Vibration criteria analysis on floor at laboratory room

To cite this article: T N T Chik et al 2019 IOP Conf. Ser. Earth Environ Sci. 220 012021

View the article online for updates and enhancements.
Vibration criteria analysis on floor at laboratory room

T N T Chik¹, T A Yew¹, M H W Ibrahim¹ and N A Yusoff²

¹Jamilus Research Centre, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, Malaysia
²RECESS Centre, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, Malaysia

Corresponding author: thayati@uthm.edu.my

Abstract. Engineer is now facing a significant challenge related to the vibration problem in the structure. Building is subjected to the significant dynamic load induced by people will generate the dynamic forces. The objectives of this study are to model a three storey building by using Finite Element Modelling (FEM) and perform the vibration criteria plot on floor at laboratory building due to people walking. A vibration excitation source is generated by people walking at four different points. The Finite Element (FE) analyses such as modal analysis and transient analysis are carried out in ANSYS and the data are further generated via MATLAB (VSATs) software to assess the vibration criteria plot (VC). After evaluation, the vibration criterion of survey laboratory fell under VC-E which contributed to the highest percentage plot which is 40 percent of vibration criterion at the certain points. The maximum Root Mean Square (RMS) curve for survey laboratory is 10 micrometers/sec which fell under VC-C at the certain points. VC-C criterion is the good standard for most lithography and inspection equipment up to 1 micron detail size. Thus, survey laboratory has fulfilled the vibration requirements based on the Gordon standard since the VC-E (less severe) criterion is more suitable to allocate the survey equipment for the certain location. The floor vibration performance is analyzed and compared with the guideline and standard such as Generic Vibration Criteria by Gordon in which the vibration level is under minimum permissible level for sensitive equipment.

1. Introduction
Vibration produced by the occupants which subjected to significant dynamic load will cause several problems in the building. Rhythmic dynamic actions which are come from human activities is the causes of unwanted floor vibration in building structures. Human activities include people walking, sporting events, dance, jumping or even gymnastics [1]. There are many sources of vibration capable of producing motion sufficient to be perceptible by the occupants of a modern building. Typical examples of these vibration sources are traffic of heavy vehicles on nearby roads, huge machinery in nearby constructions sites and human activities on floor decks, such as walking, jumping and running. Vibrations produced by human activities are the most common type which walking is a daily activity everywhere [2].

The survey laboratory at the Faculty of Technology Management and Business (FPTP) building in UTHM campus is having the most critical problems which lead to the cracking of the slab and it is quite harmful to the occupants. Vibration analysis becomes crucial to be carried out here, in order to ensure that the building is compliance with the standard requirement from Generic Vibration Criteria by Gordon. A Finite Element Analysis (FEA) technique is used to systematically approach vibration
Finite element ANSYS software package is used to model three storey building of FPTP building and the Vibration Serviceability Tools (VSATs) software will be used to identify the Vibration Criteria (VC) of the this laboratory.

2. Vibration
Vibration can lead to excessive deflection and failure on the building structures. The vibration can be weak for identification or can be in large devastating vibrations that occur due to natural or manmade disasters such as earthquakes [3]. Correspondingly, vibrations comprised of regular cyclic motion of the frequency and amplitude. The amplitude is refers as a peak acceleration on the floor vibrations since acceleration is used to determine the acceptability limit of the floor.

2.1 Human induced vibration
Dynamic forces of periodic or transient nature are generated by the human activities. Slabs in building such as offices or apartments are subjected to the dynamic forces induced by people activities such as walking, running, jumping or even dancing. These will occur when an office building contains facilities such as running tracks on roofs, exercise rooms, dance hall or gymnasia. Running could be contemplated in long floors or corridors but this will only occur in isolated instances [4].

2.2 Laboratory vibration
Appropriate vibration criteria analysis is essential to establish when designing the laboratories. The vibration may cause to the degradation of performance of the sensitive equipment inside the laboratory and may lead to wastage of cost. Laboratories needs high precision of measurement but the high vibration level may lead to inconsistent measurement results and high transients can lead to the damage of metrology equipment [5].

2.3 Finite element modelling (FEM)
Element Modelling (FEM) can mathematically model and numerically solve complex problems to assess design and saving valuable design time and money in construction and safety aspect. ANSYS software is finite element analysis software in which enables the user to develop models of structures, products, components or systems. ANSYS program is used to propose the computational model by adopted the usual mesh refinement techniques. Whereas, MATLAB software is a high level programming language and interactive environment that allows user to conduct computational intensive task. VSATs programming is in house developed software in MATLAB will assess the vibration serviceability of floors, evaluation of new floor design and to investigate the vibration behaviour.

