2019 Rock Dynamics Summit– Aydan et al. (eds)
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Consideration of structural stability for Oya underground quarry with dynamic response

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ABSTRACT: Oya tuff, which is categorized as soft rock, has been excavated in Oya area of Utsunomiya City, Tochigi Prefecture, Japan, for building stone and retaining walls for several decades. It is one of the most commonly used rock materials in Japan. As a result, there are many abandoned underground quarries existing in this area. After the 2011 East Japan Great Earthquake, the consideration of the seismic responses of underground quarries has become very important. Almost all of Oya underground quarries have been excavated using room and pillar method except some, which are long wall type. In the study, the quarry under investigation is an active room and pillar type and this paper presents the field measurement techniques used to study the seismic response and micro tremor of the quarry. Through the seismic response analysis, this study tried to clear underground quarries. A numerical model was then developed using a FDM to assess the dynamic stability of the quarry.

1 INTRODUCTION

There are over 200 abandoned underground quarries located in Oya town, Utsunomiya city and Tochigi prefecture, Japan. Those underground quarries have been excavated by mining Oya tuff as a building stone for retaining walls and decoration plate for interior walls of houses. In the past there has been sinkholes caused by the underground mines of Oya tuff and in 1989 there was a huge land subsidence which resulted in some property such as houses being damaged (Oyagi and Hungr, 1989). Recently, another collapse occurred in Oya town during the 2011 Great East Japan Earthquake; however, this time, it was collapse of a semi underground mine pillar in Oya town (Aydan, 2015). With occurrence of this events, underground quarries are considered as unstable, therefore, several study was conducted to evaluate the stability (Katayose et. al, 2008, Seiki et. al, 2007 and 2016).

Previous study tried to understand the pillar movement in seismic wave and micro tremor. And it shows the movement of a part of the underground quarry (Seiki et. al, 2018).

This study tried progress the characteristics of seismic response of Oya tuff underground quarry through field monitoring and numerical analysis. At first the author carried out selecting seismic record and calculating amplitude ratio via FFT technique to clarify site effect of seismic response in Oya tuff underground. Secondly, we also measured micro tremor in/above the active underground quarries and calculated H/V spectrum (Nakamura, Y.,2008) to understand the relation of seismic response in/above the quarries deeply instead of the seismic record. Finally, we carried out the numerical analysis of Finite Differential Method to simulate the seismic response to understand the dominant frequency of the underground quarries and the ground in Oya.

2 SEISMIC RESPONSE OF UNDERGROUND QUAERRY

2.1 *Introduction to seismic analysis*

In this study, the authors carried out field seismic measurement at underground quarry and above ground. We also considered the dynamic stability of seismic response of the underground quarry with Fourier spectrum and natural frequency. We fereed the data measured by Observation center for

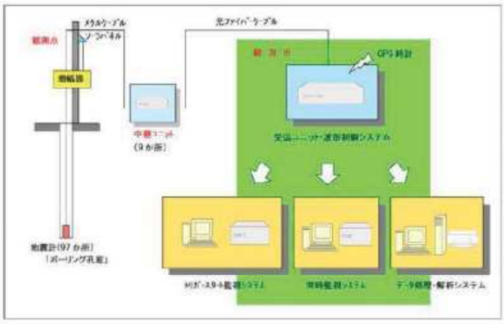

Figure 1. Concept for observation system in Oya.

ruined underground quarry. Whereas, Observation system for Oya tuff ruined underground quarries which consisted in 97 velocity meters, has measured tremor by cracking and spalling the roof and walls of those underground quarries and monitored the structural stabilities integrally for the those safety. The system is also monitoring ground water depth. The acquired data is analytically used for evaluating the collapse of the ruined quarries. Figure 1 show the system diagram. Velocity meters of 3 components, i.e. one vertical and two horizontal direction or 1 component, vertical direction only, are equipped at individual measuring point. Velocity meter for 1 components are settled because it is enough to catch the tremor induce by cracking and spalling. However,only at concerning point, the 3 component one are equipped. The instruments are bullied at the bottom at the borehole of 66 mm in diameter installed under over 20m from the ground surface due to neglect artificial noise on the ground. And amplifier was equipped at individual point to get precise tremor wave-shape by solar panels (See Fig. 2). Measured data was transferred into optical digital signal and reached at the observation centre.

