第 45 回岩盤力学に関するシンポジウム講演集
公益社団法人土木学会　2017 年 1 月　講演番号 1

STABILITY ASSESSMENT OF ROCK BLOCK BY VIBRATION ANALYSIS

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Previous studies on rock fall, about the dynamics ahead of the actual collapse, have been carried out through empirical methods, lab and field experiments and numerically. The researches mainly evaluated the behaviour of rock blocks based on the observations from vibration characteristics and stability. The latter led to an investigation to be undertaken on vibration characteristics in relation to mechanical stability for rock blocks using a different numerical approach method; 3-dimensional Finite Difference Method (FDM) program Flac^{3D}. During the simulation, waves were induced into the model to comprehend the effects of mechanical stability on the vibration characteristics. Comparison with empirical results revealed a functional similarity.

Keywords: *rock fall, vibration, numerical analysis*

1. INTRODUCTION

Rock falls are described as the downward movement of the detached rock block from a slope of the cliff [1)]. The fall is characterised by either freefall, bouncing, toppling or sliding of rocks. The occurrence of rock fall is a significant concern in mines and road highways even though they pose less damage than the bench, stack and slope failure. Unlike other modes of failure, rock falls are considered not to have precursors thus unpredictable, and this factor shifted the focus of most researchers to the mitigation of rock falls than detection based on the occurrence of frequencies and observations from specification locations. Prediction of a failure requires a precursor typically, for instance in stack failures, change in parameters such as displacement and velocity mostly caused by moisture change, blasting, jacking and orientation of fractures, can be used to detect the movement before the failure, and this highly depends on the time taken to collapse. Advances in slope failure prediction in the past two decades have become more reliable and widely used as more remote sensing, and contact techniques are developed which include RADARs, GeoMos and inclinometers[2)], just to mention a few. One approach that has been developed was to try and use the photographic detection by[3)] in which sequence of photos taken to show and detect a change in position as rock falls take place. However, due to the time is made to process the pictures the approach, it was recommended for long-term monitoring. Ground-based remote sensing apparatus such as the Terrestrial Laser scanners and ground-based InSAR have given the possibility to really to detect the rock fall due to their ability to collect dense data at high accuracy. High-resolution data from cars and (TLS) have proven to be capable of detecting pre-failure deformations[4)] even for centimetric displacement[5)]. Nevertheless, the latter apparatus is suitable for spatial prediction of rockfalls over the long term. Rockfall still poses a challenge due to its nature of instantaneous time of collapse and not so easy to measure warning signs such as a gradual change in displacement.

Recently[6)] carried out an empirical simulation in the lab illustrated in Fig. 1 to investigate the vibration characteristics of rock blocks as precursors, using a hammer to generate vibrations and U- Doppler to record and monitor a relationship between vibration signatures and stability was established. Since there is an empirical relationship, a numerical model was developed in a simulating numerical code Flac^{3D} to relate vibration characteristics to the stability of rock blocks. In the simulation process, the focus was on how the mechanical parameters known to be affecting the stability of the rock blocks could alter the vibration characteristics and the possibility of the vibration characteristics subsequently being used to determine the stability of rock blocks. The numerical simulation has been carried out with Finite Element Method (FEM) by[7)] and confirmed the relationship between mechanical stability and dominant

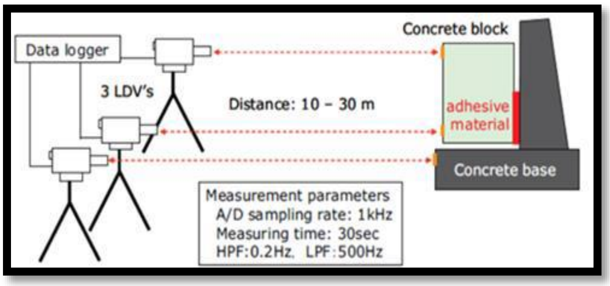


Figure 1. Schematic diagram of the measuring system in the lab[6)]

Table 1. Mechanical properties of the materials used for the model

Parameter	Bulk modulus (Pa)	Shear modulus (Pa)	Cohesion (Pa)	Tensile strength (Pa)	Density (kg/m^3)
Concrete	1.7×10^9	0.9×10^9	2.1×10^7	4×10^6	2400
Bonding block	1.73×10^9	0.86×10^9	2.1×10^6	0.85×10^6	–

frequency of block vibration, both qualitatively and quantitatively. Nevertheless, the mechanism that causes a specific frequency range at the failure state has not been cleared yet; they made an observation that the overturn safety factor is determined by the dominant frequency of the rock block.

