Research on Application of FEM Analysis to Braced Excavation

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Abstract: It is becoming possible to do detailed numerical analyses for the various mechanical behavior of braced excavation by researching and developing the numerical analysis technique such as the finite element method (FEM). However, the mechanical behavior of braced excavation has not been clarified fully both in theory and in experience. Therefore, improving the prediction accuracy during the prior design is very important for making the observational method of braced excavation more effective. In this paper, FEM analyses were performed for a model of braced excavation by using Geotechnical Finite element Elastoplastic Analysis Software GeoFEAS(2D). As the constitutive law of ground, MC-DP model and Duncan-Chang model were applied. The results were compared and discussed with that of a site measurement, and the effects of the constitutive law of ground on the analyzed result were verified. For the difference between the results, the reason was investigated by the analyses adjusting the elastic modulus of ground, and the appropriate application of the constitutive law was researched.

Keywords: numerical analysis, retaining wall, FEM, constitutive law

1 Introduction

In recent years, It is becoming possible to do detailed numerical analyses for the various mechanical behavior of braced excavation by researching and developing the numerical analysis technique such as the finite element method (FEM). The observational method connecting mechanical behavior measured in the process of construction is becoming an effective design and construction technique.

However, it must be paid attentions when applying the observational method that the mechanical behavior of braced excavation has not been clarified fully both in theory and in experience and the prediction accuracy during the prior design is not quite enough.

Therefore, improving the prediction accuracy during the prior design is very important for making the observational method of braced excavation more effective. In this research, in order to improve the prediction accuracy during the prior design, FEM analyses were performed and the results were compared and discussed with the result of a site measurement.

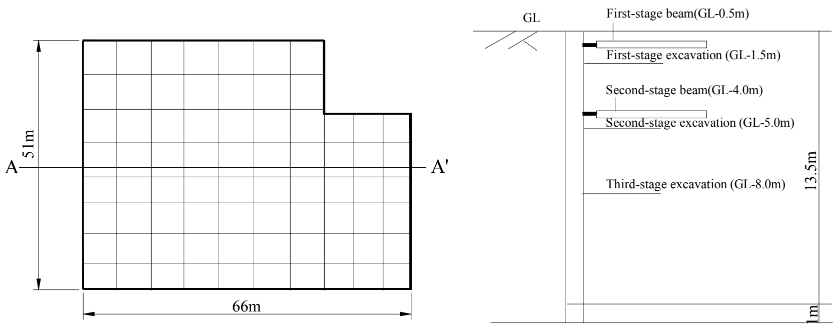
2 Outline of Braced excavation Case

The plan view and cross-sectional view[1] are shown in Figure 1. The horizontal range of excavation is 66×51(m) and the depth of final excavation is 8m.

3 Outline of FEM Analysis

For the A-A' section shown in Figure 1 (a), the simulation analyses were performed by plane strain FEM utilizing Geotechnical Finite element Elastoplastic Analysis Software GeoFEAS(2D) [2]. The finite element meshes are shown in Figure 2. Due to symmetry, the half of configuration section was modeled and the width and back range were assumed to 30m and 117m respectively. The retaining wall and the strut were modeled by beam elements.

As boundary conditions, the lateral surface was fixed in the horizontal direction and was treated as roller contact in the vertical direction. The bottom surface was fixed in both horizontal and vertical direction. The analysis was divided into five processes as listed in Table 1. The finish time of each process is also listed in Table 1. The MC-DP model and Duncan-Chang model were applied. For all the cases, the total stress analyses were performed.



