PARTIAL GROUND IMPROVEMENT FOR DEEP EXCAVATION IN SOFT CLAY

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This paper presents design optimization using partial ground improvement including buttress and partial base grouting for deep excavation in soft clay.

1. INTRODUCTION

For excavation work in soft clay condition, earth retaining wall movement is always a concern especially in urban area where requirement is stringent. Ground improvement method like base grouting is often employed to tackle the problem. As soil improvement is usually a time consuming and expensive solution, optimized design such as buttress (wall-type) and partial base grouting (strut-type) is deemed necessary. Application of these optimization strategies in soft clay condition is studied and presented. In addition, in order to solve complicated soil-structure interaction problem by employing finite element method (FEM), few theories applicable in commercial software are introduced.

2. THEORIES

Buttress Wall

Refering to Figure 1, buttress is a soil improvement method by constructing jet grouting walls with designed length (L), width (W), depth (D) and spacing (B) in front of earth retaining structures.

a. Japanese Method

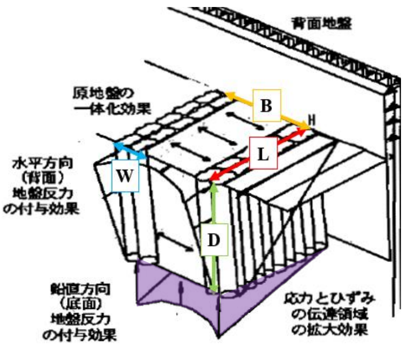

Figure 1 Illustration of buttress using Japanese Method

Shimizu Institute of Technology has published a guide for buttress design (2003) based on FEM analysis and model experiment. Treated soil is modelled as soil block in FEM software. Additional end bearing which is highligted in purple in Figure 1 is considered for this approach.

The improved horizontal subgrade reaction, K_h', can be determined by adopting smaller value of Eq. 1 and Eq. 2 while improved undrained shear strength, C', can be estimated by Eq. 3.

$$K_h' = K_{h0}\left(1 + \frac{L-2}{D}\right) \quad (1)$$

$$K_h' = A_p K_{h1} + \left(1 - A_p\right) K_{h0} \quad (2)$$

$$C' = A_p C_1 + \left(1 - A_p\right) C_0 \quad (3)$$

where, K_{h0}: horizontal subgrade reaction of original soil; K_{h1}: horizontal subgrade reaction of buttress wall; C_0: undrained shear strength of original soil; C_1: undrained shear strength of buttress; A_p: ratio of improvement, W/B

b. Taiwanese Method

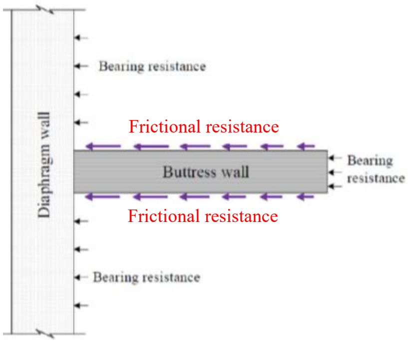

Figure 2 Illustration of buttress using Taiwanese Method

Hsieh and Lu (1999) suggested to model buttress wall as an elastoplastic spring considering friction along the buttress body (Figure 2). Friction is assumed fully mobilised when buttress wall has 1cm deformation (Eq. 4).

$$K_R = F_s/\Delta \quad (4)$$

where, F_s: friction along the buttress body, $2Lf_s$; f_s (kN): $2N$ for sand, $\alpha_0 C_0$ for clay; N: SPT-N values; α_0: reduction factor based on experience, 1 is adopted; Δ: deformation of buttress to fully mobilise skin friction

Partial Base Grouting

As shown in Figure 3, partial base grouting is a strut-type ground improvement work. The improved soil parameters can be determined using either equivalent properties method or equivalent displacement method.

a. Method 1 – Equivalent Properties:

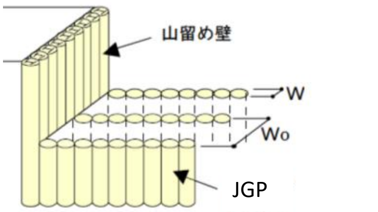

Figure 3 Illustration of partial base grouting

Based on the JGP width, W, and spacing, W_0, presented in Figure 3, equivalent Young's Modulus and undrained shear strength of the treated soil are:

$$E' = \left[E_{JGP} W + E_{soil}(W_0 - W)\right]/W_0 \quad (5)$$

$$C' = \left[C_{JGP} W + C_0(W_0 - W)\right]/W_0 \quad (6)$$

b. Method 2 – Equivalent Displacement:

Parameters of grout are factored by displacement ratio, β, to estimate equivalent parameters of treated soil, where

$$\beta = \frac{\delta_{\text{fully grouted soil}}}{\delta_{\text{partially grouted soil}}} \quad (7)$$

Two displacements in Eq. 7 can be obtained by applying same pressure on fully grouted soil as well as partially grouted soil, which is presented in Figure 4. The equivalent parameters will be

$$E' = \beta E_{JGP} \quad (8)$$

$$C' = \beta C_{JGP} \quad (9)$$

Keywords: Ground improvement, Buttress, Partial base grouting, Soft clay, FEM

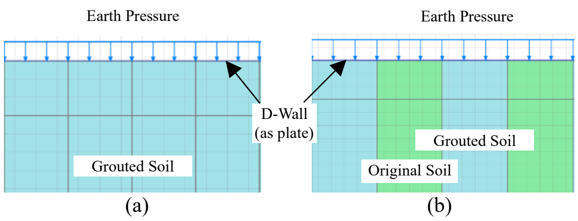

Figure 4 Model of (a)fully grouted soil (b)partially grouted soil

In addition to conventional verifications for full grouting, structural stability of partial base grouting needs to be checked as it works as a strut-and-waler system.