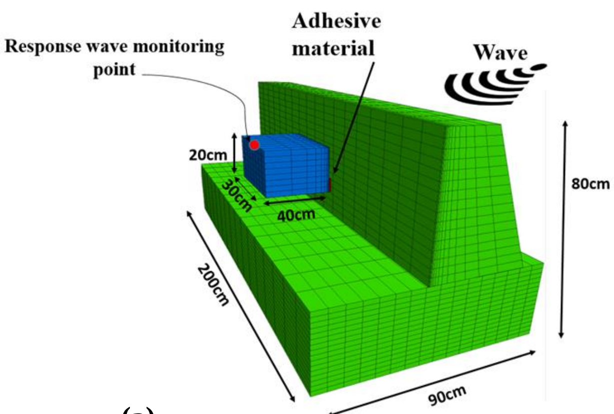
2. SIMULATION OUTLINE

A numerical program Flac^{3D} was used to perform the simulation. The setup used in the laboratory experiment was created in the FDM program with almost same measurements, as shown in Figure 2(a), with the small cube representing the concrete block fixed on a large concrete base. The contact/adhesive between the two blocks could be embodied in two ways the interface option or using an additional third block. However, the latter was preferred and used over the former due to the ease of in which its properties can be adjusted to change the stability of the rock block to the desired level. With the use of the additional block, three models were developed with different bonding lengths as shown in Table 1, similar to the lab experiment. Figure 2 (b) shows the cross sections of blocks with varying lengths of bonding. To use the bonding length as the only mechanical parameter affecting the stability, other material properties such as cohesion and tensile strength were adjusted to be equal to the standard concrete used by[6], then kept constant in all models during the simulation see Table 1. Therefore, an assumption has been made that the larger the bonding length, the more the block is stable and the shorter the length it is vice versa. However, the material properties of the bonding material used in the numerical model were different from the adhesive used in the practical experiment due to unavailability of the data. All model cases were subjected to an equal pulse intensity to represent the hammer at the same time duration in a dynamic state of Flac^{3D} code. In all the model runs the response vibration monitoring point was placed at the same location at the front of the small block as illustrated in Fig. 2(a). The boundary condition at the base was fixed, and on the sides, appropriate boundary condition was prescribed for the dynamic analyses.

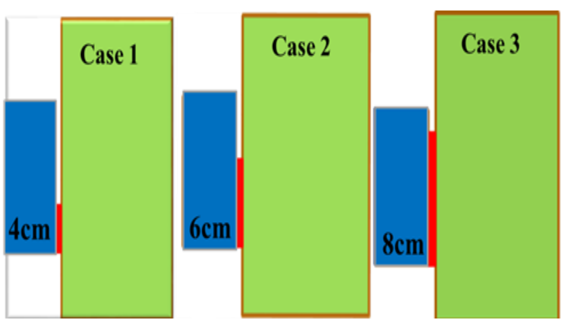
The state of the bonding material likewise it was put to investigation during the simulation processes. Thus it was monitored for the type of strain it has undergone. The strain conditions were checked immediately after the pulse stopped for all the cases, this allowed to check strain level changes from the start of the free vibration until all the end of the simulation after 1second of the dynamic mode.

3. RESULTS AND DISCUSSION

As stated before, models were subjected to a single pulse for a specific time interval of the whole run to induce the vibration and then monitored throughout remaining dynamic time, however, focused on the post-pulse energy transmission behaviour. The latter enabled the blocks to shake or vibrate freely after the pulse was stopped and



(a)



(b)

Figure 2. (a) Model setup in Flac^{3D}; and **(b)** cross-section of the three cases with different length

