一般講演

資源開発技術／開発機械／岩盤工学

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[1K0107-11-02] 露天掘り鉱山の残壁の掘削変位に及ぼす粘土層の影響 Effects of Clay Zone on Mining-induced Deformation of Rock Slope in Open Pit Mine

〇リッツ ウイ[1]、アマグ クレメント[1]、児玉 淳一[1]、福田 大祐[1]、藤井 義明[1] （1. 北海道大学）
〇Uy Rith[1], Clement Amagu[1], Jun-ichi Kodama[1], Daisuke Fukuda[1], Yoshiaki Fujii[1] （1. Hokkaido University）

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Clay Zone, Rock slope, Deformation, Excavation, 2-D elastic analysis

Stability assessment of rock slopes is an important issue for open pit mines. Instability of rock slopes may result in slope failure, causing not only loss of production but also unexpected expenses for rehabilitation. Furthermore, fatal accidents may occur due to rock slope failure, making slope monitoring critically important in open-pit mining. To respond to these problems, factors which affect rock slope deformation have been investigated. Displacement of a natural slope is usually resulted from inelastic deformation such as sliding. However, displacement of a cut rock slope in an open-pit mine may be often induced by elastic deformation due to excavation. In previous studies, impact of regional rock stress on elastic deformation due to excavation was cleared. Effect of mining pattern on that was also investigated. However, the impact of geological formation including weak rock formation has not much cleared although geological formation is likely to affect the deformation. In this study, the impact of clay zone which is often seen in a limestone quarry was investigated by elastic analysis on 2-D numerical models with clay zone. Then, effects of dip angle, location and thickness of clay zone were analyzed by assuming Young’s modulus of clay zone is much lower than that of base rock. It is found that presence of clay zone does not change deformation mode of the rock slope but magnitude of displacement at rock surface is affected by feature of clay zone. Backward displacement is commonly seen in horizontal direction and magnitude of it depends on dip angle, location and thickness of clay zone.

1. Introduction

In open pit mines, instability of rock slope is not good for safe operation unless there is a hazard to the miners or a significant loss of production. Therefore, there is a need to study rock slope deformation in order to ensure stability of the rock cut slopes. Mining-induced elastic deformation of rock slopes in pit-type mines have been investigated by some researchers[1)-7)] because the early detection of rock slop instability can be estimated from the measured of the models by comparing with the observed data. Najibet al.[1)] investigated the elastic deformation of the pit-type mine at surface and subsurface. Nakamura et al.[7)] measured deformation behavior of rock slope due to excavation in a pit-type limestone mine using multi-stage extensometers. They found that the deformation behavior of rock slope formed in slate was significantly different from that formed in limestone. This showed that elastic deformation of rock slope in pit-type mine can be affected by geological structure or mechanical properties of rock mass. However, elastic deformation of rock slope due to effect of clay-zone has not been clarified yet although clay-zone is often observed in limestone quarries. In this paper, the effect of weak formation (clay-zone) existing in rock slope of limestone pit-type mines on mining-induced deformation was investigated with the case of changing depth, dip angle and thickness of clay-zone, using 2D elastic analysis.

2. Analytical method

In the real application, open pit mines consist of many rock types but in this study; only clay layer and limestone for a general basic were investigated. Clay is very weak rock if compares to limestone. To clarify, the deformation at the surface of rock slope due to the effect of existing clay-zone in pit-type mines, 2-D elastic analysis approach was adopted, and analysis was carried out on rock slope deformation with excavation steps of 25 m each until a maximum depth of the pit, 750m and slope angle of 450. In the analytical models, there were three basic types of model with different dip angles, thickness, and locations of clay-zone. The cases include; changes in the dip angle of 0, 45^0 and 90^0 of clay-zone (Table 1), changes in the locations of clay-zone at progressive distances of 250 m with different dip angles, where x=0 was the basic model located at the middle of the left rock slope (Table 2), and varying thickness of clay-zone of 2.5m, 12.5m, 25m, 50m, 75m, and 100m with different dip angles (Table 3). Nodal forces due to gravity were applied to the entire model in the vertically downward direction to generate the initial stress field. The dimension of the model is 2500m and 6000m for vertical and horizontal respectively (Fig.1). Rock mass was assumed to be an isotropic and elastic body. The nodal displacement perpendicular to the right, left and the bottom surface of the model were fixed at zero. All analyses were carried out under a plane-strain condition using six-node triangular elements.The excavation was successively completed throughout 30 steps with an excavated depth of 25m per step. Mechanical properties of the analytical models was shown in Table 4.

