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# 3-D analysis on deformation behavior of ground behind retaining wall in shaft excavation

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ABSTRACT: The deformation mechanism of the ground behind retaining walls in shaft excavations is discussed through three-dimensional numerical analyses. The deformation behavior of the ground behind retaining wall in a field test of shaft excavation is reproduced through an elasto-plastic three-dimensional finite element analysis. The applicability of numerical analysis is confirmed through comparison between analytical and measured results. From the analytical results, development of failure zone as well as deformation behavior for each excavation stage in the ground behind retaining wall is elucidated. Finally, deformation mechanism is discussed based on the relationship between deformation behavior and development of failure zone.

## 1 INTRODUCTION

In urban areas in the world, many kinds of infrastructures have been highly developed. In the case where excavation works are carried out in those areas, predicting the deformation behavior of ground due to excavation works and estimating the effect of ground deformation on the neighboring structures are most important.

By the way, in most of excavation works in urban areas, the shape of excavation areas is polygonal, so that the retaining walls are not infinitely long in comparison with their width and height. Deformation of ground behind retaining walls, therefore, does not occur in plane strain. A three-dimensional analysis is required in order to accurately simulate the deformation behavior of ground behind retaining walls in these excavations.

In this paper, a three dimensional analysis is carried out, in order to accurately simulate the deformation behavior of ground behind retaining walls in shaft excavations and to elucidate its deformation mechanism. Firstly, a field test of shaft excavation is presented. Secondly, the deformation behavior of ground behind retaining wall in the field test is reproduced through a numerical analysis, in which an elasto-plastic three-dimensional finite element method is applied. From the results of the analyses, development of failure zone as well as deformation behavior for each excavation stage in the ground behind retaining wall is elucidated. Finally, the deformation mechanism of ground behind retaining wall is discussed based on the relationship between deformation behavior and development of failure zone.

## 2 FIELD TEST OF SHAFT EXCAVATION

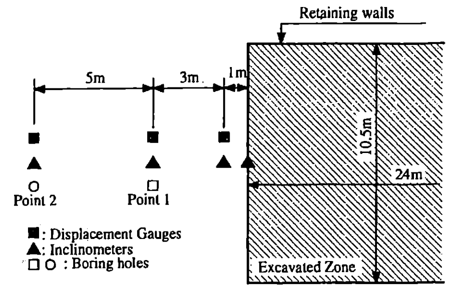
Figure 1 shows the outline of a field test of shaft excavation (Sakamoto et al, 1993). The field test was carried out at a reclaimed land in the Osaka Bay area. The excavated zone had a rectangular shape, 24 m×10.5 m in plane. The excavation work was carried out by three stages. The depth of excavation was 4.9 m at the final stage. Steel sheet piles were used as retaining walls, which were supported by two struts. Lateral and vertical displacements of the ground were measured by inclinometers and displacement gauges, respectively, as shown in Figure 1.

## 3 NUMERICAL SIMULATION

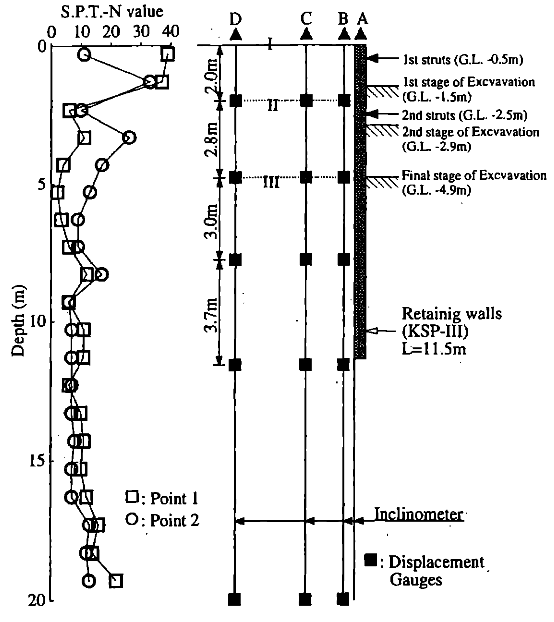
In the numerical simulation, a three-dimensional elasto-plastic finite element method is applied. Figure 2 shows the analytical area for numerical analysis. It has been already elucidated that the deformation behavior of ground behind one side of retaining walls in shaft excavations is not affected by deformation of the other side (Oda et al, 1999). The analytical area was determined from this fact, considering the symmetry of ground deformation.

