© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie

ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Vibration Assessment on Various Distance to Demolition Works

Tuan Norhayati Tuan Chik[1*], Eric Soo Teck Lung[1], Nor Azizi Yusoff[1], Mohamad Taufik Tumiran[1], Ahmad Hafiz Farhan Mohd Suhaimi[1]

[1]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussien Onn Malaysia, 886400 Parit Raja, Batu Pahat, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2020.12.09.009

Received 18 November 2020; Accepted 07 December 2020; Available online 30 December 2020

Abstract: Abstract: Vibration has been a serious problem to be discussed over the past years. Vibration has caused cosmetic damages to buildings and annoyance to the occupants of the building. Sources of vibration are usually produced by construction work, traffic, seismic effect and human activities. In this paper, the amplitude of vibration caused by demolition has been analyzed and the level of vibration and level of damage caused have been determined. Besides, the effect of the vibration strength due to distance from the source has also been studied. The vibration data due to demolition work was obtained and analyzed by using MATLAB software. The analyzed data in graphical form were compared with the Gordon vibration criteria to obtain the vibration limit and the level of vibration damage according to DOE (Malaysia) standard as well. The results indicated that the vibration at 1m distance and 10m distance from the vibration source will cause minor damage to the building whereas the vibration at 25m distance from the source is at the caution level. By comparing the Gordon vibration criteria curve, the vibration from 1m, 10m and 25m distance from the demolition vibration source are not suitable for sensitive equipment. This study also proved that the vibration strength will decrease as the distance from the source increases due to the loss of vibration energy during the propagation of vibration waves. Hence, the further the distance from the source, the weaker the strength of the vibration and lower level of damage on surrounding buildings.

Keywords: Vibration, assessment, distance, comparison, demolition

1. Introduction

Vibration has always been the major concern to the engineers during the planning and construction stages. It has been reported that many complaints have been forwarded to the courts and the authorities due to the vibration caused by their buildings [1]. Vibration has caused cosmetic damages like plaster and window glasses cracks in the resident's house and caused discomfort, psychological stress and health diseases to the occupants of the building. Vibration would cause damages to sensitive equipment, structural components damages and nuisance to human health and comfort [2].

The vibration caused on the building will be one of a temporary nature but the disruption may cause permanent damages to the property and nuisance to the local population [3]. Property damages like window cracks and plaster cracks are considered as a minor problem which can be solved by repairing and replacing the damaged parts. The major problem in property damages is the cracks in structural members like beams and column that would lead to structural failure of a building which would bring harm to the residents and the people surrounding the building.

Construction activities, blasting and traffic are the main sources of ground vibration that would eventually contributes some effects on the building [4]. Construction activities like demolition of old buildings for various purpose

*Corresponding author: thayati@uthm.edu.my

are widely carried out in the urban areas. The concern about the vibration has been growing as the urbanization becomes denser [5]. The densification in the urban development of cities has increase the risk for buildings and people of getting affected by the vibration [6]. This is due to the buildings in the urbanized area are closely constructed to each other. Hence, the vibration received by the surrounding buildings are high enough to cause damages to the buildings and discomfort to the people. The level of vibration is often monitored using vibration measurement and compare with vibration standard to prevent it from causing damages to buildings.

Therefore, the aim of this paper is the amplitude of vibration signal obtained from demolition works were analyzed and compared within various distance to the specific buildings. The vibration assessment also was evaluated in accordance to the specific guidelines in order to ensure the buildings were comply with the limit.

2. Background of Vibration

Vibration is an oscillatory movement of the particles of the elastic medium that displaced about the equilibrium point and tend to restore its equilibrium. The motion could be harmonic, periodic or a general motion in which the amplitude changes with the time [7]. The theory of vibration is strongly related to the law of conservation of energy where the energy cannot be either created or destroyed but it can change its form. The energy that involves in the vibratory system are kinetic energy and potential energy. In the vibration of a system, the energy is transferred between kinetic energy and potential energy [8].

The derivation of general vibration equation is derived from the second-order ordinary differential equation through the application of Newton’s second law. The coefficients of the accelerations, velocities and displacements in the differential equation act as substitutes for the physical parameters such as inertia and damping. It can be classified into several types which include free vibration, forced vibration, damped vibration and resonance. Free vibration is vibration that will continue to oscillate by itself after an initial disturbance provided no external force is acting on it. Forced vibration is created when an external force is exerted on a system whereas damped vibration is the vibration that experience energy loss in the vibrating system. There are few types of damping exist which are underdamped, overly damped and critically damped. Resonance is a vibration problem that happens when the frequency coincides with or close to the natural frequency of a structure [9]. During resonance, the amplitude of the vibration is greatly amplified which could lead to structure failure if the vibration limit is exceeded.

