Dynamic Analyses on Floor Structure due to Soft Ground Vibration at UTHM Campus

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Abstract: Ground borne vibration is a common problem nowadays. Each person no matter in urban or rural town will not escape from this problem. For low vibration level, this problem may not affect the structure, occupants and equipment. However, if these levels are not controlled or monitored continuously, the situation may become more serious in terms of vibration serviceability for any structures. The campus area in UTHM has not escaped from this problem. The campus is situated on a soft ground condition.In addition, the construction work in the campus for the construction of several additional buildings may give some additional disturbance. Not only students, staffs who are working in the campus are also disturbed withthese situations. Registrar office building had been taken into consideration for the purpose of this study. It is one of the areas that required a high level of comfort. High vibration levels may annoy the occupants inthe building. Therefore, the effects of vibration on the building structure have to be evaluated. To examine the sensitivity level of the building, Finite Element Method (FEM) was performed using ANSYSv14 and MATLAB software to remodel the building in order to reveal the effect of vibration clearly. After being compared to the Vibration Criteria (VC) curve which was used as a guideline, the VC level for this building is at VC-Bcurve which is less than ISO standard for the office building.

Keywords: Dynamic analysis, floor, soft ground, vibration

1. Introduction

Ground borne vibration can be a serious concern for nearby neighbours of a transit system route or maintenance facility, which causing buildings to shake and rumbling sounds to be heard. In contrast to airborne noise, ground borne vibration is not a common environmental problem. It is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads [1]. Some common sources of ground borne vibration are trains, buses on rough roads, and construction activities such as blasting, pile-driving and operating heavy earth-moving equipment.

The effects of ground borne vibration include feel able movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings [1]. Building damage is not a factor for normal transportation projects, with the occasional exception of blasting and pile-driving during construction. Annoyance from vibration often occurs when the vibration exceeds the threshold of perception by only a small margin. A vibration level that causes annoyance will be well below the damage threshold for normal buildings [1].

This study will only focus on ground borne vibration and impact to the building. In addition, vibration sources taken into account in this study also includes to external resources only, where it is based on the assumption that the internal sources will not give major impact to consumers, buildings and equipment.

2. Objectives of the Study

The first objective of this research was to perform the dynamic analyses on building subjected to the ground borne vibration signal. Building performance level indicates that whether the build is able to perform properly. For example, for an office building, it should serve to provide a comfort environment to the occupants on duty inside the building, providing protection to the equipment in the office, and provide a safe structure for occupied buildings. Building capacity can also be seen from the lifespan of a building. Buildings that have a high level of performance usually have no structural damage, no defects and can provide protection and comfort to the

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occupants and have a high life expectancy.

Besides, this study also aims to produce a structural response model of office building by using the finite element method from ANSYS software. A complete plan of the building must be obtained first in order to produce thecomprehensive model, including building dimensions, beam sizes, columns and all other relevant information.

The third objective is to predict the vibration response criteria of the floor structure due to measured ground borne vibration input. The prediction can be determined by referring to the curve of vibration criteria guideline, where office buildings should be in the ISO with the amplitude of 400μm/s [2].

UTHM campus is located on the soft soil site. Because of that, this study is essential to predict the structural behaviour under those vibration inputs.

3. Ground Borne Vibration

Ground borne vibration is man-made vibration which propagated from the ground into the buildings. It may come from external sources such as railways, roads or construction work and usually classified as a low frequency vibration [3]. This vibration can be transmitted over significant distances depending on the source and transferred to the structure of a building where it can affect both the occupants of the building and the building structure itself [1].

The vibration of the transit structure excites the adjacent ground, creating vibration waves that propagated through the various soil and rock strata to the foundations of nearby buildings. The vibration propagates from the foundation throughout the remainder of the building structure [1]. In a soft ground condition, the vibration may attenuate and triggered disturbance to the structure. The maximum vibration amplitudes of the floors and walls of a building often will be at the resonance frequencies of various components of the building.

The vibration of floors and walls may cause perceptible vibration, rattling of items such as windows or dishes on shelves, or a rumble noise [1]. The rumble is the noise radiated from the motion of the room surfaces. In essence, the room surfaces act like a giant loudspeaker causing what is called ground-borne noise. Ground-borne vibration is almost never annoying to people who are outdoors. Although the motion of the ground may be perceived, without the effects associated with the shaking of a building, the motion does not provoke the same adverse human reaction. In addition, the rumble noise that usually accompanies the building vibration is perceptible only inside the buildings [2].

