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Earth pressures against the excavation wall in a jointed rock mass

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ABSTRACT: This paper examined the magnitude and distribution of earth pressure against the excavation wall in a jointed rock mass. Based on a physical model test and its numerical simulation, extended parametric studies were conducted considering different rock and joint conditions. The results of earth pressure in a jointed rock mass were compared with Peck's empirical earth pressure for soil ground. The comparison indicated that the earth pressure in a jointed rock mass can be significantly different from Peck's earth pressure. Accordingly, the effect of rock and joint conditions should be considered when designing the excavation wall in a jointed rock mass.

1 INTRODUCTION

Many studies have examined the earth pressure against an excavation wall, including Peck (1969), Tschebotarioff (1973), and Weatherby (1998), which are mostly applicable to soil grounds such as sand and clay. Among them, the empirical earth pressures proposed by Peck (1969) and Tschebotarioff (1973) have been widely used in practice for designing excavation support systems under soil conditions. Because previous studies have generally focused on soil-based measurements, it is unclear whether the findings could be extended to rock strata. Few studies have examined the earth pressure on support systems in rock strata by considering the ground-wall interactions and rock and joint characteristics, which are important factors influencing the magnitude and distribution of earth pressure. This is likely due to the complexity and difficulty of examining the interactions between the wall and jointed rock mass. Recently, Son (2013), and Son and Park (2014) reported the results of the earth pressures in jointed rock masses. The results clearly showed that the earth pressure can be higher for rock strata than soil ground when the rock and joint characteristics are under unfavorable conditions, such as a joint condition that induces sliding as well as weathered joint and rock conditions. On the other hand, the results showed that the earth pressure might be much lower than the soil ground when the rock conditions are favorable.

This conference paper provides some parts of the results that have been presented in the previous study and the examined results are expected to provide a better understanding of earth pressure against the excavation wall in a jointed rock mass.

2 NUMERICAL APPROACH

Based on a physical model test and its numerical simulation (Figs. 1 and 2), extended parametric studies were conducted considering different rock and joint conditions.

A numerical approach was described in the previous studies (Son, 2013 and Son and Park, 2014), but it is briefly described again. The 2-D Universal Distinct Element Code (UDEC, 2004) was adopted. The rock blocks, wall and struts were simulated as separate elastic units. The joints between the rock blocks and the interfaces between the walls and rocks were modeled using the Coulomb slip model. The analysis model for this study was 68.8 m $\times$ 31.5 m, and the excavation wall, which was a soldier pile and timber lagging wall, was installed to a depth of 20.5 m (Fig. 3).

The excavation width was assumed to be 20 m and the final excavation depth was 19 m. Eight stages of excavation were carried out to obtain the distribution and magnitude of the earth pressure. Before the first excavation, an initial equilibrium was obtained with an earth pressure coefficient of 0.5 at rest. At this stage, the boundary condition was a roller at each end of two vertical boundaries and at the bottom boundary. After ensuring the initial equilibrium conditions, all displacements were reset to zero, and the wall was installed to a depth of 20.5 m. The first excavation was conducted up to 1.0 m, followed by the installation of the first strut at 0.5 m over the excavation line. After the first excavation, additional excavation work was performed every 3 m, followed by strut installation at 3 m intervals, which was 0.5 m above each excavation line, whereas wall stabilization was confirmed after each excavation stage. The final excavation was carried out up to 19.0 m, and the strut was not installed at the final stage. The study considered hard and moderately weathered rock types, and the joint property of each rock type was classified as good, fair, poor, or very poor (see Table 1).

The joint inclination angles were 0°, 30°, 60°, and 90°, which were measured in the counterclockwise direction from the horizontal lane.

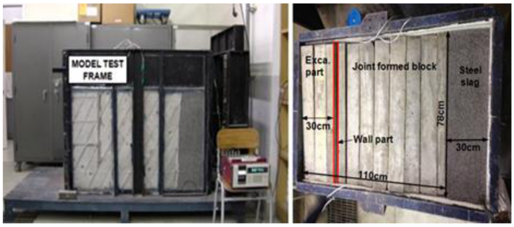

Figure 1. Set-up for a physical model test.

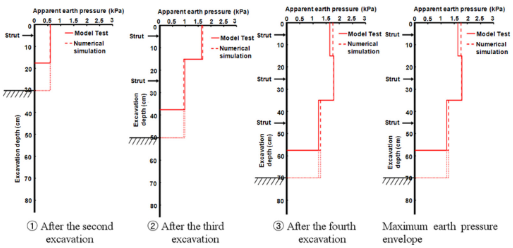

Figure 2. Comparison of the results between the model test and the numerical simulation.