Table 1. Model Characteristics of changing dip angles

Model types			
Dip angle of clay-zone (^{0})	0	45	90
Thickness of clay-zone (m)	25		

Table 2. Model Characteristics of changing location of clay-zone

Location of Clay-zone (coordinate-x)									Dip angle (^{0})	Thickness (m)
			0	250	500	750			0	25m
-750	-500	-250	0	250	500	750	1000	10250	45	
-750	-500	-250	0	250	500				90	

Table 3. Model types which is changing thickness of clay-zone

Thickness of clay-zone						Dip angle (^{0})
2.5m	12.5m	25m	50m	75m	100m	0
						45
						90

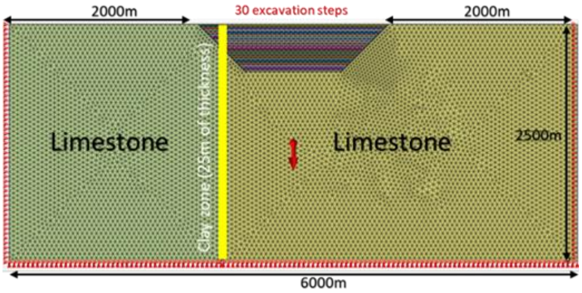


Fig 1. Dimension and mesh type of body model

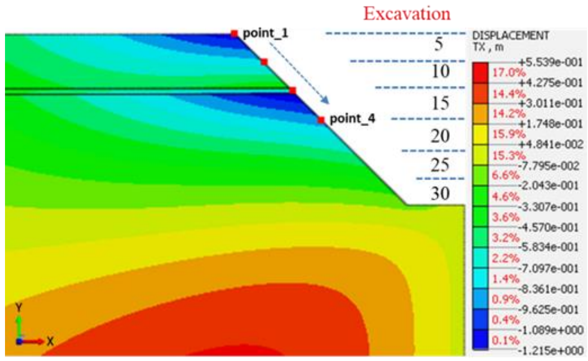
3. Results and Discussion

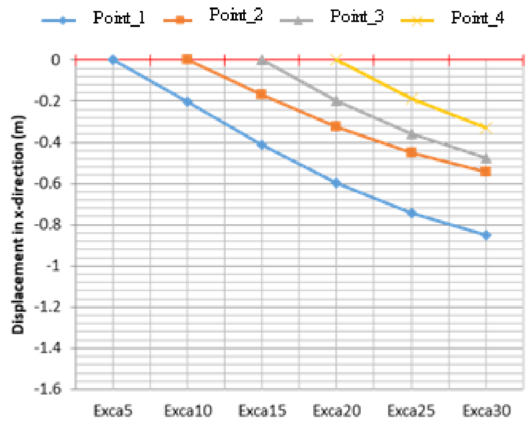
There were so many models which have been done, but only some specific case had been shown in discussion with the normal case of clay-zone, which showed the same result as the homogeneous limestone, backward displacement for all excavation steps. The cases of clay-zone located horizontally at depth of 750m of the pit with the basic thickness of 25m, and inclination of clay-zone with thicknesses of 100m were discussed in this paper because their results were very effective to the cut rock slope deformation. Also, only the results of surface displacement of rocks slope and stress distribution from the analytical models were shown for understanding its characterization.

Table 4. Mechanical properties of limestone and weak rock

Material	Young's modulus (GPa)	Poisson's Ratio ν	Unit weight γ (kN/m³)
Limestone	5.0	0.10 0.20 0.30 0.40	27
Weak rock	1.0 0.5 0.1 0.05	0.20 0.30 0.40	18