2.2 *Analytical condition*

In previous study mainly carried out analysis, it focuses on apparently huge seismic wave. However as the huge seismic wave may largely affect to the seismic response, the author adopt middle range seismic data to the numerical analysis. On the other way, the authors also apply seismic wave data recorded near epicentre on the bottom of the geological model. It gave the exaggerate results against the collops possibility. In this study, the author apply the seismic wave data recorded in Oya area. It is more realistic way to simulate the seismic response. To neglect the difference among the epicentre location of seismic data as small as possible the authors chose the seismic data from the proper location, of epicentre, south-west part in Ibaragi prefecture for the analysis. To neglect the difference of transmitting feature, we chose the seismic data of epicentre which are deeper than 50 km. And to get characteristics of the seismic wave in the analysis, we chose the magnitude of seismic waves, Mj, which are greater than 3.0 (See Table 1). Additionally the authors selected the seismic waves which are able to distinguish among P-wave and S-wave in those records. And we categorize the data group into the data before rising ground water or no-water in the quarries and the data of the quarry filled with ground water. Later, we will name those groups as no ground water and filled ground water, respectively. We chose every

(a) (b) (c)

Figure 2. Monitoring system for Oya underground quarries (a) solar panel and pole for observation point with amplitude,(b) seismology meter (SM-4-3D), (c) transmitting unit .

Table 1. Factor f or selecting seismic wave data.

Items	Option
Area of epicenter	Southwest of Ibaraki Prefecture Lat.: 36.019 N – 36.358 N Long: 139.685 E – 140.109 E
Depth of epicenter	Greater than 50 km
Magnitude Mj	Greater than 3.0

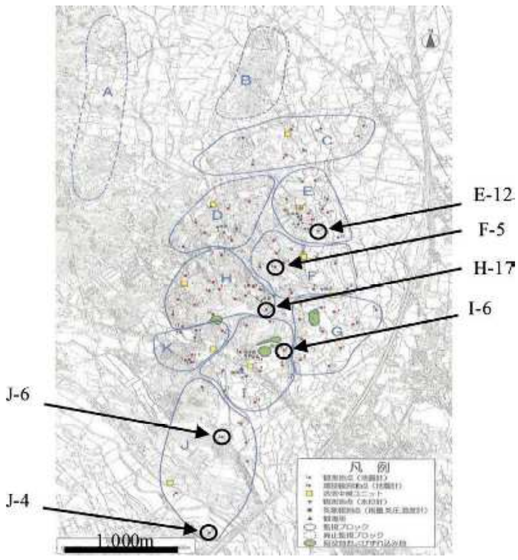

Figure 3. Observation points in Oya

16 monitoring point in the two groups. Figure 3 shows 6 observation points for analysis. In this analysis, we normalize the results of FFT analysis on every points by the results on the point J-4 and calculate the amplitude ratio of FFT, because the observation point J-4 locates most south part in Oya observation region and the seismic wave from southwest part in Ibaraki Prefecture may reach the top points. The amplitude ratio helps us to understand the characteristics of transmission for the seismic wave in this field. And we add the observation point J-6 which has no water in the ruined quarry beneath the observation point. We used the seismic wave from the beginning of P-wave to subsiding S-wave without the part of noise on the wave-shape. Figure 4 shows typical seismic wave for the FFT analysis.

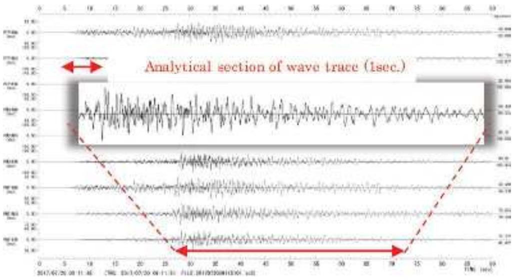

Figure 4. example of seismic record measured in Oya.

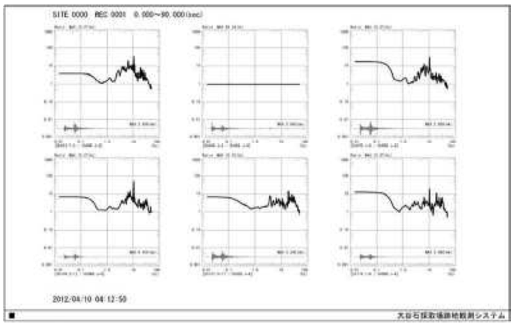

Figure 5. example of FFT spectrum on an observation point

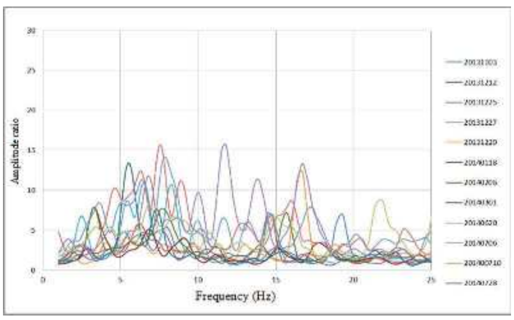

Figure 6. Example of Fourier spectrum of seismic wave on individual observation point.