4. Sources of Ground Borne Vibrations

There are two types of the ground borne vibration sources such as:

i. External Sources
ii. Internal Sources

4.1 External Sources

Traffic flow is one of the sources that caused ground borne vibrations. When a vehicle travels through a road, it would induce vibration. The vibration is then transferred to the environment through the ground. If a building located close to a road with high traffic flow, vibration level will increase. Moreover, the vibration levels are also influenced by the size of vehicles using the road, whereas heavy vehicles or heavy trucks using the road, the more noticeable vibration will be obtained.

Velocity of the vehicles also affects the level of vibration. Vehicles moving with higher velocity will often result in a higher vibration. Factor of road conditions also influence this level of vibration. Smooth road means smooth traffic flow and this also means low level of vibration. This condition becomes vice versa as to the bad condition of road.

4.2 Internal Sources

Besides external sources, equipment inside the buildings can also generate vibration but in a small scale [5]. Examples of the sources inside the building are like electrical and mechanical equipment [4]. Examples of electrical equipment that can produce vibrations are like air-conditioning, fans, cooling towers and so on. Otherwise the examples of mechanical equipment which can generate vibration are like elevators, escalators, and automatic doors. Vibrations can also be produced from equipment or machinery that used by the occupants e.g. printers, scanners, and so on. The vibration from this source may not be too high and will not affect the occupants and equipment in the building.This sources are not considered for this study.

5. Vibration Receivers

Human, equipment and buildings are categorised in vibration receivers. It is defined the parties that are affected from the vibration that occurs. Since ground borne vibration is vibration transmitted through the soil as a medium, almost all objects that contacted with the soil will be affected. This means all the structures which are closed to the source of vibrations will receive the effect of vibration. Vibration wave transmitted from the sources through the ground and then received by the base of the building which then transferred to the columns, beams, slabs, walls, etc. including people who were inside the building.

Distanceis also one of the aspects which can influence the acceptance of vibration. If a structure is closed to the sources of vibration, it will receive higher effects of vibration. However, if the structure is far from sources of vibration, the effect of vibration will reduce [6]. The effects on the structure might be cracked, broken etc. For the occupants'effects, it included the comfortless of the occupants in the building. While for the equipment, it might be image blurring for computers and scanners, improper functioning sensitive facilities inside the building.

Fig. 1 shows the illustration of ground borne vibration sources and receivers. For this study, source that has been taken into consideration is external sources only. It shows the vibrationwaves from the sources transmitted to each layer of soil then receive by the structure. Building, people and equipment act as the receivers. Vibration wave which transferred from soil move to building structure, then receive by the people and equipment inside.

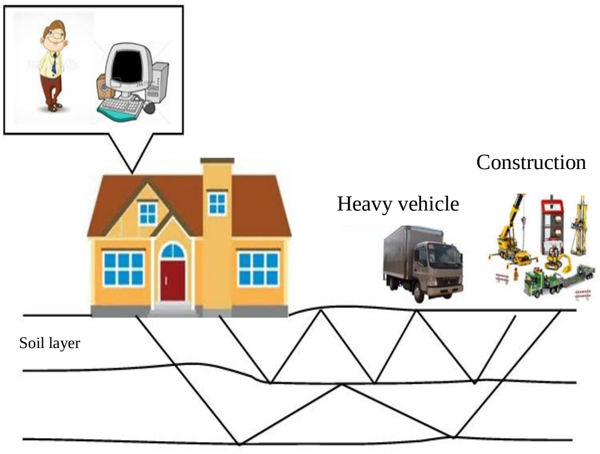


Fig. 1 Ground borne vibration sources and receivers. (adapted from Kuo [6])

6. Vibration criteria (VC) Curve

The criterion curves were developed in the 1980's in response for a need for design standards to accommodate a wide range of tools and instruments used by the microelectronics, medical and biopharmaceutical industries. The curves and descriptors that accompanied them were necessarily "generic" in the sense that they were intended to meet the needs of all tools within each category as best the authors could judge based on experience mingled with tool-specific specifications, often incomplete provided by manufacturers [5].

Vibration criteria curves are commonly used in the design of facilities such as buildings and instruments that are sensitive to vibrations. It was published by the International Society for Optics and Photonics (SPIE) in 1991 and by the Institute of Environmental Sciences and Technology (IEST) in 1993. Every curve of the criteria from VC-A to VC-E are associated with line width or size detail which is a representation of the device capabilities of each curve can be related [8].

