Excavation analysis on a large-scale slope composed of folded geological structure considering variation of lateral earth pressure coefficient

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1. INTRODUCTION

Ohishi and Terakawa (2019) reported a large-scale deformation on a cut slope composed of folded mudstone layers and tuff breccia layer in Rajamandala, Indonesia. Additionally, the mudstone contained the component of smectite detecting by XRD. During the slope cutting process, unexpected large deformation whose maximum deformation of installed piles was more than 1.0 m were observed. **Figs. 1** shows the analytical mesh and the obtained pile displacements at the objective site through the field measurements and the analyses (Yuan et al, 2021). Compared the field measurements with the analyses, the difference between them could be found. It was thought that toppling of folded mudstone layers, swelling of mudstone due to repeated heavy rainfall and state of in-site stress should be considered on the numerical works. To be specific, the slope was formed by horizontal compression due to tectonic movement, as horizontal tectonic stress acted on the mudstone and tuff breccia. It is thought, therefore, that the large deformation was observed as shown in **Fig. 1** (a). Up to now, many studies were conducted to reproduce the tectonic stress. According to study of Potts et al. (1997), state of stress in a slope containing strongly over-consolidated clay was reproduced by high coefficient of lateral earth pressure K_0, as analysis under high K_0 conditions over 1.5 could show a failure zone is similar to the site. It implied that K_0 can be used to reproduce some special state of stress such as over consolidated condition of the mudstone layers. In this manuscript, the analyses focused on the influence of lateral earth pressure have been carried out and the deformation behavior of the objective slope has been discussed.

2. METHOD AND PARAMETERS USED IN ANAYSIS

The present analysis applied finite difference method operated in FLAC2D under total stress condition; ground water condition was not considered. As Ohishi and Terakawa (2019) classified the types of the rocks by XRD and μ-X ray CT, D_L is the highly-weathered mudstone, D_H is the moderately weathered mudstone and C_L is the non-weathered mudstone. Constitutive models of each rock were as it followed: rigid materials as C_L and tuff breccia were under elastic model, weathered mudstone as D_L and D_H were Modified Cam-Clay model, and other area was Mohr-Coulomb model. Meanwhile, the piles in the stratum were modeled by the beam structure subjected to bilinear model which was elasto-perfect-plastic model.

Process of excavation analysis follows;

I. In self-gravity analysis, all materials were set to be elastic with Poisson's ratio ν = 0.4999 to receive the initial stress state with K_0 approximately equaling to 1.0.

II. After self-gravity analysis, constitutive model for all materials were reset and horizontal stress σ_x of mudstone was defined by vertical stress σ_y as (1). And then, the area of Excavation 1 was removed in the analysis (**Fig. 1 (a)**).

$$\sigma_x = K_0 \times \sigma_y \tag{1}$$

III. After Excavation 1 was removed, CS-8 was inserted into the slope and A area in Excavation 2 (see **Fig. 1 (a)**) was removed. And then, CS-13 was inserted into the slope and the rest part of Excavation 2 (B area) was removed. **Table 1** and **Table 2** show the parameters of rock and piles. Note that the type of rock in Ex.1 is C_L and the one in Ex.2 is D_L. To evaluate the influence of K_0 on the slope deformation, three cases of K_0 = 1.0, 1.25 and 1.5 were analyzed.

Table 1 Parameters of rocks (Tanaka, 2004)

Parameters	D_L	D_H	C_L	TD	TB
ρ [g/cm^3]	1.855	1.834	2.014	1.684	2.100
ϕ [degree]	15.10	8.00	28.35	12.50	17.80
c [kPa]	31	99	830	83	100
ν	-	-	-	0.30	0.34
E [MPa]	78.2	105.4	186.4	6.0	1900.0
λ	0.2	0.25	-	-	-
κ	0.085	0.04	-	-	-

Table 2 Parameters of piles

Parameters	Pile
Length [m]	30
E [Mpa]	2×10^8
Area [m^2]	0.608
I_x	2.94×10^{-2}
Yielding strength [kPa]	2.05×10^5
Z_{px}	9.18×10^{-4}
M_p [kN・m]	188.19

3. ANALYSIS RESULT

Figs. 2 describe the vector maps of the displacement in the slope after all excavations. From the figures, it can be obviously obtained that under influence of high-level horizontal stress displacements in D_L and D_H area are upward direction. The maximum displacement appears on the middle part of the slope which is D_L area. This is related to the weak mechanical properties of D_L mudstone. With increase of K_0, the directions of the displacement vectors tend more leftward. The changes of the displacement vectors variated by K_0 imply that in the target slope higher K_0 can strongly influence on the deformation of D_L layer.

Figs. 3 are the graphs of the displacements and the bending moment distributions of the piles (CS-8 and CS-13). It should be mentioned that Fig.3(b) is the bending moment distribution of piles at the timing that B part of Excavation 2 was removed and the slope had not reached equilibrium state. From **Fig. 3 (a)**, it is simply confirmed that the displacements of piles tend to increase with higher K_0. The increment of displacements

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decreases between K_0 = 1.25 and K_0 = 1.5. Although the deformation of the slope under different values of K_0 is obvious, the differences of the pile displacements are small in higher K_0. From the **Fig. 3 (b)**, the bending moment of the piles during excavation process reached plastic moment. This is to say that while higher K_0 can lead to piles reaching yielding for more times, number of times might show fewer changes in high K_0 condition.

