STABILITY EVALUATION OF AN UNDERGROUND QUARRY WITH JOINTS IN OYA

Utsunomiya University student member ○ Tumelo Dintwe
Utsunomiya University member Takafumi Seiki

1 INTRODUCTION

Underground mines stability is of great concern in geotechnical division mainly for a safe working environment in the mine (Mortazaria, et al., 2009). Stability in the underground space is affected by a couple of factors, however, in this paper, attention will be on the discontinuities and dynamic elements. The underground mine under investigation is a room and pillar type, and that suggests it is inevitable not to focus on the pillar stability as major considerations. The room and pillar type mines, pillars are accountable for the entire support of the overburden load from the rooftop up to the surface. Additionally, there ought to be firm through the mining process and in some cases even for post-mining activities . Furthermore, discontinuities in general, are zones of weakness. Thus if it is found in a rock mass or an intact rock, it reduces its strength. Discontinuities cause different types of failures in rock mass depending on their position, orientation and inherent joint properties, and where ever observed critical assessment should be taken. In most cases, discontinuities pose great risks when predominantly found on the pillars, as a result, leading to the possibility of fall of grounds or overall failure of the underground. This paper aims to evaluate stability considering discontinuity effects on Oya tuff underground quarry with a numerical code Flac^{3D}. On static scenarios, structures tend to be stable with the presence of near vertical discontinuities. However, in the dynamic conditions such as earthquakes, initiation of structure failure may occur at discontinuities, it is, therefore, necessary for the investigation put dynamic states into consideration. Figure 1 shows the active quarry under investigation located in Oya town, Utsunomiya city, Tochigi prefecture, Japan.

2 STABILITY ASSESSMENT

Not much research has been put to study the behaviour of the quarries with corroboration of engineering and scientific experiments at Oya underground quarries. However, Seiki, et al.,(2016).performed numerical simulations on a different quarry located nearby the room and pillar quarry and concluded the underground space to

Figure 1. Oya underground quarry

be safe based on the static and dynamic analyses and field observations. Currently, workers in the quarry use a checklist to assess the conditions of the walls and the pillars modified by. Seiki, et al., (2016). From the judgement of the observation, recommendations are made, and support systems are installed, or backfill is used for support. In assessing underground spaces particularly room and pillar, the primary stability evaluation usually address the listed components listed below. However this paper focuses on the joint discontinuity effects and dynamic state due to earthquakes

1. The pillar stress levels
2. Roof and floor behaviour
3. Pillar condition, shape and volume
4. Extraction ratio
5. Discontinuities
6. Dynamic state

The above-stated stability affecting components are discussed in detail by various authors. The stress levels can be estimated using the tributary area method which gives a conservative stress estimate that is related to the extraction ratio. The relation was illustrated in Brady & Brown, (2004) showing that for a small increment in exaction ratio, a high-stress level is obtained. Roof spans

Key words: Oya undergrond quarry, Joints, Numeical analysis, Seismic response
Contact adress: Utsunomiya University, Graduate school of Engineering,
Rock Mech. Lab. 028-689 -6218, E-mail:mt166474@cc.utsunomiya-u.ac.jp

are above the pathways that allow access to the operation areas, and for that, it has to be stable throughout the mining life for safe access. For obtaining stable roofs, the process starts with the design up to monitoring and maintenance. The design prominently relies on the practical experience and success of the already existing layouts (Zipf, 2001). However, the condition of roofs is controlled by overburden, horizontal stress and the intrinsic mechanical properties (Kortnik, 2009). The latter allowed for rock mass rating methods to be used for early assessment and even indicate support for low rating spans. The above practices are found to be inadequate and are supplemented by numerical methods that account for relatively all the stability affecting components. Comprehensive numerical simulations carried out in (Mortazaria, et al., 2009), point out the importance of pillar width to height *w/h* ratio to the behaviour pillar stiffness and strength. It confirmed the previously known theory and practice that when *w/h* reduces stress levels increase, however, it is the intrinsic rock properties that control the failure or load carrying capacity at *w/h* less than 1 (Mortazaria, et al., 2009).