Vibration can be induced by many kinds of sources and affect the surrounding with different level of vibration depending on the type of sources. It is mainly divided into two which are internal source and external source. Internal source occurs when the vibration is generated within the structure. This includes human induced vibration like walking, dancing and jumping [10]. External source is the source of vibration that is transmitted though the ground supporting of the structure. Some common examples of external source are construction work, traffic induced vibration and seismic effect. In the vibration damage threshold, peak particle velocity (PPV) is used to identify the potential damage due to the best correlated with case history data of damage occurrence [3].

2.1 Demolition Works

Demolition means completely or partially dismantle of buildings and other structures using pre-planned and controlled method. The method of demolition is depending on the project conditions, site constraints, and sensitivity of the neighborhood and availability of equipment. The demolition method includes top down method, hydraulic crusher, wrecking ball, implosion etc. Each kind of the demolition methods will produce different kinds of level of vibration depending on the operation way of the machinery.

In demolition works, the method commonly used for demolition is the explosive method. This is because explosive method is often used to increase the work efficiency as a small explosive charge is sufficient to take down the building in a short period of time. As for non-explosive method, it would take a long period of time to finish it and it is costly [11]. The vibration levels in the surrounding buildings of demolition work is likely to be affected by the site activity which include the type of activity, type of tools, operation and duration, the frequency content of vibration created, the ground condition, radiation damping, distance between activity and receiver building foundation and superstructure design [12].

2.2 Vibration Criteria

Vibration criterion curve was developed in the late 1900s for the need for design standards to accommodate a wide range of equipment, tools and sensitive structures. This criterion curve is used to provide safe level of vibration for all the sensitive equipment, tools and sensitive structures.

Vibration criteria (VC) curves were developed by Colin G. Gordon and his colleagues to act as a design standard to accommodate a wide range of tools and instruments used by the microelectronics, medical and biopharmaceutical industries [13]. These tools are all sensitive to vibration as they would get damaged or lose accuracy when these tools experience minor vibration. The VC curves are widely used throughout the world to design and evaluate the performance of microelectronics fabrication facilities. With the needs in technology and tool developments, the curves were further developed and modified to be used in wider range of vibration. The VC curve is shown in Fig. 1. Table 1 shows the description of application for each curve.

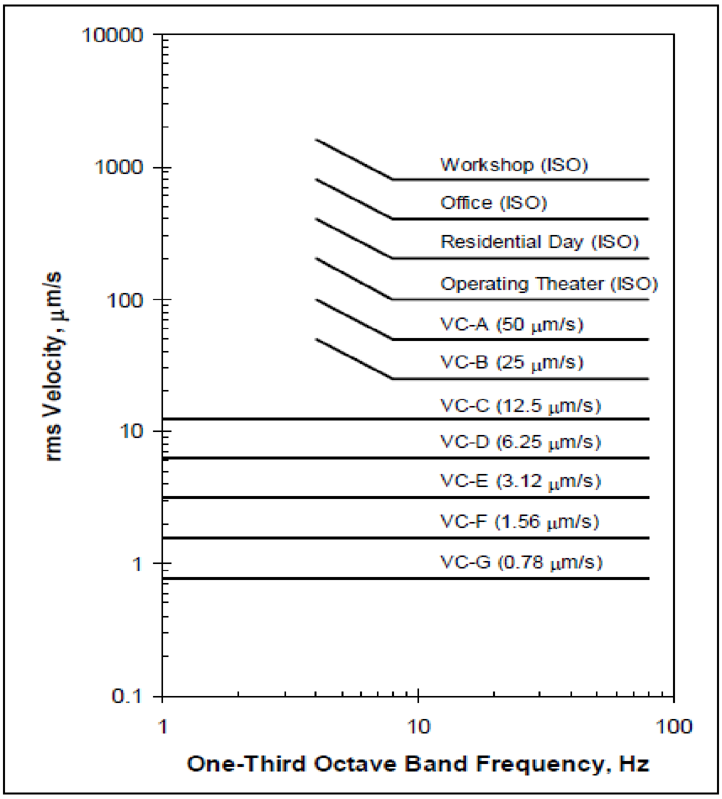


Fig 1 - Generic vibration criterion curves for vibration-sensitive equipment and the ISO guidelines for people in buildings [14]

Table 1 - Application and range of the vibration criteria curve of Fig. 1 [14]

