PARTICLE SIZE EFFECT IN MODEL RETAINING WALL ON PASSIVE MODE WITH GRANULAR MATERIAL

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ABSTRACT

This paper presented a particle size effect on model retaining wall by comparing the experimental and finite element analysis. The experiments were conducted with air-dried Toyoura sand and Soma sand in plane strain condition, both sand are standard sand in Japan. The wall was moved horizontally into sand. The heights of sand mass in these experiments were 5 cm, 10 cm and 15 cm. The finite element analysis employed a constitutive model in which non-associated strain hardening-softening elasto-plastic material was employed. This analysis introduced the effect of shear band thickness. The results obtained from the finite element analysis showed a good agreement with the results obtained from the experimental investigation. From both experimental and analytical results, there was evident of particle size effect due to shear banding.

Keywords: retaining wall, progressive failure, particle size effect, model test, finite element analysis, passive earth pressure, shear band, plane strain

INTRODUCTION

Earth pressure problems are of great interest in geotechnical engineering and closed-form solutions are widely used for the evaluation of earth pressure coefficients in the design of retaining structures.

The various theoretical approaches were based on a rigid plastic theory (Coulomb, Rankine, Terzaghi, etc.) seem to be the most accepted ones. But these theories cannot explain a progressive failure in sand mass. Nakai (1985), Simpson and Wroth (1972) evaluated retaining wall problem by using finite element analysis. Tanaka and Mori (1997) evaluated the progressive failure of retaining wall in passive mode by comparing the experimental result with the finite element. Davis (1980) experimented on retaining

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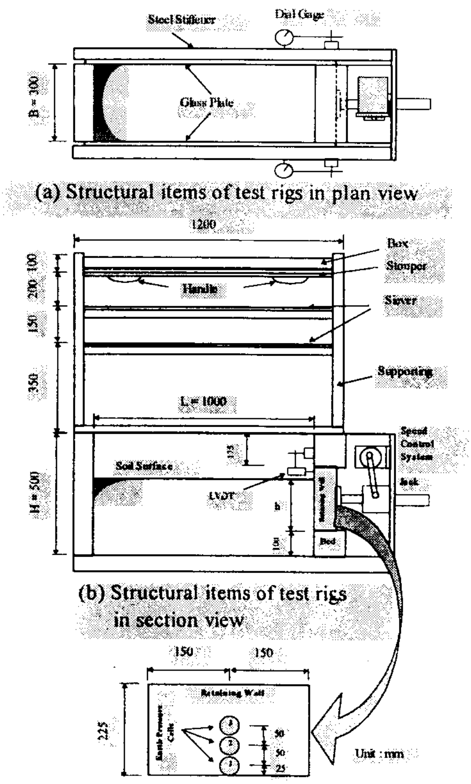


(a) Structural items of test rigs in plan view

(b) Structural items of test rigs in section view

(c) Location of the earth pressure cells.

Fig. 1. The testing apparatus

wall using both small wall (300 mm high) and large wall (3 m high), and stated that the scale effect had a very important influence on the mechanism of deformation and failure in sand: that of the relative importance of shearing and dilatancy for different wall sizes. The scale effect is an important problem in soil mechanics because it causes trouble in transformation of the model test results to prototype. The scale effect on footing and anchor problems has been under taken by some investigators (Ovesen (1979) and Kimura et al. (1985), Tatsuoka et al. (1991), and Sakai and Tanaka (1998)).

Stone and Wood (1992) reported that the scale effect was caused by the progressive failure due to shear banding. Sakai et al. (1998) evaluated the difference in the scale effect on anchor problem with dense sand having different particle size, and reported that it is necessary to consider the particle size effect when evaluating the scale effect due to progressive failure. Until now, the researches which conducted in retaining wall problems have not been enough to explain the scale effect and particle size effect.