The mechanical behavior of geomaterials are represented by an elasto-plastic constitutive model, which has yield function, (f), in Eq. (1) and plastic potential, (g), in Eq. (2).

$$f = q - \eta_f p' = 0 \qquad (1)$$



a) Plane



b) Side

Figure 1. Outline of a field test of shaft excavation

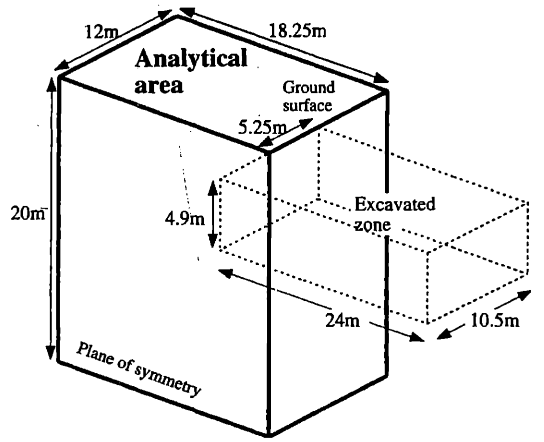


Figure 2. Analytical model

$$g = q - \eta_d p' \tag{2}$$

where p' and q are the mean and deviator stresses, and $\eta_f$ and $\eta_d$ are the stress ratio at failure and the dilatancy parameter, respectively. Also, the elastic modulus of the geomaterial is expressed by Eq. (3).

$$E = E_0 (p'/p'_0)^m \tag{3}$$

where E and m are the elastic modulus and the material parameter, respectively, and the subscript 0 denotes values at reference state. Table 1 shows parameters used in the numerical simulation.

Table 1. Parameters used in the numerical simulation

| Parameters | values |
|---|---|
| $\eta_f$ | 0.984 |
| $\eta_d$ | -0.169 |
| $E_0$ | 19.6Mpa |
| $p'_0$ | 29.4Mpa |
| m | 0.7 |

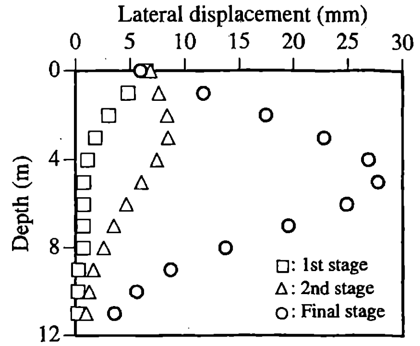


Figure 3. Distribution of lateral displacement of retaining wall

In the numerical simulation, the lateral displacements of retaining wall measured through the inclinometer-A in the field test is applied to the analytical model, in order to verify the deformation behavior of ground behind retaining walls. Figure 3 shows the measured distribution of lateral displacements of the retaining wall. The maximum value of lateral displacements at the final stage of excavations was 28.3 mm at the final excavation depth of 4.9 m.

## 4 VERIFICATION OF NUMERICAL ANALYSIS

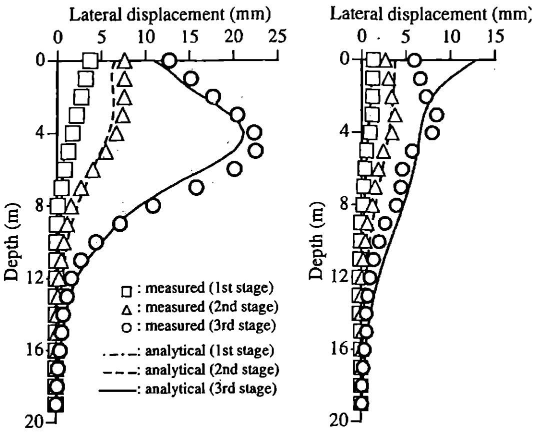
Figures 4 and 5 show comparison between measurements in the field test and analytical results of the numerical simulation. Their agreements are reasonably good in both distributions of lateral and vertical displacements at each excavation stage. Consequently, the numerical simulation can reproduce the deformation behavior of ground in the field test, followed by verifying the applied numerical simulation.