Vibration Curve	Amplitude, μm/s	Detail size, μm	Application and experience
Workshop (ISO)	800	N/A	Distinctly perceptible vibration. Appropriate to workshops and no sensitive areas.
Office (ISO)	400	N/A	Perceptible vibration. Appropriate to offices and no sensitive areas.
Residential day (ISO)	200	75	Barely perceptible vibration. Appropriate to sleep areas in most instances. Usually adequate for computer equipment, hospital recovery rooms, semiconductor probe test equipment, and microscopes less than 40X.
Operating theatre (ISO)	100	25	Vibration not perceptible. Suitable in most instances for surgical suites, microscopes to 100X and other equipment of low sensitivity.
VC-A	50	8	Adequate in most instances for optical microscope to 400X, microbalances, optical balances, proximity and projection aligners, etc.
VC-B	25	3	Appropriate for inspection and lithography equipment (including steppers) to 3μm line widths.
VC-C	12.5	1 - 3	Appropriate standard for optical microscopes to 1000X, lithography and inspection equipment (including moderately sensitive electron microscopes) to 1μm line widths. TFT-LCD stepper/scanner processes.
VC-D	6.25	0.1 – 0.3	Suitable in most instances for demanding equipment, including electron microscopes (TEMs and SEMs) and E-Beam systems.

VC-E	3.12	< 0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, small target systems, E-Beam lithography systems working at nanometer scales and other systems requiring extraordinary dynamic stability.
VC-F	1.56	N/A	Appropriate for extremely quiet research spaces, generally difficult to achieve in most instances, especially cleanrooms. Not recommended for use as a design criterion, only for evaluation.
VC-G	0.78	N/A	Appropriate for extremely quiet research spaces, generally difficult to achieve in most instances, especially cleanrooms. Not recommended for use as a design criterion, only for evaluation.

2.3 Department of Environment (DOE), Malaysia Guideline

The guideline provides the vibration limits for steady state vibration, short-term vibration and single event impulsive excitation in buildings. The vibration limit in the guideline does not guarantee the absence of damage but it can reduce the possibility for the damage to occur. The acceptance of the vibration is assessed against the potential structural damage in buildings [15]. Each of the range of vibration limit represents the level of the potential damage in buildings. Therefore, the recommended vibration limits can be used to estimate the effect of the vibration to the building.

Table 2 shows the recommended limits for damage risk in buildings from steady state vibration where there are four kinds of damage level which are safe, caution level, minor damage and major damage. It is recommended not to exceed the upper limit of caution level under normal circumstances.

Table 2 - Recommended limits for damage risk in buildings from steady state vibration [15]

Damage Description	Vertical Vibration Peak Velocity v_{max}, [mm/s] (0 to Peak) , (10-100 Hz)
Safe	Less Than 3
Caution Level (Damage Not Necessary Inevitable)	3 to 5
Minor Damage	5 to 30
Major Damage	More Than 30

2.4 MATLAB Software

The word MATLAB originates from the word Matrix Laboratory. It is a state-of-the-art mathematical software package which is used extensively in both academia and industry. This is because it uses high-level programming language to perform computationally intensive tasks faster than then other programming languages. The function of MATLAB in vibration analysis is to analyze the dynamic response with the generic desired critical values [16]. In MATLAB, it allows the series of commands to be written into a file and execute the file as complete unit. This file is called the .m file. The main program has to be created in the form of m-file to specify the input data, call the relevant program and display the results. This includes the ModalV program which is used to generate one-third octave velocity spectra graph and vibration response graph with time history and frequency. Fig. 2 shows the vibration analyses process in MATLAB without involving ANSYS software in this study. The excitation (input) should be the vibration data from demolition works. The response (input) will be the graph obtained from the MATLAB analysis process.

3. Vibration Monitoring

The vibration monitoring data is obtained from demolition works at MRT Bukit Bintang, Kuala Lumpur infrastructure construction site. Bukit Bintang area is one of the cities in Kuala Lumpur that has high popularity. There are many tall and large buildings located in Bukit Bintang and the construction site is surrounded by many buildings like Lot 10 shopping mall and Bukit Bintang Plaza which can potentially be affected by the vibration due to the demolition work. The collected data by using Laser Doppler Vibrometer (LDV100) as shown in Fig. 3. The data then are further analyzed and determined if the vibration caused is in compliance with the vibration criterion. The LDV100 is set up based on six difference distances which has been planned as 1m, 5m, 10m, 15m, 20m and 25m from the sources of demolition works. The demolition work is carried out using hydraulic rock hammer. Therefore, the construction work must be done with extra cautious as the high vibration caused by demolition work could lead to failure of these buildings which would endanger the lives of the people around Bukit Bintang area. Fig. 4 shows the surrounding of the construction site at Bukit Bintang, Kuala Lumpur.

