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A large-scale experimental study of soil-nailed structures

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ABSTRACT: The soil nailing method have been developed on the basis of experimental works as well as theoretical backgrounds. As for the experimental research works, most of the data have been measured during the application of load in service. However, not only the soil-nailed structure behavior in service but also the failure behavior of the structure are the major concerns to evaluate and even establish a design method of soil-nailed walls. In this study, a relatively large-scale experiment was carried out to figure out the failure behavior of soil-nailed wall. A number of data have been acquired and well compared with the results of numerical analysis.

1. INTRODUCTION

A number of successful applications of soil nailing techniques to support temporary or permanent earth retaining structures have been executed over the world.

The soil nailing analysis/design methods have been developed on the basis of experimental works as well as theoretical backgrounds. For the analysis and design of soil-nailed earth structures, the methods developed by Shen & Bang(1992), Schlosser(1992), Stocker(1990), Juran(1990), ect., have been used. Among those, Juran's method is based on the limit kinematical limit concept whereas the others are based on the limit equilibrium concept. Also, a new approach was suggested by Jewell(1992), in which the bending stiffness of nails is considered.

As for the experimental research works, most of the data have been measured during the application of load in service. However, not only the soil-nailed structure behavior in service but also the failure behavior of the structure are the major concerns to evaluate and even establish a design method of soil-nailed walls.

In this study, a relatively large-scale experiment was carried out to figure out the failure behavior of soil-nailed wall. A number of data such as, displacements of the wall, axial tensile strains generated in nails, soil pressures near the wall, etc., have been acquired. The measured data have been well compared with the results of numerical analysis.

2. A LARGE-SCALE MODEL

2.1 Outline of model

Fig.1 represents an outline of the experimental model.

The height of vertical wall is 2m and the wall retains a sand material which has the properties of $\gamma = 1.82 t/m^3$, $\phi = 39°$ and c=0. The grain-size-distribution of the sand used in the experiment is shown in Fig. 2. The sand deposit contains total 16 number of nails(4x4) which have lengths of 1.5m. The horizontal and vertical spaces of nails are 0.5m and the nails are inclined to 10° from the horizontal plane. A nail is composed of a steel bar and cement grouting surrounding the bar. The diameters of steel bar and nail hole are 0.01m and 0.06m, respectively.

The wall have been constructed by top-down sequence to simulate the actual construction process. In an actual case, a shotcrete is used to form the face of the reinforced earth retaining structure. However, thin wood boards, instead, were attached to the front side of the excavated soil layer in this experiment. Since the main function of shotcrete is to prevent the sand from spilling locally between nails, the wood boards would exert the function of shotcrete.

The behavior of soil-nailed wall during excavation was observed. After the completion of excavation, a uniform surcharge pressure was applied to the surface of retained soil and it caused the nailed wall to fail. The data obtained

