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Prediction method of the displacement of surrounding ground during excavation

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ABSTRACT: Excavation works cause the displacement of surrounding ground and structures. This paper shows a method to predict of the displacement by using the Winkler model analysis method together with Finite Element Method (FEM). This method takes into consideration the nonlinearity of soil properties. In this paper, this method is applied to an excavation work. The result of comparison of analysis results and measured data shows that this method is effective for prediction of displacement of surrounding ground.

1 INTRODUCTION

Excavation works cause the displacement of surrounding ground and structures. This paper shows a method to predict of the displacement by using the Winkler model analysis method together with Finite Element Method (FEM).

By the general finite element method, it is difficult to predict the displacement of earth retaining walls during excavation compared with Winkler model analysis. This paper shows a method to predict the displacement of the surrounding ground by defining the results of Winkler analysis, prediction accuracy of the displacement is high, as boundary condition to the wall position of the Finite Element Method (FEM). This method is called "forced displacement method".

In forced displacement method, generally the soil properties are treated as linear elastic materials in FEM. This paper shows a method to treat the soil properties as non-linear materials in forced displacement method. The surrounding ground has non-linear properties that hardness changes depending on distortion.

This paper presents a case study applied forced displacement method to an excavation work near to a railroad. This case study compares the result of non-linear analysis with linear analysis.

2 GEOLOGICAL OUTLINE

Figure 1 shows geological outline and the section for analysis. From the surface of the ground to

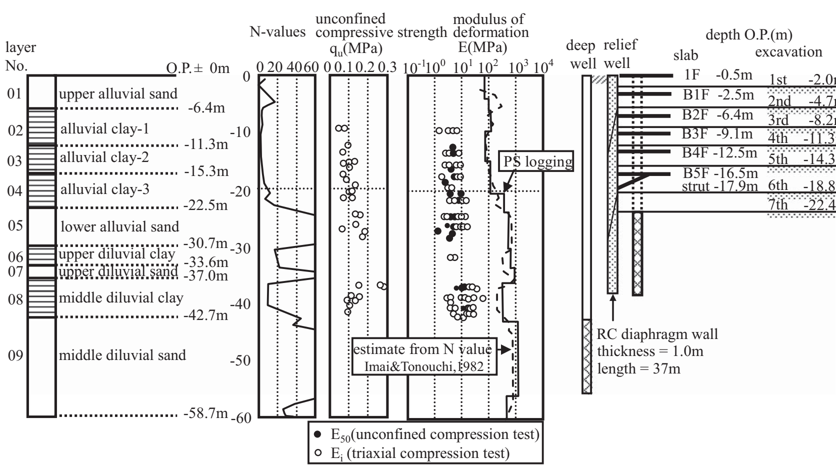


Figure 1. Geological outline and the section for analysis.

Table 1. Soil properties.

Layer no.	Soil	Bottom depth OP—m	γ_t kN/m^3	ν	V_s m/sec	E_{ps} kN/m^2	c kN/m^2	ϕ deg	k_h*B kN/m^2
01	Sand	6.4	16.7	0.33	130	76,000	0	20	2280
02	Clay	11.3	15.7	0.499	130	76,000	25	15	2280
03	Clay	15.3	15.7	0.499	150	101,000	37	15	3030
04	Clay	22.5	15.7	0.499	270	327,000	60	10	9810
05	Sand	30.7	18.6	0.33	320	518,000	0	45	15540
06	Clay	33.6	16.2	0.499	240	266,000	166	10	7980
07	Sand	37.0	18.6	0.33	320	518,000	0	40	518000
08	Clay	42.7	16.2	0.499	240	266,000	↑ for Winkler analysis		
09	Sand	58.7	19.6	0.33	460	1,126,000			

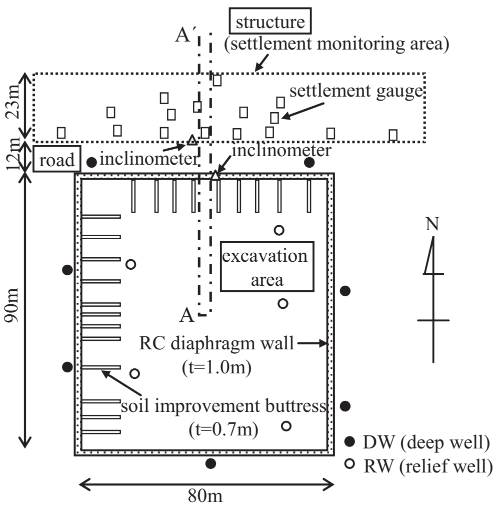


Figure 2. Plan of the excavation and measurement points.

about O.P. (Osaka pale) –22.5 m, alluvial soft clay accumulates, and the N-value is 0–1. Alluvial sand accumulates from O.P.–22.5 m to –30.7 m. Firm diluvial clay and sand underlie the alluvial sand.

