Dynamic Analysis of an Office Building due to Vibration from Road Construction Activities

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Abstract. Construction activities are widely known as one of the predominant sources of man-made vibrations that able to create nuisance towards any adjacent building, and this includes the road construction operations. Few studies conclude the construction-induced vibration may be harmful directly and indirectly towards the neighbouring building. This lead to the awareness of study the building vibration response of concrete masonry load bearing system and its vibrational performance towards the road construction activities. This study will simulate multi-storey office building of Sekolah Menengah Kebangsaan (SMK) Bandar Enstek at Negeri Sembilan by using finite element vibration analyses. The excitation of transient loads from ground borne vibrations which triggered by the road construction activities are modelled into the building. The vibration response was recorded during in-situ ambient vibration test by using Laser Doppler Vibrometer (LDV), which specifically performed on four different locations. The finite element simulation process was developed in the commercial FEA software ABAQUS. Then, the experimental data was processed and evaluated in MATLAB ModalV to assess the vibration criteria of the floor in building. The vibration level of floor in building is fall under VC-E curve which was under the maximum permissible level for office building (VC-ISO).

1. Introduction

Masonry can be interpreted as a material that manufactured in individual unit and bonded with normal or specialised mortar. It can be variety in material aspects. The naturally availability of stone is responsible for being the oldest building material ever known to humans. However, modernisation of human construction helps in improvising the scope of masonry material and quality. Nowadays, numerous types of masonry have been introduced to the construction industry. Concrete Masonry Unit (CMU) is one of the latest inventions that have been penetrated onto construction industry globally and locally. CMU is closely related with development of load bearing construction industry. Malaysia is one of the country that trying to practice this system in local construction industries as it is carrying multi benefits such as environmental eco-friendly, economical construction system and adequate architectural benefits [1]. The good example of building that fully practiced such system in local industry is SMK Bandar Enstek which located at Bandar Baru Enstek, Negeri Sembilan. Its office building as shown in figure 1 is chosen as an investigation site for field measurement in order to obtain the vibration signal from construction activities.

The fundamental question that has been highlighted few years back is whether vibration due to construction activities would give negative impact towards masonry structure or not. Generally, construction activities owned the potential to produce vibration levels that causing harm to the structures as well as annoyance to the occupants and this includes the road construction activities. The vibration from construction-related able to create vibration waves that propagates through the various soil and rock strata which would generate certain degree of resonant. In Malaysia, the issue regarding on impacts of construction-induced vibration towards adjacent buildings reported quite frequently and more concerning is that most of the local building design criteria are not aware in practicing and applying the vibration factor.

Figure 1. Office building at SMK Bandar Enstek

2. Literature review

2.1. Concrete masonry load bearing system

Concrete masonry load bearing system is one of the best alternative construction methods in overcoming the local problematic issues such as material prices, construction cost, equipping low cost housing demand and land prices. This system offers multi betterments in terms of speed of the construction, durability, environmentally friendly practices, low cost and aesthetically pleasant [2]. The concrete masonry construction herein deals exclusively with one of the unique construction approach, where it is fully adopted the mortared construction method. Such system also fully applied the concept of load bearing wall, which means the building loads are distribute by the wall element. The main element of the structural system is the Concrete Masonry Unit (CMU) as shown in figure 2.

Figure 2. Concrete Masonry Unit (CMU)

2.2. Road construction activities

Road construction activities are often interrelated with ground borne vibrations which may be generated by variations in the forces applied directly or indirectly to the earth surface. It is generally influence by certain related processes or acoustic coupling of infra-sound into the ground. The magnitude of triggered vibrations is in wide range due to the unlike factors of the construction machineries or the type of operations. Some of the common machineries used in road construction activities are vibratory roller compactor, tandem roller compactor, asphalt paver, pneumatic roller and dump truck. Ground borne vibration generated by civil engineering activities especially due to construction works often cause noticeable vibrations in buildings. It may leads to range consequences, depending on the degree of vibration and other related factors. Generally, the construction vibrations effects can range anywhere

from imperceptible to annoyance to building occupants and operations of building sensitive equipment. Basically, there are standard values and guidelines have been introduced by authorities regarding on this issue. The most common codes used are BS5228-4:1992, BS7385-2:1993 and BS6472-1:2008 [3].