3.1 Case clay-zone located horizontally

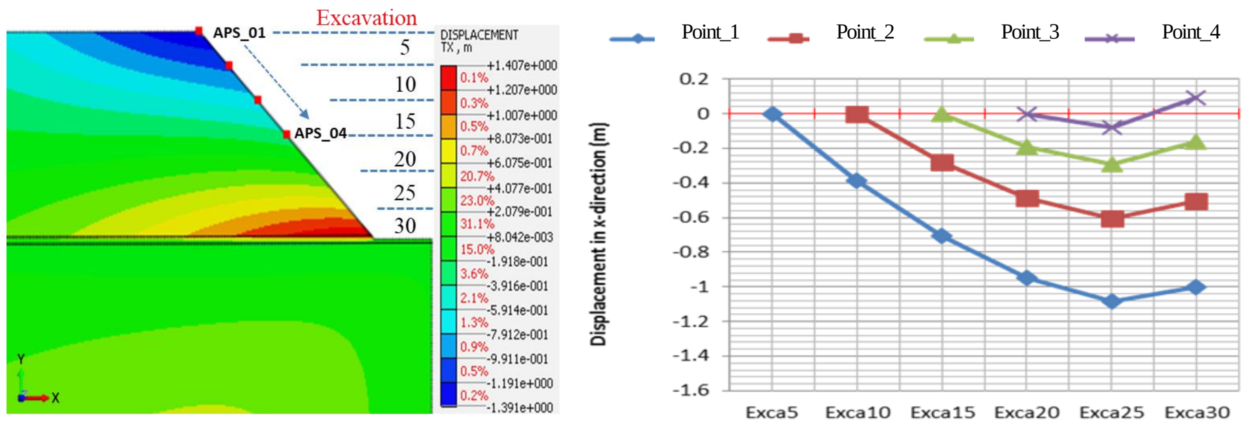




(a) Distribution (b) At points 1 to 4

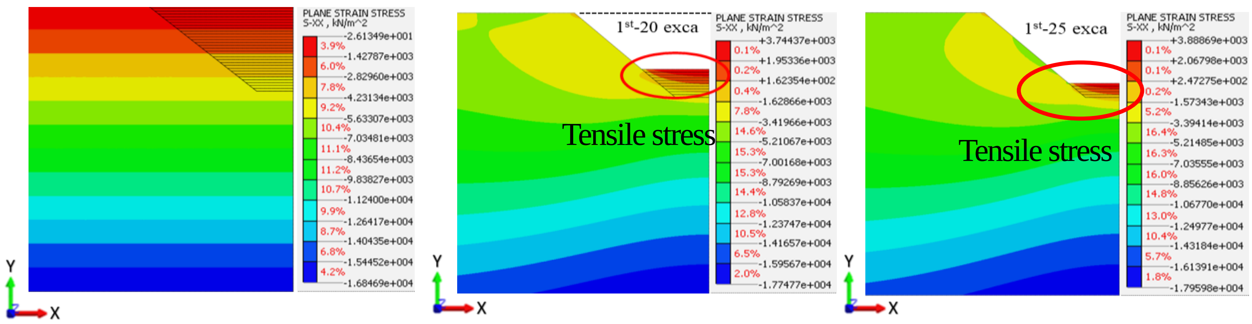
Fig. 2 The displacement of rock slope at the surface of the pit-type mine for the case of existing clay-zone located horizontally at depth of 250m.

Displacement at the surface of the pit-type mine was measured by Automated Polar System (APS), and designated as point_1 to point_4 (Fig.2a). The model result of the displacement distribution of rock slope of existing clay-zone located horizontally at depth of 250m shown backward displacement for all the excavation steps (Fig. 2b). The displacement distribution of rock slope in the case that existing clay-zone located horizontally at the depth of 750m was shown in (Fig. 3a). The tendency of the displacement of rock slope indicates forward displacement at the excavation step of 25 (Fig. 3b).



(a) Distribution (b) At points 1 to 4

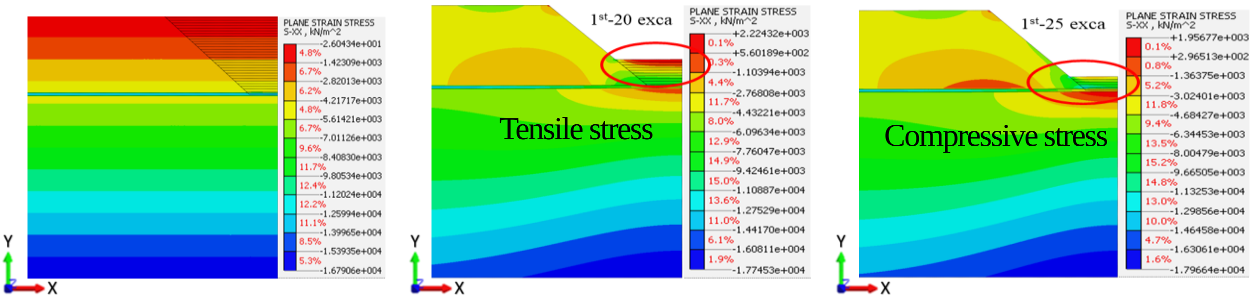
Fig. 3 The displacement of rock slope at the surface of the pit-type mine for the case of existing clay-zone located horizontally at depth of 750m.