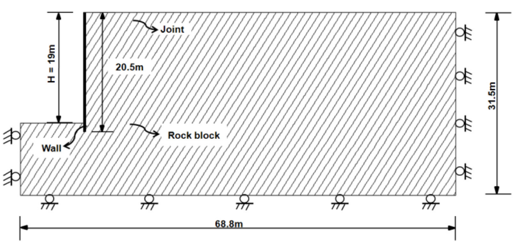

Figure 3. Numerical modeling (a case of joint inclination angle of 60° with 1.0 m joint spacing).

3 RESULTS AND ANALYSES

Fig. 4 compares the apparent earth pressures for hard rock due to the varying joint shear conditions and joint inclination angles with Peck's empirical earth pressure based on the sand ground with a friction angle of $\phi = 35°$. Here the apparent earth pressure was calculated using the method in Peck (1969). In other words, the magnitude and distribution of earth pressure on the support system were inferred from the strut load.

Fig. 5 shows the ratio of total earth load per meter of wall induced from the numerical analysis for hard rock under various joint shear conditions and joint inclination angles to Peck's empirical earth load per meter of the wall for the sand ground.

For the joint inclination angle of 30°, the apparent earth pressures were higher than those of the joint inclination angle of 0° under all joint shear conditions, but the pressures were lower than Peck's earth pressure. The increase in earth pressure was more significant

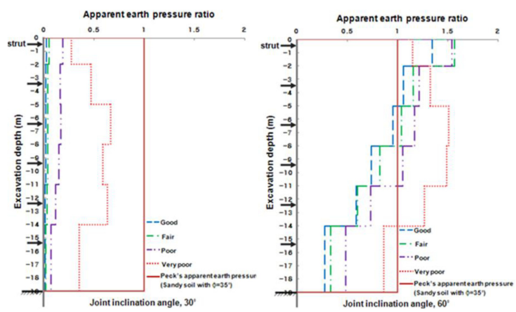

Figure 4. Earth pressure distribution and magnitude under various joint shear conditions (Hard rock).

Table 1. Properties of wall, rocks, joints, and interfaces in the extended numerical analysis.

Rock type	Wall	Rock and joint									Interface between rock and wall			
		Rock			Joint									
	E_wI_w (Mpa.m^4)	E_r (MPa)	ν	γ_t (kN/m^3)	Joint shear condition	c, σ_t (MPa)	ϕ (°)	ϕ_r (°)	k_n (MPa/m)	k_s (MPa/m)	c, σ_t (MPa)	ϕ (°)	k_n (MPa/m)	k_s (MPa/m)
Hard rock	23.20	1.0×10^5	0.2	26.5	Good	0	50	35	2.33×10^5	0.96×10^5	0	33	2.33×10^5	0.96×10^5
					Fair	0	40	32	2.33×10^4	0.96×10^4	0	27	2.33×10^4	0.96×10^4
					Poor	0	35	31.5	2.33×10^3	0.96×10^3	0	23	2.33×10^3	0.96×10^3
					Very Poor	0	30	30	2.33×10^2	0.96×10^2	0	20	2.33×10^2	0.96×10^2
Moderately weathered rock	23.20	1.0×10^3	0.25	24.5	Poor	0	35	31.5	2.33×10^3	0.96×10^3	0	23	2.33×10^3	0.93×10^3
					Very Poor	0	30	30	2.33×10^2	0.96×10^2	0	20	2.33×10^2	0.96×10^2

E_wI_w= flexural stiffness of wall; γ_t = unit weight of rock; E_r = elastic modulus of rock; ν = Poisson's ratio; c = cohesion of joint or interface; σ_t = tensile strength of joint or interface; ϕ = friction angle of joint or interface; ϕ_r= residual friction angle of joint or interface; k_n = normal stiffness of joint or interface; k_s = shear stiffness of joint or interface

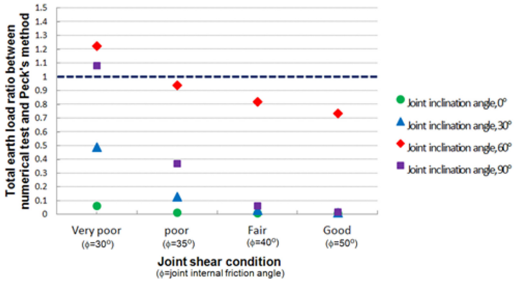

Figure 5. Comparison of the total earth load per meter of wall between the numerical tests for hard rock and Peck's empirical method.

