Investigation of Quarry Blast-Induced Vibration to Structures

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ABSTRACT

In Malaysia, blasting is a widely used technique for rock breakage in mining, quarrying and construction industry. The use of explosives to execute blasting operation generates ground vibrations, which result into damage potential to structures and substantial nuisance to the local population. This study investigates the effect of rock blast to structures. A field experiment is carried out to obtain the ground vibration parameters due to quarry blast activities. Blast vibration measured on the ground use as input to excite the structures. Dynamic responses of five frame models subjected to the measured ground vibrations induced are analyzed through finite element modelling (FEM). Dynamic responses and frequency obtained from the analysis are used to quantify the damage potential of the structures. Numerical results are compared with standards of permissible vibration levels. The effects of quarry blast-induced ground vibration on dynamic response of different buildings criteria are discussed.

KEYWORDS

Blast-Induced Ground Vibration, Structural Response, Frequency

INTRODUCTION

Blasting is one of major economical operations to break the rock in order for it to be excavated or removed. As an explosive charge detonated in a shot hole, a rapid discharge of energy takes place within a short period causing tremendous rise in pressure and temperature. Most of energy released will be utilized in the breakage of the rock; however, a significant percentage is wasted. The wasted energy is dissipated away and caused environmental impacts; for instance ground vibration, air blasts and fly rocks. Of all impacts, ground vibration is most concern in this study.

Many public complaints have been received by local authorities related to the blast activities. Most of the complaints are related to structural response such as houses shake. Therefore, this study provides an investigation of the effect of quarry blast-induced vibration. According to Siskind et al. (1980) and Jimeno et al. (1995), generation of ground vibration from the detonation of explosives can cause significant damage to the structures and annoyance to residents in the vicinity of quarries. The residential houses which in close range to the blast location may experience significant disturbance due to blast operations. The potential connection between blast vibrations and damage to structure and its components has often been questioned. Historically, the answers that have been published are dependent on vibration levels and frequencies together with recommended maximum levels in order to prevent such criteria being exceeded. USBM was at the forefront of studying the effects of blast vibration. Over a period of 40 years, the USBM prepared detailed reports which covered the aspects of vibration generation, propagation and the impacts on residential structures (Siskind, 2000).

There has been limited publication of structural response induced by quarry blast vibrations. Based on the literatures, many studies are carried out with a similar approach, which is experimental based. Nevertheless, most of them are context dependent where the results are subject to the study area only, and the results are based on site characteristics, propagation of seismic waves in the ground and blasting criteria. Therefore, the application of computational modelling should be used to evaluate vibration levels during early stages of design, making it possible to foresee material damages on structures.

This study investigates the effects of ground vibration to structure at a certain distance from the blast area. Measurement of ground vibration was conducted at the closest residential building to the blast location. The tests are performed to obtain ground acceleration and frequency of the nearby structures resulted from blast activities. Finite element model (FEM) is developed to analyse responses of five low-rise and high-rise reinforced concrete (RC) frames subjected to blast vibration. Numerical results are compared to the established standards of allowable vibration levels. The effects of quarry blast-induced ground vibration on dynamic response of RC buildings criteria are discussed.

BLAST-INDUCED GROUND VIBRATION

The study was carried out at quarry located in a suburban area in Johor, Malaysia. The quarry had been operated since 1965 and produces granite for the construction industry in Johor Bahru, Malaysia. The residents live and work nearby often complaint about the vibration caused by the blast activities. As the purpose of the study to investigate the vibrations response of a structure, measurement of blast vibration was carried out nearby the residential house in the vicinity area of quarry. The distance of measuring point to the blast location is 660 m.

Field trial was conducted with blasts initiated at quarry bench. The parameters of charge quantity per hole and the distance between the blast and measuring station were recorded. Drill diameter was 76 mm and the depth of shot holes were up to 12 m. Burden varied from 3 to 6 m. Similarly, spacing varied from 4 and 7 m. The number of holes charges and detonated in a blast were 70. The explosive detonated per delay was 87 kg.

