A simple evaluation method of adjacent ground settlement due to excavation work

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ABSTRACT: The prediction of back-fill settlement due to the excavation work is getting important, particularly in the urban area. The finite element simulation would be a suitable choice to answer it. However, it is less feasible in practice to carry it out because input parameters needed in the F.E. simulation are not sufficiently provided in advance at the stage of design work. In the past, some simple evaluation methods for predicting the back-fill settlement due to excavation works were presented by Peck, Long and Moormann et al. and so on. In this paper, a new method capable for predicting the back-fill settlement at the stage of design work is proposed, taking account of design parameters, i.e. soil parameters, retaining wall parameters and construction sequences. The proposed method is built up based on a lot of monitored records obtained from sites and the numerical results obtained from a series of F.E. simulations for imaginary excavation works. It is designed to be simple and useful at the stage of design work. This method consists of two parts, predictions of the maximum amount of back-fill settlement and the distance from the retaining wall. Finally, some case studies in which the proposed new method was applied to actual excavation sites in Japan are presented.

1 INTRODUCTION

In addition to the safety of retaining walls and bottom ground into excavation area, influences on adjacent structures and a ground are very important subjects for excavation works. In urban area, since there exist many structures and lifelines buried in the underground, the excavation work in the urban area often undergoes severe restrictions. Therefore, particularly in the urban area, it is necessary to predict accurate movement of adjacent ground and structures associated with the excavation work.

This paper describes a new method capable for predicting the back-fill settlement at the stage of design work, taking account of design parameters, i.e. soil parameters, retaining wall parameters and construction sequences.

2 STUDY FLOW

The new method proposed here was built based on many F.E. simulations and monitored records, as explained by a flow in Figure 1. Firstly, we tried to extract a major influential factor on the ground settlement from F.E. simulation results. Then, a new prediction method was constructed based on the major factor extracted so as to explain monitored records. Herein, care is taken in arranging the proposed method so as to be simple. The prediction method proposed has been characterized as follows.

(1) It is a diagram type.
(2) Parameters employed in the method are easily determinable and do not need extra samplings and laboratory tests.

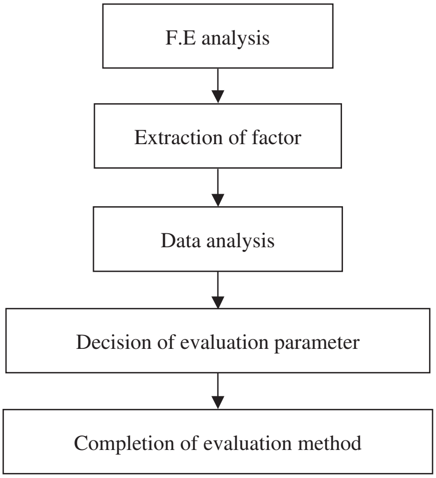


Figure 1. Study flow chart.

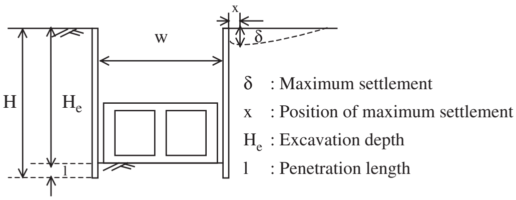


Figure 2. Maximum settlement (δ) and position of maximum settlement (x).

(3) A maximum settlement and the position of maximum settlement can be estimated (see Figure 2.).

3 NEW SIMPLE SETTLEMENT PREDICTION METHOD

3.1 *F.E. Analysis*

The influential factors on the ground settlement were examined from a series of parametric studies using the F.E. analysis. The retaining wall stiffness, retaining wall model, excavation width, excavation depth and position of support, penetration depth were examined. Three F.E.M. models for the retaining model were chosen. Table 1 shows these three analysis models and Table 2 indicates input properties of retaining wall used in the parametric studies. The analysis conditions are summarized in Table 3 and Figure 3. Soil parameters tabulates in Table 4. Totally 28 cases are examined as summarized in Table 5. Figures 4, 5 are examples of analysis results. Important factors for the ground settlement suggested from the model F.E.M. analyses are (1) Excavation width, (2) Wall stiffness

Table 1. Retaining wall model.