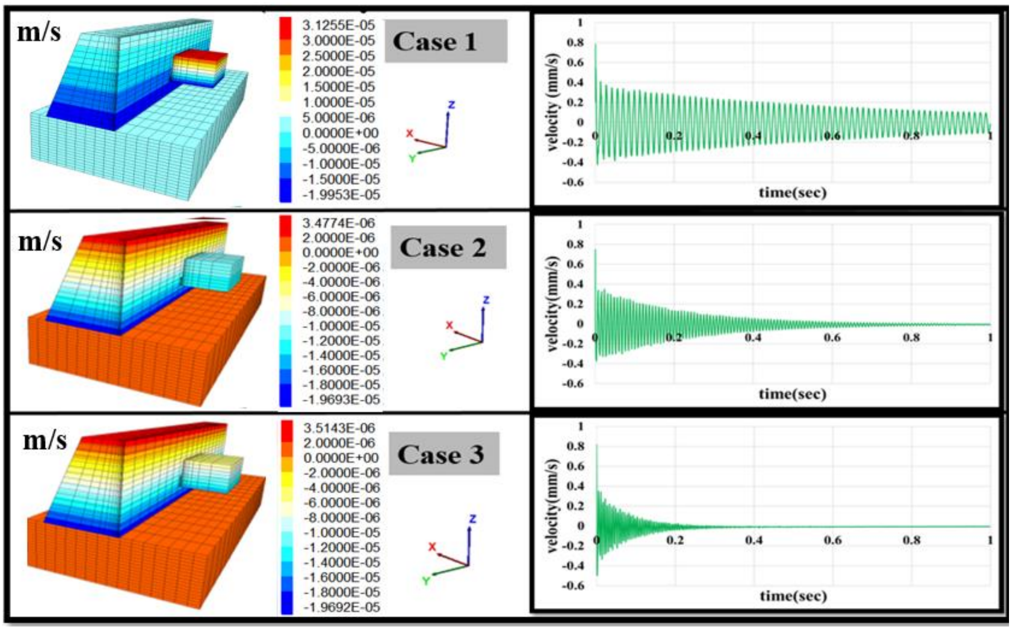


Figure 3. Velocity contours and velocity-time graph of the cases

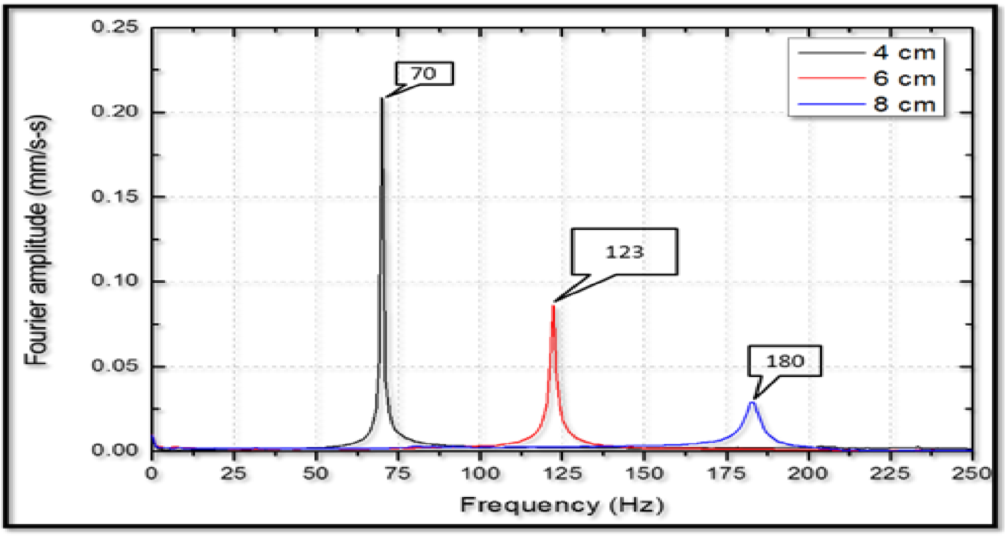


Figure 4. (a) Fourier spectrum for each case

allowed the evaluation of vibration characteristics as a function of stability. It is observed that models had different wave responses, Figure 3(a) shows the velocity contours distribution of the three cases, and it can be seen that case 1 rock block had higher velocities concentrated at the topmost part the block indicating more freedom movement and the base being at rest. The subsequent cases showed quite higher velocity concentration at the back of the concrete base top around the area where the pulse was applied however case 2 displaying more mobility of the concrete block than case 3.

In order to monitor the mobility of the model cases over time as well the characteristics of the response waveforms, velocity was plotted against time for all the cases as shown in Fig. 3. Velocity-time plots allowed to evaluate the waveforms in the frequency domain see Fig 4 for Fourier Fast Transform (FFT) analysis which confirmed the high velocities, intermediary, and low-velocity amplitudes observed in the velocity time graphs of case 1, 2 and 3 respectively. The dominant frequency values for all cases were obtained from the FFT curve.