Blast loadings resulted from the detonation of explosives are determined by measuring the vibrations on the ground. Two measuring points in vertical and horizontal direction are allocated near the foundation of the structure. To ensure the accelerometers are adequately coupled to the ground, a small hole of about 20 cm deep was dug. The instrument used for the measurement consists of a IMC CS-3008 Data Acquisition and two single axis accelerometers with sensitivity of 0.1 V/g and 1 V/g respectively. The time histories of the acceleration response were measured when the blast is detonated. From the time series plot, only the horizontal accelerometers recorded noticeable vibrations while the vertical just captured noise. Therefore, only the horizontal vibrations are presented in the paper and used as input to excite the structures.

Baseline correction of the measured data is performed to overcome the uncertainties regarding the initial conditions for ground vibration and position of the zero acceleration axis. Figure 1 shows the corrected horizontal ground acceleration time history measured 660 m from the blasting operation. Its velocity response spectrum and power spectrum is also shown in the figures. It is observed that ground vibration energy lies between 7 and 25 Hz. This is based on peak-picking technique of power spectra (Bendat and Piersol, 1993). The velocity response spectrum shows three significant peaks. The first peak occurs at about 6.5 Hz and the second peak at 13 Hz, whereas the third peak occurs at 25 Hz. Frequency values of ground vibration were below 40 Hz, which is considered as low frequency according to international standards. Thus, the potential damage occur to the nearby structure is higher than those in high frequency which greater than 40 Hz.

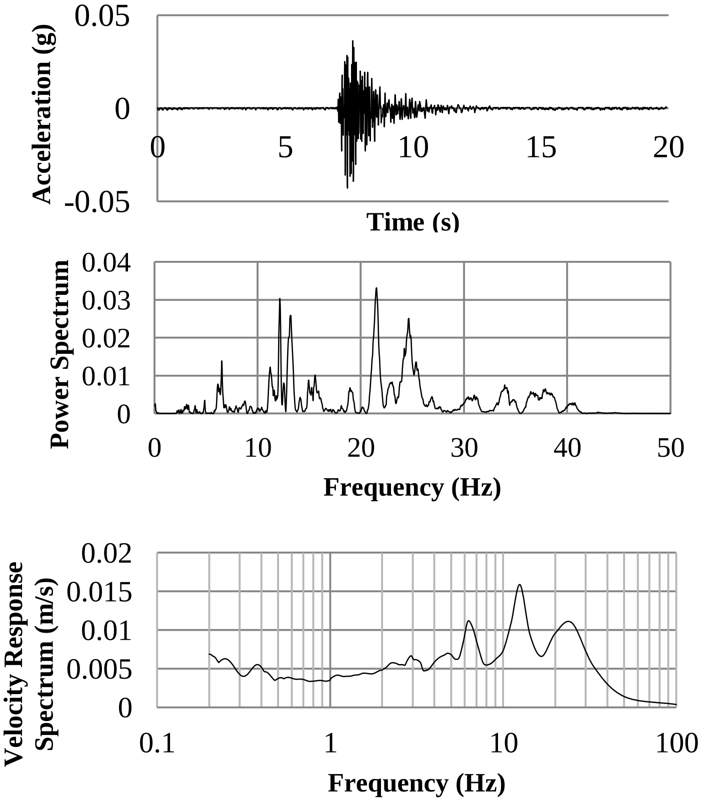


Figure 1. Recorded horizontal ground acceleration, its response spectrum and power spectrum.

Structural model

Different models were used to simulate the dynamic response of building excited by ground vibration induced by quarry blasting. In this study, five reinforced concrete (RC) frames of different floor levels, namely 2-storey, 4-storey, 8-storey, 16-storey and 20-storey frames, designed according to BS8110. All frames have two bays with storey heights of 3.0 m and the bay width is4.0 m as shown in Fig. 2. The concrete used has the Young's modulus of 20 kN/mm² and the uniaxial compressive strength of 30 N/mm². The dimensions of beams and columns and their reinforcement ratios of five frames, as well as the loading used are the same as described by Hao et al (2001). For all models, linear elastic behaviour is assumed.