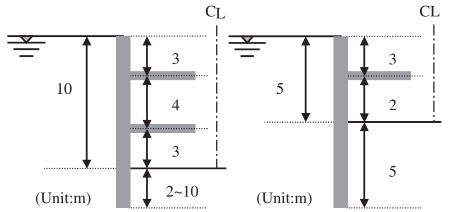
Model name	Content
Model 1	Solid + Beam element
Model 2	Solid element
Model 3	Beam element

Table 2. Retaining wall properties.

	Modulos of deformation E(kN/m^2)	Cross section area A(m^2)	Cross section secondary moment I(m^4)
Beam element	2.10×10^8	1.74×10^{-2}	4.03×10^{-4}
Solid element	$5.55 \times 10^5 \sim 10^7$	6.00×10^{-1}	1.80×10^{-2}

Table 3. Analysis conditions.

Subject	Contents
Analysis code	DACSAR (soil/water coupled elasto-viscoplastic analysis)
Dimension	Two dimensional plane strain
Model area	Half section model
Ground properties	PI = 20 and 40 (see Table 3)



(a) Excavation depth = 10m (b) Excavation depth = 5m

Figure 3. Analysis model.

Table 4. Soil parameters.

Plasticity index	20	40
Dilatancy index	0.051	0.074
Limited stress ratio	1.220	1.022
Un reversible ratio	0.917	0.917
Coefficient of earth pressure at rest	0.524	0.608
Pre-consolidation stress (kN/m^2)	1.0	1.0
Coefficient of Permeability (m/day)	3.34×10^{-3}	1.42×10^{-3}
Effective poisson's ratio	0.344	0.378

Table 5. Analysis case.

No.	Plasticity index	Retaining wall Model	Retaining wall Stiffness (kNm^2/m)	Excavation width (m)	Excavation depth (m)	Penetration length (m)	Position of support (m)
1	20,40	1	98000	10	10	5	5
2	20,40	1	9800	10	10	5	5
3	20,40	1	49000	10	10	5	5
4	20,40	1	490000	10	10	5	5
5	20,40	1	980000	10	10	5	5
6	20,40	2	98000	10	10	5	5
7	20,40	2	9800	10	10	5	5
8	20,40	2	980000	10	10	5	5
9	20,40	2	49000	10	10	5	5
10	20,40	3	98000	10	10	5	5
11	20,40	3	980000	10	10	5	5
12	20,40	1	98000	10	5	5	5
13	20,40	1	98000	15	5	5	5
14	20,40	1	98000	20	5	5	5
15	20,40	1	98000	25	5	5	5
16	20,40	1	98000	30	5	5	5
17	20,40	1	98000	40	5	5	5
18	20,40	1	98000	50	5	5	5
19	20,40	1	98000	12.5	10	5	5
20	20,40	1	98000	20	10	5	5
21	20,40	1	98000	30	10	5	5
22	20,40	1	98000	40	10	5	5
23	20,40	1	98000	50	10	5	5
24	20,40	1	98000	10	10	2	5
25	20,40	1	98000	10	10	7	5
26	20,40	1	98000	10	10	10	5
27	20,40	1	98000	10	10	5	3
28	20,40	1	98000	10	10	5	10

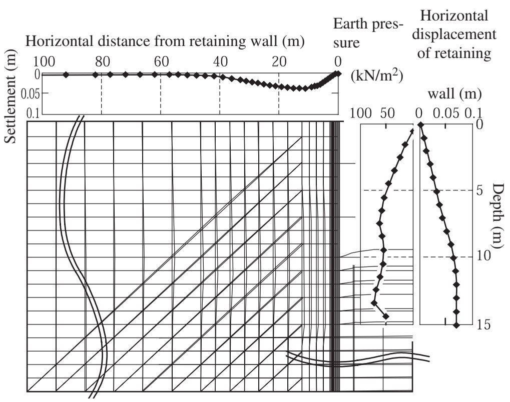


Figure 4. Analysis result (1).