The VC curves are now widely accepted throughout the world as a basis for designing and evaluating the performance of microelectronics fabrication facilities where continuity of vibration-free tool performance is essential. The curves and their descriptors are reviewed in the light of continued and projected future tool developments taking into account through experience on past and present projects [8].

The form of the criteria is taken through asset of one-third octave band velocity spectra and labelled vibration criterion curves VC-A to VC-E. The curves are shown in Fig. 2, including with the International Standards Organization (ISO) guidelines for the effects of vibration on people in buildings. The criteria apply to vibration as measured in the vertical and two horizontal directions [9]. The details description each curves are described in Table 1. This curve will be used as a basic reference in the further vibration structural response of this study.

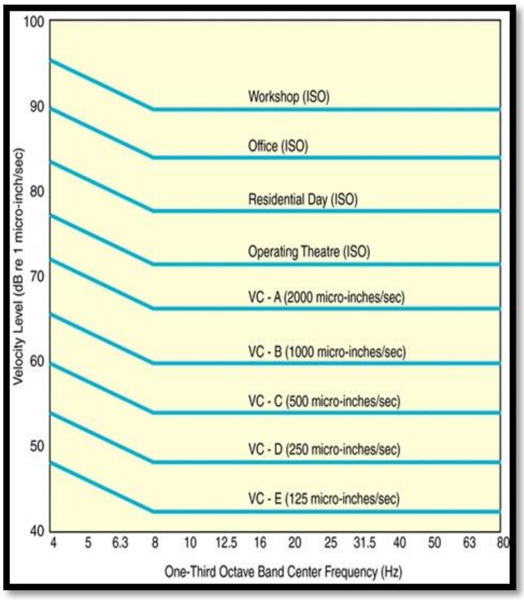


Fig. 2 Generic vibration criterion (VC).[8]

Table 1 Application and interpretation of the generic vibration criterion (VC) curves. [8]

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 nanometre scales and other systems requiring extraordinary dynamic stability.

*N/A: Not available

7. Finite Element Method (FEM)

The Finite Element Method (FEM) can be defined as a numerical technique that is based on approximation of differential equation that model problems arising in physics and engineering. This method involves subdividing a geometrical space also called domain into a finite number of smaller region called mesh [10].

FEM is the dominant discretization technique in structural mechanics. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called finite elements or elements for short [11]. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points.

Finite element can be categorised into three namely one-dimensional elements, two-dimensional elements, and three-dimensional elements [10]. This is referred by Fig. 3 (a), (b) and (c).

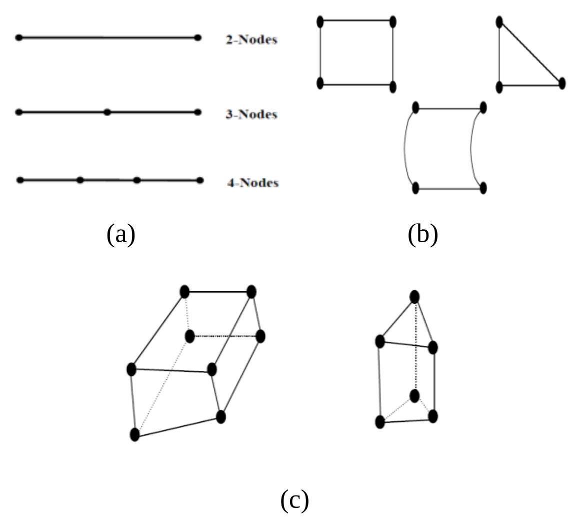


Fig. 3 Elements (a) one-dimensional, (b) two-dimensional, and (c) three-dimensional. [10]

Finite element modelling is a default normal method for determining the dynamic performance of structures by saving valuable design time and money in construction. In this study, the numerical simulation of vibration response of office building was carried out by using ANSYS, finite element package and VSATs (Vibration Serviceability Assessment Tools)software, which was developed in MATLAB (Mathematics Laboratory) interface and algorithm [12].

ANSYS is finite element analysis software which enables the researcher to develop models of structures, products, components or systems. It can apply operating loads or other design performance conditions and also can optimise a design early in the development process to reduce production costs, while MATLABis a high-level programming language and interactive environment that enables the researcher to perform computationally intensive tasks. All the relevant outputs from ANSYS were processed in MATLAB programmes, which then determine the absolute response of the structure, and to compare the structural performance with generic vibration criteria. The flow of the whole finite element analysis for this study is shown in Fig. 4.