2.4 Generic vibration criteria (VC)
In this study, specific vibration criteria guideline is used in order to investigate the performance of the structures. Vibration criteria commonly used in the design of facilities which hold a wide range of the vibration sensitive equipment. Figure 1 shows the VC-A (least severe) to VC-E (most severe) is taken through asset of one-third octave band velocity spectra including with the International Standards Organization (ISO) guidelines for the effect of vibration on people in the building [6]. Table 1 shows the application and range of the vibration criteria limits including ISO criteria for human taking into account through experience on past and present projects.
**Figure 1.** The Gordon generic vibration criterion curves [6].

**Table 1.** Application and interpretation of the generic vibration criterion (VC) curves [6].

| Criterion Curve | Max Level micrometers/sec, rms | Detail Size microns | Description of Use |
|-----------------|--------------------------------|---------------------|--------------------|
| Workshop (ISO)  | 800                            | N/A                 | Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas. |
| Office (ISO)    | 400                            | N/A                 | Feelable vibration. Appropriate to offices and non-sensitive areas. |
| Residential Day (ISO) | 200    | 75                  | Barely feelable vibration. Appropriate to sleep areas in most instances. Probably adequate for computer equipment, probe test equipment and low-power (to 20X) microscopes. Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100X and for other equipment of low sensitivity. |
| Op. Theatre (ISO) | 100    | 25                  | Adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners, etc. An appropriate standard for optical microscopes to 1000X, inspection and lithography equipment (including steppers) to 3 micron line widths. |
| VC-A            | 50                             | 8                   | A good standard for most lithography and inspection equipment to 1 micron detail size. |
| VC-B            | 25                             | 3                   | |
| VC-C            | 12.5                           | 1                   | |
Suitable in most instances for the demanding equipment including electron microscopes (TEMs and SEMs) and E-Beam systems. 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 and other systems requiring extraordinary dynamic stability.

### 3. Methodology

Survey laboratory at Faculty of Technology Management & Business (FPTP) building as shown in figure 2, located at UTHM campus, Parit Raja, Johor was selected as the case study for this investigation, where the in-situ vibration test have been carried out at the selected location. Three storey FPTP building have been modelled by using ANSYS software whilst the subsequent process was preceded in MATLAB which generated the output (time history).

![Figure 2. Plan view of Survey Laboratory.](image)

#### 3.1 Finite element modelling technique

In this study, the numerical simulation of vibration criteria on survey laboratory at FPTP building was carried out by using ANSYS, finite element software package and MATLAB interface with certain algorithm known as Vibration Serviceability Assessment Tools (VSATs). All relevant output generated by ANSYS were processed by means of MATLAB programmes, to determine the response of the structure and to compare the structural performance with generic vibration criteria. Figure 3 shows the flow of Finite Element analysis which showing the link of using ANSYS and MATLAB. ANSYS will analyse the model of structure to generate dynamic response in output. MATLAB will precede the analysis process by calculating the output of ANSYS with the generic criteria values.

![Figure 3. The structural vibration criteria analysis process [7].](image)
3.2 Modal analysis
A modal analysis is a technique to determine the vibration characteristics of structures which consists of natural frequencies (the frequency at which the structure tend to naturally vibrate), mode shapes (which shape the structure would tend to vibrate at each frequency) and mode participation factors (the amount of mass that participates in a given direction for each mode) while it is being designed. The building has dimension of 85m x 65m in plan and a total height of 12m. The basic structure consists of a reinforced concrete frame which has columns and beams with various cross sectional dimensions. The frame structure supports slabs with same thickness of 200mm.

The parameters of the building were developed as shown in table 2 which is the properties of the constituent element used in the model, while table 3 shows the exact size and length of beam. The concrete graded at 40 N/mm². The beam and column elements were modelled in ANSYS by using BEAM4 element, while the slab was modelled by using SHELL63 element.

| Materials          | Density (kg/m³) | Elasticity | Elastic Modulus (GPa) | Poisson Ratio |
|--------------------|-----------------|------------|-----------------------|---------------|
| Concrete masonry   | 2500            | 38         | 38                    | 0.2           |
| Slab               | 3250            | 38         | 38                    | 0.2           |
| Steel bar          | 7850            | 38         | 38                    | 0.2           |

| Floor   | Size beam (m) | Length beam (m) |
|---------|---------------|-----------------|
| Ground floor | 0.20 x 0.75   | 8.50            |
|         | 0.20 x 0.60   | 8.10            |
|         | 0.30 x 0.75   | 9.50            |
|         | 0.20 x 1.20   | 5.65            |
|         | 0.30 x 0.75   | 9.50            |
| First Floor | 0.20 x 0.60   | 6.70            |
|         | 0.40 x 0.85   | 9.50            |
|         | 0.30 x 0.75   | 9.50            |
| Second floor | 0.20 x 0.85   | 6.00            |

3.3 Transient analysis
Transient dynamic analysis is also known as time-history analysis which is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. Transient analysis can use to determine the time varying displacements, strains, stresses, and forces in a structure which responds to any combination of static, transient and harmonic loads.