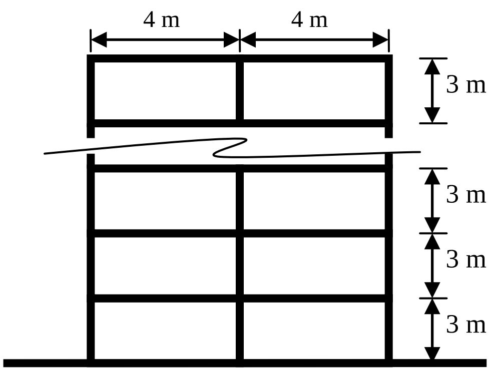


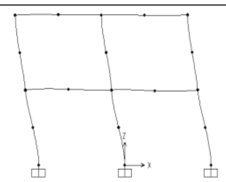
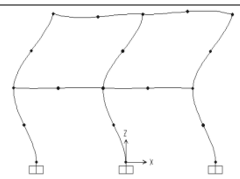
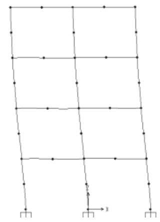
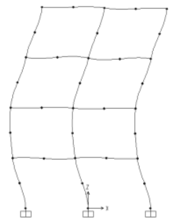
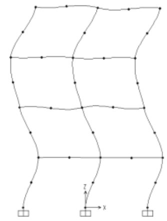
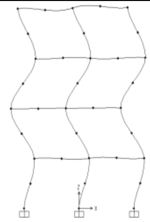
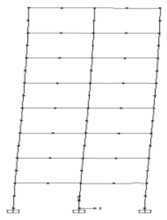
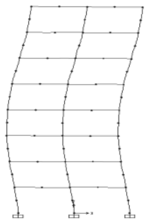
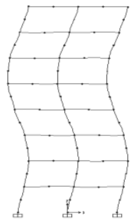
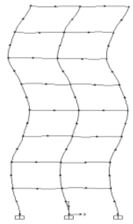
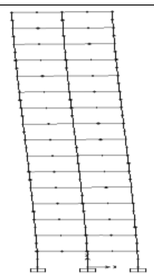
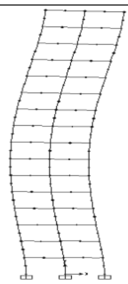
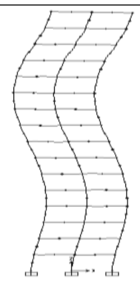
Figure 2. Structural frame

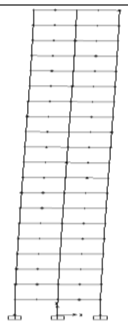
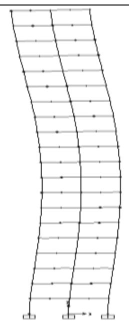
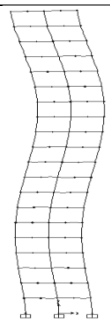
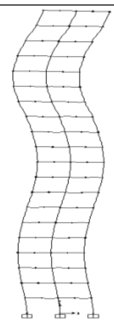
The equation of motion for a structure excited by ground acceleration can be expressed as:

$$M\ddot{y} + C\dot{y} + Ky = M\ddot{y}_o \quad (1)$$

where M, C, and K are mass, damping and stiffness matrices of the structure respectively; $\ddot{y}, \dot{y},$ and y are acceleration, velocity and displacement vectors, respectively; $\ddot{y}_o$ is the vector of ground acceleration induced by blasting and $M\ddot{y}_o$ is the effective force applied to the base of the structure. An integrated software SAP2000 is used to carry out numerical simulation of dynamic response of the structure. In computer modelling, all elements are assumed to be rigid in their own plane. All the components of the structure are considered without cracks or damages. Five percent of viscous damping is assumed for all the vibration modes in the analysis to consider the effect on free vibration phase. Table 1 lists the first four vibration frequencies of five building models. According to study performed by Dowding (1985), the typical natural frequency values of structures lies between 5 and 15 Hz, become lower as the number of floors increase. In this study, only horizontal ground vibration and lateral structural response are considered in the analysis as discussed above.

Table 1. First four vibration frequencies of building models

Building model	Mode 1	Mode 2	Mode 3	Mode 4
2-storey	 5.55 Hz	 16.31 Hz		
4-storey	 3.16 Hz	 9.89 Hz	 17.35 Hz	 24.13 Hz
8-storey	 1.59 Hz	 4.68 Hz	 8.23 Hz	 11.81 Hz
16-storey	 0.84 Hz	 2.42 Hz	 4.52 Hz	 6.08 Hz