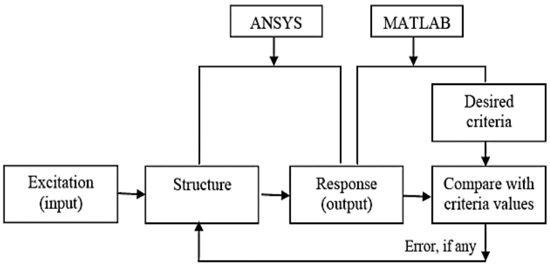


Fig. 4 The structural vibration analysis process. [12]

This application is started with the processing ofthe vibration input into the ANSYS applications to obtain natural frequency of the building and also the mode shape. Input for this study is taken from a realdata which measured on ground floor of the building as shown in Fig. 5.

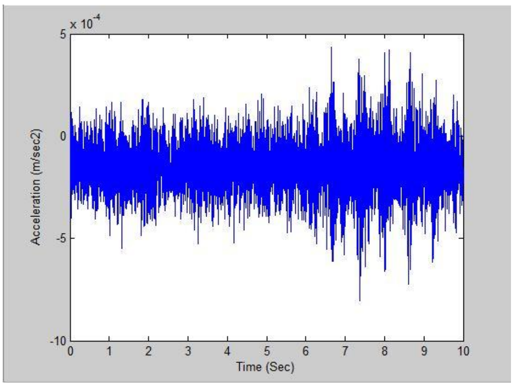


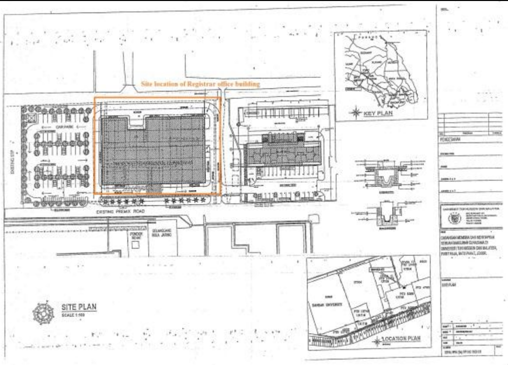
Fig. 5 Vibration input from field measurement at the ground floor of the registrar office, UTHM

Then after being processed in the ANSYS, the data obtained will then be transferred into the MATLAB application. MATLAB application will analyse the data from ANSYS and the output produced will be used to determine the level of vibration incurred by the building. The data is then compared to the vibration criteria curves which used as a guideline. If it passes, the study will be completed, but if it is beyond the guideline, the data should be included once again in order to reduce the vibration response on building or proposed other methods to control the vibration level on buildings. Steps are repeated until the satisfied value obtained which fulfilled the guideline curves.

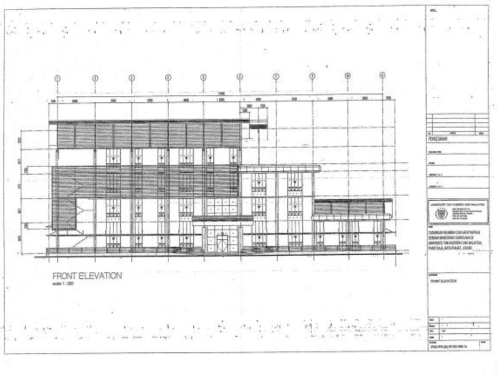
8. Results and Discussions

Fig. 6 shows the Registrar office building, site location on the plan and the front view of the building.

(a) Registrar office building(Front view)



(b) Location of the building at UTHM campus



(c) Front elevation of the building

Fig. 6 Registrar office building and its location

Fig. 7 shows the complete model of a whole building structure of Registrar office using FEM combined with

(a)

command method in ANSYS. Meanwhile, Fig. 8 (a), (b), (c), and (d) show the area of slab for the ground floor view to third floor.