(a) Plan view (b) Cross-sectional view

Fig. 1 Configurations of braced excavation

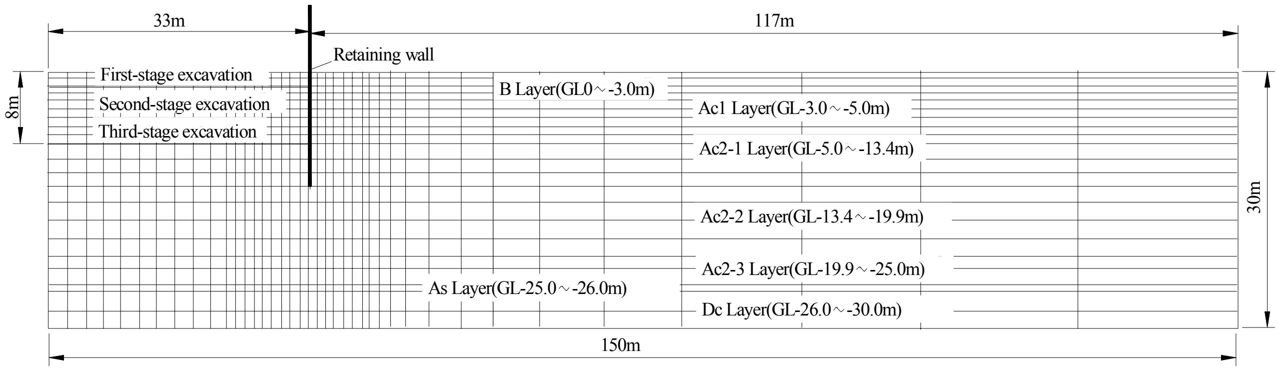


Fig. 2 Finite element meshes

Table 1 Analysis process

No.	Analysis process	Finish time
1	First-stage excavation	12th day
2	Preloading first-stage strut	13th day
3	Second-stage excavation	35th day
4	Preloading second-stage strut	36th day
5	Third-stage excavation	55th day

3.1 MC-DP model

For MC-DP model, Mohr-Coulomb equation is used to yield criterion and Drucker-Prager equation is used to plastic potential. Soil is considered as frictional materials and the failure is induced primarily by shear deformation.

In this paper, MC-DP model was first applied and the material parameters are given in Table 2. The analyses with dilatancy angle of $\psi = \phi$ and $\psi = 0$ were performed. Then, in order to make the analyzed results approach to the measured results in each excavation stage, the elastic modulus of ground were adjusted and the analyses were performed.

3.2 Duncan-Chang model

In Duncan-Chang Model[3], the relationship between principal stress and tangential elastic modulus is defined as Equation 1 and 2, in which the stress-strain relationship modeled by hyperbola and the effect of confining pressure on the change of rigidity are considered.

$$E_i = K \cdot P_a \left(\frac{\sigma_3}{P_a} \right)^n \tag{1}$$

$$E_t = \left\{ 1 - \frac{R_f (1 - \sin\phi)(\sigma_1 - \sigma_3)}{2c \cdot \cos\phi + 2\sigma_3 \sin\phi} \right\} \cdot E_i \tag{2}$$

where, E_i is initial elastic modulus; E_t is tangential elastic modulus; P_a is atmospheric pressure; c is cohesion coefficient; ϕ is friction angle; σ_1 and σ_3 are maximum and minimum principal stress; K and n are experimentally determined constants;

R_f is failure ratio. The material parameters are given in Table 3.

Table 2 Material parameters of ground(MC-DP model)

Layers	Depth (m)	Unit weight γ (kN/m^3)	Poisson's ratio ν	Elastic modulus E (MPa)	Cohesion c (kPa)	Friction angle ϕ (°)	Dilatancy angle ψ(°)	
							$\psi=\phi$	$\psi=0$
Filling soil	0.0～3.0	15.0	0.33	16.8	0	25	25	0
Silt(Ac1)	3.0～5.0	15.7	0.45	3.8	16	9.9	9.9	0
Silt(Ac2-1)	50～13.4	14.5	0.45	7.7	32	0	0	0
Silt(Ac2-2)	13.4～19.9	14.0	0.45	11.1	49	9.8	9.8	0
Silt(Ac2-3)	19.9～25.0	14.7	0.45	15.4	72	1.2	1.2	0
Fine sand(As)	25.0～26.0	18.0	0.33	56.0	0	35	35	0
Mud stone(Dc)	26.0～30.0	19.5	0.45	388.5	185	0	0	0

Table 3 Material parameters of ground(Duncan-Chang model)