3. CASE STUDY

Excavation with soil profile given in Figure 5 is studied. For 17.85m excavation, allowable wall displacement requirement is 0.5% of excavation depth, which is 89.25mm.

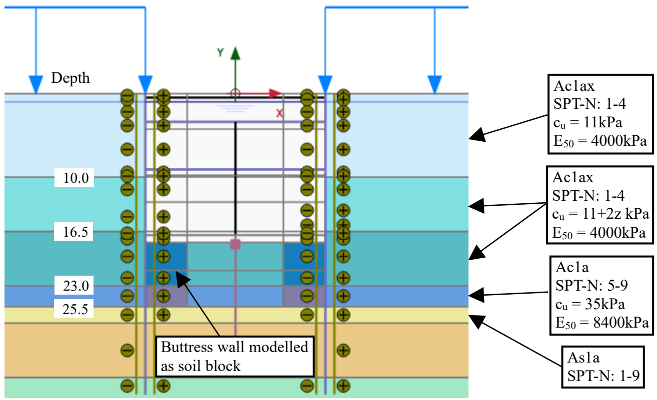

Figure 5 Soil profile for case study

Case 1 studies excavation with buttress wall. Case 2 is introduced to study the effectiveness of buttress in vertical direction. Partial base grouting will be studied in Case 3 in comparison with buttress option.

Buttress wall with 1.5m width, 5m length and 8m spacing as well as partial base grouting with 3m thickness are proposed. Young's Modulus and undrained shear strength of grout are 100MPa and 300kPa, respectively.

Properties of the treated soils are given in Table 1. Original soil strength can be referred to Taiwanese Method as only soil springs are modelled as buttress in the model. In Plaxis model, improved horizontal subgrade reaction using Japanese Method will be converted to Young's Modulus by the equation suggested in Earth Temporary Structure Specification by Japan Road Association (JRA):

$$E' = K_h / 0.24\alpha \qquad (10)$$

α : Corrective coefficient based on Young's Modulus determination method.

Table 1 Properties for treated soils

Case	Method	Remark	Treated Depth (m)	C' (kPa)	E_{50}' (kPa)	K_R (kPa)
1	Buttress Wall	Japanese	17.85 - 23	80.9	5846	-
		Taiwan		30.3	4000	31850
		Japanese	23 - 25.5	84.7	18480	-
		Taiwan		35	8400	35000
2		Japanese	10 - 16.5	70.1	5846	-
		Taiwan		17	4000	18850
		Japanese	16.5 - 23	79.8	5846	-
		Taiwan		29	4000	31850
		Japanese	23 - 25.5	84.7	18480	-
		Taiwan		35	8400	35000
3	Partial Base Grouting	Method 1	17.85 - 20.85	165	52000	-
		Method 2		150	50000	-

Table 2 Comparison of results

Case	Method	Remark	Result		
			Wall Disp. (mm)	Moment (kNm/m)	Shear (kN/m)
1a	Buttress Wall	Japanese	133	5184	1826
1b		Taiwan	166	5909	2165
2a		Japanese	127	4996	1865
2b		Taiwan	156	5712	2193
3a	Partial Base Grouting	Method 1	83	3547	1376
3b		Method 2	88	3702	1439

Based on the result for buttress wall in Table 2, Japanese Method (Case 1a and 2a) gives more advantageous result than Taiwanese Method (Case 1b and 2b), possibly due to the fact that the resistance below the bottom of grouted body is considered and the undrained shear strength of soft soil increased significantly with soil improvement. Although the treated depth is doubled in Case 2 compared with Case 1, reduction of wall displacement is very small for both methods. In other words, upper part of the buttress is ineffective. Moreover, as wall movements of both cases are exceeding the requirement of 89.25mm, it is concluded that application of buttress is less likely to be effective in the very soft clay condition given in this study.

On the other hand, partial base grouting can control the wall displacement satisfactorily while bending moment of the wall is acceptable for the proposed D-Wall. Both Method 1 (equivalent properties) and Method 2 (equivalent displacement) provide similar results.

4. CONCLUSION

Japanese Method and Taiwanese Method provide comparable results for buttress wall design. The former might give slightly more advantageous result based on the study. For partial base grouting, although equivalent displacement method might give more accurate result compared to the equivalent properties method, the latter might be preferred for its simplicity.

For excavation in very soft clay, buttress wall tends to be ineffective as it moves together with the soil, while partial base grouting can be a practical and economical solution, especially for narrow excavation.

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