Table 1 shows soil properties. Modulus of deformation,E_{ps}, of each layer is estimated form the results of PS logging carried out at a site nearby.

3 OUTLINE OF THE EXCAVATION WORK AND THE MEASUREMENT

3.1 *Excavation work*

Figure 2 shows the plan of the excavation area and measurement points. The plane size of the site is about 80 m × 90 m, and the excavation depth is 22.4 m.

The excavation method is inverted construction method. RC diaphragm walls of thickness 1.0 m is installed to O.P.–37.0 m as earth retaining walls (Fig. 1).

3.2 *Measurement*

There is a structure (a railroad viaduct) in the north side of the site (Fig. 2). Between the site and the structure, there is a road of 12 m in width.

Settlement of ground surface under the viaduct are measured with settlement gauges. Horizontal displacement of ground in the distance of 15.1 m from the earth retaining walls are measured with inclinometer.

4 OUTLINE OF FEM ANALYSIS

4.1 *FEM analysis model*

Figure 3 shows 2-Dimension FEM model. The displacement of the results of Winkler analysis are defined as boundary condition to the RC diaphragm wall position of the FEM model.

Only the ground of the back side of earth retaining walls is modeled and influence of load of building and removed soil in excavation area is ignored.

The analysis domain of the back ground is 96 m. This is equivalent to about 4 times of the excavation depth. The analysis domain of the depth direction is 90 m from the final excavation level. This is approximately equal to excavation width.

As for the boundary condition of the back end, the vertical direction is free, and the horizontal direction is fixed. As for the boundary condition of the bottom of the FEM model, the vertical direction and the horizontal direction are fixed. The load of the structure 77.4 kN/m^2 acts on the ranges from distance 12.0 m to 35.0 m from the earth retaining walls.

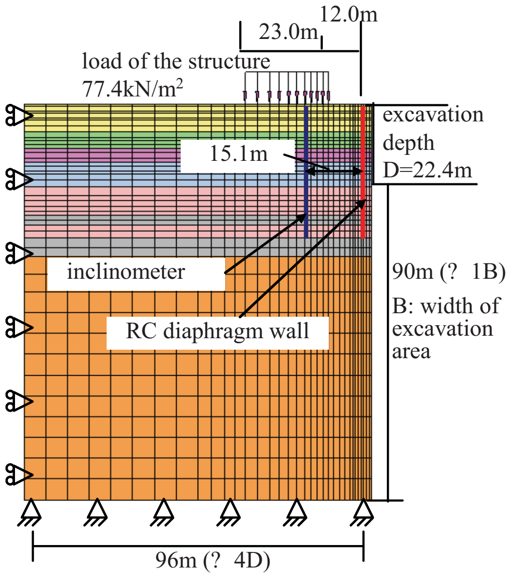


Figure 3. 2-dimension FEM model.

4.2 *Soil materials*

The soil is modeled as two-dimensional plane distortion element. The soil properties is set by two ways, one is treated as linear elasticity and the other is non-linear elasto-plastic body.

By the linear elastic analysis, modulus of deformation and Poisson's ratio are evaluated in E_{ps}, ν shown to Table 1 each.

In the non-linear analysis, modulus of deformation is estimated as shear modulus ratio concerning shear strain shown to Figure 4. In analysis, it is similar to multi-linear this curve. Initial modulus of deformation and Poisson's ratio of this case are evaluated in E_{ps}, ν shown to Table 1 each. Analysis errors occur so that modulus of deformation changes with the change of the distortion in the non-linear analysis. Each analysis step is divided into 100 smaller steps to reduce this analysis errors.

4.3 *Evaluation of load of the structure*

Load of the structure acted on the back side as shown in Figure 3. To confirm the influence of the difference in handling of the load, three cases of following analyses were carried out.