3.4 Vibration Serviceability Analysis Tools (VSATs)
The model obtained from VSATs analysis is visualized by colours which illustrate the critical (blue) areas and less critical (yellow) areas. Critical areas means the area is prone to vibration and it will causes annoyance to the occupants and also structural damage.

4. Results and discussions
All the obtained results are discussed comprehensively in this section. Modal analysis, transient analysis and vibration serviceability provided the expected results from those analyses.

4.1 Modal analysis results
Modal analysis was performed to determine the dynamic properties of the floor structure of the FFTP building when subjected to different frequency modes. The displacement of the column is not considered in this study, thus change in horizontal direction is not taken into consideration. Therefore this study only focused in the vertical direction which shows the changes on floor behavior. The vertical
displacement for roof area is critical than the ground floor in which the vibration data for roof area is
critical than the others floor. The factor which included the moment of inertia, permanent load,
distance from the ground and the type of the support applied.
The highest peak displacement is represented by red colour while the minimum displacement is
represented by blue colour. Green colour areas show a little displacement and it is not so obvious. Areas
which have highest deflection are not recommended for sensitive equipment. This region will likewise
cause the annoyance or discomfort to the occupier. Figure 4 shows the tenth of mode shape of modal
analysis generated by ANSYS. Most of the structure indicated sway mode shape from mode 1 with
natural frequency 1.15 Hz to mode 10, 1.75 Hz. The vertical deflection on floor is not too obvious.

![Mode shapes of three story building.](image)

**Figure 4.** Mode shapes of three story building.

4.2 **Transient analysis results**

Transient analysis was conducted by using ANSYS software to determine the dynamic response of a
structure. Figure 5 and figure 6 show the time history graphical data for Point 2 at each floor of FPTP
building. The results clearly show that walking exerted higher vibration response by the slabs. The peak
acceleration for the first floor and second floor were about 1.70 x10\(^{-3}\) m/s\(^2\) and 2.10 x10\(^{-3}\) m/s\(^2\). The output
value was increased after being modelled in transient analysis which from 0.13x10\(^{-4}\) m/s\(^2\) to 0.17x10\(^{-3}\)
m/s\(^2\) at the first floor. Similar behavior shown at the second floor which was increased from 0.39x10\(^{-4}\)
m/s\(^2\) to 0.210x10\(^{-3}\) m/s\(^2\).
When the vibration signal was applied into the structure, the acceleration values of each floor increased due to vibration effect from walking activities. Humans movement influence the vibration on the floor. The similar situation occurred at the both floors.

**Figure 5.** VSATs walking test results for Point 2 at first floor of FPTP.

**Figure 6.** VSATs walking test results for Point 2 at second floor of FPTP.

### 4.3 Vibration serviceability analysis

Vibration Serviceability Analysis Tools (VSATs) enable results from different models to be compared and also can be used for assessing vibration serviceability of structures where the model properties and serviceability is known. Figure 7 indicates the mode shapes of the first tenth modes obtained by using VSATs modal analysis. Results obtained from VSATs modal analysis shows the mode shape identical to the mode shape from ANSYS. For the mode shape 1 until mode shape 7, the yellow colour (most critical) area located on the Point 1 (P1) and Point 2 (P2) but from mode shape 8 until 10 the dark blue colour (least critical) is allocated at these points. In conclusion, overall of the slab is in the blue region which is least critical.

Vibration criteria analysis was carried out by using VSATs transient analysis. The black blue color areas represent the highest VC level which is above the ISO standard, while light blue color areas represent an ISO standard VC level. The lowest VC standard is shown by yellow color areas which is VC-E. Highest VC level is unsuitable for areas with sensitive equipment while lowest VC level is appropriate for office and non-sensitive areas.