## 5 DEFORMATION MECHANISM

Figure 6 shows the development of both failure zone and distribution of lateral displacements at the plane of symmetry. The failure of soils was defined by Eq. (4)

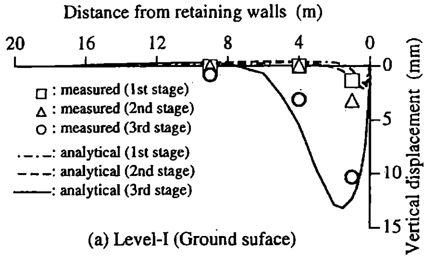
$$\eta/\eta_f \big|_{\text{at each element}} \geq 1.0 \tag{4}$$

where $\eta$ is the stress ratio. At the 1st stage of excavation, the failure of soils occurs close behind the retaining wall in a depth shallower than the excavation

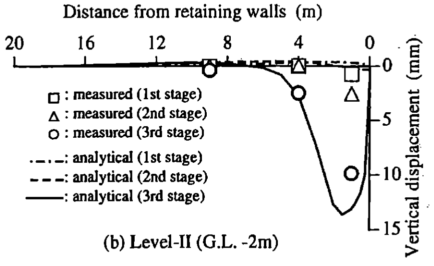


(a) Line-B (b) Line-C

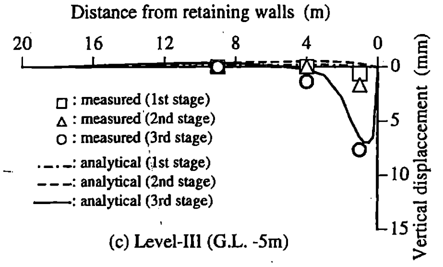
Figure 4. Comparison between measured and analytical lateral displacements of ground behind retaining walls



(a) Level-I (Ground suface)



(b) Level-II (G.L. -2m)

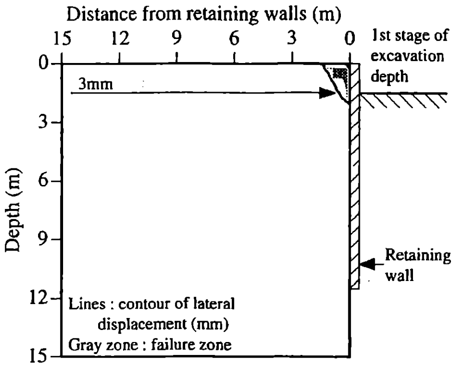


(c) Level-III (G.L. -5m)

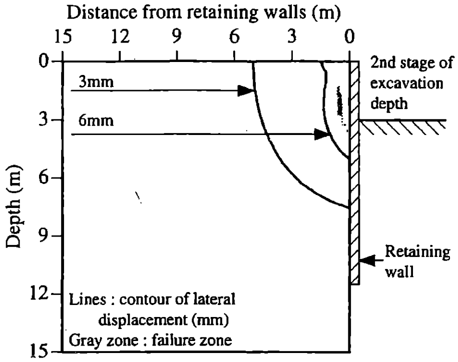
Figure 5. Comparison between measured and analytical vertical displacements of ground behind retaining walls

depth. At the 2nd stage of excavation, the failure zone shifts to a zone about 1m far from the retaining wall. Also, the shape of failure zone is transformed to a narrow band. At the final stage of excavation, the failure zone expands remarkably. Its shape becomes a wide band. It reaches the ground surface from the retaining walls at a depth deeper than the final excavation depth.

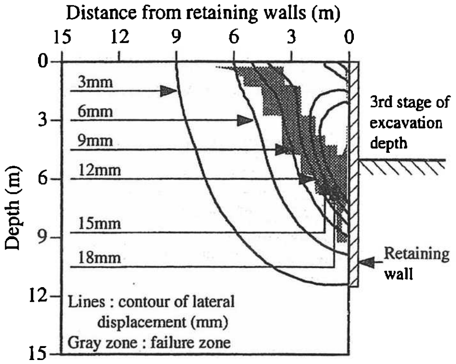
The lateral displacements increase as advancing the stage of excavation. Especially, they increase remarkably at the final stage of excavation. The zone in which the lateral displacements of over 9mm occur is almost enclosed by the failure zone at the final stage of excavation.



a) 1st stage of excavation



b) 2nd stage of excavation



c) 3rd stage of excavation

Figure 6. Development of both failure zone and distributions of lateral displacements at plane of symmetry

Figure 7 shows the distribution of lateral displacements and failure zone at the ground surface at the final stage of excavation. Both failure of soils and significant lateral displacements occur directly behind the retaining wall. Also, the zone in which the lateral displacements of over 9mm occur is enclosed by the failure zone.