2.3. Generic vibration criteria

Vibration Criterion (VC) curves are the building vibration guideline which generally applied to the design facilities equipped with vibration-sensitive systems or instruments, as well as for reference purpose of engineering research especially involving building vibration performance. The generic criteria curves are developed by Colin Gordon as shown in figure 3. The generic criteria curves Colin Gordon are proposed based on the set of one third octave band velocity spectra level which is from VC-ISO to VC-E [4]. VC-ISO further divided into four categories which are operating theathre, residential day, office and workshop. Generally, it is arranged in ascending order where VC-E is the lowest vibrational response while ISO is the highest vibrational response.
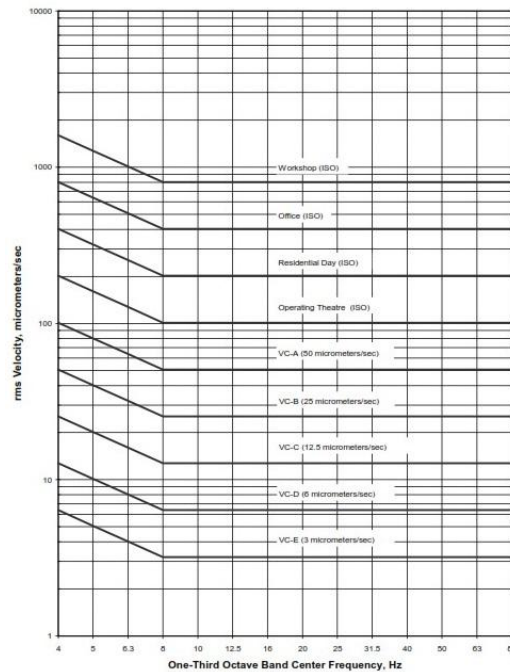

Figure 3. The Gordon generic vibration criterion curves [4]

3. Materials and methods

3.1 Methodology

This study handles complex problems of dynamic impulse which, in particular, subjected to the uncommon structural system in local construction industry which is masonry structure. The class of such problems are often considered as a complex field of study as it involving numerous issues arise especially during the numerical modelling and field testing. Therefore, the key element to achieve the study goals is by implementing comprehensive and organised procedures entirely [8].

3.2 In-situ ambient vibration test

The main purpose of in-situ ambient vibration test is to collect the structural vibration response of the building due to the ground borne vibration of road construction activities. The device used to record the vibrational response data is Laser Doppler Vibrometer (LDV). It was performed on four different selected locations in the building which are B (office room), C (office room), D (multimedia room) and E (library room) for as shown in figure 4. Further descriptions regarding on field testing details are shown in table 1.
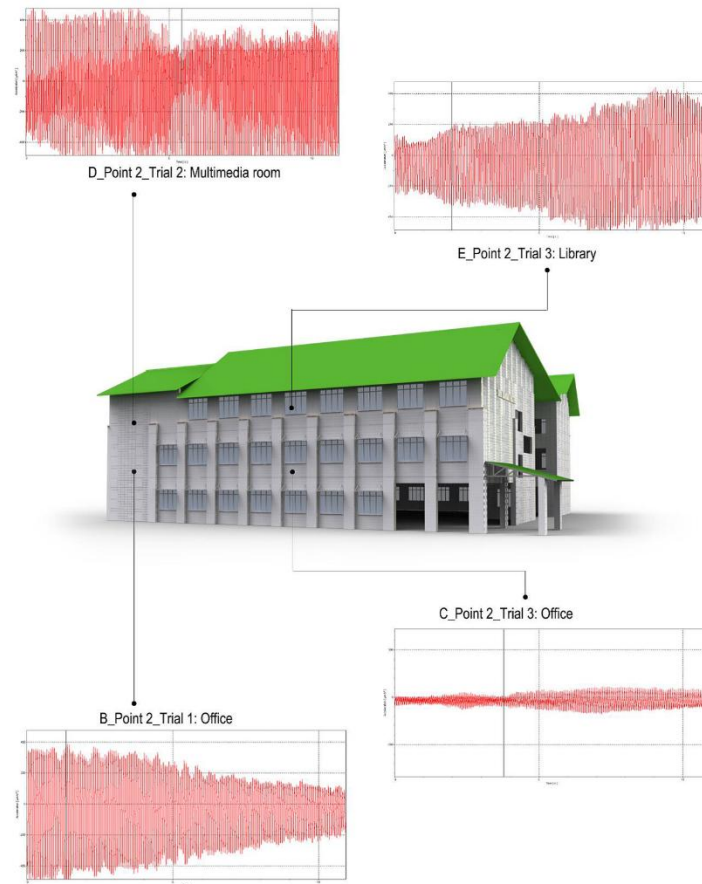
Figure 4. Selected in-situ ambient vibration test result [8]