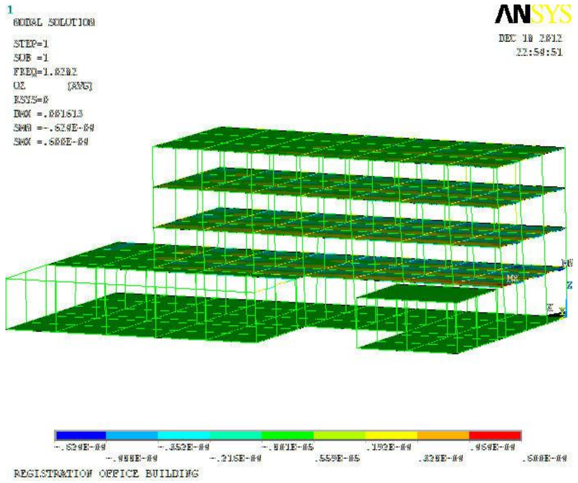


Fig. 7Complete model for Registraroffice in ANSYS

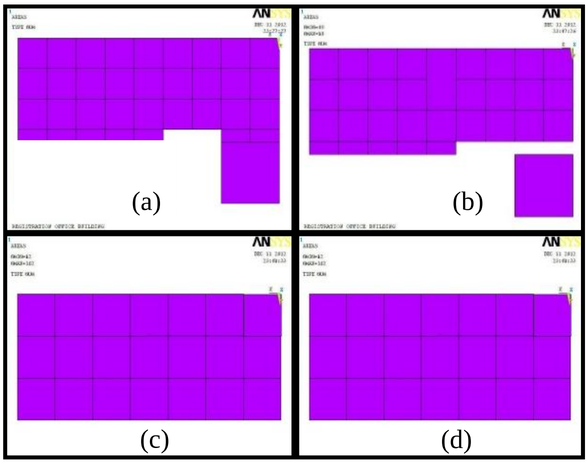


Fig. 8 (a) Ground floor view, (b) first floor view, (c) second floor view, (d) third floor view

8. Deform Shape Pattern Analysis

From the analysis of ANSYS and MATLAB, the mode shape can be obtained as it is set to one hundred modes and each mode showed a different pattern.Fig. 8 shows the mode shape pattern for the first tenth modes from modal analysis in ANSYS.The fundamental mode has natural frequency 1.02 Hz, swayed into y-direction. Mode 2 is also swayed, but into x-direction with 1.01 Hz, almost similar frequency with the first mode. Mode 3 is torsional with 1.31 Hz and increased up to 3.27 Hz for Mode 4. Columns deformed on vertical directions as can be seen on Fig. 9. The building shows no obvious deformation for the rest of the mode.