(a) Initial stage (b) 20th stage (c) 25th stage

Fig. 4 Stress distribution for the case that homogeneous limestone

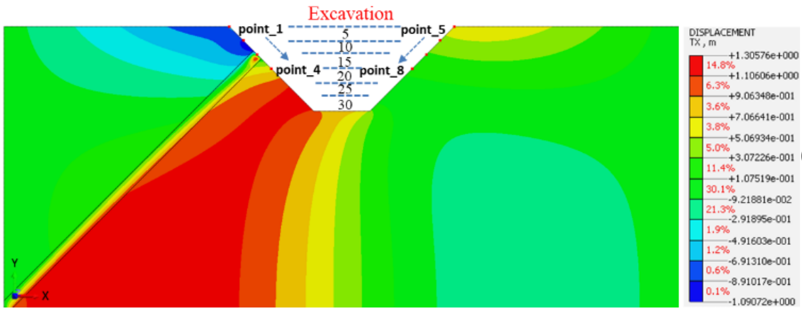
In the case of homogeneous limestone, stress distribution at the floor indicated tensile distribution as shown in Fig. 4 (b) and Fig.4 (c)., implying that rock slope deformation was contraction, but changed to extension when clay-zone exist horizontally at the pit floor of the pit-type mine as shown in Fig. 5 (b) and Fig. 5 (c), as a result of stress state changed from tensile to compressive.



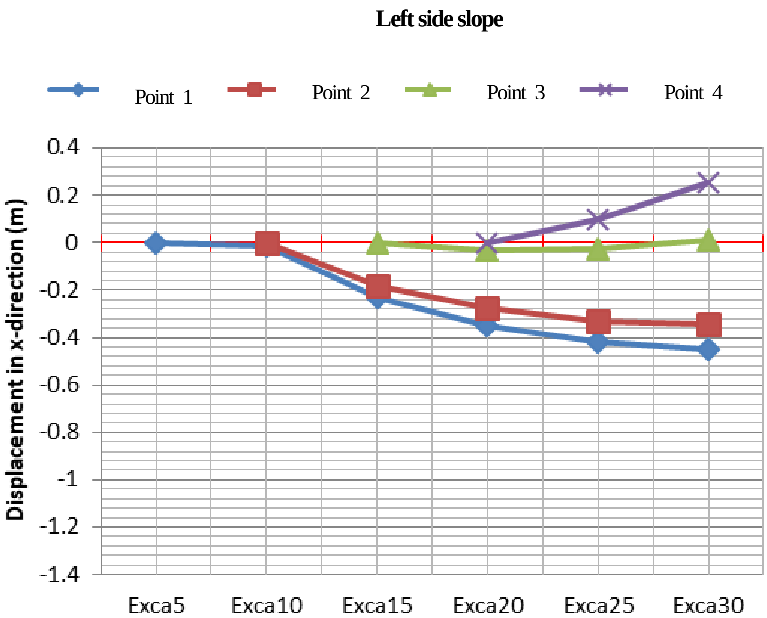
(a) Initial stage (b) 20th stage (c) 25th stage

Fig. 5 Stress distribution for the case of existing clay-zone located horizontally at the floor of the pit.