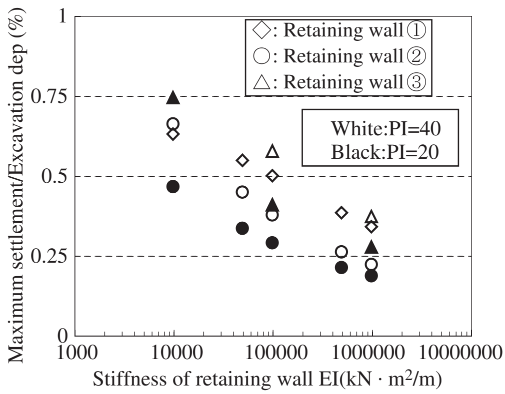


Figure 5. Analysis result (2).

(3) Soil properties, in order. It is found that the maximum settlement is more influenced by modeling of the retaining wall than the difference of soil properties. Namely, the maximum settlement was larger in order of model 2, model 1 and then model 3.

3.2 *Measured data*

The measured records in 42 sites were collected from technical reports published in the past by Japan railway companies and the other companies. Items which were paid attention to in this study are summarized

Table 6. Subject of site data.

	Soil	Retaining wall	Construction	Measured data
Subject	Strength Grouting Groundwater	Stiffness Penetration depth Kind of support	Width Depth Method Process	Deformation of ground Deformation of retaining wall

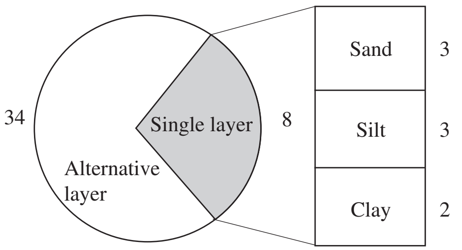


Figure 6. Classification of ground conditions.

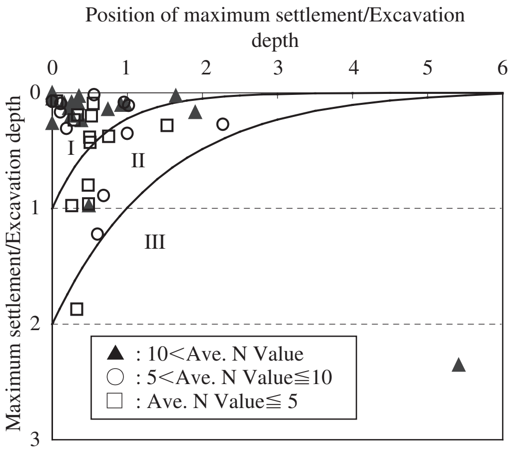


Figure 7. Peck's diagram.

in Table 6. Figure 6 shows classification of ground conditions among the collected records. Most sites are categorized into the alternation layers ground.

The research by Peck (1969) can be cited as a pioneer work, relating to the prediction of adjacent ground displacement. We dropped our measured data on his diagram first and investigated its applicability. Figure 7 shows the Peck's diagram on which our 42 site data are plotted. In the figure, the measured strength was represented by the average value of blow counts (N value) in every layer, using Equation (1). About 80% numbers of data (N value > 10) are plotted in the area (I) on the Peck's diagram and 60% (N value < 10) are in the area (II, III).