Table 1. Point of measurements

| Point	Time	Level	Description
B	4.30 – 5.00 pm	L2	Office
C	5.00 – 5.30 pm	L2	Office
D	5.30 – 6.00 pm	L3	Multimedia
E	6.00 – 6.30 pm	L3	Library

3.3 Mechanical properties of materials
The modelling of the building began with the definition for the mechanical properties of the masonry constituents. The values implemented in this project were defined based on data available on some literature, related to studies in buildings with similar properties as well as the Masonry Society Joint Committee (MSJC) code. According to Milošević, Bento and Cattari [5] and Braconi and Tremea [6], the property value of each elements adopted in macro-model technique shall be calculated and assigned as mean value of the element constituents. This is due to the homogenisation approach in macro-modelling technique for masonry finite flement analysis. Therefore, the finalised properties of model parts used in ABAQUS are shown in table 2.

Table 2: Material properties [5] [6]

| Local	Materials	Weight Density (kg/m^3)	Elasticity		Plasticity	
			Elastic Modulus	Poisson ratio	Yield stress	Plastic strain
Wall panel	CMU Steel bar Mortar Grout	2945	6.3x10^9	0.2	54x10^6	-
Slab	Reinforced concrete Soffit block and joist	3250	18x10^9	0.2	30x10^6	-

3.4 Finite element modelling

The modelled structure of office building was carried out in the ABAQUS/CAE program. In order to model the masonry building structure, macro-modelling technique was applied. Generally, there are two major category in modelling task of masonry structures, which are micro-modelling and macro-modelling technique. However, macro-modelling technique was used as it is suitable to be applied for a large scale masonry structures which involve complex geometrical aspects. The modelled structure of office building is consists of 14 macro-element parts which was then being assembled into single form of building structure as shown in figure 5. The assembled parts is made up of 23434 elements and 47276 nodes.
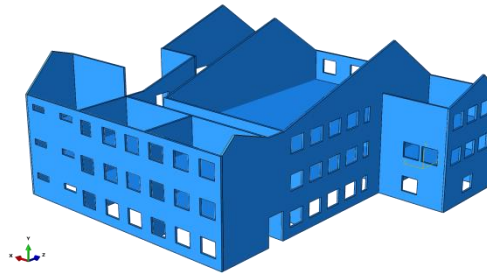
Figure 5. Modelled structure of office building

4. Results and discussions

4.1 Gravity loading

The stresses and stiffness state in the structure must be initialized before any intended analyses were performed. The gravity loads were applied onto the modelled structure, negatively in horizontal direction. Thus, this analysis was performed with the aim to initialize the stress, stiffness and other related parameter in the structure which can be developed from gravity loads. Besides, the implementation of gravity loads ensure the realistic result of each analysis can be achieved. This analysis can be succeed by performing the static general analysis. The gravitational analysis towards the modelled structure is shows in the figure 6.
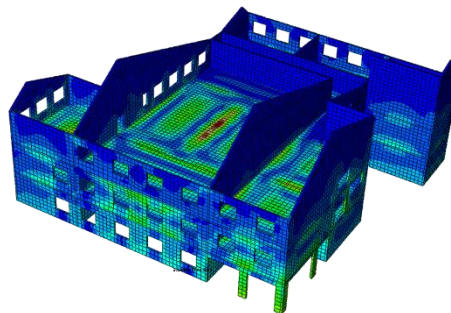
Figure 6. Result of gravitational analysis

4.2 Natural frequencies extraction

Natural frequency extraction is the process where eigenvalue of modelled structure is extracted to calculate its natural frequencies and the corresponding mode shapes. In ABAQUS, eigensolver of Lanczos was chosen due to its suitability for a large scale of modelled structure as well as existence of multi-elements in a single system like multi-storeyed building structure. In this study case, 100 number of eigenvalues requested to obtain range of natural frequencies and its mode shapes.