2.3 *Results of FFT analysis*

We carried out Fourier spectrum analysis near the underground quarry with no ground water and filled water at all observation points. Figure 5 shows the example one. Figure 6 shows the result of FFT analysis of the all seismic wave data on the all observation points. As those spectrum includes dispersion widely in 16 seismic wave data before and after raising ground water level even though we neglect the characteristics of transmitting path of those waves, we have averaged those FFT spectrum to simplify those figures and show the results in Figure 7 and 8.

Transmitting feature shows that there is peak value between about 5.0Hz and 10 Hz shown in Figure 7 and 8. Additionally, there is peak value from about 15.0 Hz to 17.0 Hz after rising ground water in the ruined quarry shown in Figure 8. Comparing the amplitude ration before rising ground water with that after rising ground water, the amplitude ratio after rising ground water level is smaller than that before one. The value of observation point J-6 where the quarry has no ground water took apparently high amplitude ratio in all observation points shown in Figure 8. Based on those results it has been clear that underground quarries shows the peak of seismic response in about 5.0Hz -10Hz. Additionally, amplitude ratio after rising ground water tend to go down. Especially this tendency is

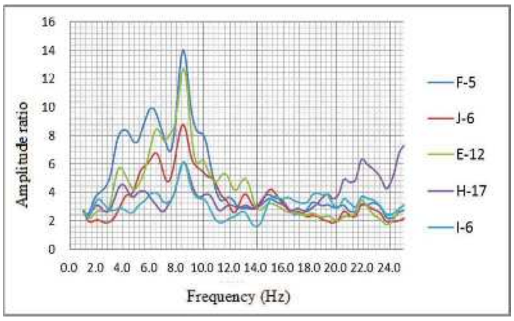

Figure 7. transmitting feature of underground quarries before rising ground water.

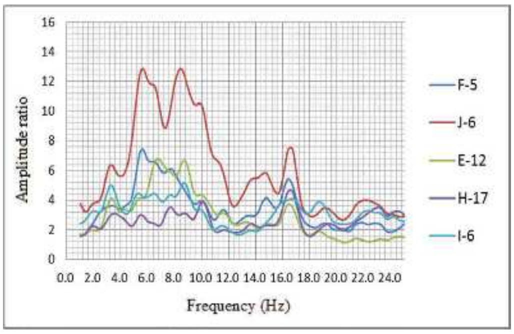

Figure 8. transmitting feature of underground quarries after rising ground water.

remarkably shown in the observation points H-17 and I-6. The amplitude reduction may indicate that the ground water inside of the ruined quarries affect to settle and develop the structural stability against seismic event. However, even though peak value of amplitude ratio around 15.0 Hz – 17.0 Hz is shown after rising ground water, this tendency is not seen before rising ground water and the observation point J-6 around the underground quarry with no ground water and some of observation points shows the peak value around 17.0Hz before and after rising ground water, the authors think that the peak amplitude ration around 17 Hz may be the characteristics of epicentres.

3 MICRO TREMOR ANALYSIS

Even though micro tremor and seismic wave are essentially different each other, relativity among them are recognized. So it is regarded that analysis of micro tremor gives same results by seismic wave. In this chapter, the authors carried out FFT analysis of observation data of micro tremor.

3.1 *Introduction to the analysis*

In this study, we used micro tremor measuring instrument, which has 2 components for horizontal velocity and 1 component of vertical one in a box. We settled the instrument and surveyed micro tremor at the base floor in the active underground quarries for Oya tuff. (J-5 and E-16 in Figure 9). Every measurement took 15 minutes for measuring micro tremor in three components. And we also compared the data and the data measured on the ground. We analyzed 3 components on FFT and calculated H/V spectrum.

3.2 *Result of analysis for micro tremor*

Figure 10.and 11 shows the results of active underground quarry A (it is a room and pillar type quarry, shown in J-5 in Figure 9) and B (it is a long wall type quarry shown in E-16 in Figure 9). We think those figures shows no special aspect of the underground quarries. The results above ground shows that the peak values are around 9.0 Hz - 11 Hz at the active underground quarry A and it is 6.0 Hz at the quarry B.

On the other hand, it is difficult to recognize the peak value in both underground quarries because the data include the effect of rock mass of Oya tuff instead of structure of the quarries as the measurement s carried out the on the base floor. However, the data on the ground includes the effect of the underground.