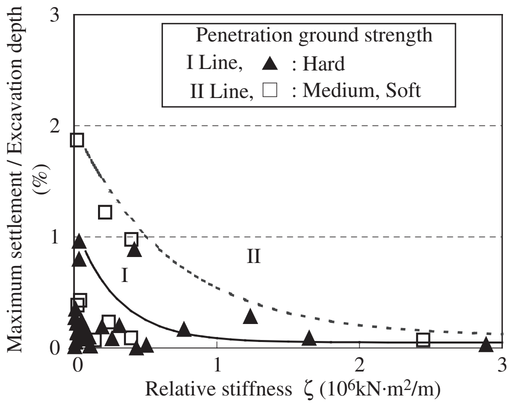


Figure 8. Prediction diagram of maximum settlement.

3.3 *Estimate index*

The method proposed here consists of very simple two estimate parameters. One is so called equivalent stiffness, defined by Equation (2) which is formulated in terms of N value and bending stiffness of retaining wall, EI. Another is relative stiffness, defined by Equation (3)

$$\overline{N} = \frac{\sum (N_i \cdot H_i)}{H} \tag{1}$$

which is expressed by the equivalent stiffness, excavation depth, excavation width and penetration length of retaining wall. These parameters are commonly used in the stage of design work and then easily determinable. Any extra test is not required.

3.4 *Prediction method of settlement*

Figures 8, 9 show diagrams to predict the ground settlement. The maximum settlement can be estimated from Figure 8 and the position of maximum settlement from Figure 9. Furthermore, since the maximum settlement would be much influenced by the strength of ground, the ground strength is classified into three levels, that is, 'hard',

equivalent stiffness

$$\xi = \frac{\sum (\sqrt{N_i} \cdot H_i) \cdot EI}{H} \tag{2}$$

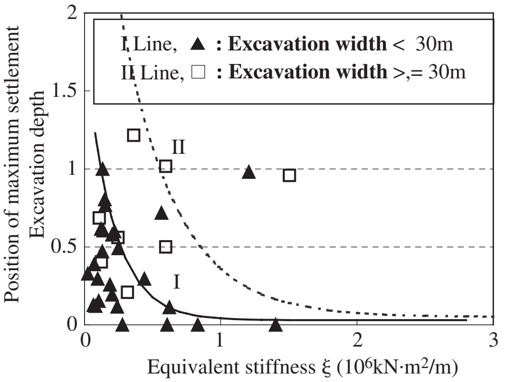


Figure 9. Prediction diagram of position of maximum settlement.

Table 7. Penetrated ground strength.

Classification	Classification of soil	N value
Soft	Sand	10 less than
	Clay	5 less than
Medium	Sand	10 more than 20 less than
	Clay	5 more than 10 less than
Hard	Sand	20 more than
	Clay	10 more than

Table 8. Application conditions.

Subject		Content
Excavation condition	Width	10 m∼50 m
	Depth	About 40 m more less
	Distance	1.0 more times to excavation width
Estimation index		Maximum settlement, Position of maximum settlement
Construction method		No consideration

relative stiffness

$$\zeta = \xi \cdot \frac{l \cdot w}{H_e^2} = \frac{\sum(\sqrt{N_i} \cdot H_i)}{H} \cdot \frac{l \cdot w}{H_e^2} EI \qquad (3)$$

'medium' and 'soft', based on N value in our method, as shown in Table 7. In the diagram for predicting the position of maximum settlement, the excavation width is employed as an additional index. There can be recognized two regions in the diagram at the excavation width being 30 m.

Thus, this method has been made up for a designer to be useful. When the graphical method proposed here is used, first, the designer calculates the only two parameters, the "equivalent stiffness" and the "relative stiffness" which are formulated in terms of usual parameters used at the stage of design work, the stiffness of retaining wall, the excavation depth, the excavation width and N value. Then, by specifying the strength of ground, the maximum settlement and its position are predictable by the graphical manner as proposed above.

4 CONCLUSION

We proposed a simple method to predict the maximum settlement and the position of maximum settlement of adjacent ground in the stage of design work for an excavation work. This method consists of two diagrams, in which some easily determinable design parameters are required. Thus, this method has been made up to be sufficiently simple, wide applicability is guaranteed. Table 8 shows the application condition of this method.

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