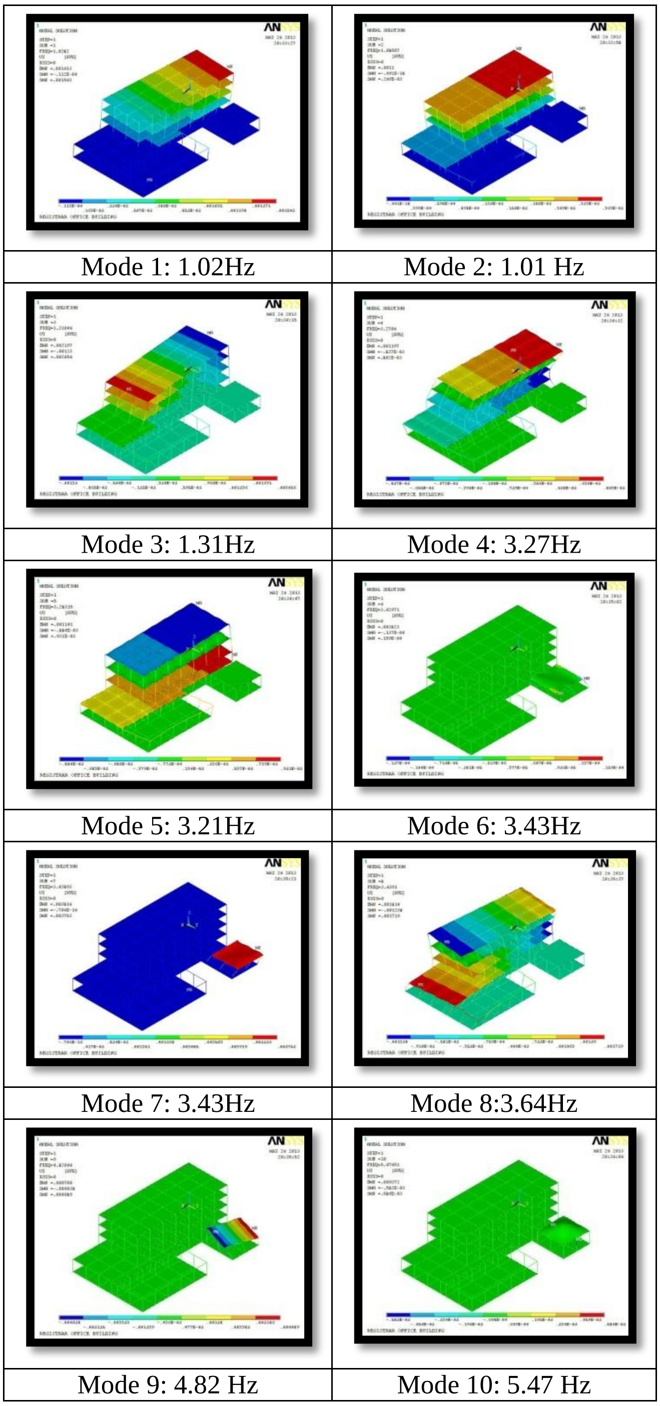


Fig.9 The first tenth mode shape of Registrar office

Detail description for each mode as shown in Fig. 9 is described in Table 2 for both directions, horizontally and vertically. The displacement value for both directions shows the deformation of the structure in finite element modelling.

Table 2 Mode description for the first tenth modes

Mode	Frequency (Hz)	Mode Description	Displacement Value
1	1.02	Horizontal (H): No changing Vertical (V): Slightly changing	H: 0.000043 m V:0.001543 m
2	1.01	Horizontal: Medium changing Vertical: Medium changing	H: 0.001067 m V: 0.000269 m
3	1.31	Horizontal: No changing Vertical: Medium changing	H: 0.000631 m V: 0.002056 m
4	3.27	Horizontal: Major changing Vertical: Medium changing	H: 0.000856 m V: 0.000802 m
5	3.21	Horizontal: Major changing Vertical: Medium changing	H: 0.000661 m V: 0.000931 m
6	3.43	Horizontal: No changing Vertical: Medium changing	H: 0.003747 m V: 0.000016 m
7	3.43	Horizontal: No changing Vertical: Slightly changing	H:0.000018 m V:0.003753 m
8	3.64	Horizontal: Slightly changing Vertical: Slightly changing	H:0.000550 m V:0.001719 m
9	4.82	Horizontal: No changing Vertical: Slightly changing	H:0.004064 m V:0.008089 m
10	5.47	Horizontal: No changing Vertical: Slightly changing	H:0.000579 m V:0.000584 m

The model was analysed under 100 modes due to obtain the peak response of natural frequency and vertical behaviour of the floor structure on building. Thus, Mode 40 has shown the obvious vertical deformation when compared to 100 modes obtained in the analysis. Fig. 10 indicates the deformed shape for Mode 40 which showing that all floors (first, second and third) has vertical deformationwith natural frequency 11.4 Hz.It indicated that at frequency 11 Hz, the structure will have peak response on vibrations.

Further analysis on each floor is carried out using VSATs, the algorithm programmed in MATLAB interface in order to verify the floor behaviour from results obtained in ANSYS. Fig. 11 (a), (b), and (c) show the deformed shape for Mode 40 on each floor from first floor to third floor respectively using VSATs.Mode shape from ANSYS shows the whole office building, while results from VSATs show the mode shape of every floor. The mode shape obtained from both ANSYS and VSATs should be or almost the same.

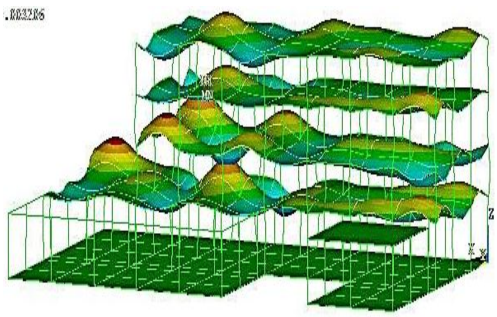
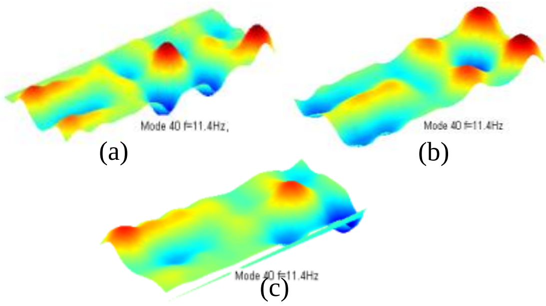


Fig. 10Deform shape for mode 40 (11.4 Hz) in ANSYS



(a) (b) (c)

Fig. 11Deform shape for mode 40 (11.4 Hz) in VSATs, (a) first floor, (b) second floor, (c) third floor

Mode shape analysiswas done to determine the condition of the floor structure of the building when subjected to different frequency modes. In the analysis by ANSYS, the first tenth modes show no significant changes on the floor as described in Table 2.Changes in the horizontal direction are not taken into consideration since the displacement at the column is not priority in this study. The consideration is only vertical direction which showing the major changeson floor behaviour.