At joint contacts, mobility generally depends on two aspects that is joint stiffness and strength. Joint stiffness is classified it to two, normal and shear stiffness, both of which are defined as the ratio of normal stress to normal displacement and peak shear stress to shear displacement. Stiffness is controlled by the condition of joint contact surfaces, that is a property of the joint filling material at the contact or properties of the fracture surface itself determine the stiffness value. It should be noted that without contact joint stiffness is zero. It is accepted that stiffness could be infinite if the joint is completely mated.

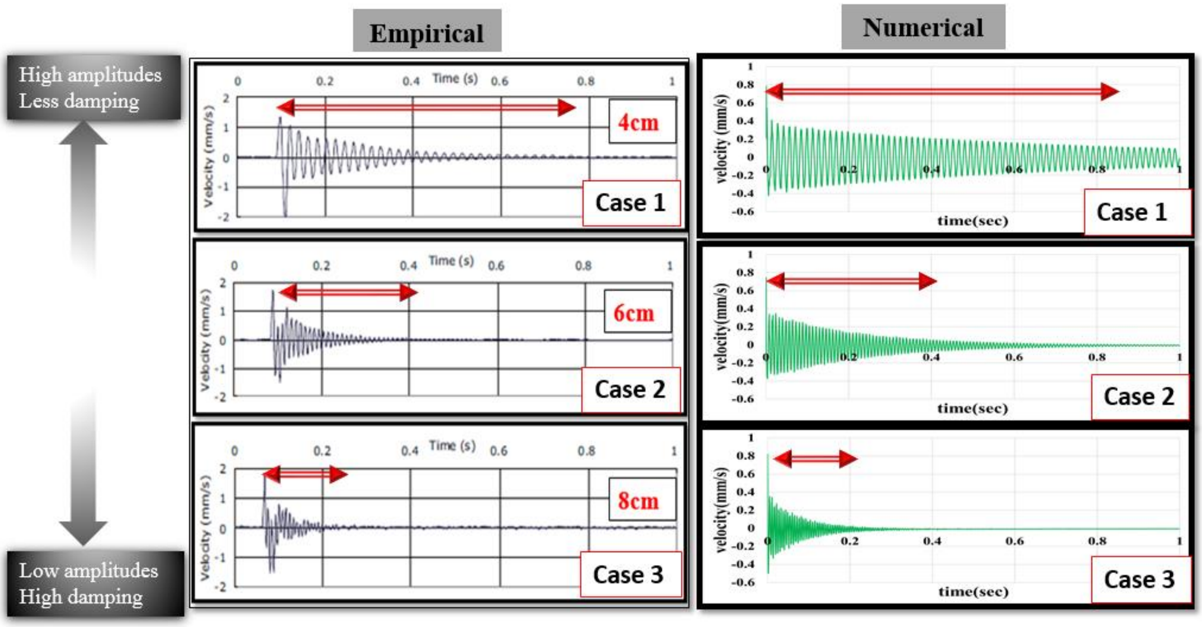


Figure 5. Comparison of empirical and numerical velocity results

Shear stiffness is estimated by on a single joint by dividing shear stress formula by the joint length L_x[8] in Eq. (1) as follows:

$$Ks = \frac{100}{Lx}\sigma_n \tan[JRClog_{10}\left(\frac{JCS}{\sigma_n}\right) + \emptyset r\ ] \qquad (1)$$

Where K_s is shear stiffness and L_x is the joint length. *JRC* is the joint roughness coefficient, *JCS* is the joint compressive strength, ϕ r is the joint friction angle between the joint walls and σ n is the normal effective stress acting on the joint surface

By taking note of the K_s in formula proposed by[8], the length of the joint vital in determining the stiffness, so by increasing the extent of the bonding material at a joint, range of the open joint will concurrently reduce as the opening at the joint closes up. Additionally, the presence of the adhesive material offers resistance by friction at contact, in turn, restricting movement; perhaps it could explain the results obtained from the three cases.