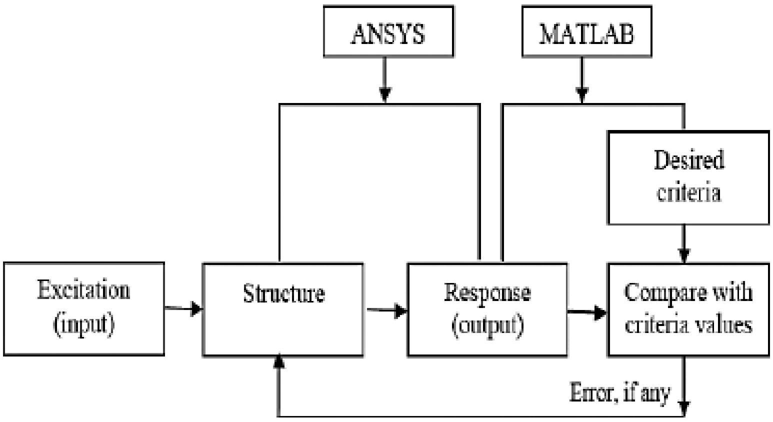


Fig 2 - Vibration assessment analysis process in MATLAB [16]

Fig 3 - Laser Doppler Vibrometer (LDV 100)

Fig 4 - Surrounding of Bukit Bintang MRT construction site [17]

4. Vibration Data and Discussion

ModalV analysis are utilized to perform the demolition and vibration data. In ModalV analysis, the various types of graph were produced for each of the data processed. The graphs include the vibration response with time history and frequency and the one-third octave velocity spectra. Besides that, spectrogram were also generated through ModalV analysis. The results obtained from the one-third octave velocity spectra graph then be used to compare with the vibration criteria from Gordon whereas the vibration response with time history is compared with the DOE guideline [15]. Table 3 shows vibration velocity against distances for each of measurement. There were five measurements were conducted during the peak time at the site with six distances.

Table 3 - Data collected for demolition work by hydraulic rock hammer [17]

Distance (m)	Measurement of vibration velocity (mm/s)					
	1	2	3	4	5	Average
1	10.1	11.4	10.5	14.4	25.3	14.34
5	9.90	9.87	11.3	7.39	7.88	9.27
10	7.28	7.37	6.41	10.1	5.18	7.27
15	4.01	3.87	10.9	7.86	6.58	6.64
20	5.88	4.13	3.57	9.87	5.18	5.73
25	2.68	5.18	3.14	4.32	3.76	3.82

The six different distances which are 1m, 5m, 10m, 15m, 20m and 25m overall in complete measurement. However, for the further analyses in ModalV analysis, only three which 1m, 10m and 25m were taken into account. The average reading from five measurement was also calculated. From the Table 2, it indicated that for distance 1m showing the highest value of vibration velocity which is 14.34 mm/s compared to the longest distance of 25m is about 3.82 mm/s. The detail plot for each distance is shown in Fig 5.

Fig. 5(a) shows the demolition vibration velocity for measurement 1. The vibration velocity was the highest at 1m distance which is 10.1 mm/s. At 5m distance from the vibration source, the vibration velocity decreased slightly to 9.9 mm/s and then continue to decrease drastically to 7.28 mm/s at 10m distance and 4.01 mm/s at 15m distance. The velocity surges to 5.88 mm/s at 20m distance and falls to 2.68 mm/s at 25m distance. Fig. 5(b) depicts the demolition vibration velocity in the second measurement. The vibration velocity was initially at 11.4 mm/s and dives sharply until the distance of 15m where the velocity is at 3.87 mm/s. The velocity was then increased gently from 10m distance to 25m distance.

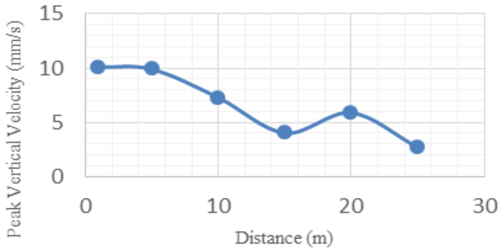
Fig. 5(c) describes the peak vertical velocity for demolition vibration for measurement 3. The graph illustrates that the peak vertical velocity fluctuates as the distance from the source increases. At 1m distance, the velocity is 10.5 mm/s and it grows modestly to 11.3 mm/s at 5m distance. The velocity was then decreased to 6.41 mm/s at 10m distance and rose back to 10.9 mm/s at 15m distance. From 15m to 25m distance, the velocity plummets rapidly to 3.14 mm/s at 25m distance.

Fig. 5(a) shows the demolition vibration velocity for measurement 1. The vibration velocity was the highest at 1m distance which is 10.1 mm/s. At 5m distance from the vibration source, the vibration velocity decreased slightly to 9.9 mm/s and then continue to decrease drastically to 7.28 mm/s at 10m distance and 4.01 mm/s at 15m distance. The velocity surges to 5.88 mm/s at 20m distance and falls to 2.68 mm/s at 25m distance. Fig. 5(b) depicts the demolition vibration velocity in the second measurement. The vibration velocity was initially at 11.4 mm/s and dives sharply until the distance of 15m where the velocity is at 3.87 mm/s. The velocity was then increased gently from 10m distance to 25m distance.

