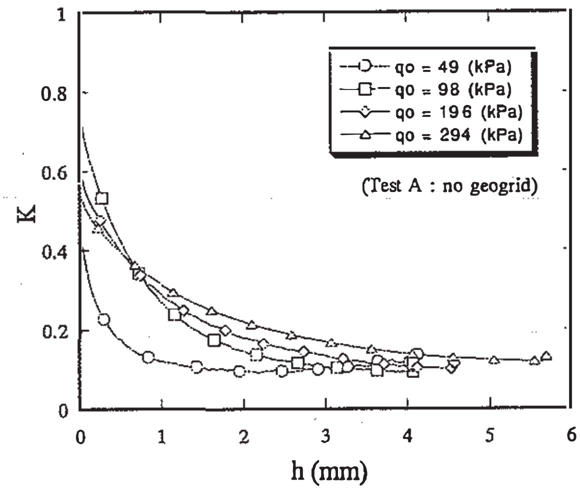


Fig.2 K values (Test A)

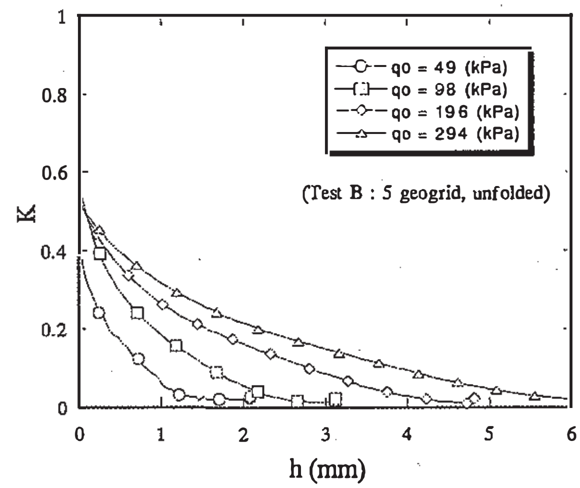


Fig.3 K values (Test B)

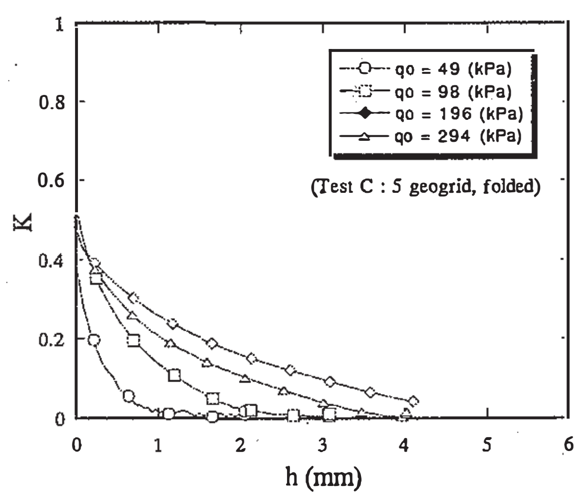


Fig.4 K values (Test C)

The comparisons of behaviour of the K values for the different reinforcement configurations of Test A, B and C are shown in Figs.5 and 6. Figs.5 and 6 shows the comparison for the surcharge pressures of 98 and 196 kPa, respectively. The influence of reinforcement on the reduction of earth pressures towards active states is clearly seen in these diagrams.

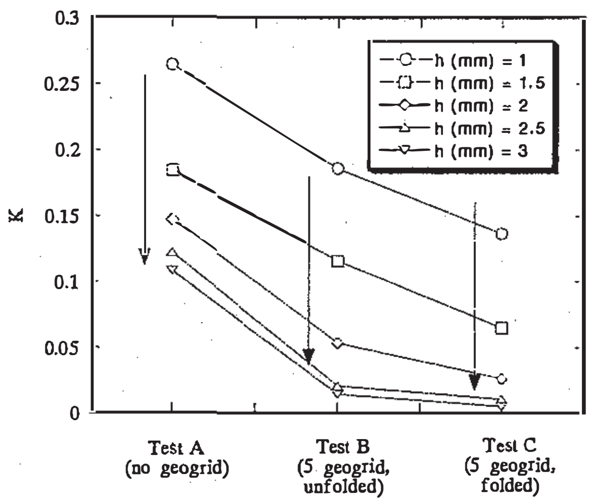


Fig.5 Comparison of K values (qo = 98 kPa)