In this paper, we attempt to explain the difference of the particle size effect and the scale effect due to progressive failure on retaining wall (horizontal translation) on passive mode by comparing the experimental results with the finite element analysis. The sand used for the tests were Toyoura sand and Soma sand, and only for finite element analysis, the data for Leighton-Buzzard sand

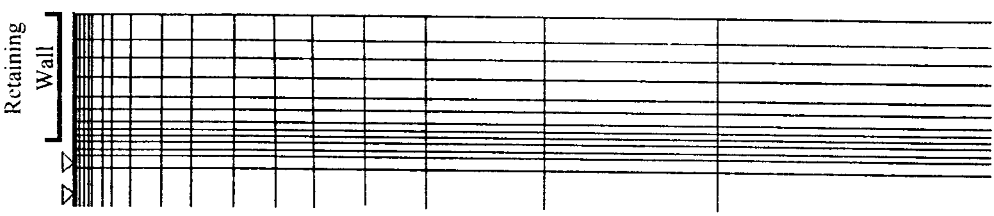


Figure 2. Finite element mesh

was also evaluated. All tests were conducted in normal gravity condition.

TESTING APPARATUS AND ANALYTICAL METHOD

A testing apparatus consisted of soil bin, movable retaining wall and driving system. The soil bin was fabricated of steel (in Figure 1). Both sidewalls of soil bin were made of 10 mm thick glass plates. The movable retaining wall was made of aluminum. Three earth pressure cells were attached on the model retaining wall to measure the distribution of earth pressure on the wall (in Figure 1(c)). In all tests, the wall was moved into sand mass with speed of 0.005 mm/sec. The sands which were used for the test were Toyoura sand (Gs=2.64; D_r=90 %; d_{50} =0.16 mm) and Soma sand (Gs=2.64; D_r=91 %; d_{50}=0.45 mm). Sand mass was prepared by pouring the air-dried sand through two sieves as shown in Figure 1(b). The dry density was 1.64 - 1.65 g/cm^3 for Toyoura sand, and 1.57 - 1.58 g/cm^3 for Soma sand. The relative densities were approximately 95 % for both sands. The heights of sand mass (h) above wall were 5 cm, 10 cm and 15 cm. In order to observe the shear band development in sand mass, thin vertical colored sand layers were placed adjacent to the glass wall.

The finite element analysis has been carried out by Tanaka (1997). The constitutive model for non-associated strain hardening-softening elasto-plastic material was introduced, and shear band thickness could be introduced as characteristic length into a constitutive equation. The finite element mesh used for the analysis is shown in Figure 2. The input data for the analysis was based on the data obtained from the test by using air-pluviated dense Toyoura sand (Tatsuoka et al, 1986). The dry density (γ_d), residual friction angle (ϕ_r), poisson's ratio (υ) and initial shear modulus (G_0) were assumed to be γ_d = 1.64 g/cm^3, ϕ_r = 34^0, υ= 0.3, G_0 = 80000 kN/m^2.

The confirmation of the results of triaxial compression test by the finite element method using one element (2 cm $\times$ 4 cm) were carried out employing the material properties with and without shear band. The calculated stress-strain-volume change relationship under σ_3 = 98 kPa is shown in Figure 3.

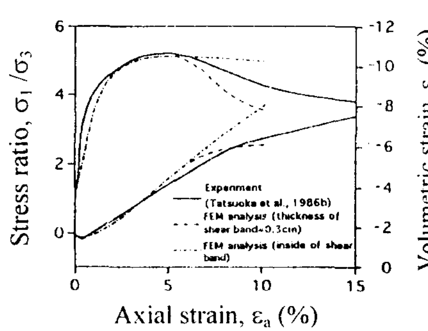
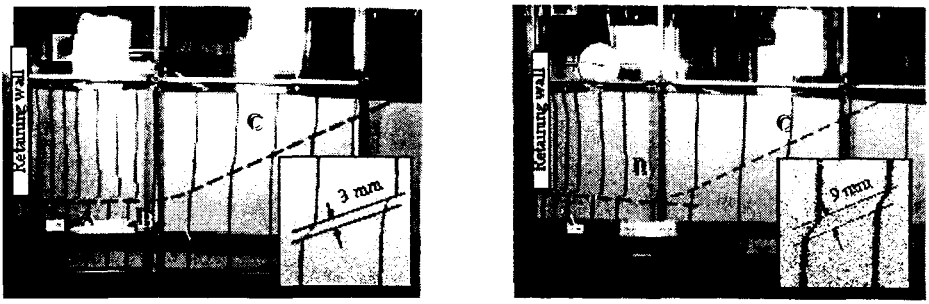