Based on the result, the modelled structure obtained its first mode shape at 3.72Hz and reach to the peak of 100th mode shape at 35.65Hz. At the first mode shape, critical deformation occurred at A-shape wall (Library_internal) in x-direction. At 100th mode shape, the building experienced critical deformation at both wall and slabs structure (X, Y and Z-direction) which occurred at level 2 and level 3. The result of natural frequencies extraction is illustrates in figure 7.
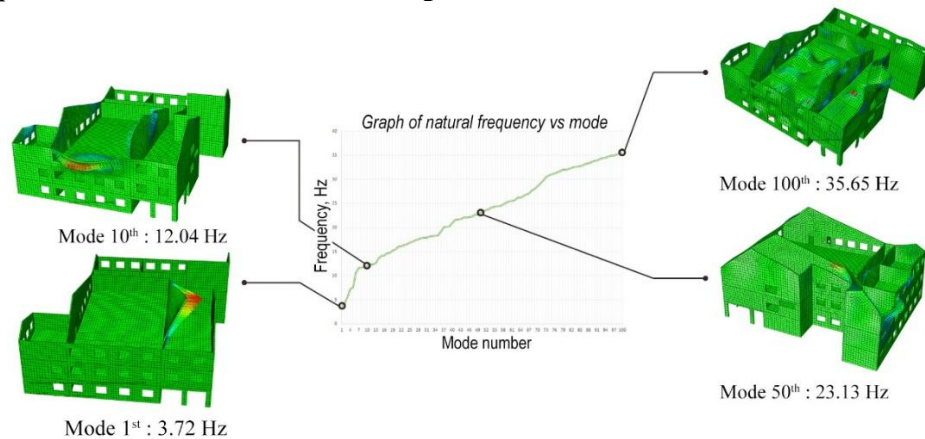

Mode 10th : 12.04 Hz

Mode 100th : 35.65 Hz

Mode 50th : 23.13 Hz

Mode 1st : 3.72 Hz

Figure 7. Result of natural frequencies extraction

4.3 Transient analysis

Transient analysis herein deals exclusively to study and analyse the vibrational response of modelled structure due to the dynamic excitations load obtained from the field testing. The excitation loads were applied on the locations specified from the field testing as shown in table 1. Based on the result, the critical responses occur at Point D which followed by Point E (for both field testing days (Day 1 and Day 2). Specifically, the peak acceleration value for Point D on Day 1 is 7.06×10^{-4} m/s^2 while 1.961×10^{-4} m/s^2 for Day 2. From the results obtained, the vibrational responses for Day 1 data were generally massive compared to the Day 2 results data. This is due to the operation of heavy compaction works which dominated by the vibratory roller compactor machine. This machine able to produce high pressure load onto the ground with 25 tonnes with continuous impact.

The vibrational responses of Point D (Level 3) shows the highest values compared to other points because it is located at the highest level of the building. It is influenced by the sway factor of the building [7]. Even though Point E is at the same level as Point D, yet it is located near to the supporting system. Theoretically, the structural systems become more rigid to the vibration transmission when it is near to supports system. Thus, this factor explains the differences of result data between those points. The result of transient analysis is illustrates in the figure 8.
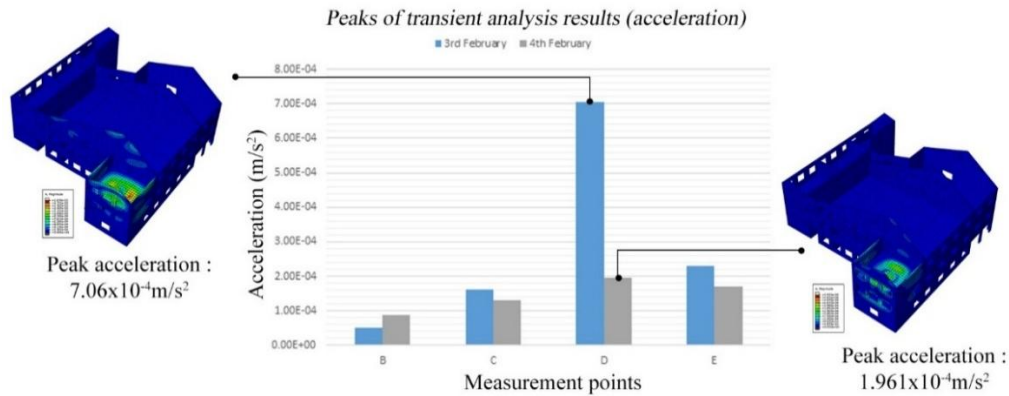
Figure 8. Results of transient analysis