20-storey	 0.70 Hz	 1.95 Hz	 3.53 Hz	 5.07 Hz

RESULTS AND DISCUSSION

The experimental values of acceleration served to analyse the propagation of the vibration response along the structural height. In this study, ground acceleration extracted from IMC device output is used as input to simulate finite element (FE) models of the specified structures. The maximum response values of the structures and their corresponding frequencies are then observed. In general, the acceleration response under seismic condition is preferred to be below 2.5 m/s² (Lee and Liang, 2005). Of all largest acceleration response values, none of them have exceeded the limitation

Table 2 summarises the largest structural response of models subjected to recorded vibration.. Among the models, the largest displacement and velocity occur at the roof level. However, the largest acceleration responses occurred at the tenth floor. This indicates that the dynamic responses are dominated by low vibration modes of structures, although the dominant ground vibration frequencies are much higher than the natural vibration frequencies of the structures. This indicates that the structures are prone to vibrate at their lower modes. However, it should be noted that low frequencies vibration can be harmful to the structures, because they tend to absorb more energy and progressively deform with time until plastic deformation occur. Moreover, the low frequencies vibrations have a longer duration which in turns will cause damage to the structure. More discussions on this will be provided in the next section.

Table 2. Largest structural response of models subjected to recorded vibration

Building model	Displacement, m (Floor Level)	Velocity, m/s (Floor Level)	Acceleration, m/s² (Floor Level)
2-storey	2.820E-05 (Roof)	1.611E-03 (Roof)	1.123E-01 (1st floor)
4-storey	5.620E-05 (Roof)	1.583E-03 (Roof)	7.768E-02 (1st floor)
8-storey	3.279E-05 (Roof)	1.283E-03 (Roof)	8.995E-02 (Roof)
16-storey	6.445E-05 (Roof)	1.605E-03 (8th floor)	1.366E-01 (10th floor)
20-storey	1.119E-04 (Roof)	1.431E-03 (19th floor)	1.161E-01 (8th floor)

Response Spectra Observations

Based on the anticipated ground vibration and structural characteristics of the building, peak response spectra curves are generated by determining the peak values of the response time histories in frequency bands. In this study, the ground acceleration is taken as input and the corresponding response spectra of the building for 5% damping is computed. Figure 3(a) - (f) illustrates the peak lateral structural response spectra of low rise building (8-storey) and high-rise building (20-storey) models subjected to the recorded vibration of 660 m from blast location. The purpose of the comparison is to determine the influence of vibration on different building's criteria. The peak response spectra of the other models which are not shown have a similar pattern to those illustrated in Figure 3.