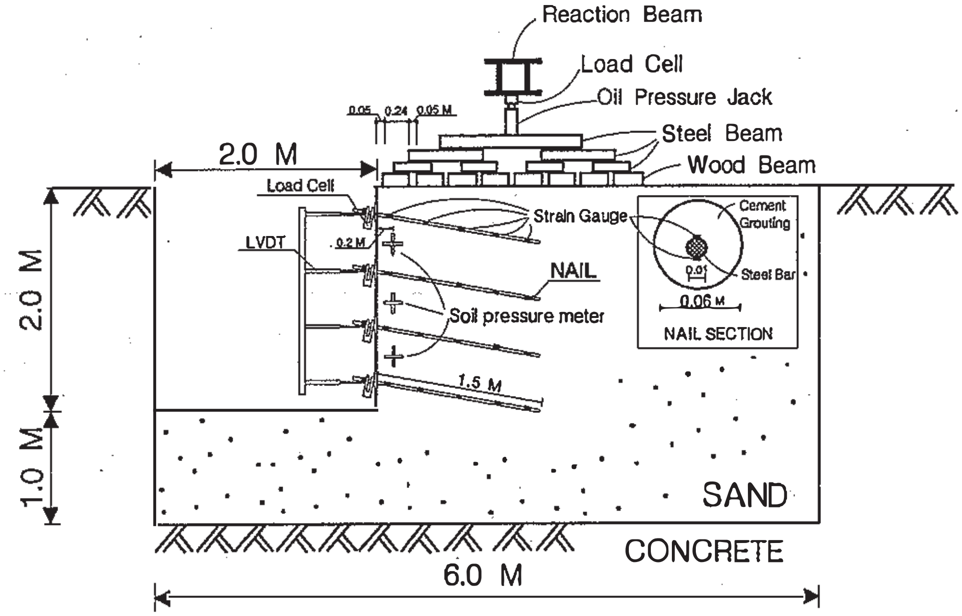


Fig.1 An outline of the experimental model

during the experiment were compared with the results obtained from the numerical analysis.

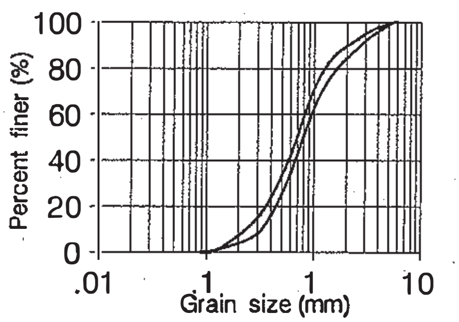


Fig.2 Grain-size-distribution of sand

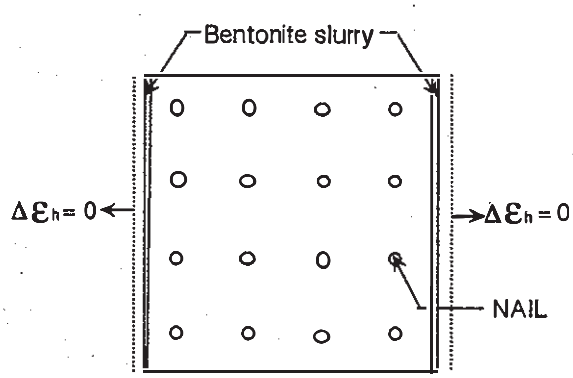


Fig.3 Boundary condition

2.2 Experimental devices

2.2.1 Large test chamber

A large test chamber(3m in height, 2m in width, and 6m in length) was used to make a uniform sand deposit. It also contained a large size reaction H-beam to bear the repulsive force upto 200tons. To minimize frictional resistance along the boundary of the chamber, a bentonite slurry was used. Due to the large stiffness of the chamber wall, it seems reasonable to consider that the horizotal displacement be restricted(Fig. 3)

2.2.2 Application of surcharge load

After finishing the excavation and setting the soil-nailed wall model, an equipment was

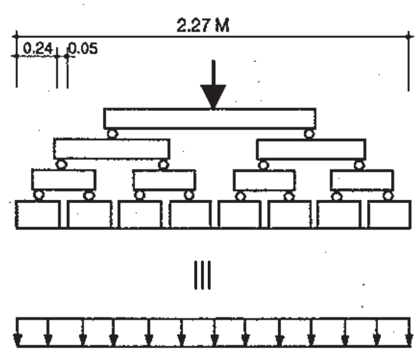


Fig.4 Loading equipment

provided to give a uniform surcharge pressure behind the wall up to which it causes a failure of the wall. The load applied by an oil pressure jack to the top block of the loading equipment which has a shape of pyramid(Fig.4) was sequentially transmitted to the last bottom layer of blocks which develops a uniform surcharge load to the surface of the retained soil deposit.