2.1 Seismic response

Various cases around the world of earthquake effects on underground space are discussed by Bäckblom, et al., (2001), the mentioned cases include tunnels mines and repository spaces. As it could be anticipated, from the stated citations in (Bäckblom, et al., 2001) Japan recorded more cases than other countries under investigation, however majority of the cases were effects on tunnels. For seismic damage on underground in Japan, Aydan, (2014) assessed the destruction in this structures after the 2011 great earthquake. From the list of the damaged structures research (Aydan, 2014), one was the collapse of the semi-underground quarry located in Oya in the neighbourhood of the presently studied quarry. Oya underground quarries are considered shallow structures as mining depths currently are less than 100m. Shallow structures are more susceptible to seismic damage than deep underground openings (Bäckblom, et al., 2001), and the surface ground motions are known to be much more strong than the subsurface motions. A recent study of longwall type quarry 2km away from the current study area, has shown that increase in wave velocities results in high strain levels on roofs (Seiki, et al., 2016). Pillars experience dynamic loading during earthquakes and in response, failure may occur as the pillar strength is reduced. The ground motion can cause development of fractures as cracking and spalling take place and leading to rock falls.

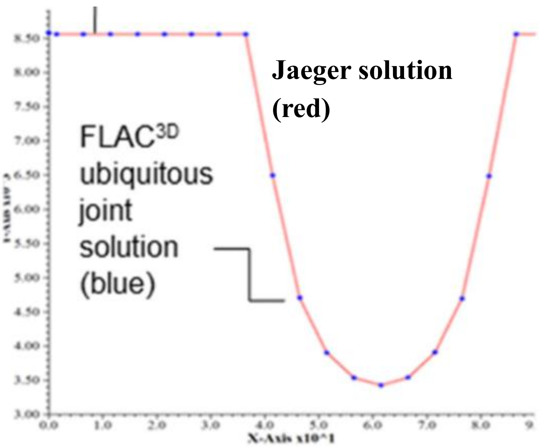

Figure 2 showing the rock strength variation against the specified dip angle modified from (Sainsbury & Sainsbury, 2017).

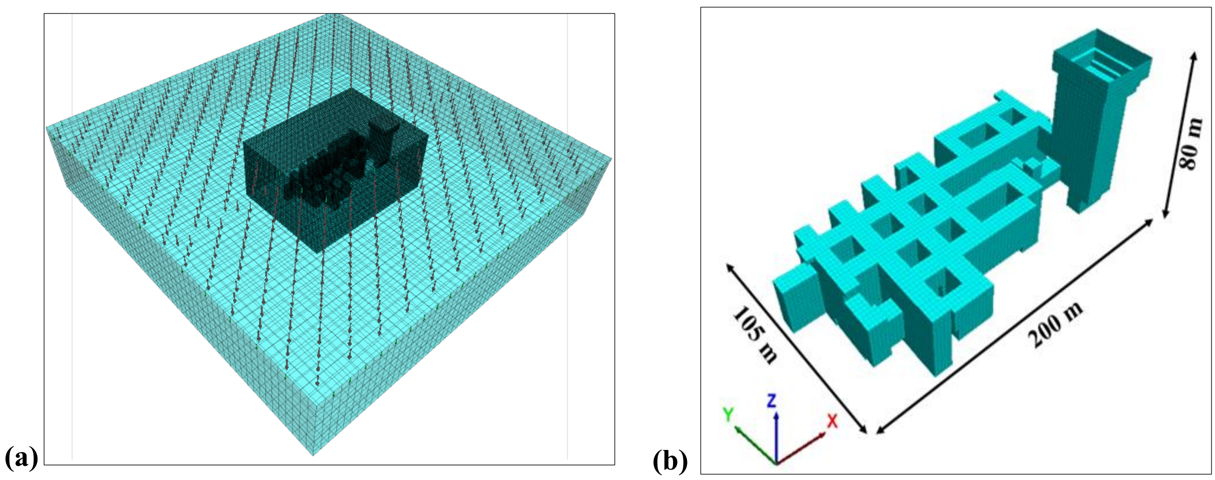

Figure 3. **(a)** 3D Model setup of Oya underground quarry; **(b)** excavated regio