Linear case: Soil properties are linear. Structure load is not considered.
Non-linear case A: Soil properties are non-linear. Structure load is not considered.
Non-linear case B: Soil properties are non-linear. Stress distortion state by the load is considered.

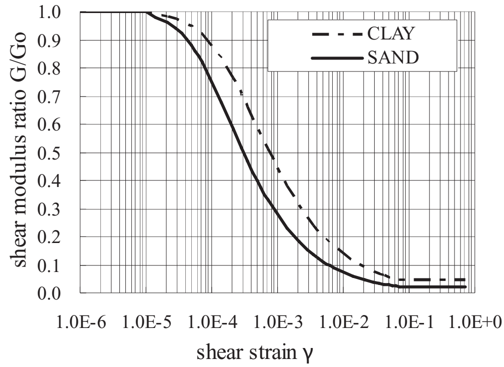


Figure 4. G/Go-γ curves of soil.

In non-linear case B, structure load acts in analysis step1, and modulus of deformation is reduced depending on the distortion of each soil element. Displacement of the soil is returned to beginning in analysis step 2. Modulus of deformation reduced in step1 is inherited on this occasion. The displacement of the results of Winkler analysis are defined as boundary condition to the RC diaphragm wall position of the FEM model in analysis step 3 (Fig. 5).

4.4 *Forced displacement*

Figure 6 shows forced displacement to the RC diaphragm wall position analyzed by Winkler method. Soil properties for Winkler method are in Table 1 and lateral earth pressure are shown in Figure 6.

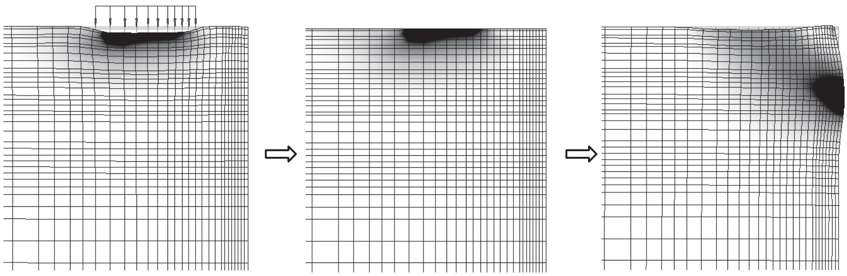
Measured displacement of the RC diaphragm walls by inclinometer are shown in Figure 7. The analysis value almost accords with measurement value except displacement of the top of the wall from 5th to 7th excavation. The maximum displacement of 7th excavation is about 30 mm. It occurs at depth form O.P.–14 m to –15 m.

5 FEM ANALYSIS RESULTS

5.1 *FEM analysis results*

Figure 8 shows examples of the FEM analysis results. This figure shows the composition of the displacement of vertical direction and horizontal direction of final excavation step (7th excavation). The maximum of ground displacement in the linear and non-linear case A analysis appears close to the wall and the displacement becomes smaller as to leave from the wall.

In non-linear case B, because of the surcharge, displacement of viaduct area is large. This analysis



step1: Structure load acts and modulus of deformation is reduced depending on the distortion of each soil element.

step2: Displacement of the soil is returned to beginning. Modulus of deformation reduced in step1 is inherited on this occasion.

step3: The displacement of the results of Winkler analysis are defined as boundary condition to the RC diaphragm wall position.

Figure 5. Analysis step of non-linear case B.

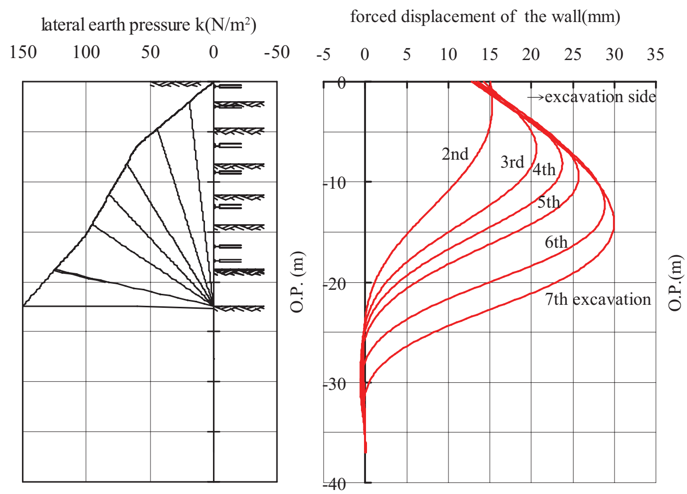


Figure 6. Forced displacement analyzed by Winkler method.