Figure 3. Simulated stress-strain volume of triaxial test

EXPERIMENTAL AND ANALYTICAL RESULTS

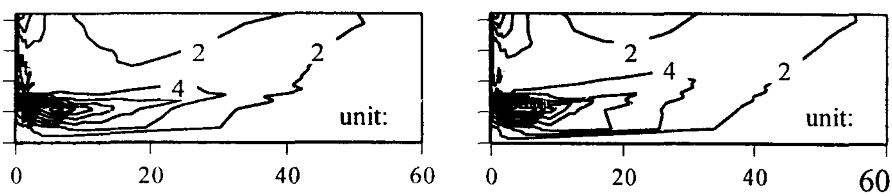
Figure 4 gives a photographic representation of the shear band propagation with Toyoura sand and Soma sand for h = 15 cm at displacement of 20 mm. The developments of localization are almost similar. Initial localization develop into sand mass from the toe of wall (shear band A). The second localization (shear band B) develop almost horizontal, and the third localization (shear band C) is following the second localization and reaches the soil surface. From Figure 4, the shear band thickness (w) is 3 mm for Toyoura sand and 9 mm for Soma sand. This result indicates that the thickness of shear band is known to be 20 times the mean particle diameter.

Figure 5 shows the contour of the maximum shear strain at peak condition for Toyoura sand and Soma sand obtained from analysis for h = 15 cm. The shear strain shown in these figures are apparent maximum shear strain that averaged value at the element level. It shows that the direction of localized narrow zone obtained by analysis is approximately identical with the direction of the shear band observed by experiment.



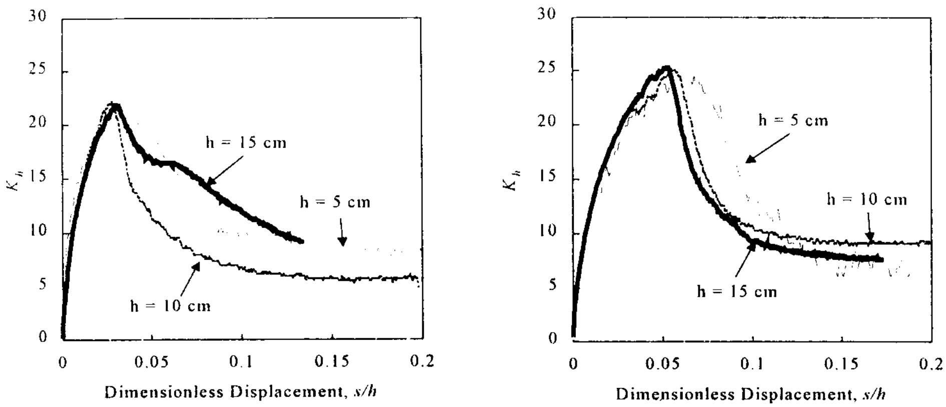
a. Toyoura sand
b. Soma sand

Figure 4. Propagation of shear band for Toyoura and Soma sand with h = 15 cm



a. Toyoura sand
b. Soma sand

Figure 5. Contours of maximum shear strain at peak condition of passive earth pressure, obtained from analysis in h = 15 cm



a. Toyoura sand b. Soma sand

Figure 6. The relationship between K_h and s/h

Figure 6 shows the relationship between horizontal passive earth pressure coefficient (K_h) and dimensionless displacement (s/h; s: displacement, h: height of sand mass) obtained by experiments. It is shown that peak value of K_h for Toyoura sand is 22 and for Soma sand is 25. The peak value of K_h for Toyoura sand (d_{50}=0.16 mm) is lower than for Soma sand (d_{50}=0.45 mm). There is clear evidence of particle size effect.