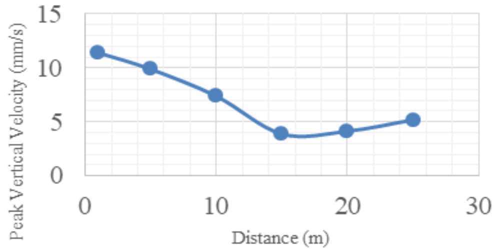
Fig. 5(c) describes the peak vertical velocity for demolition vibration for measurement 3. The graph illustrates that the peak vertical velocity fluctuates as the distance from the source increases. At 1m distance, the velocity is 10.5 mm/s and it grows modestly to 11.3 mm/s at 5m distance. The velocity was then decreased to 6.41 mm/s at 10m distance and rose back to 10.9 mm/s at 15m distance. From 15m to 25m distance, the velocity plummets rapidly to 3.14 mm/s at 25m distance.

The vibration velocity of ambient vibration in measurement 4 is illustrated in Fig. 5(d). The graph shows that the peak vertical velocity fluctuates with the increase of the distance from the source. At 1m distance, the velocity is the highest which is 14.4 mm/s and it fall to 7.39 mm/s at 5m distance. The peak vertical velocity was then rose to 10.1 mm/s at 10m distance. At 15m distance, it declines to 7.86 mm/s and then rises to 9.87 m/s at 20m distance and decreases to 4.32 mm/s at 25m distance.

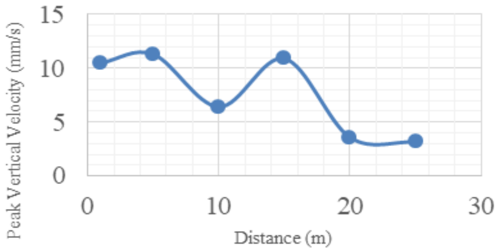
Fig. 5(e) depicts the demolition vibration velocity for measurement 5. The graph shows that the peak vertical velocity is decreasing exponentially to the distance from the vibration source. The peak vertical velocity was the highest at 1m distance which is 25.3 mm/s. The velocity declines drastically to 7.88 mm/s at 5m distance and then to 5.18 mm/s at 10m distance. The velocity was increased slightly to 6.58 mm/s at 15m distance and decrease gradually from 15m distance to 25m distance where vibration velocity is 5.18 mm/s and 3.76 mm/s at 20m distance and 25m distance respectively.