Highest peak displacement (both directions) is represented by the red area while the minimum displacement is represented by the blue area. Green areas were experiencing a little displacement and not so obvious. This deformation may have an impact on the equipment and occupants. For areas with the maximum deflection, that area is suggested not suitable for sensitive equipment and people in that area also may be affected.

9. Vibration Criteria Analysis

Further analysis was carried out on vibration criteria response for each floor using specific software, VSATS to obtain the vibration serviceability.Fig. 12 shows the average level of the vibration criteria curve is 48% of the total area of the floor at VC-B. Meanwhile Fig.13 shows the plot of VC-B by light green area. Red areas represent the lowest value of VC which is VC-D. The red area is the location which received the lowest vibration level due to position of columns on the floor based on the original plans.

Blue areas represent the areas with the highest VC level which is at ISO standards, and perceptible to vibrations. Therefore it can be suggested that the blue areas unsuitable for sensitive equipment. Although the VC recorded was the highest compared to other areas, but they were still below the maximum value of an office building under ISO standards. It is suitable for operating theatre and residential areas.

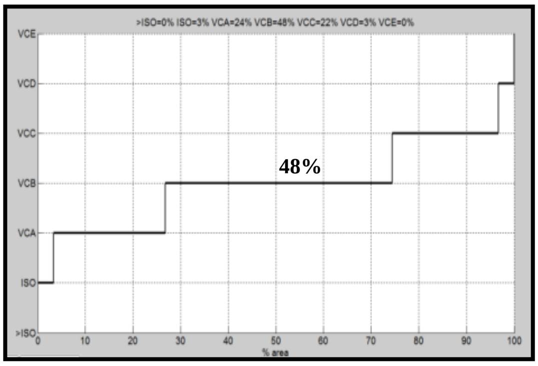


Fig. 12 The average level of the VC-B for the first floor

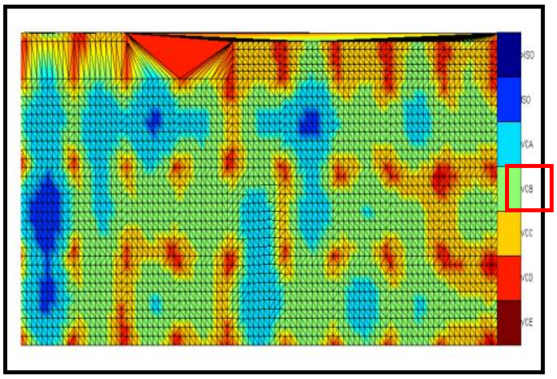


Fig. 13 VC-B for the first floor

Similar situation also occurred at second floor, which the majority of the vibration response for second floor still at VC-B. This can be seen in Fig.14 which shows that majority of VC level for second floor is at VC-B by 44%from total areas. Distribution of vibration response plot for second floor is slightly different with first floor as shown in Fig. 15. Pantry and gallery areas show high vibration level based on dark blue plot. Therefore, it is not a suitable place to locate very sensitive equipment in that area.

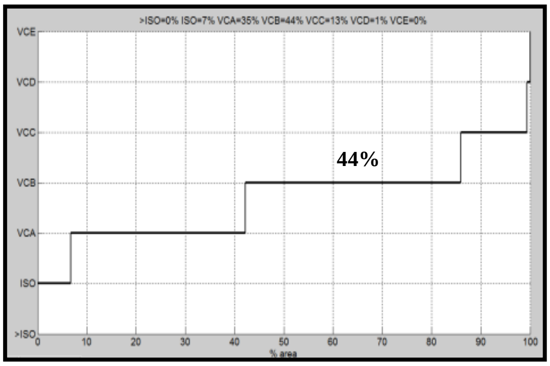


Fig. 14 The average level of the VC-B for the second floor

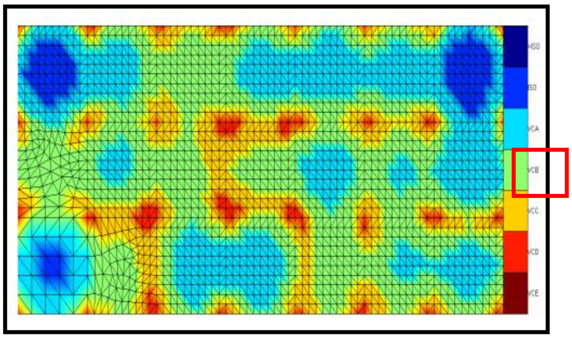


Fig. 15 Overall level of VC-B for the second floor

Fig.16 and Fig.17 shows the situation of the third floor which is same as first floor and second floor where the majority of the VC level is in VC-B with the 48% of the total areas. However, for third floor, there are no area with VC level exceed VC-A. It shows that the higher floor will reduce the vibration response on that floor.