2.2.3 Measurements of data

Several instruments installed in the experimental model to measure data are as follow:

1. Soil pressure cells were buried at three spots near the wall to measure the variation of horizontal and vertical soil pressures induced during excavation and loading sequences.
2. Four LVDTs were installed at the face of the wall and three LVDTs at the top surface of soil to measure displacements.
3. A set of two strain gauges(at the top and bottom of nail at several locations) to measure tensile strains.
4. Load cells were installed between nail and wall face to measure the axial force acting at the wall face by the nails.

3. COMPARISON OF THE RESULTS

The data measured through the large-scale loading test simulating a soil-nailed structure were compared with the results calculated by FLAC program. The 10-tons intensive load was applied step by step by the oil pressure jack to the top of pyramid type loading equipment. The load was uniformly distributed to the surface of soil behind wall, producing a surcharge of 2.2t/m^2(Fig.4).

3.1 Wall deflections

The displacements along the face of wall and the surface of soil behind wall were plotted with the load increments in Fig.5 through Fig.7. As shown in Fig.5, the displacement profile along the wall abruptly increased during the load increment of 60 to 70 tons. It might be thought of that the load increment begin to develop significant plastic strains in the soil. The load increment of 100 to 108 tons caused the soil-nailed wall to fail.

3.2 Soil pressures

Fig.8 represents horizontal and vertical soil pressures at the three locations behind the wall.