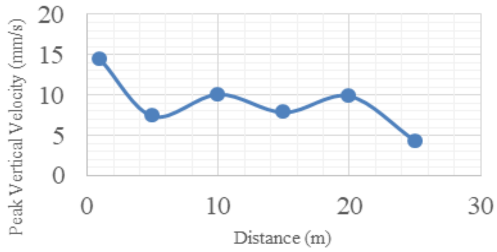
(a) Measurement 1



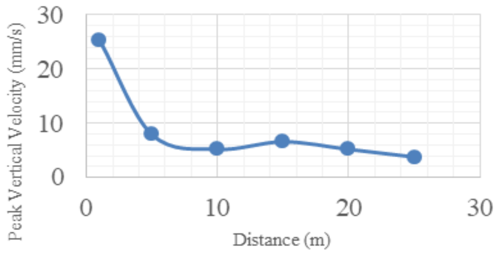
(b) Measurement 2



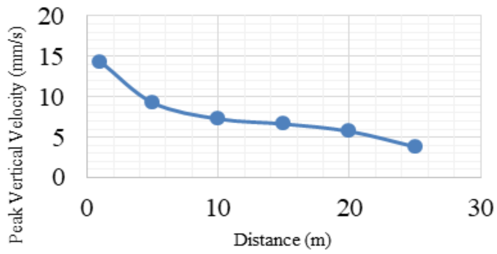
(c) Measurement 3



(d) Measurement 4



(e) Measurement 5



(f) Average Reading

Fig 5 - Peak vibration velocity against distance for demolition work

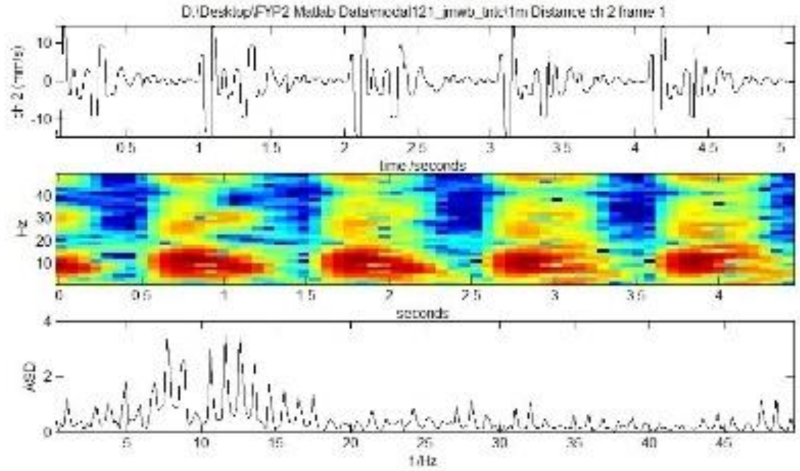
In Fig. 5(f), it shows the average reading of peak vertical velocity of all 5 trials for each distance from the vibration source. From this figure, the relationship between the peak vertical velocity and distance from the source can be identified. The peak velocity was decreased when the distance for the vibration source was increased. Therefore, the points that are further from the sources will tend to feel less vibration.

Based on the graphs plotted, most of the graphs are having high velocity at 1m distance and the lowest velocity is located at 25m distance from the vibration source. Therefore, it can be concluded that the vertical velocity will decrease as the distance from the source increases. This is due to the damping effect caused by the friction of the soil resulting in lower velocity. However, this explanation is defied at the distance of around 15m to 20m from the source as the velocity is increased at around 15m to 20m distance. This is probably due to the effect of soil condition on the attenuation of the vibration velocity. The stiffer soil will result in higher vibration velocity or vice versa.

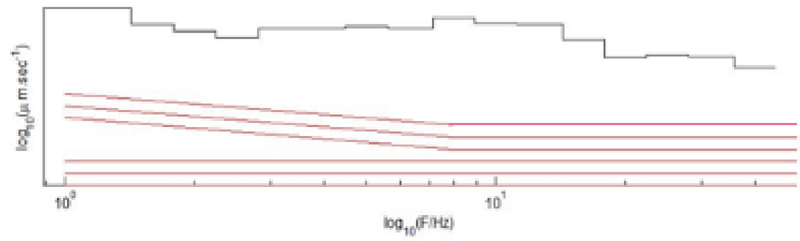
4.1 ModalV Analysis Evaluation

The vibration data obtained from the measurement was then processed in developed ModalV analysis in Matlab software. The main purpose of this analyses are the visualization and graphs can be plotted containing the vibration response with time history, frequency, spectrogram and also one-third octave band frequency including vibration criteria (VC) curve. ModalV provided the significance plotted and VC curve showing the peak responses occurred at the certain time and frequency. Fig. 6 to Fig. 8 show the three different distances that have been selected from overall measurements to perform the vibration assessment.

In the graph of time history, the vibration is increased for every one second interval. The increased velocity is caused by the impact generated by the hydraulic rock hammer during the demolition work. The vibration velocity dampens after the impact due to the resistance within the soil. The peak vibration velocity at 1m distance is 14.4 mm/s as shown in Fig. 6(a). Based on the limit of DOE guidelines, the vibration will cause minor damage to the building surrounding it as the peak vibration velocity is within the range of 5 mm/s to 30 mm/s. For the frequency graph, it depicts the maximum frequency of the vibration wave at 1m distance from the source within 50 Hz. The vibration velocity is the highest when the frequency is in the range of 5 – 15 Hz whereas the lowest velocity is at the frequency range of 35 – 45 Hz.



(a)



(b)

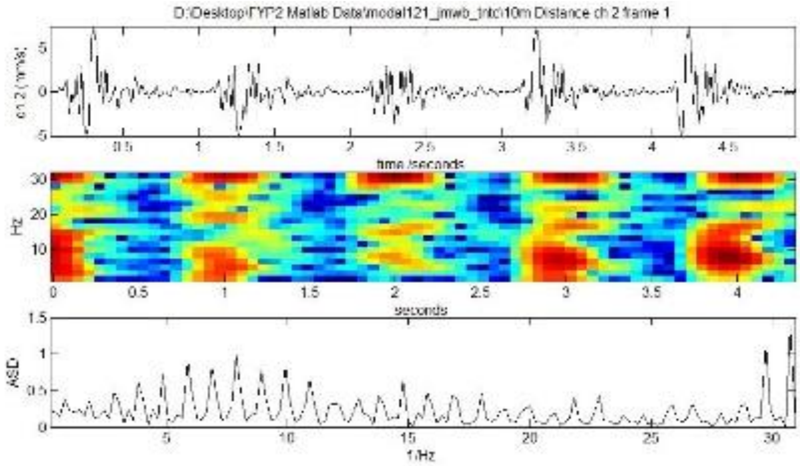
Fig 6 – (a) Vibration response with time history graph, spectrogram and frequency graph, (b) One-third octave band frequency graph with VC curve at 1m distance from demolition point

The time history graph, spectrogram and frequency graph at 10m distance is shown in Fig. 7. In the time history graph, the vibration wave increases every one second. The velocity is high when the time is at 0.25s, 1.25, 3.25s and 4.25s. The peak vibration velocity in this graph is 7.28 mm/s. Therefore, it states that the vibration is at minor damage level as the peak velocity is within 5 mm/s and 30 mm/s when compared with DOE guidelines as shown in Fig. 7(a). In the frequency graph, the maximum frequency of the vibration at 10m distance is 31.25 Hz. The highest velocity occurs when the frequency range is in 29 – 31 Hz while frequency range of 23 – 25 Hz has the lowest vibration velocity.