Layers	Depth (m)	Unit weight γ (kN/m^3)	Poisson's ratio ν	K	R_f	n	Cohesion c (kPa)	Friction angle ϕ (°)
Filling soil	0.0～3.0	15.0	0.33	7520	1.0	0.5	0	25
Silt(Ac1)	3.0～5.0	15.7	0.45	934	1.0	0.5	16	9.9
Silt(Ac2-1)	50～13.4	14.5	0.45	211	1.0	1.0	32	0
Silt(Ac2-2)	13.4～19.9	14.0	0.45	120	1.0	1.0	49	9.8
Silt(Ac2-3)	19.9～25.0	14.7	0.45	290	1.0	1.0	72	1.2
Fine sand(As)	25.0～26.0	18.0	0.33	1716	1.0	0.5	0	35
Mud stone(Dc)	26.0～30.0	19.5	0.45	10646	1.0	0.5	185	0

4. Analysis Result and Discussion

4.1 Displacement of retaining wall

(1)MC-DP model

Figure 3 shows the displacements of retaining wall with MC-DP model for each excavation stage. For the results before adjusting the elastic modulus of ground, the deformation shapes of all excavation stages are consistent in general. The analyzed results with $\psi=\phi$ and $\psi=0$ are almost identical. The difference between the measured and analyzed maximum displacements is 11mm for the first-stage excavation, 15mm for the second-stage excavation and 5mm for the third-stage excavation. For each excavation stage, the analyzed values are greater than measured value. For the results after adjusting the elastic modulus of ground, the ratio of the adjusted elastic modulus to the original elastic modulus for the layer with maximum displacement is 1.84 for the first-stage excavation, 1.26 for the second-stage excavation and 1.01 for the third-stage excavation.

(2)Duncan-Chang model

Figure 4 shows the displacements of retaining wall with Duncan-Chang model for each excavation stage. The deformation shapes of all excavation stages are consistent in general and the analyzed values agree with the measured values. The differences between the measured and analyzed maximum displacement are -1mm, -3mm and -8mm respectively for the three excavation stages and the analyzed values are smaller than the measured value for each excavation stage. For this case, it can be said that Duncan-Change model is appropriate.

4.2 Variation of displacement of retaining wall

(1)MC-DP model

For MC-DP model, the analyzed and measured displacements of retaining wall at the point with 5m and 10m depths (GL-5.0m and GL-10.0m) are shown in Figure 5. It can be seen that there is a difference between the measured and analyzed value for both before and after adjusting the elastic modulus of ground. The analyzed results with $\psi=\phi$ and $\psi=0$ are almost identical. As the results of displacement of retaining wall, the analyzed values before the adjustment have a large difference from the measured values. The analyzed values after the adjustment became close to the measured values, but the value with GL-5.0m for the third-stage excavation is large relatively.

(2)Duncan-Chang model

For Duncan-Chang model, the results are shown in

Figure 6. There are differences between the calculated and measured value but they are in range of small error. The value with GL-5.0m for the third-stage excavation is large relatively.