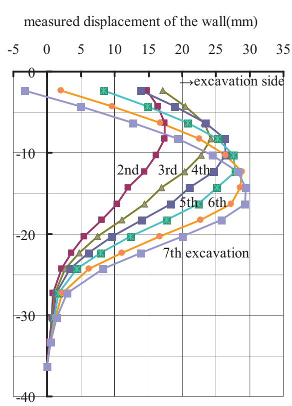


Figure 7. Measured displacement of the wall.

result shows the influence of the hardness reduction that occurred by analysis step 1. The conventional forced displacement method cannot consider the influence of such local ground hardness reduction, because the method treats the ground as linear.

5.2 *Vertical displacement of ground surface*

Figures 9–11 show the vertical displacement of ground surface in FEM analyses with measured data. Results of step 2, 4, 7 are shown as representative.

The analysis results of settlement of linear and non-linear case A which do not consider influence of load of the structure show the peak at a position from about 5 m to 10 m from the wall and it gets smaller gently depending on the distance

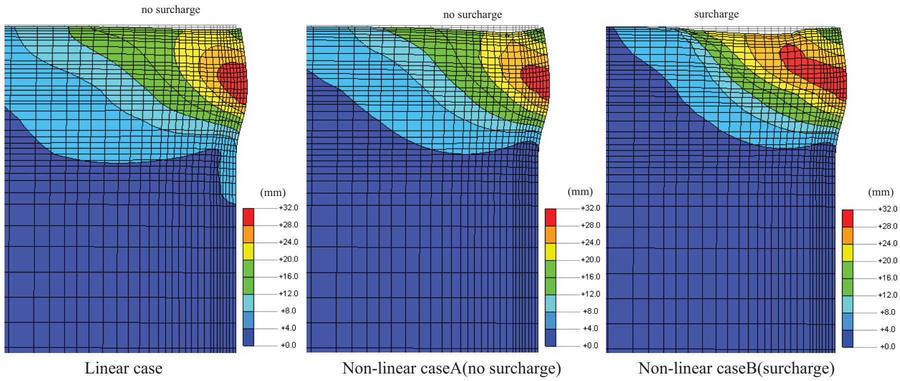


Figure 8. Composition of the displacement of vertical and horizontal direction of FEM analysis.

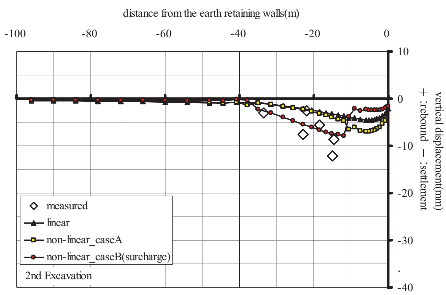


Figure 9. Vertical displacement of ground surface.

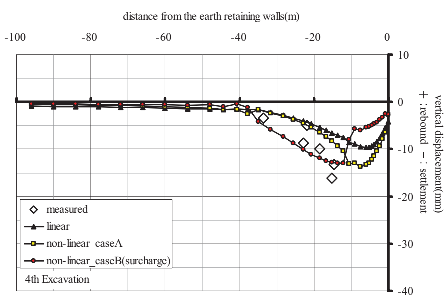


Figure 10. vertical displacement of ground surface

Figure 10. Vertical displacement of ground surface.

from the wall. On the other hand, according to the measurement data, the large settlement occurs under the viaduct. Although the difference of the local maximum is large, the analysis result of non-linear case B shows the tendency of the measurement data.

This result shows that this method is effective as prediction technique of settlement of the surrounding ground.

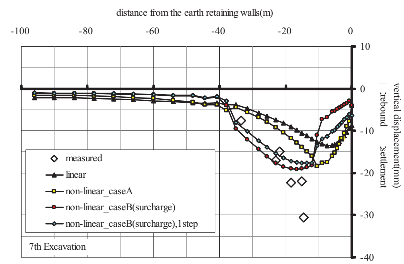


Figure 11. Vertical displacement of ground surface.