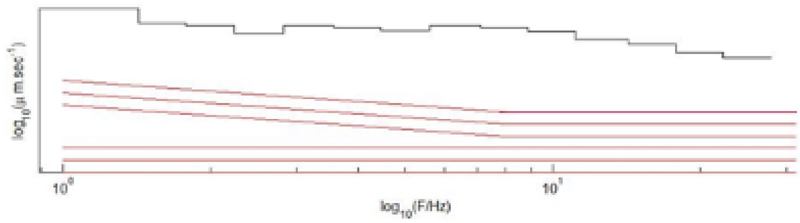
Fig. 8(a) presents the graphs include the graph of time history and frequency and spectrogram at 25m distance. According to the time history graph, the dampening of the vibration shock happens very quickly after 0.5 seconds of vibration. This is probably due to the decrease in vibration strength as the vibration wave propagates further away from the source. According to DOE guidelines, the demolition vibration of 3.76 mm/s is in the caution level where the damage to the building is not necessarily unavoidable. From the frequency graph, it shows that the frequency is the highest within the frequency range of 14 – 16 Hz. The frequency is the lowest in the frequency range of 0 – 4 Hz. The vibration has the maximum frequency of 16.13 Hz.

While for one-third octave band frequency with VC curve at 1m, 10m and 25m distance, as can be seen in Fig. 6(b), Fig. 7(b) and Fig. 8(b) respectively, the total Root Mean Square (RMS) velocity value from the vibration exceed the VC curve of ISO level which is 50 µm/s as shown in Fig. 1 and Table 1 that have been investigated by Gordon [13, 14]. ISO level indicated that the area is prone to vibration. Therefore, the affected area will experience distinctly perceptible vibration which is not safe for workshops and non-sensitive areas as the demolition vibration will cause damage to the workshop equipment.

Based on the graphs produced by ModalV analyses, it can be seen that the damping time of the vibration shortens when the distance from the vibration source is increased. This is because the vibration strength is weakened as it propagates through a very far distance which will result in shorter damping duration. From the frequency graphs, most of the high amplitude vibration occurs when the frequency is in the range of 5 Hz to 15 Hz. It means the time taken for a complete cycle of wave is longer when the hydraulic rock hammer is operating. In the one-third octave band frequency graph, all three graphs from three different distances have exceeded the ISO level curve and indicated similar response which means all of these places are not suitable for workshop and all kinds of sensitive equipment such as a laboratory or cleanroom as described in Gordon guidelines [14]. However, when referred to DoE guideline, it provided the damage risk to observed building. In this case, it affected minor damage to building with the nearest to the sources of excitation (demolition works).

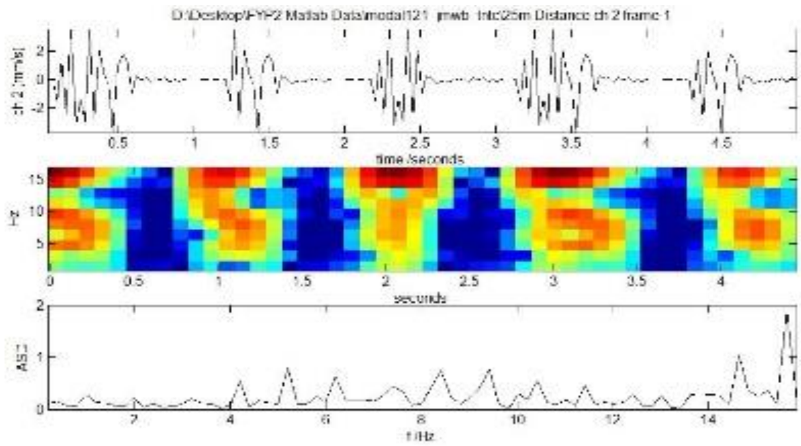


(a)