4. CONCLUSION

This paper reports the study of numerical analysis of a cut slope with high-level horizontal stress state reproduced by coefficient of lateral soil pressure K_0>1.0. In accordance with analysis results, vector of displacement shows prominent increase along with increasing K_0. This result implies that higher horizontal stress can actually lead to larger displacement of slope. Meanwhile, displacements of piles show increase with higher K_0 but a special phenomenon is also observed that under higher K_0 condition, increment of pile displacement tends to be lower. This is because the yielding of piles during analysis. However, displacement of slope in this study is still smaller than the observed value by clinometers in the site and thusly further studies on the influence of other factors such as water and time-dependent creep are expected.

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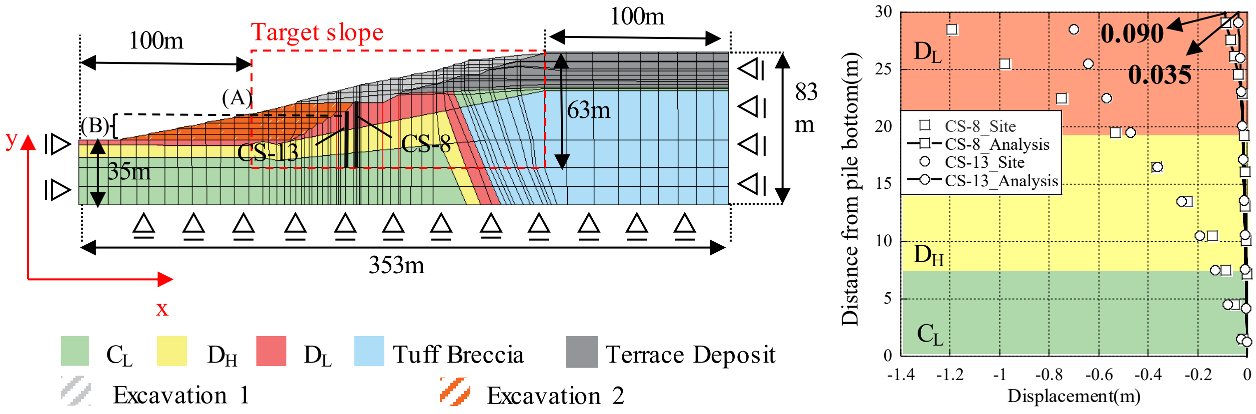


(a) Distribution of target slope (Mesh for analysis) (b) Displacement of piles

Fig.1 Distribution of target slope and displacement of pile (Yuan et al, 2021)

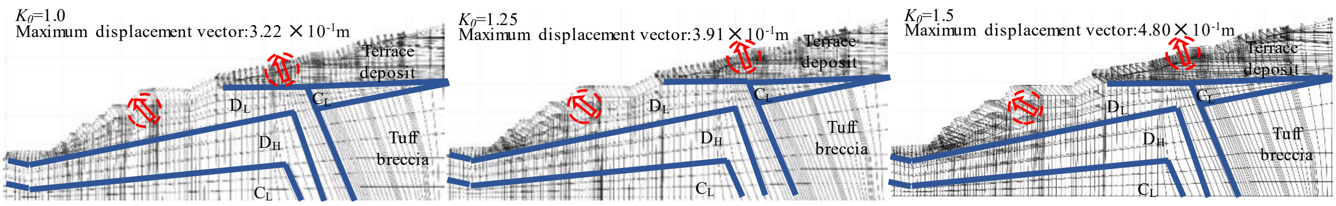
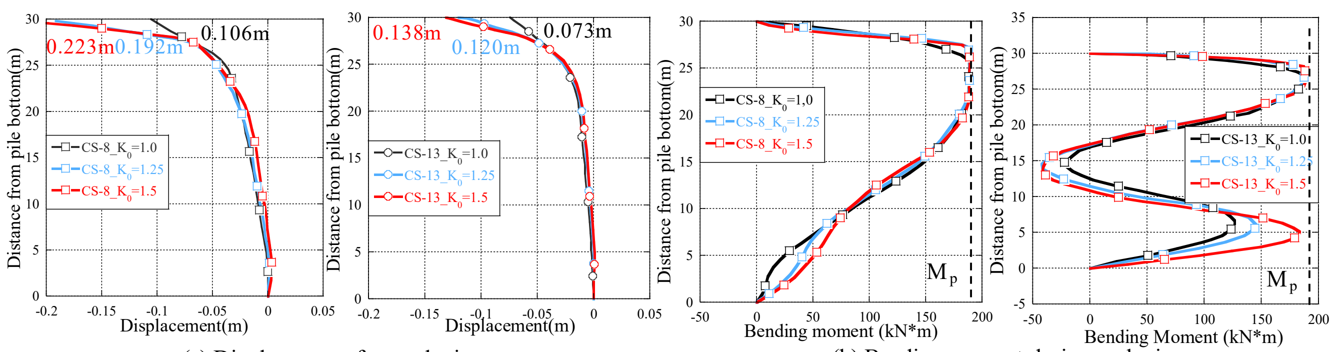


Fig.2 Vector of displacement of slope after excavation under different K_0 conditions



(a) Displacement after analysis (b) Bending moment during analysis

Fig.3 Displacement after excavation analysis and bending moment during analysis