Table 1 Mechanical properties of Rock and Joint

	Bulk modulus (GPa	Shear modulus (GPa)	Cohesion (MPa)	Friction angle (°)	Tension strength (Pa)
Rock	1.38	0.91	2.1	30	1.08×10^6
Joint	-	-	0.03	20	0

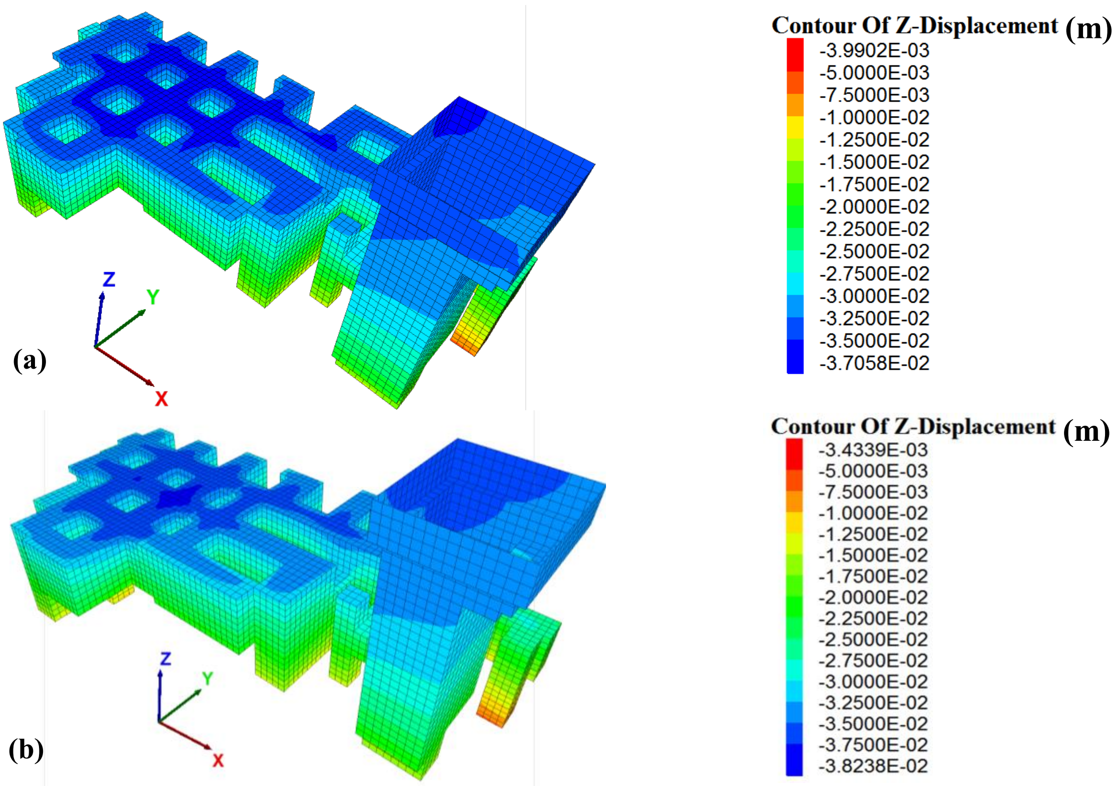

Figure 4. Displacement contours. **(a)** No joint, **(b)** with joint

2.2 JOINT DISCONTINUTIES

Presence of joints in a rock medium reduces the strength of the rock and rock mass. The effets of joints on rocks has For modeling contitutive models are an option to represent joint implicitly in continuum numerical models. Rafeh, et al.,(2015) developed a yield criterion that demonstrates the joint effect on the strength of the chalk material. The orientation (dip angle) of the of the weak plane dictates the strength, stress distribution within the rock (Rafeh, et al., 2015) , same results were previously obtained with another alternative proposed model (Agharazi, et al., 2011). All works mentioned above suggesting consititutive models, compared the proposed models with the built-in models of Flac^{3D} and a clear fitting correlations were achieved. In Flac^{3D} the ubiquitous model follow the analytical theorem developed by Jaeger, (1960). The results of the strength variation in a rock sample due to the presence of a single weak plane is shown in Figure 3. Both Jaeger model and Flac^{3D} ubiquitous joint model result in a U-shaped strength curve (Figure 3) at varying joint orientations (Sainsbury & Sainsbury, 2017).