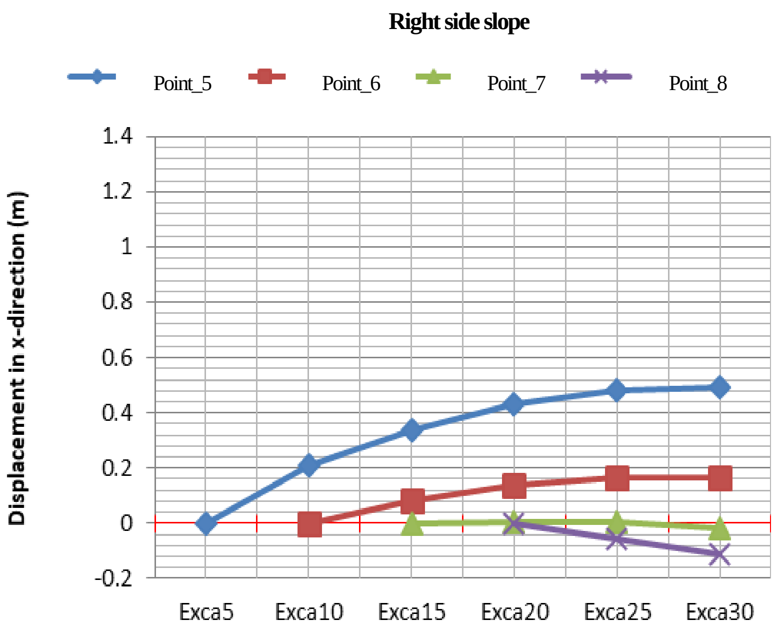
3.2 Case clay-zone located incline with thickness 100m



(a) Distribution



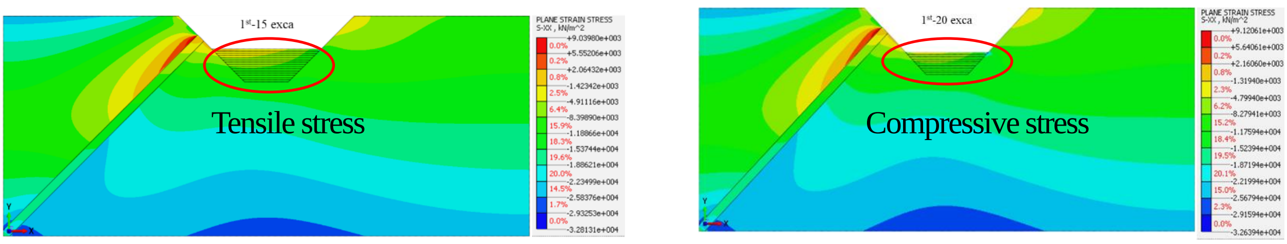
(b) At points 1 to 4 on left side slope



(c) At points 1 to 4 on right side slope

Fig. 6 The displacement of rock slope at the surface of the pit-type mine for the case of *effected by clay-zone* with the changing of thickness of 100m and the dip angle of 45^0.

There are many models for the case of changing thickness, but the only two models which have the dip angle of 45^0 with the thickness of 75m and 100m showed the different tendency of the displacement. Because of the cases 75m and 100m of thickness looked mostly the same results, so that only case 100m of thickness was showed for the discussion. Forward displacement was found at the excavation 20 for both side of rock slope, see Fig 5.



(a) 15th stage (b) 20th stage

Fig.7 Stress distribution for the case of existing clay-zone in the case of changing thickness of 100m and dip angle of 45^0.

Stress state at excavation 15, Fig 6(a), showed tensile stress, but turned to compressive stress at excavation 20, Fig6 (b). Therefore, rock slope deformation of the pit-type mine was changed from contraction to extension when the excavation passed through 15^{th} step.

2. Conclusion

To clarify the elastic deformation of rock slope for the open pit mines, 2D elastic analytical models were used. Dip angle, location and thickness of clay-zone were the basic factors for a geological structure of mining side. From the result, effects of weak rock formation (clay-zone) lying on rock slope of pit-type limestone quarries on mining-induced deformation were clear understood. The elastic analytical result clarified the effects of existing of clay zone on deformation of the cut rock slope of open pit. The presence of clay zone on the cut rock slope with the changing dip angle, location and thickness shows the significance to understand the characteristic of rock slope deformation. It can also notices that the effects of clay zone with changing the location and thickness give extension deformation in some cases, which was found when the excavation is progressively to near the layer of clay zone, typically when clay-zone is located horizontally at the depth of 750m and inclined clay-zone of 100m thick is inclined at dip angle of 45^0. Therefore, the contraction deformation was normally as the result of elastic deformation of rock slope. Even contracted or extended deformation of rock slope, the stability of the slope was still stable because of elastic deformation.

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