4. COMPARISON OF NUMERICAL AND EMPIRICAL RESULTS

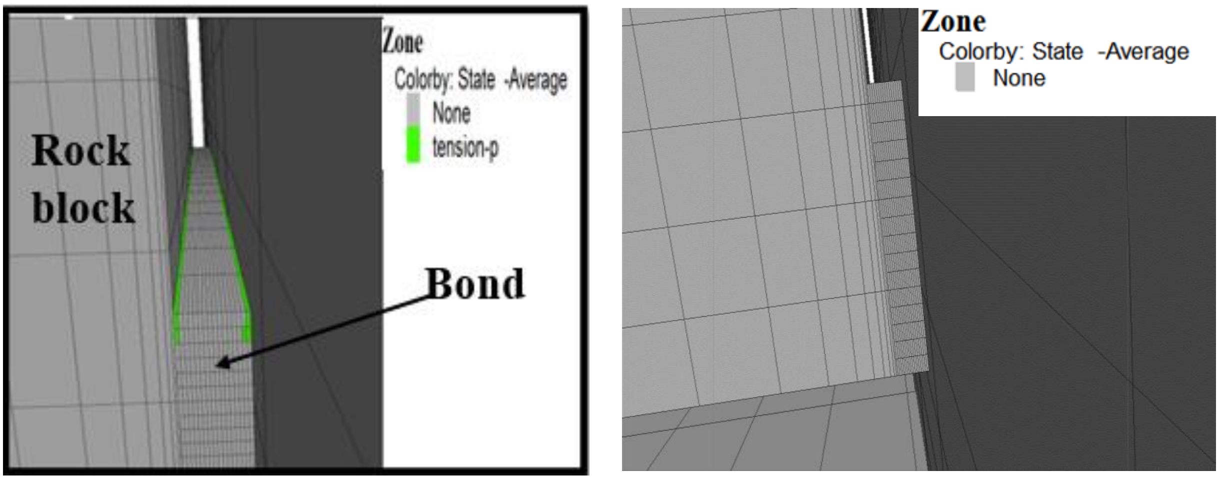
To check the validity of the numerical outcomes the numerical results had been compared with the empirical findings. On the analysis of both numerical and practical results, it was apparent that results are similar qualitatively. Figure 5 shows the results from the two methods, the case 1 models tend to have higher amplitudes at low frequencies and this changes more with case 3 models where amplitudes get reduced and frequencies increase. This trend in the amplitudes and frequencies is brought about by the level of stability in the block because the unstable blocks have less restriction in movement due to small bonding surface area and result in a weak bond. Therefore when they receive excitation energy from the wave, it will take more time for their oscillations to decay until rest see Figure 6.

Concurrently these oscillations will be defined by a high amplitude that takes a while to decrease and return to rest, consequently leading to few number of complete cycles in other words that are at low frequencies and long wavelengths. The outcome differs in stable blocks situation as oscillations take less time to decay to rest due to the restrictions of movement since the bonding surface area is large. The vibrations here can only make oscillations with progressively decreased small amplitudes that complete cycles in a short time. Moreover, measurably the waveforms obtained from the numerical process showed higher values of amplitudes and frequencies than the laboratory counterpart, this could be due to the limitations encountered during the mathematical simulation process.

As mentioned before, it will be meaningful to assess the deformation state of the bonding material at the end of the simulation. The assessment will enable validation of the assumption made at the start of the investigation that bonding length is directly proportional to stability. Yield zones developed on the case 1 model, indicating tensional failure of the bond. Other cases, zones behaved elastically until the end, with no strained zones. However, case 2 showed that has higher strain increment than case 3.

5. CONCLUSION AND FUTURE WORK

Two different techniques used vibration to evaluate and analyse the stability of a rock block have been presented. The conducted investigation showed that both results had similar vibration waveform trends regarding velocity, amplitudes, frequency and damping. In brief, the way the energy dissipates in unstable and stable blocks is different, and it can be illustrated by analysing the vibration



(a) **(b)**

Figure 6(a) Yield state of case1 bonding length **(b)** Yield state of case 2 and 3