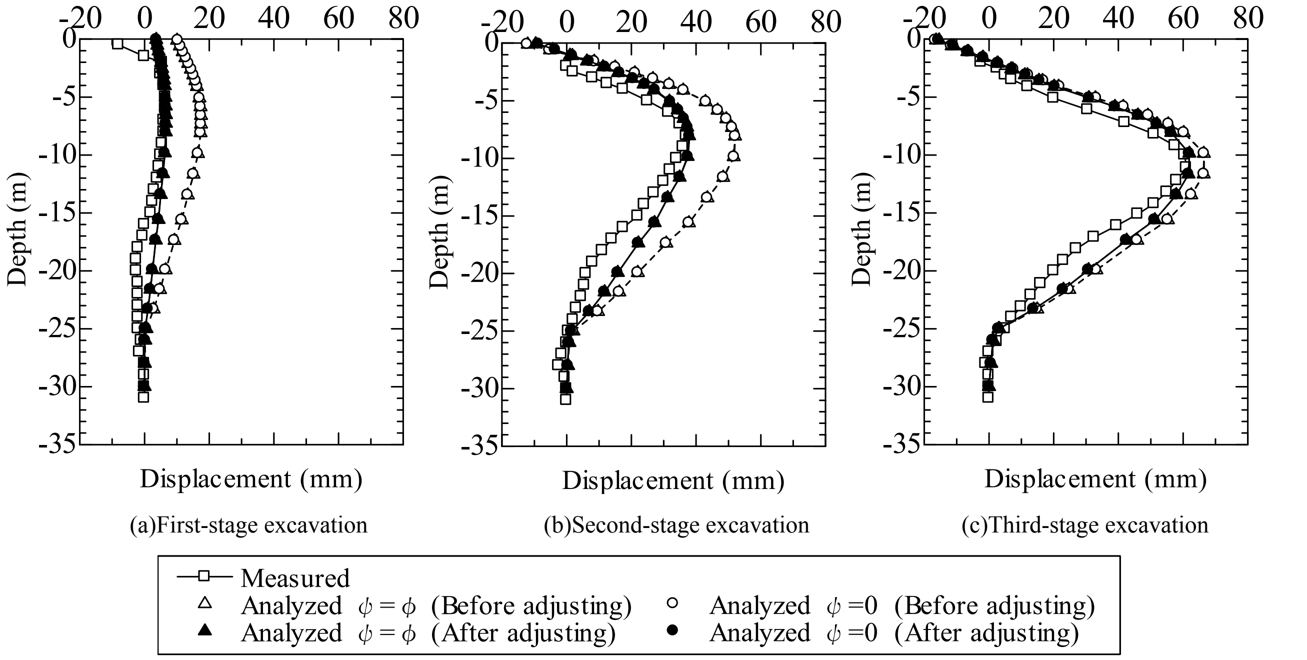


Fig. 3 Displacement of retaining wall (MC-DP model)

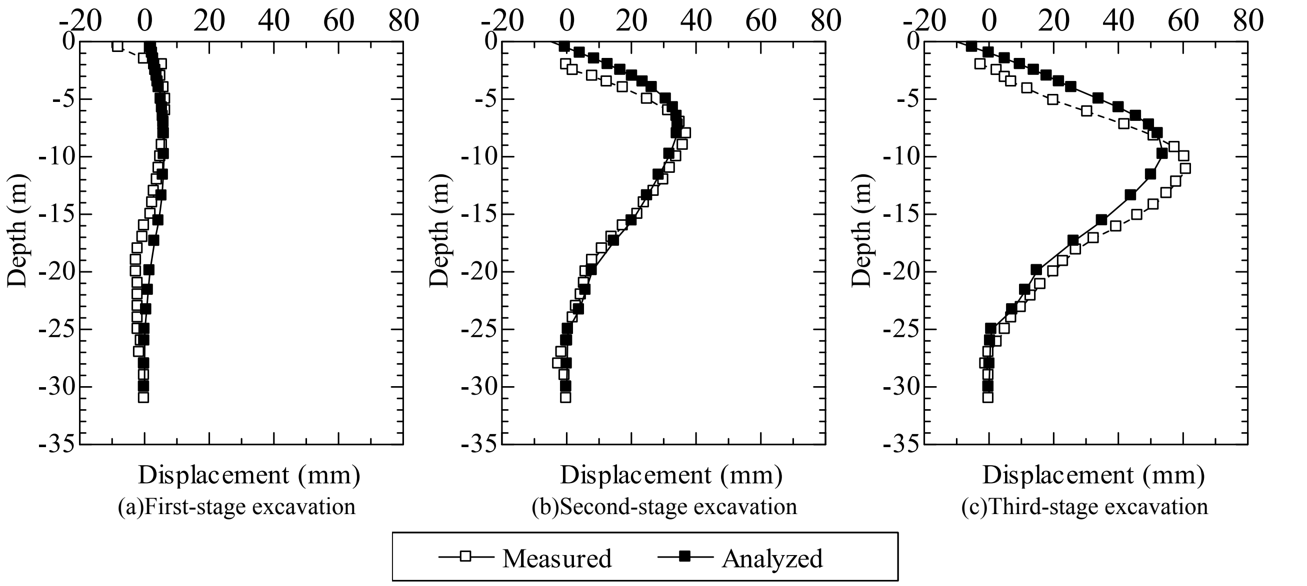


Fig. 4 Displacement of retaining wall (Duncan-Chang model)