Figure 8 shows the distribution of vertical displacements and failure zone at the plane of symmetry at the final stage of excavation. As shown in Figure 5, the significant vertical displacements in the ground do not occur at both 1st and 2nd stages of excavation. They occur only at the final stage of excavations. The zone in which the vertical displacements of over 3mm occur has the wedge-shaped. It is

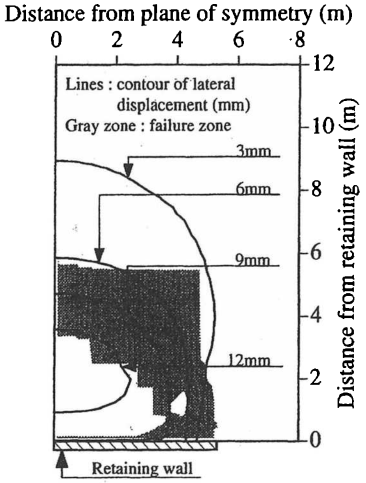


Figure 7. Distribution of lateral displacements and failure zone at ground surface at final stage of excavation

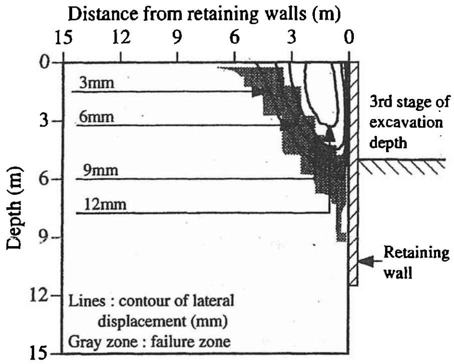


Figure 8. Distribution of vertical displacements and failure zone at plane of symmetry at final stage of excavation

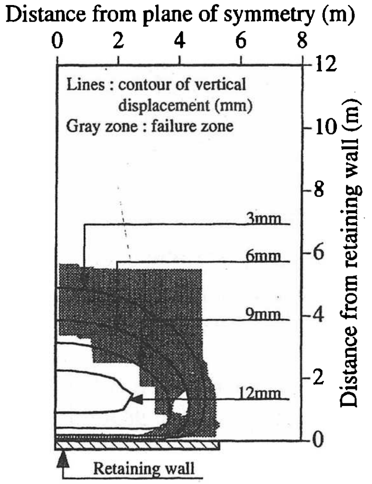


Figure 9. Distribution of vertical displacements and failure zone at ground surface at final stage of excavation

almost enclosed by the failure zone.

Figure 9 shows the distribution of vertical displacements and failure zone at the ground surface at the final stage of excavation. The significant vertical displacements occur just behind the retaining wall, as is the case for the lateral displacements. Also, the zone in which the vertical displacements of over 3mm occur is enclosed by the failure zone.

Summarizing the above-mentioned, the significant deformation, especially, vertical displacements occurs only at the final stage of excavation. Also, the band-shaped failure zone is formed. It reaches the ground surface from the retaining wall. The zone in which the significant deformation occurs is almost enclosed by the failure zone. It is suggested that the deformation behavior of ground is closely related with the failure of soils in the ground. That is, as the strength of soils at failure state is fully mobilized, the resisting function of soils to the sliding in the failure zone would deteriorate. Consequently, the sliding of soil mass enclosed by the failure zone occurs, so that the both lateral and vertical displacements of the enclosed zone increase.

By the way, the shape of failure zone in the ground behind retaining wall is similar to the pattern of slip lines based on the rigid perfectly plastic theory as shown in Figures 6(c) and 8. It is suggested that the zone in which significant deformation occurs could be predicted through application of the rigid perfectly plastic theory.

## 6 CONCLUDING REMARKS

In this paper, three-dimensional deformation behavior of ground behind retaining wall in the field test of shaft excavation was reproduced through a numerical simulation. The deformation mechanism is discussed based on the relationship between deformation behavior and development of failure zone. Main conclusions are summarized as follows:

1. Both failure of soils and significant deformation of the ground occur just behind the retaining wall.
2. The resisting function of soils to the sliding in the failure zone would deteriorate, so that the sliding of soil mass enclosed by the failure zone occurs.
3. The significant deformation, both lateral and vertical displacements, occurs in the zone enclosed by the failure zone.
4. It is suggested that the zone in which significant deformation occurs could be predicted through application of the rigid perfectly plastic theory based on the shape of failure zone.

## REFERENCE

Oda, K., Matsui, T. and Hatsuda, H., 1999, Effect of analytical area on deformation behavior of ground behind retaining walls in 3-dimensional numerical analyses, Proceedings of the Annual Conference of Civil Engineers 1999, Kansai Chapter of Japan Society of Civil Engineers: pp. III-64-1-III-64-2 (in Japanese).

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