4.4 Vibration criteria (VC curve)

The VC-curve analysis is the process to assess the vibrational performance of structure based on the standard level of generic vibration criterion curve. Generally, there are five categories of VC-curve, which are VC-ISO (highest vibration level), VC-A, VC-B, VC-C, VC-D and VC-E (lowest vibration level). This analysis is performed based on the time history output data obtained from the ABAQUS program, which is then being processed in the ModalV program in MATLAB software. Among all points, the Vibration Criterion for Point D shows the critical values compared to other, where the maximum of frequencies occurred in the range of 30Hz to 35Hz (for Day 1 data) and 35Hz to 45Hz (for Day 2 data) [8]. This is because of the high acceleration responses which obtained from the transient analysis in ABAQUS. The vibration criterion curve for Point D is shows in the figure 9.
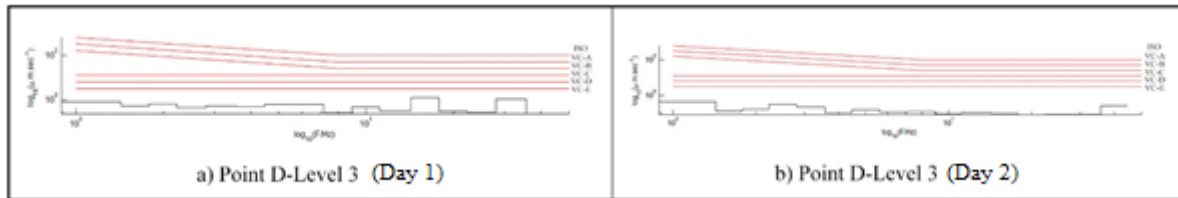

Figure 9. One third octave velocity spectra with vibration criterion curve at Point D (a) Day 1 data, (b) Day 2 data

Based on table 3, it can be inferred that the overall vibration criterion for the office building is falls in the range of VC-E, where the allowable peak of velocity is equals to $3\mu ms^{-1}$. According to the standard from Gordon [4], the maximum allowable of Vibration Criterion level for an office building is VC-ISO, where the peak velocity value is equals to $400\mu ms^{-1}$. Thus, this explains that the building is suitable to be used for the purpose of office building due to the low vibration criterion magnitude.

Table 3. Point of measurements

Points	Vibration Criterion	
	Day 1	Day 2
B	VC-E	VC-E
C	VC-E	VC-E
D	VC-E	VC-E
E	VC-E	VC-E

5. Conclusions

Concrete masonry load bearing system which comprise of different masonry constituents resulting a great performance against the ground borne vibrations. The loading of distribution character of masonry structure is of high importance for the whole response of the structure (wall transfer load). In this study, the overall Vibration Criterion for office building is falls in the range of VC-E which is much lower compared to the permissible level of office building (VC-ISO). It can be concluded that the vibrations triggered by road construction activities unable to produce the human-annoyance, damage of masonry building structure as well as disturbance towards the building utilities. In facts, the Vibration Criterion obtained shows that the concrete masonry load bearing system building structure is less response towards the transmitted ground borne vibration. This proves the statement made by Ecological Building Systems Ltd. [9], claimed that the concrete masonry load bearing system offers better resistance under dynamic loading compared to other conventional system.

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