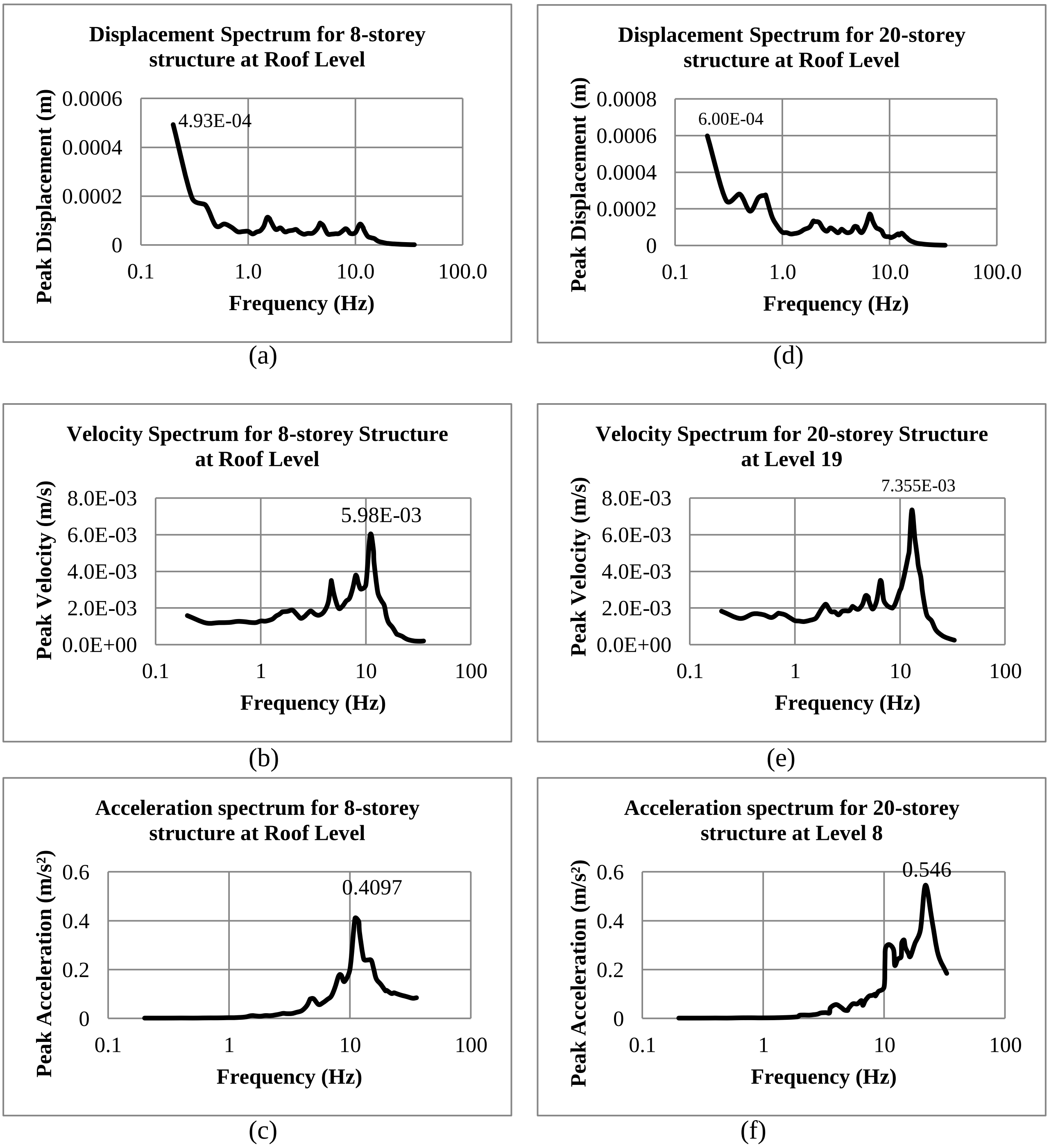


Figure 3 (a) – (f). Maximum structural response spectra of low-rise and high-rise models subjected to recorded vibration at 660 m from blast operation.

As shown in the figure, the high-rise building has larger displacement response value compared to the low-rise building. Among the models, the high-rise building experiences the largest displacement response. The low-rise model has significant displacement response occur in a frequency band of 0.2 Hz. The same pattern also occurred in other models, where the largest displacement occurs in a frequency of 0.2 – 0.3 Hz. This observation indicates that both low-rise and high-rise structures respond to the blast-induced vibration at their lower modes. However, the maximum displacement does not occur at the natural frequencies of the five models. This indicates that resonance does not occur at the structural vibration modes as the dominant ground vibration frequency is much higher than the natural vibration frequencies of the structure. Usually the dominant frequencies of blast induced ground vibration could occur at higher mode frequencies and typically range between 4 to 150 Hz. Since the dominant frequency of blast vibration as indicate in Figure 1 is between 7 to 25 Hz, it excites the low vibration modes.

From Figure 3 (b) – (e), it is observed that the high-rise building also experiences larger velocity and larger acceleration response value compared to low-rise building. The frequency bands associated to the dominant acceleration responses is much higher within the range of 11 Hz to 25 Hz than those of the dominant velocity responses. As expected, they are also higher than those of the dominant displacement responses.

Comparison with Standards

Table 3 lists the maximum responses of five models and their corresponding frequencies where they occur. It can be seen the largest displacement is 0.60 mm, the largest velocity is 7.36 mm/s and the largest acceleration is 764.5 mm/s².

Table 3. Maximum structural lateral responses

Response	2-storey		4-storey		8-storey		16-storey		20-storey	
	Value	Freq. (Hz)	Value	Freq. (Hz)	Value	Freq. (Hz)	Value	Freq. (Hz)	Value	Freq. (Hz)
Dis. (mm)	0.52	0.2	0.56	0.2	0.49	0.2	0.52	0.2	0.60	0.2
Vel. (mm/s)	6.10	15	6.50	3	5.98	11	4.06	6.1	7.36	13
Acc. (mm/s²)	764.5	15	440.3	16.5	409.7	11	545.8	22	545.8	22

The measured of peak velocity responses and frequency of five models were evaluated by taking into consideration several established damage criteria which are, United States Bureau of Mines (USBM) and German DIN. This regulation used to predict and compare the vibration intensities of the nearby structures. In this study, five RC buildings are in the class of modern homes and residential buildings according to USBM and DIN 4150 criteria respectively. Based on the USBM criteria, it is observed that the peak velocity response values of all models were below allowable limit and no damage is likely to occur as can be seen in Figure 4. And according to German DIN 4150 Part 3 standard, where vibration velocity is taken at uppermost full storey, the peak response of five models is below the acceptable limit which is less than 15 mm/s. These indicate the ground vibration induced by quarry blasting will not damage the RC structures located 660 m from the blast location.