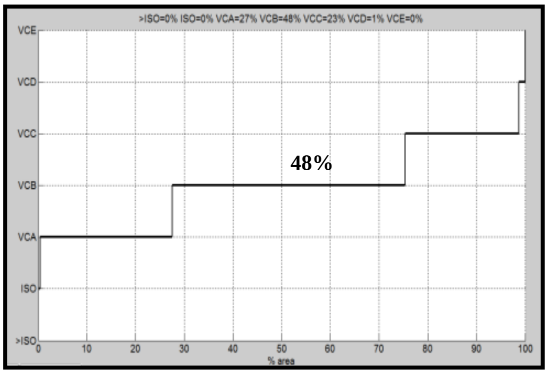


Fig. 16 The average level of the VC-B for third floor

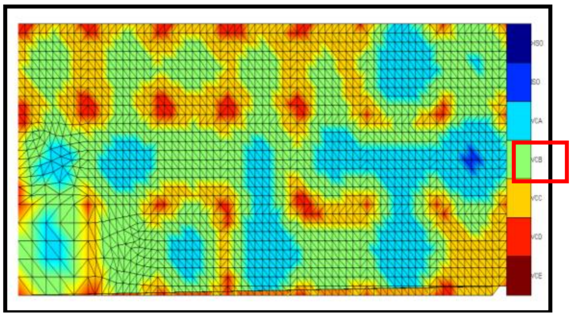
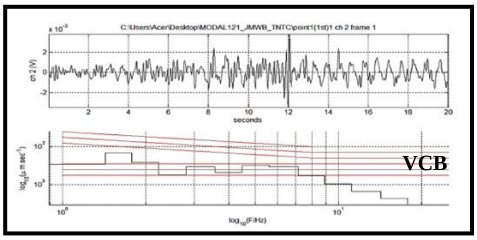


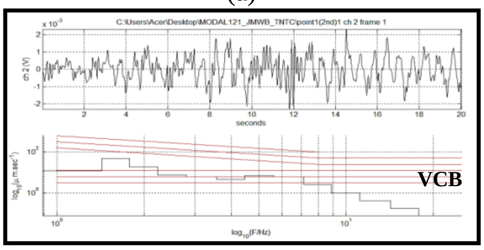
Fig. 17: Overall level of VC-B for third floor

The vibration analysis for certain point was carried out to obtain the vibration criteria (VC) curve as described earlier in the generic vibration guideline in Fig. 2. The analysis is carried out in specific MODAL algorithm in MATLAB software to produce the VC curve as similar with the VC guideline. Fig.18(a), (b) and (c) shows the VC curve obtained from a specific point at each floor from first floor to third floor. Average point has been considered since all the point shows almost the same curve. It is also indicated that all floors is at VC-B.

Analysis in VSATs and MODAL provided the same result for office building, which is vibration response on all floors, is at VC-B. Since both results from VSATs and MODAL analysis shows the same criteria, this has been proving that the overall vibration level for each floor at office is VC-B.



(a)



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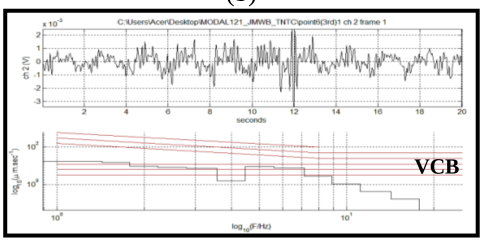

(c)

Fig.18VC curve for each floor (a) first floor, (b) second floor, (c) third floor

10. Conclusions

Based on the results obtained, UTHM Registrar office building is complying with the ground borne vibration sensitivity standards, when referring to the generic vibration criteria guidelines. This is because, based on the study, the average value of the vibration level for this building is at VC-B while the maximum allowable vibration is at ISO level.This means that the vibration incurred by the building will not have an impact on the structure, peoples, and equipment which located in the building and receive less vibration.

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