4.3 Axial force of strut

(1)MC-DP model

The axial forces of first-stage and second-stage strut analyzed by MC-DP model are shown in Figure 7. For both two figures, the tendencies of variation of the analyzed and measured axial forces are consistent in general and the analyzed values agree with the measured value. The analyzed results with $\psi = \phi$ and $\psi = 0$ are almost identical.

The analyzed values before and after adjusting the elastic modulus of ground are consistent in general. Differing from this result, the displacement of retaining wall creates a large difference when adjusting the elastic modulus of ground as shown in Figure 5. It can be considered that the axial force is created when the strut is preloaded and varies with the variation of displacement of retaining wall. As shown in Figure 7, the analyzed axial forces induced by preloading before and after adjusting the elastic modulus of ground are almost identical. It can be found from Figure 5 that the displacements of retaining wall before and after

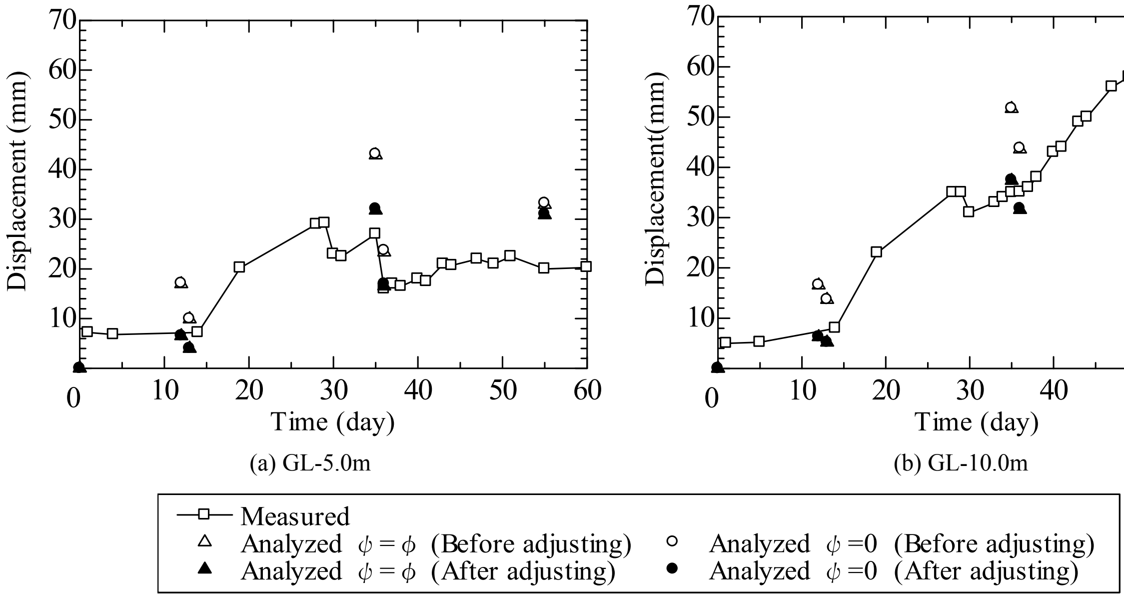


Fig. 5 Variation of displacement of retaining wall (MC-DP model)