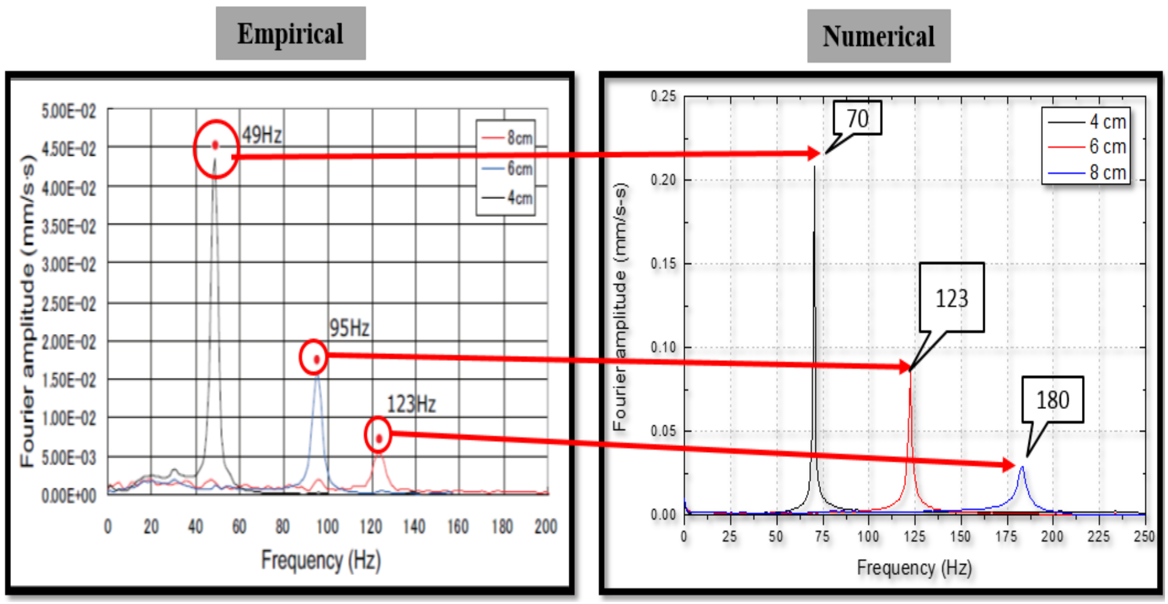


Figure 7. Comparison of the FFT results of empirical and numerical models

waveforms of each stability condition. Qualitatively the results are in agreement although quantitatively there is a considerable difference, possibly caused by the difference in material properties of the adhesive material used in the experimental and numerical models, and the impact of the wave, therefore, requires further investigation. Moreover to take other stability affecting factors into consideration such as joint stiffness, block, e.g. size, position, as well as the frequency at the point at which the block is about to fall or break.

With regard to the bonding length, it can assuredly be concluded that it has a direct effect on the joint strength or the contact area by way of increasing or reducing the stiffness of the joint. From the numerical analysis, it is noted that vibration response has the potential to be applied in the stability evaluation of the block when scrutinising it against the length of bonding material. However, the extent to which it could be potentially be used it is yet to be determined and both empirically and numerically.

References

1) D. Cruden and D. Varnes, "Landslide Types and Processes," 1996.

2) F. Ramsden, N. Coli, A. I. Benedeti, A. Falomi, L. Leoni and A. Michelin, "Effective use of slope monitoring radar to predict slope failure at Jwaneng Mine, Botswana," *The Southern African Institute of Mining and Metallurgy, slope stability*, 2015.

3) E. L. MuHugh and J. M. Girard, "Evaluating techniques for monitoring rock falls and slope stability," *Proceedings, 21st International Conference On Ground Control Mining*, 2002.

4) L. Di Matteo, S. Romeo and D. S. Kieffer, "rock fall analysis in an Alpine area by using a reliable integrated monitoring system: results from the Ingelsberg slope (Salzburg Land, Austria)," *Bulletin of Engineering Geology and the Environment*, 2017.

5) A. Abellan, J. Calvet, J. M. Vilaplana and J. Blanchard, "Detection and spatial prediction of

rockfalls using terrestrial laser scanner monitoring," *Geomorphology,* p. 162 171, 2010.

6) H. Saito, M. Tsuji, Y. Ohtsuka, F. Lehman, F. Murata, G. Ma, K. Sawada, A. Yashima and T. Fukata, "A study on evaluating rock slope stability by remotely-positioned Laser Doppler Vibrometers," *Proceedings of the 10th SEGJ International Symposium,* pp. 384-387, 2011.

7) S. Minoura, F. Uehan and H. Saito, "fundamental study on evaluating rock slope stability measurement and using remote vibration measuring system," *Computational Methods in Structural Dynamics and Earthquake Engineering,* pp. 3403-3414, 2013.

8) N. R. Barton and V. Choubey, "The shear strength of rock joints in theory and practice," *Rock Mechanics,* 1977.