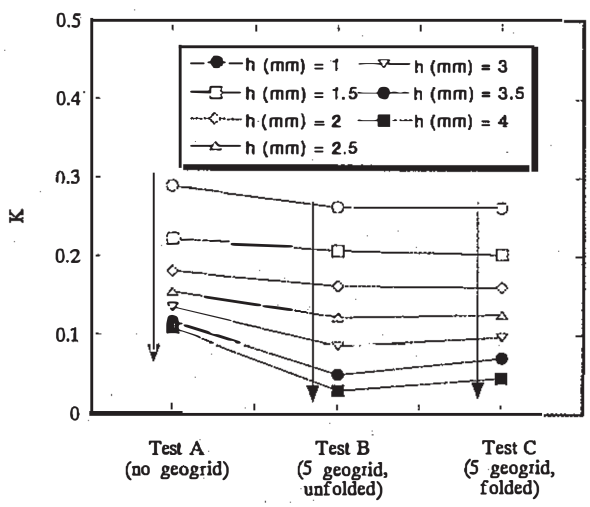


Fig.6 Comparison of K values (qo = 196 kPa)

4 K_b VALUES AT THE BACK WALL

The earth pressure σ_{hb} measured at the back wall is discussed below. σ_{hb} is the average of EPC7 and 8 readings. Figs.7, 8 and 9 show behaviour of the K_b values against the wall displacement h away from the model backfill, where $K_b = \sigma_{hb} / \sigma_v$. It can be seen first of all that the earth pressure coefficient K_b reduces as the retaining wall moves away. The significance of these results is that the lateral stress relief gradually occurs within the soil in the direction normal to the wall movement, even at a considerable distance from the moving wall, and the horizontal displacement necessary to develop fully mobilized states becomes larger as the surcharge pressure becomes greater.

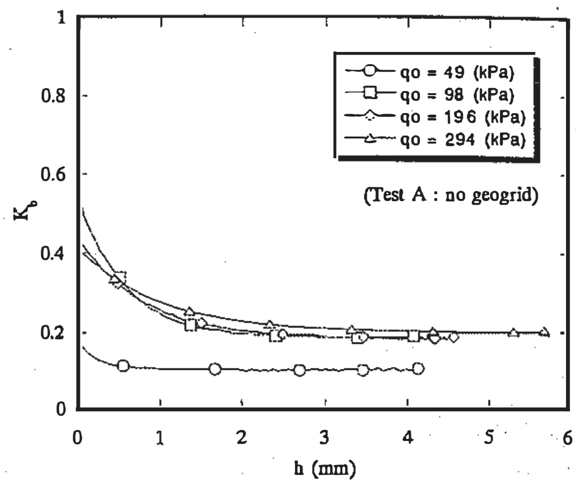


Fig.7 K_b values (Test A)

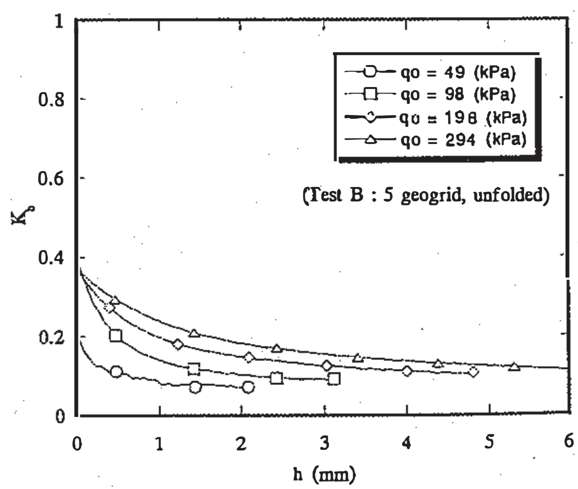


Fig.8 K_b values (Test B)

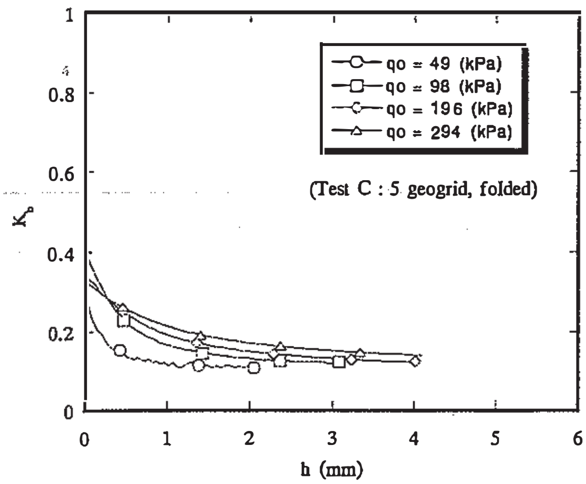


Fig.9 K_b values (Test C)

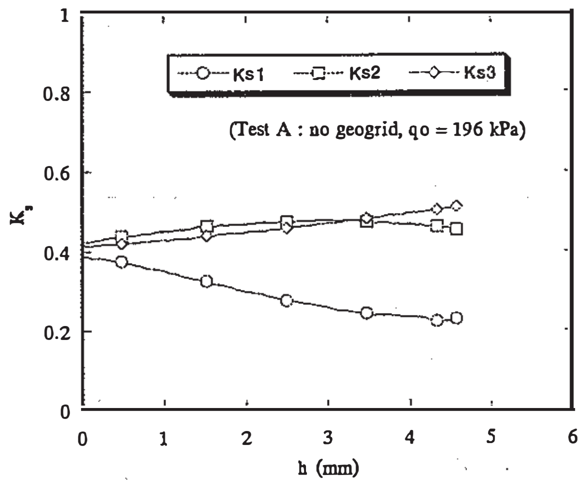


Fig.10 K_s values (Test A)