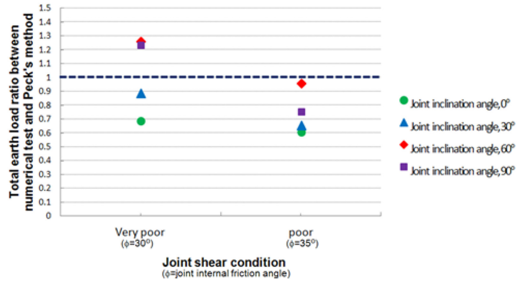

Figure 7. Comparison of the total earth load per meter of wall between the numerical tests for moderately weathered rock and Peck's empirical method.

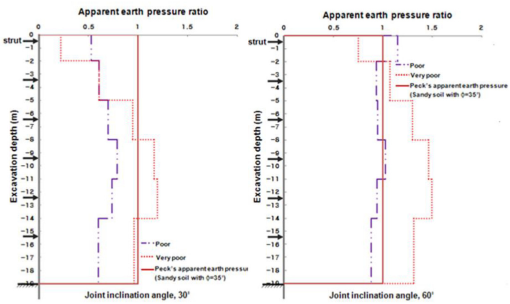

Figure 6. Earth pressure distribution and magnitude under various joint shear conditions (Moderately weathered rock).

under poorer joint shear condition. The ratio of total earth load (induced earth load/Peck's earth load) was only 0.02 under the good joint condition and it was 0.49 under the very poor joint condition.

For the joint inclination angle of 60°, where joint sliding was induced, the apparent earth pressure was significantly different from the results of the other joint inclination angles. The overall distribution of apparent earth pressures was higher at the upper part of the wall and decreased with depth. The maximum apparent earth pressure at the upper part of the wall was higher than Peck's earth pressure, regardless of the joint shear conditions, although it decreased with depth, except under the very poor joint condition. The ratio of total earth load was 0.74 under the good joint condition, and it was 1.23 under the very poor joint condition.

Fig. 6 compares the apparent earth pressures for moderately weathered rock. Fig. 7 shows the ratio of total earth load per meter of wall induced from the numerical analysis for moderately weathered rock.

For the joint inclination angle of 30°, the distribution of apparent earth pressure was similar to that of the joint angle of 0° but was of greater magnitude. The apparent earth pressures under the poor and very poor joint conditions were much higher than those of hard and slightly weathered rocks with the joint inclination angle of 30°. The ratio of total earth load was 0.66 under the poor joint condition and it was 0.89 under the very poor joint condition.

For the joint inclination angle of 60°, the apparent earth pressure under the poor joint condition was similar to Peck's earth pressure along the wall. The apparent earth pressure under the very poor joint condition was higher than that suggested by Peck but was similar to those for hard and slightly weathered rocks with the joint inclination angle of 60°. The ratio of total earth load was 0.96 under the poor joint condition and it was 1.26 under the very poor joint condition.

4 CONCLUSIONS

This paper examined the magnitude and distribution of earth pressure against the excavation wall in a jointed rock mass. Following conclusions were drawn.

The worsening of rock condition produced an increase in earth pressure However, when there is joint sliding, the earth pressure is less likely to be dependent on rock type, although the distribution of earth pressure may take on different shapes. The joint shear condition and joint inclination angle had a significant effect on earth pressure in jointed rock mass and there was a significant increase in earth pressure as the joint condition deteriorated and the joint slid. As rock conditions worsened, the rate of increase in earth pressure was more apparent under better joint conditions.

The magnitude and distribution of earth pressure on the strut-supported systems of open cuts in jointed rock masses were strongly dependent on the type of rock, the joint shear condition and the joint inclination angle. The results clearly suggested that the earth pressure in jointed rock masses can be significantly different from that in soil ground depending on rock and joint conditions. Therefore, these factors should be taken into consideration when designing wall systems in jointed rock masses safely and economically.

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REFERENCES

Itasca Consulting Group, Inc. 2004. *Universal Distinct Element Code*, User's Manual, Minneapolis, Minnesota, U.S.A.

Peck, R.B. 1969. "Deep Excavations and Tunneling in Soft Ground. State-of-the-Art report." Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, State-of-the Art Volume, pp. 225–290.

Son, M. 2013. Earth pressure on the support system in jointed rock mass, Canadian Geotech. Journal, Vol. 50, No. 5, pp. 493–502.

Son, M. and Park, J. 2014. Physical model test and numerical simulation of excavation walls in jointed rock masses, Canadian Geotech. Journal, 10.1139/cgj-2013-0081.

Tschebotarioff, G. P. 1973. Foundations, Retaining and Earth Structures. 2nd Ed., MGH.

Weatherby, D. E. 1998. Summary Report of Research on Permanent Ground Anchor Walls. Vol. 4, Conclusions and Recommendations, Report FHWA-RD-98-068, FHWA, McLean, VA.