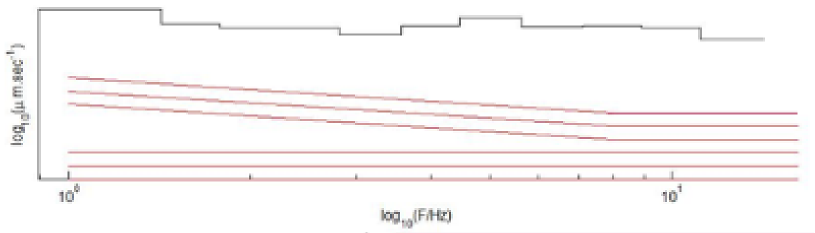


(b)

Fig 7 – (a) Vibration response with time history graph, spectrogram and frequency graph, (b) One-third octave band frequency graph with VC curve at 10m distance from demolition point



(a)



(b)

Fig 8 – (a) Vibration response with time history graph, spectrogram and frequency graph, (b) One-third octave band frequency graph with VC curve at 25m distance from demolition point

5. Conclusion

The graph of vibration peak velocity against distance from the vibration source shows that the amplitude of the vibration is decreasing as the distance from the vibration source is increased. However, the vibration strength can also be disrupted or varied due to the soil condition where different stiffness of soil exist along the distance of the propagation path. According to Department of Environment (2007), the demolition vibration at 1m and 10m distance from the source will cause minor damage to the surrounding building. The minor damage includes cosmetic cracks, window cracking and other. As for demolition vibration at 25m, the damage caused by the vibration is in the caution level where possibility of causing damage on building is very low. The demolition vibration amplitude at 1m distance, 10m distance and 25m distance from the vibration source are beyond the ISO level curve when compare with Gordon's vibration criteria. Therefore, all of these locations are not appropriate for workshop and laboratory with sensitive equipment such as microscopes and microbalances as the equipment will be damaged or malfunction error.

Acknowledgement

This research work is supported by the TIER1 Grant code H259 at Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat, Johor.

References

[1] F. Schiappa de Azevedo and J. Patricio (2004). Annoyance and damage in buildings caused by vibrations. Considerations for a vibration control good practice, pp. 1–14, 2004
[2] J. M. Proença and F. Branco (2005). Case studies of vibrations in structures, *Rev. Eur. Génie Civ.*, vol. 9, no. 1–2, pp. 159–186
[3] B. M. New (1990). Ground vibration caused by construction works, *Tunn. Undergr. Sp. Technol. Inc. Trenchless*, vol. 5, no. 3, pp. 179–190
[4] A. Hashad (2015). Additional stresses on buildings induced by vibration effects, *Water Sci.*, vol. 29, no. 2, pp. 134–145
[5] N. Taillefer, M. Villot, P. Jean, and H. H. Nguyen (2015). Vibration due to construction : a case study, Paris
[6] P. Persson, L. V. Andersen, K. Persson, and P. Bucinskas (2017). Effect of structural design on traffic-induced building vibrations, *Procedia Eng.*, vol. 199, pp. 2711–2716
[7] A. A. Shabana (2006). *Theory of Vibration*, 2nd ed. U.S.: Springer-Verlag New York, Inc.
[8] R. E. Blake (2010). *Basic Vibration Theory*, 6th ed. New York: The McGraw-Hill Companies, Inc.
[9] A. Longinow and W. R. Hannen(2009). Floor Vibrations in Buildings, *Pract. Period. Struct. Des. Constr.*, vol. 14, no. 4, pp. 143–145, Nov.
[10] D. E. Allen (1990). Building Vibrations from Human Activities, *Concr. Int. Des. Constr.*, vol. 12, no. 6, pp. 66–73
[11] D. Isobe (2018). Blast Demolition Analysis of Buildings, in *Progressive Collapse Analysis of Structures*, New York: Elsevier Inc., pp. 81–92
[12] D. M. Hiller (2017). Construction and Demolition Vibration Study, State of Jersey
[13] C. G. Gordon and S. Mateo (1991). Generic Criteria for Vibration-Sensitive Equipment, in *Proceedings of International Society for Optical Engineering (SPIE)*, pp. 71–85
[14] Amick, C. H. Gendreau, M. Busch, T. and Gordon, C. G. (2005). Evolving Criteria For Research Facilities: I–Vibration, *SPIE Conference 5933: Buildings for Nanoscale Research and Beyond.*California: SPIE. pp. 1 – 13.
[15] Department of Environment (2007). The Planning Guideline for Vibration Limit and Control in the Environment *Book 3 of 3*. Kuala Lumpur: Department of Environment Malaysia
[16] T. N. Tuan Chik, J. Brownjohn, and M. Petkovski (2010). Finite element analysis of ground borne vibrations in sensitive buildings using inputs from free field measurements, *Proc. ISMA2010 Int. Conf. Noise Vib. Eng.*, pp. 759–772
[17] Mohamad Taufik Tumiran (2015). Analysis on Vibration Monitoring at MRT Infrastructure Construction Site, Master Thesis, Universiti Tun Hussien Onn Malaysia