In the case of underground quarry A, the peak value of amplitude ratio shows 5.0 Hz -10.Hz as the seismic wave response shown in the Chapter 2. The peak value, around 11.0 Hz, by micro tremor on the ground may include the effect of soil layer,

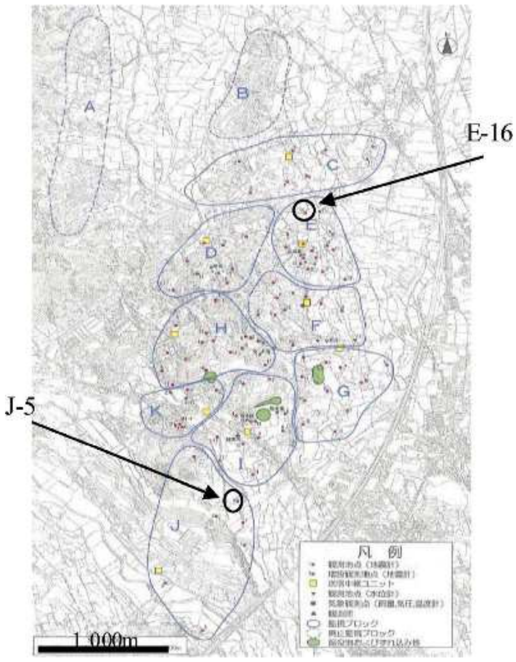

Figure 9. survey point of micro tremor in the active quarries.

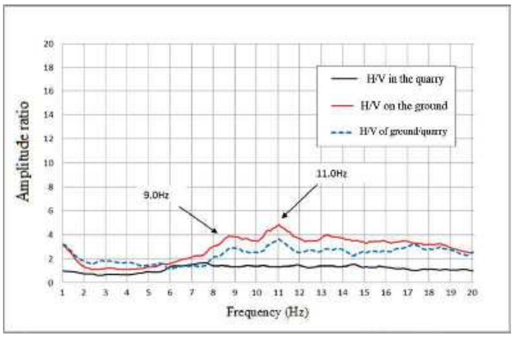

Figure 10. H/V spectrum in the underground A and its above ground.

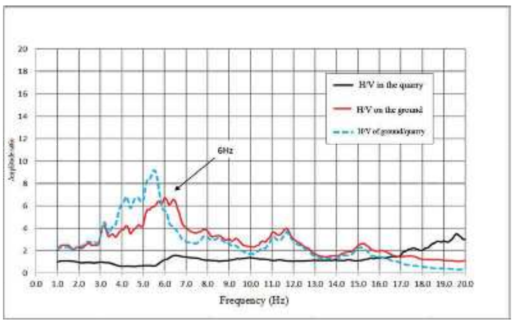

Figure 11. H/V spectrum in the underground B and its above ground.

i.e. Kanto roam layer and gravel layer laying among the ground surface and the Oya tuff layer. And the structure of underground quarry caused the peak difference. Additionally the difference of peak value between the underground quarry A and B should cause the structural difference each other.

4 THREE DIMENSIONAL DYNAMIC ANALYSIS FOR UNDER-GROUND QUARRY

4.1 *Introduction*

In this chapter, the authors carried out the numerical analysis to calculate deformation and seismic transmission for evaluating dominant frequency by on 3D-FDM software, FLAC3D. At first the authors generated three dimensional formation with proper boundary condition and initial condition of Oya area and calculated initial stress. Secondly, after excavating three dimensional structure of active underground quarry B, we applied seismic wave at the bottom of the model. Finally we have got the seismic response of the quarry.

4.2 *Numerical modelling process*

This study referred the geometry of an underground quarry for numerical analysis. It is an active quarry excavating Oya tuff and has long wall structure. Figure 12 and 13 show geological model for numerical analysis 500 m * 500 m * 100 m in this area. At first the model consisted in 1,875,000 rectangular solid shape zone. Around of the quarry, we employ fine zone which have 2 m in each side. The other zone have 10 m in each side. And we decrease height of the geological model to reduce the calculation time and apply distribution instead of overburden. To do that it is important to check the effect the inertia force. Finally we reduced the initial number of zone to 193,640. For dynamic analysis, we set free field boundary by the dash pot to regard the infinite boundary toward far from the sides

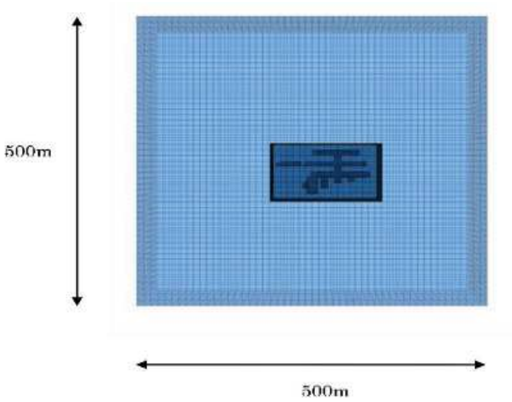

Figure 12. Overview of 3D Geological model for underground quarry (Dark blue area indicate fine zone and underground quarry.