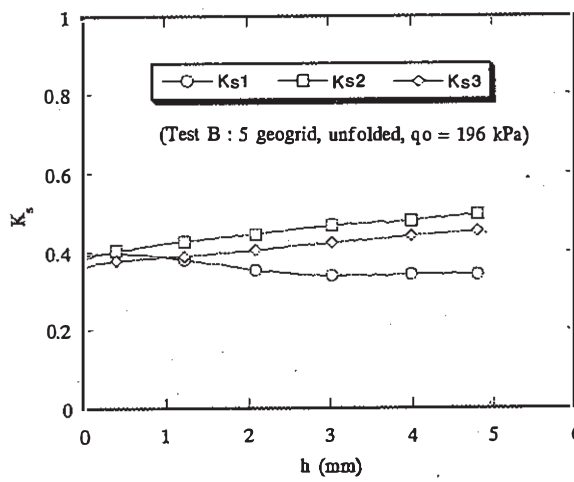


Fig.11 K_s values (Test B)

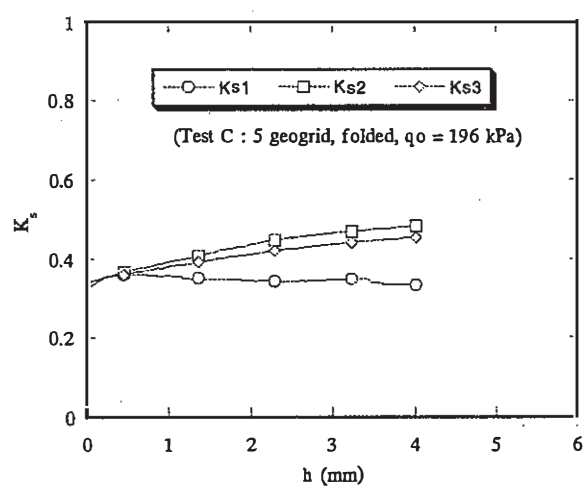


Fig.12 K_s values (Test C)

5 K_s VALUES AT THE SIDE WALL

The earth pressures $\sigma_{hs1,2,3}$ measured at the side wall are discussed below. $\sigma_{hs1,2,3}$ are the lateral earth pressures measured by EPC4, 5 and 6 which are located 0.15, 0.45 and 0.75 metre away from the model retaining wall, respectively. Figs.10, 11 and 12 show behaviour of the $K_{s1,2,3}$ values against the wall displacement h for the surcharge pressure of 196 kPa, for Test A, B and C, respectively. Here, $K_{s1,2,3} = \sigma_{hs1,2,3} / \sigma_v$, respectively.

It can be seen in Fig.10 that the earth pressure at the side of the non-reinforced soil mass immediately behind the wall gradually reduces, accompanied by the reduction of the earth pressure on the retaining wall. It should be associated with the collapse state of the soil mass immediately behind the moving wall. In turn, the earth pressures at the side of the soil mass away from the wall tend to be sustained during the wall movement. It should reflect that the soil mass away from the soil does not reach a collapse state due to the wall movement.

On the other hand, for the reinforced soil mass, as shown in Figs.11 and 12, the earth pressures at the side of the soil mass tend to be sustained, even at a position close to the moving wall. It reflect the observation made above in Figs.3 and 4, in which the earth pressure of the reinforced soil mass on the moving wall reduced almost to zero, and any collapse state was not detected. It implies that the active states of the reinforced soil mass subject to surcharge pressures of the magnitudes given in the tests are neither collapse states nor fully mobilized states.

6 CONCLUSIONS

Large-scale model tests were conducted to examine the active states of a rigid wall retaining geogrid-reinforced granular backfill. Three series of experiments were reported, which have different geogrid reinforcement and granular backfill configurations. The influence of surcharge pressures on the horizontal displacement necessary to develop active states was clearly detected, where as the surcharge pressures becomes larger, the horizontal displacement becomes greater. It was also shown that the K values of non-reinforced soil mass reduce down to 0.1 during the wall movement away from the soil, accompanying the associated reductions in the earth pressures at the side wall and back wall. It should be related to the collapse state of the soil mass immediately behind the moving wall. On the other hand, the K values of reinforced soil mass reduce down to almost zero, while the earth pressures at the side wall tend to be sustained. Therefore, the active states of the reinforced soil mass subject to surcharge pressures of the magnitudes given in the tests are considered to be neither collapse states nor fully mobilized states.

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