3 METHODOLOGY

The whole underground space was set up using Flac3D program, from the vertical shaft and to all other horizontal openings. The finite difference mesh has dimensions of 500×500×100 m (length × width × height) see Figure 3 and Figure 3(b) for the excavated zones. The model used rock property parameters collected from the laboratory experiments and are shown in Table 1. Simulation model adopted the elastic-perfect plastic constitutive model for the whole rock mass matrix using the Mohr-Coulomb criterion The bottom of the model has a rigid boundary condition while the sides had roller boundaries that enable sliding, later on, the dynamic state, roller boundaries were replaced by viscous boundary conditions and the bottom freed. Oya tuff is mostly massive, and the rock mass in the underground quarry has few joints. However, most of these joints are large and persistent. The underground rock mass has a single dominant set with steep dip angles and large spacing, and to evaluate the joint effect, the vertical joints were embedded with the Ubiquitous joint model command. The input ground motion prescribed at the model bottom for base shaking is a past earthquake data recorded at a nearby monitoring station. The maximum stress is acting in the same direction as the gravity as shown in Figure 3(a) by arrows. The confining pressure value exerted here is estimated to be 0.65MPa at a depth of 40 m around the roof walls of the quarry.

4 RESULTS AND DISCUSSION

After applying the vertical stress according to the overburden depth of 40 m acting on the quarry with total depth base of 80m shown in Figure 3(a), there was further subsidence change observed around the roof of about 3.7

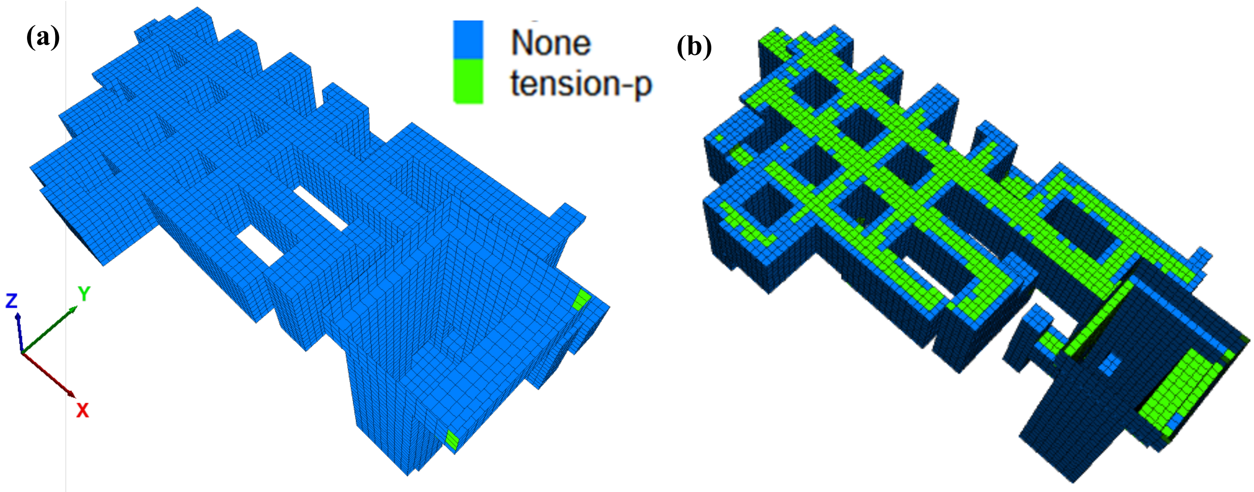

Figure 5.The excavated section showing yield zones **(a)** static **(b)** dynamic

cm. Subsequent embedment of a joint discontinuity, a subsidence of a higher value of about 3.9 cm, particularly around pillar regions with a joint. The contours of the vertical displacement are shown in Figure 4. The slight deformation change in the static state was expected since the joint dips were 90 degree dip and similar results have been obtained before The distribution of the maximum displacement decreases down from the roof to the floor of the quarry, with a maximum and lowest displacement of 4 cm and 3 mm respectively on the joint model. Figure 5 illustrates the dynamic state which simulation reveals the possibility of the roof and top shaft walls failure and, whereas static conditions showed yielding on shaft walls only.