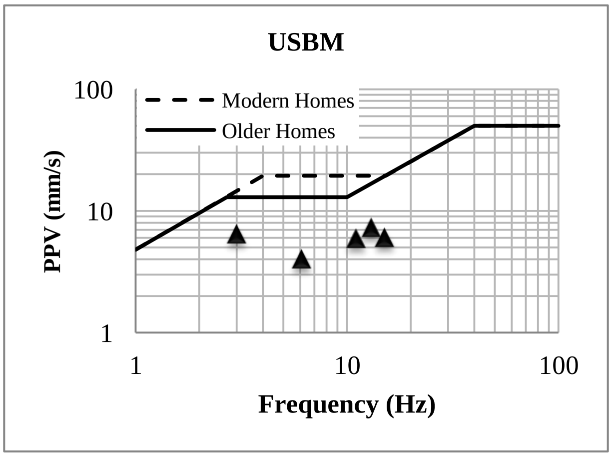


Figure 4. Evaluation of damage risk according to USBM criteria

CONCLUSION

Ground vibration was measured at the closest residential building to the blast location. The tests are performed to obtain ground acceleration on the nearby structures resulted from blast activities. Horizontal ground acceleration measured 660 m from the blast location used as input to analyse lateral dynamic response of five typical low-rise and high-rise RC buildings. The dominant frequency of quarry blast vibration lies between 7 to 25 Hz, which in close range to the dominant frequency of traffic-induced vibration (Hao et al. 2000), however, both measurements were taken at different distance from the source of vibration. According to Jayanthu et al. (2010), at distance more than 100 m, the dominant frequency of blast vibration will normally found between 15 to 30 Hz. Nevertheless, the frequency below 10 Hz is considered as critical since the potential damage might occur to the structures. From the analysis, it is found that the largest displacement and largest velocity responses occur at the top floor level. This is because of the dynamic responses of structures prone to vibrate at lower vibration modes. Besides ground vibration, low frequency noises are likely to occur and affect human beings and structures. It is important to install either active or passive isolation such as trench, as the screening method of waves from blasting to reduce both amplitude of ground vibration and noise problems.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial fund to this study from the Research University Grant (Vot. No. 01J99) of Universiti Teknologi Malaysia (UTM).

REFERENCES

Bendat J.S. and Piersol A.G. (1993). *Engineering Applications of Correlation and Spectral Analysis.* 2nd Edition, John Wiley & Sons, New York, USA.

British Standard Institution (1985). Structure use of concrete, BS8110:1985. Milton Keynes, UK: Linford Wood.

Dowding C.H. (1985). *Blast Vibration Monitoring and Control*, Prentiss Hall, Englewood Cliffs, NJ, p. 289.

Hao H., Ang T.C. and Shen J. (2001). Building vibration to traffic-induced ground motion. B*uilding and Environment.* 36. 321-336.

German Standards (1993). “Part 3 – Strcutural vibrations in building, effects on structure.” DIN4150, Berlin.

Jayanthu S., Naveen Ch., Rao G.V., Susheel Kumar B.R.V. (2010). Ground vibration in opencast mine blasts on structures vis-a-vis a local environmental effect and its mitigation through mining technology. International Conference on climate change perspectives and projections - a system approach, Hydearabd.

Jimeno L.C., Jimeno L.E. and Carcedo A.J.F. (1995). *Drilling and Blasting of Rocks*, A.A. Balkema, Rotterdam, p. 391.

Siskind D.E., Stagg, M.S., Kopp J.W. and Dowding C.H. (1980). Structure response and damaged produced by ground vibration from surface mine blasting, U.S. Bureau of Mines, R.I. 8507, p. 74.

Siskind D.E. (2000). Vibration from blastings. International Society of Explosive Engineers (ISEE).