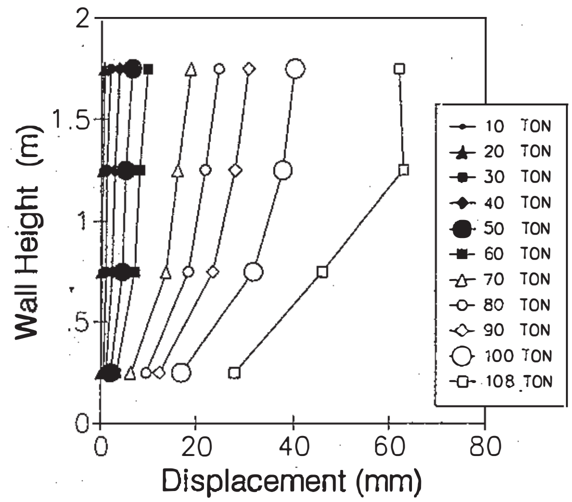


Fig.5 Horizontal displacements of the face

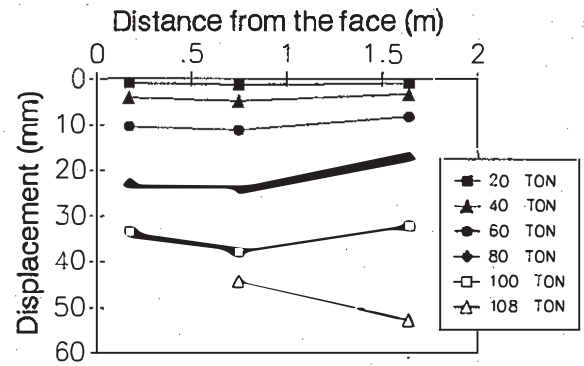


Fig.6 Vertical displacements of the upper surface

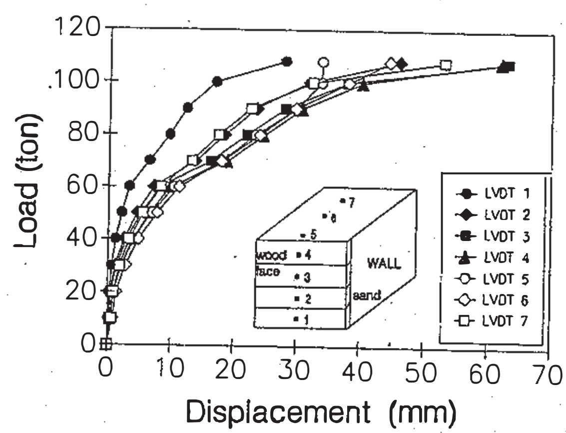
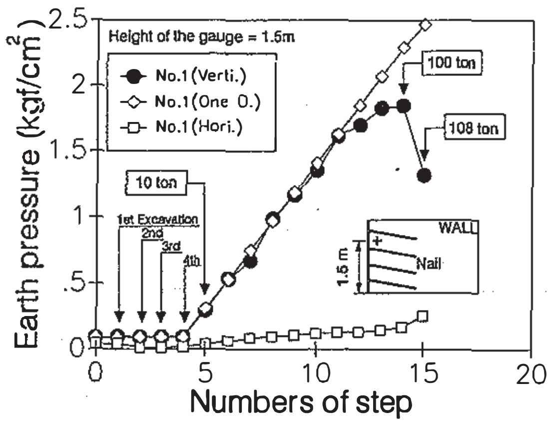
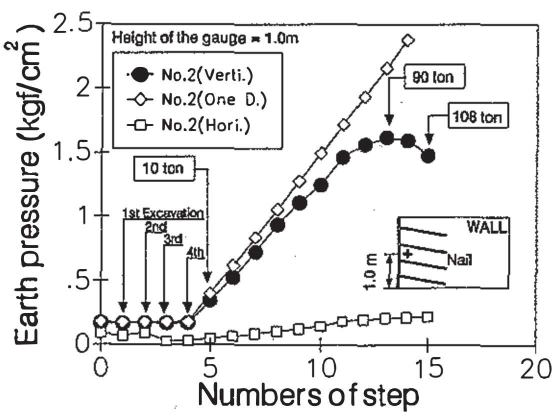


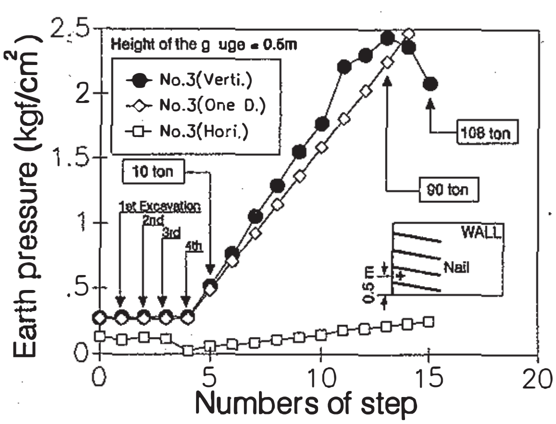
Fig.7 Displacements of the wall



(a) Locatoin of soil pressure meter
(H=1.5 m)



(b) Locatoin of soil pressure meter
(H=1.0 m)



(c) Locatoin of soil pressure meter
(H=0.5 m)

Fig.8 Soil pressures behind the wall

The horizontal pressures decreased by excavation and yet they increased gradually by the load increments. Due to the wall flexibility, the rate of increments is much smaller for the horizontal pressures than that for the vertical pressures.

The vertical soil pressure increments show good agreement with those calculated by one dimension pressure distribution theory and the excavation and horizontal of the wall have little influence on them. The plots turn down at the maximum point of about 90ton load intensity when the wall reached a limit failure state.

3.3 Axial forces and tensile strains of nails

Axial forces at the face of wall exerted by nails were plotted as loads increase. From Fig.9, the forces increased abruptly at the load application of 60 tons. This result is nearly coincidental with the result of wall displacement.

The tensile strains developed along the nails have been plotted in Fig.10. It also shows the points of maximum strains. After final stage of loading sequence, the failure states of each nail and soil layer were closely examined by carefully removing soils from the top of wall. Fig.11 represents the generated cracks in the soil layer. The failure surface of soil-nailed wall could be represented by bilinear or log-spiral lines.