Figure 7 shows both analytical and experimental results with Toyoura sand for h = 10 cm. It shows that the analytical result is very close to the experimental results.

Figure 8 shows both experimental and the analytical result, in which coefficient of passive earth pressure (K_p) is plotted

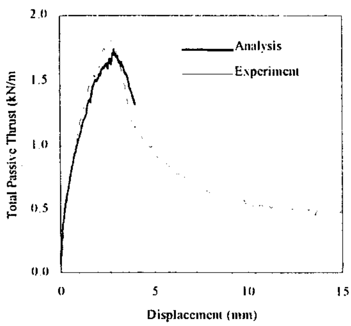


Figure 7. Analytical and experimental result for Toyoura sand

against height of sand mass (h). The result from calculation with Leighton-Buzzard sand is also plotted in this figure. K_p is defined as the peak value of K_h. These analyses were carried out employing the material properties of Toyoura sand, changing only the thickness of the shear band value (w). Since the thickness of shear band was known to be 20 times the mean particle diameter (d_{50}), w estimated to be 3 mm for Toyoura sand, 9 mm for Soma sand and 16 mm for

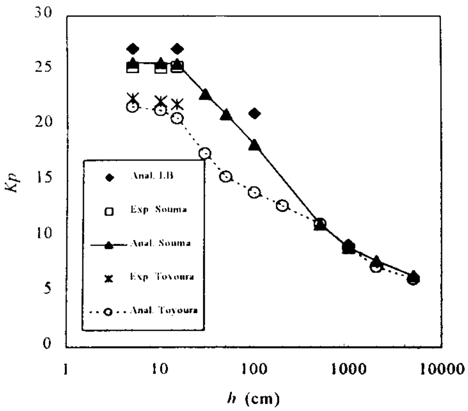


Fig. 8. Relationship between K_p and h

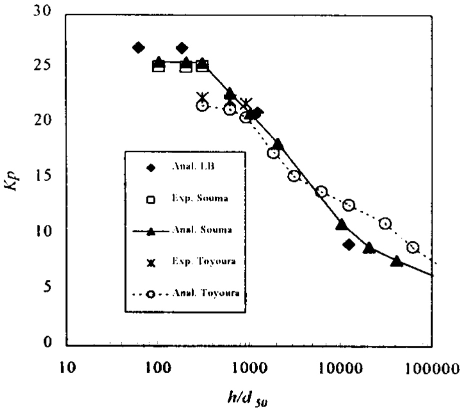


Fig. 9. Relationship between K_p and h/d_{50}

Leighton-Buzzard sand. It is showed that the particle size effect could be evaluated by finite element analysis.

Furthermore, the scale effect is not clearly seen up to h = 15 cm obtained by experiment and analysis. But it is clearly evident in the h range from 15 cm until 1000 cm obtained by analysis.

The evaluation of evidence of particle size effect due to shear banding by using the parameter h/d_{50} (h= height of sand mass; d_{50}= mean particle diameter) is important. Figure 9 shows the experimental and analytical results, which K_p is plotted against h/d_{50}. For the h/d_{50} range up to 1000, there is clear evidence of the particle size effect. The trend of the scale effect is similar for all cases in the h/d_{50} range from 1000 to 10000.

CONCLUSIONS

This study evaluates the particle size effect and the scale effect due to progressive failure on retaining wall (horizontal translation) on passive mode by comparing the experimental results with the finite element analysis. The conclusions from the results can be summarized as:

1. The finite element analysis showed good agreement with the experimental results.
2. From both experimental and analytical results, there was clear evidence of particle size effect, where the value of K_p for Toyoura sand (d_{50}=0.16 mm) was lower than for Soma sand (d_{50}=0.45 mm).
3. Although the scale effect was not clearly seen for range of h up to 15 cm, it was clearly evident in the h range from 15 cm until 1000 cm.
4. In the case of evaluating the scale effect using parameter of h/d_{50}, above the h/d_{50} range of 1000, there was clear evidence of the particle size effect. The trend of the scale effect was similar for all cases in the h/d_{50} range from 1000 to 10000.

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