5.3 *Horizontal displacement of ground*

Figures 12–14 show the horizontal displacement of ground at the position that was 15.1 m away from earth retaining walls in FEM analyses with measured data. Results of step 2, 4, 7 are shown as representative.

The measurement data of the horizontal displacement of the ground 15.1 m away from the wall shows the maximum at depth from O.P.–6 m to –10 m. Analysis results of non-linear case B accord with this tendency best. In addition, the analysis result of non-linear case A is small in comparison with it of linear. This relation is reverse in the case of settlement of ground surface.

The ratios with the measurement data of the maximum of analysis results through all steps are 69–90% in linear, 63–78% in non-linear case A, and 90–116% in non-linear case B. This result shows that this method is effective as prediction technique of horizontal displacement of the ground.

5.4 *Influence on analysis result by excavation process*

Figures 11 and 14 show the results that defined forced displacement as boundary condition of FEM of the last (7th) excavation by one step in

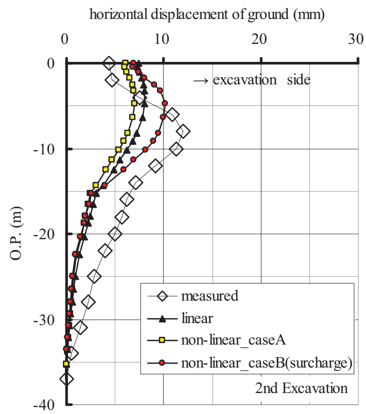


Figure 12. Horizontal displacement of ground.

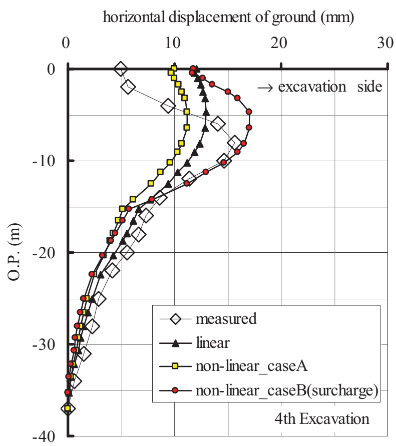


Figure 13. Horizontal displacement of ground.

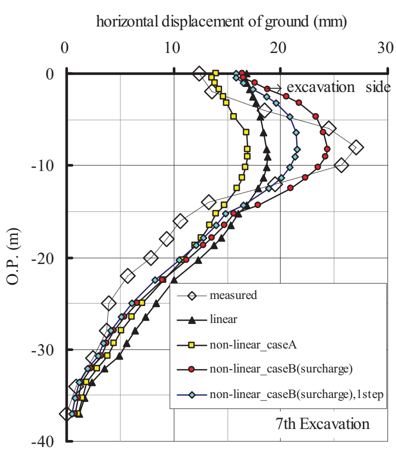


Figure 14. Horizontal displacement of ground.

defiance of the excavation process. The purpose of this examination is to confirm the influence of excavation process for analysis result.

The settlement and the horizontal displacement of the ground show the distribution that resembled the analysis result that considered the excavation process, but these maximums are about 10% smaller than them. This result suggests that prediction precision improves by considering excavation process.

6 CONCLUSIONS

This paper showed a method to predict of the displacement by using the Winkler model analysis method together with FEM. This method is called "forced displacement method".

In forced displacement method, generally the soil properties are treated as linear elastic materials in FEM. This paper presented a method to treat the soil properties as non-linear materials in forced displacement method and results of case study applied this method to an excavation work near viaduct of railroad.

According to the measurement data, the large settlement occurred under the viaduct. Although the difference of the local maximum was large, the analysis result of non-linear case B (stress distortion state by the load is considered) showed the tendency of the measurement data.

The measurement data of the horizontal displacement of the ground 15.1 m away from the wall showed the maximum at depth from O.P.–6 m to –10 m. Analysis results of non-linear case B accorded with this tendency best.

The result of comparison of analysis results and measured data showed that this non-linear method is effective for prediction of displacement of surrounding ground. In addition, prediction precision improves by considering excavation process.

On the other hand, a prediction by this analysis is difficult when large ground displacement occurs locally. This is the part needing the improvement of this method of analysis.

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