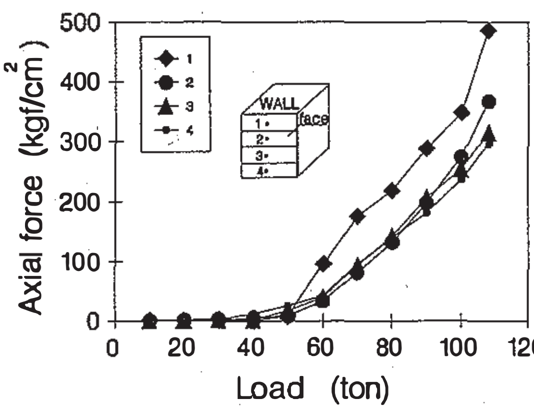


Fig.9 Axial force at the face of nails

4. CONCLUSIONS

In this study, a large scale model experiment was performed to figure out the behavior of soil-nailed wall upto failure. The measured behavior was well compared with the calculated by FLAC program. The results show that the wall displacement profile represents that a rotating type of wall face was changed from

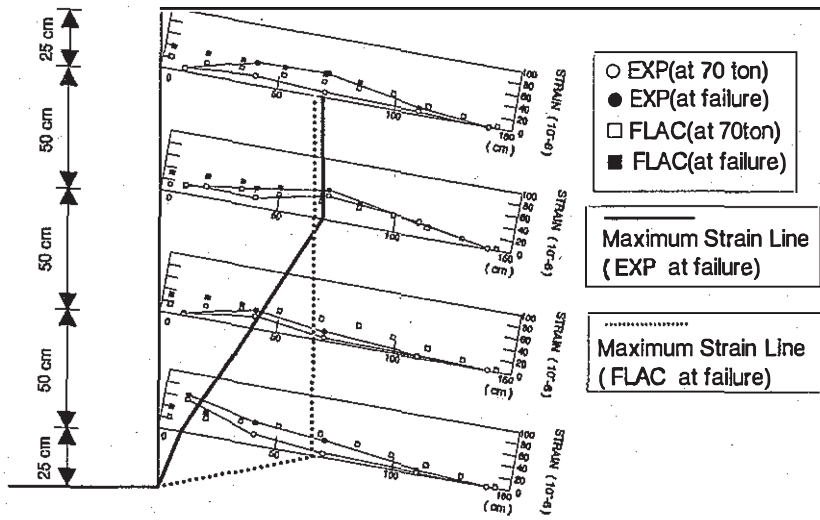


Fig.10 Axial strain of nails

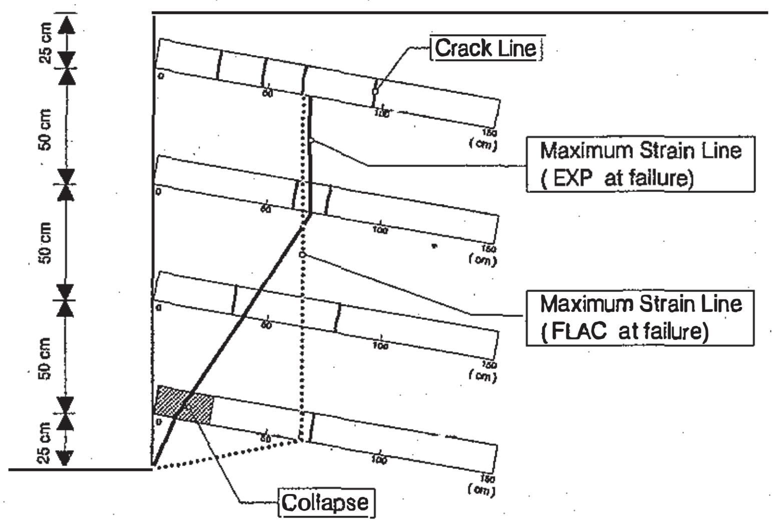


Fig.11 Crack lines of nails

linear to parabola by load increment, and progressive failure movement. The vertical soil pressure increments show good agreement with those calculated by one dimension pressure distribution theory and the excavation and horizontal of the wall have little influence on them. The failure surface of soil-nailed wall could be represented by bilinear or log-spiral lines.

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