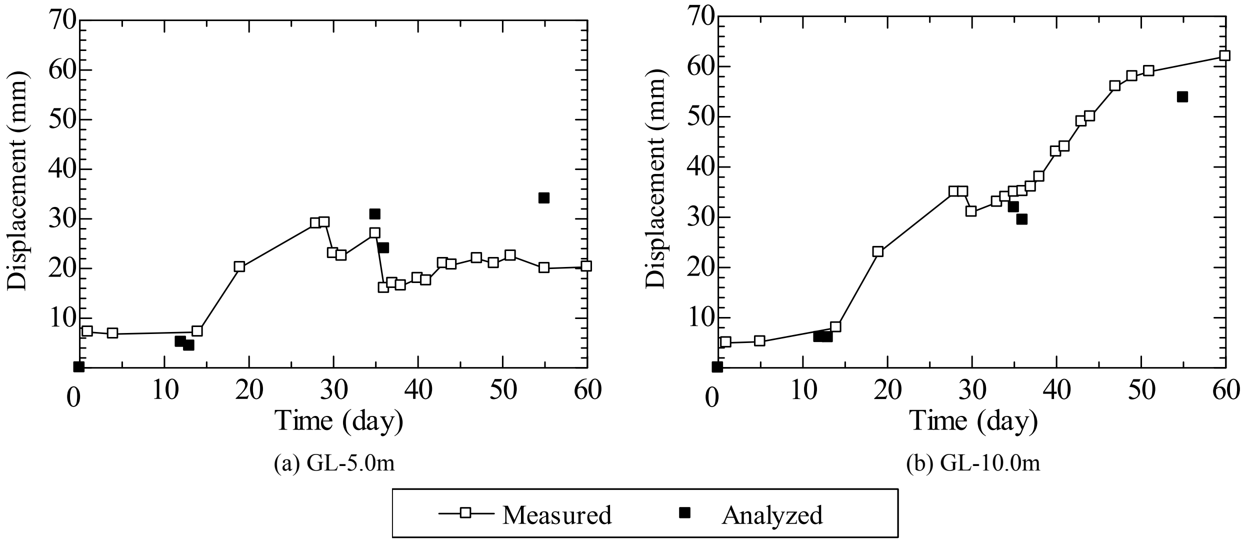


Fig. 6 Variation of displacement of retaining wall (Duncan-Chang model)

adjusting the elastic modulus of ground have a large difference, but the tendencies of variation are consistent in general. That is, the amounts of variation of displacements are close. Therefore, the analyzed axial forces before and after adjusting the elastic modulus of ground are consistent in general.

(2)Duncan-Chang model

The axial forces of first-stage and second-stage strut analyzed by Duncan-Chang model are shown in Figure 8. For both two figures, the tendencies of variation of the analyzed and measured axial forces are consistent in general and the analyzed values agree with the measured values.