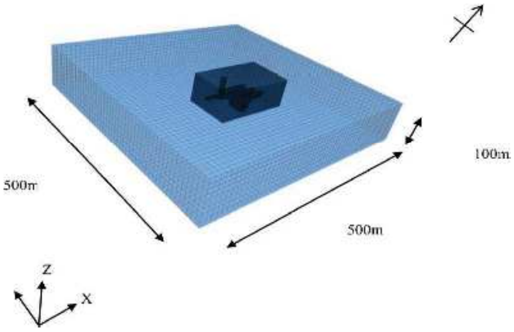

Figure 13. Plane view of 3D Geological model for underground quarry (Dark blue area indicate fine zone and underground quarry.

Table 2. Material parameter for numerical analysis.

Bulk modulus K (MPa)	1.38×10^3
Shear modulus G (MPa)	0.91×10^3
Cohesion C (MPa)	2.10
Internal friction angle ϕ (degree)	30
Tensile strength σ_t (MPa)	1.08
Density ρ_t (kg/m^3)	1.77×10^3

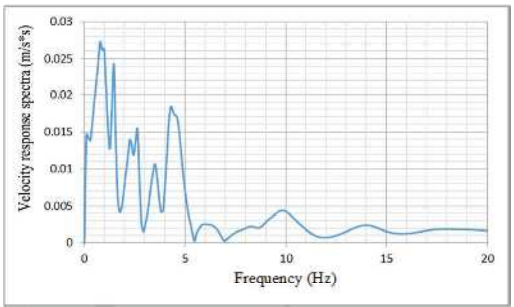

Figure 14. Seismic response at base floor in Oya underground quarry.

from geological model. We apply the apply the one of seismic waves, M4.8 in May 18, 2012 of which epicentre was located in South west of Ibaraki Prefecture and mentioned in chapter 2. Table 2 shows material parameters for the numerical analysis.

4.3 *Results of numerical analysis*

Figure 15.shows seismic response by FFT at base floor in the underground quarry and it explain the skew and gentle peak from about 4.0 Hz to10Hz except less than 4.0 Hz. It is same as micro tremor on FFT. In addition, results of numerical analysis show the other skew peak from about 1.0 Hz to 4.5Hz, it may be the structural effect of the underground quarry. It is considered that the dominant frequency of Oya area may be from about 5.0Hz to 10Hz and that of an Oya underground quarry may be from about 1.0 Hz to 4.5 Hz.

5 SUMMARY AND FUTURE WORK

5.1 *Summary*

This study has been clear the following knowledge.

Dominant frequency around Oya underground quarries is from about 5.0 Hz to 10 Hz by Fourier spectrum of seismic wave data which was recorded in Oya observation system. As amplitude ratio of those quarries after raising ground water level is smaller than those before rising ground water, it may tend that submerged underground quarries improve its structural stability.

This study measured micro tremor in 2 active underground quarries and those above ground and employ H/V process on the Fourier spectrum of 3 directional components. Roughly the results of micro tremor measured in active underground quarries also gave same tendency.

The authors also carried out three dimensional dynamic analysis by Flac3D to evaluate deformation and transmission feature in the state applying seismic wave. The peak frequencies are among about from 1.0 Hz to 4.5 Hz and from 4.0 Hz to 10 Hz at the seismic response on the base floor in the quarries. The dominant frequency of underground quarries may be regarded between about 1.0 Hz and 4.5 Hz. And the frequency between about 4.0 Hz and 10 Hz should be the dominant frequency in the Oya area. Because of attenuation in short frequency surrounding the quarries, the dominant frequency may not be observed.

5.2 *Future work*

As the dominant frequency of the velocity meter may cause the difficulty of measuring small frequency, other suitable velocity meters should be installed.

ACKNOWLWGEMENT

The authors thank to the Oya Area Development Co. for providing valuable data for this research. Additionally we also extend special thanks to the Coordinating Committee for Earthquake Prediction and the Chuden Engineering Consultants Co., Ltd. for financial support of some parts of this study.

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