5 CONCLUSION

A preliminary numerical simulation was carried out to simulate and investigate the stability of the underground quarry. Joint discontinuities embedded in the model showed that joints could be neglected for stability evaluation case of vertical joints. This study obtained quite low displacement results and predicted stable condition in the static state. Therefore more comprehensive review needs to be undertaken with the exact joint discontinuity orientations mapped from the underground quarry to validate the results and ensure stability. Moreover, simulation of the dynamic state show chances of failure and requires countermeasure recommendations

REFERENCES

Tokyo Commerce and Industry, D., 1983. Guide for quarry technique of Oya stone in Oya area (in Japanese).

Agharazi, A., Martin, C. D. & Tannant, D. D., 2011. Implementation of an equivalent continuum constitutive model for rock masses with systematic joint sets in FLAC3D. *Continuum and Distinct Element Numerical Modeling in Geomechanics,* pp. 1-9.

Aydan, Ö., 2014. Crustal stress changes and characteristics of damageto geo-engineering structures induced by the Great East Japan Earthquake of 2011. *Bull Eng Geol Environ (2015) 74:1057–1070,* p. 1064..

Bäckblom, G., Munier, C. R. & AB, S. K., 2001. *Effects of earthquakes on the deep repository for spent fuel in Sweden based on case studies and preliminary model results,* Stockholm: s.n.

Brady, B. H. G. & Brown, E. T., 2004. *Rock Mechanics For underground Mining.* third ed. Dordrecht: Kluwer Academic Publishers.

Esterhuizen, G. S., Dolinar, D. R., Ellenberger, J. L. & Prosser, L. J., 2011. Pillar and Roof Span Design Guidelines for Underground Stone Mines. *Information Circular 9526,* pp. 1-75.

Hyuing-Sik, Hyuing-Sik, Y., Won-Beom, K. & Ali, M. A., 2012. Perfomance of pillar design in underground stone mines that include discontinuities. *Geosystem Engineering,* pp. 187-194.

Jaeger, J. C., 1960. Shear failure of anisotropic rocks. *Geol Mag 97*, pp. 65-72.

Kortnik, J., 2009. OPTIMIZATION OF THE HIGH SAFETY PILLARS FOR THE UNDERGROUND EXCAVATION OF NATURAL STONE BLOCKS. *Acta Geotechnica Slovenica,* pp. 37-41.

Mortazaria, A., Hassani, F. P. & Shabaani, M., 2009. A numerical investigation of rock pillar failure mechanisms in underground openings. *Computers and Geotechnics,* pp. 691-697.

Rafeh, F., Mroueh, H. & Burlon, S., 2015. Accounting for joints effect on the failure mechanisms of shallow underground chalk quarries. *Computers and Geotecnics,* pp. 247-261.

Sainsbury, B.-A. L., Pierce, M. & Ivars, D. M., 2008. *Simulation of Rock Mass Strength Anisotropy andScale Effects Using A Ubiquitous Joint Rock Mass (UJRM) Model.* s.l., s.n., pp. 1-9.

Sainsbury, B. L. & Sainsbury, D. P., 2017. Practical Use of the Ubiquitous-Joint Constitutive Model for the Simulation of Anisotropic Rock Masses. *Rock Mech Rock Eng,* pp. 1507-1528..

Seiki, T. et al., 2016. Seismic response of numerical analysis and field measurement in Oya tuff qurry. *Eurock,* p. 8p.

Wang, W. et al., 2001. Assessment of damage in mountain tunnels due to the Taiwan Chi-Chi Earthquake. *Tunnelling and Underground Space Technology,* pp. 133-150.

Zipf, R., 2001. TOWARD PILLAR DESIGN TO PREVENT COLLAPSE OF ROOM-AND-PILLAR MINES. *108th Annual Exhibit and Meeting, Society for Mining and Metallurgy and Exploration,* p. 11p.