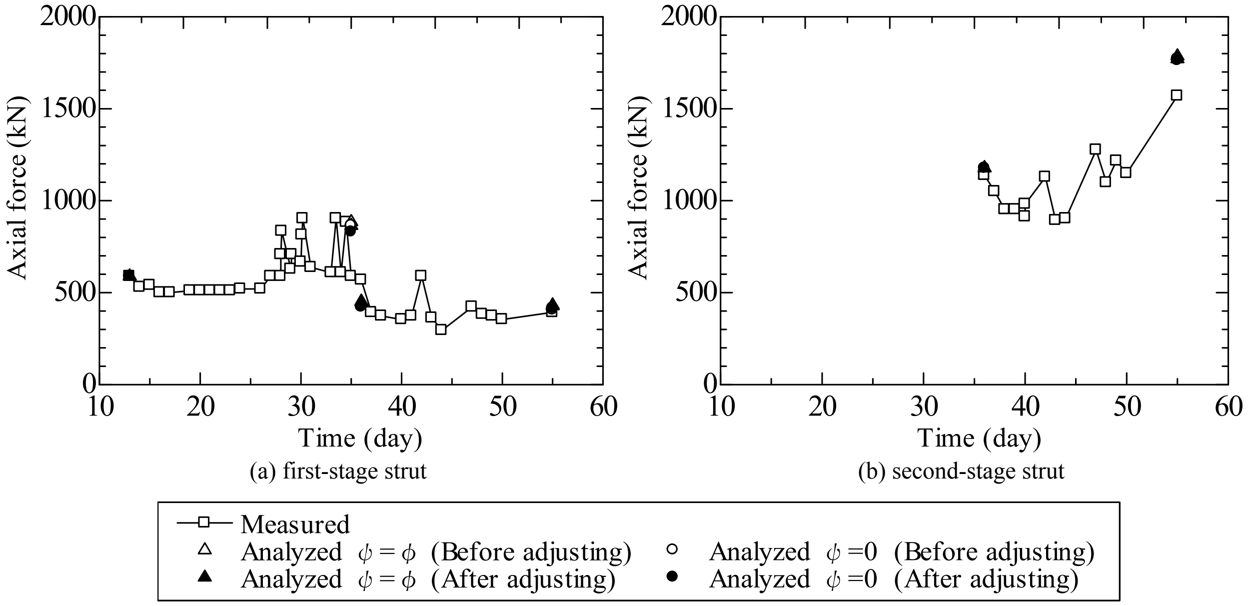
5. Conclusions

In this paper, FEM analyses in which MC-DP model and Duncan-Chang model were applied respectively were performed and the results were compared and discussed with that of a site measurement. The main conclusions are as follows.

1) For MC-DP model, the analyzed displacements of retaining wall can be approach to the measured that by

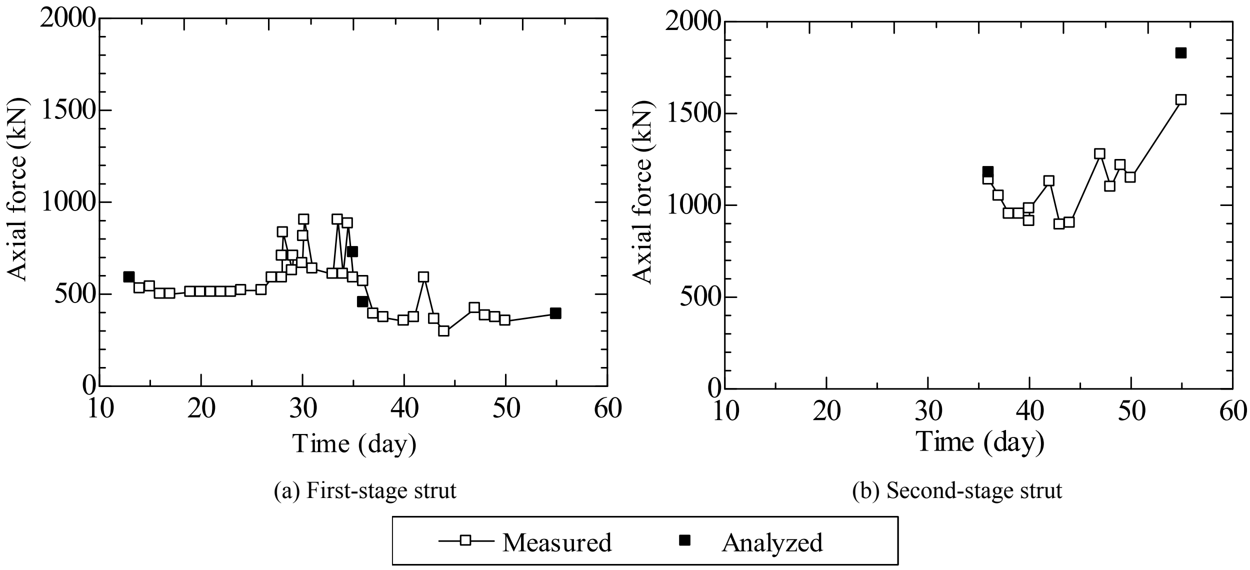
adjusting the elastic modulus of ground.

2) In the analyses, for MC-DP model, adjusting the elastic modulus of ground has a little effect on the axial force of strut.



(a) first-stage strut (b) second-stage strut

Fig. 7 Axial force of strut (MC-DP model)



(a) First-stage strut (b) Second-stage strut

Fig. 8 Axial force of strut (Duncan-Chang model)

3) For Duncan-Chang model, the analyzed values agree with the measured values. The possibility of the application of Duncan-Chang model that can consider the nonlinearity was confirmed.

In future, various case studies will be conducted and the determination method of materials parameters will be discussed. On the basis of this, the design of braced excavation by FEM analysis including the examination for the effect on the surrounding ground will be conducted.

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