By referring to the VC respond, the result indicated that both floors show almost the same vibration response where the response obtained for each floor is overall in VC-E standard range when referred to the generic vibration criteria. Figure 8(a) and figure 8(b) show P1 and P2 for the first floor and second floor is under ISO level. It means that P1 and P2 is the most critical point which subjected to the vibration as it is the place to store the machine and equipment in the Land Survey Laboratory. This also can be related to the highest value of vibration signal input that had obtained by using LDV previously on P2.
Whereas, P3 and P4 shows the floor is under VC-E level which is the level are not perceptible to vibration. This indicates that it is suitable for very sensitive areas.

| Mode/Frequency | First Floor | Second floor |
|----------------|-------------|--------------|
| Mode 1/1.12Hz  | ![Mode 1 Image](image1) | ![Mode 1 Image](image2) |
| Mode 2/1.15 Hz | ![Mode 2 Image](image3) | ![Mode 2 Image](image4) |
| Mode 3/1.15 Hz | ![Mode 3 Image](image5) | ![Mode 3 Image](image6) |
| Mode 4/1.15 Hz | ![Mode 4 Image](image7) | ![Mode 4 Image](image8) |
| Mode 5/1.15 Hz | ![Mode 5 Image](image9) | ![Mode 5 Image](image10) |
| Mode 6/1.15 Hz | ![Mode 6 Image](image11) | ![Mode 6 Image](image12) |
| Mode 7/1.15 Hz | ![Mode 7 Image](image13) | ![Mode 7 Image](image14) |
| Mode 8/1.36 Hz | ![Mode 8 Image](image15) | ![Mode 8 Image](image16) |
| Mode 9/1.48 Hz | ![Mode 9 Image](image17) | ![Mode 9 Image](image18) |
| Mode 10/1.75 Hz| ![Mode 10 Image](image19) | ![Mode 10 Image](image20) |

**Figure 7.** Ten mode shapes of the FPTP building at first and second floor.
5. Conclusions
The conclusion can be made for this case study which the both objectives have been achieved. From the vibration criterion plot, 40 percent of the vibration criterion fell under VC-E (most severe) which is the most appropriate place to allocate the sensitive equipment. The maximum Root Mean Square (RMS) curve obtained by using VSATs for Survey Laboratory is 10 micrometers/sec. According to Generic Vibration Criteria by Gordon [6], the RMS fell under VC-C which having the maximum RMS of 12.5 micrometers/sec. VC-C criterion is the good standard for most lithography and inspection equipment to 1 micron detail size.

The equipment in Survey Laboratory has magnification up to 600X which is suitable to allocate at the VC-A criterion. Thus, Survey Laboratory has fulfilled the vibration requirements based on the Gordon [6] standard since the VC-C criterion is more suitable to allocate the survey equipment. The vibration serviceability of Survey Laboratory of FPTP building is fulfilled the specified vibration criteria standard based on the level of vibration due to human walking.

This statement is proved as the 40 percent of vibration criterion for the Survey Laboratory fell under VC-E. Thus, it is proven that the Survey Laboratory is suitable to allocate the sensitive equipment but not at the Point 1 and Point 2 which are under ISO level. ISO level means the floor is free from vibration as it is the second high level in the vibration criterion.
6. References

[1] d. Silva J G S, da S. Vellasco, P C G, d. Andrade, S A L and d. Lima L.R O 2006 *Dynamical Response of Composite Steel Deck Floors*. Latin American Journal of Solids and Structures, 3, pp. 163-178.

[2] Varela W D and Battista R C 2011 *Control of Vibrations Induced by People Walking on Large Span Composite Floor Decks*. Engineering Structures 33, pp. 2485-2494.

[3] Adam D 2010 *Mechanical Vibrations*. Mechanical Engineering. West Lafayette: Fall J. Cohen, “Statistical power analysis for the behavioural sciences,” 2nd edition.

[4] Bachmann H 1995 *Vibration Problems in Structures: Practical Guidelines*. Birkhäuser Verlag, Basel, Switz. Boston, Mass.

[5] Bessason B, Madshus C, Froystein H A and Kolbjornsen H 1999 *Vibration Criteria for Metrology Laboratories*. Meas. Sci. Technol. 10, pp. 1009–1014.

[6] Gordon C G 1991 *Generic Criteria for Vibration Sensitive Equipment*. Proc. of the International Society for Optical Engineering. San Jose, United States.

[7] Tuan Chik T N, Asiew R A, Ibrahim M H W and Yusoff N A 2013 *Dynamic Performance on Multi Story Structure Due to Ground Borne Vibrations Input from Passing Vehicles*. International Journal of Integrated Engineering, 5(2), pp. 51-58.