Prediction of Traffic Vibration Effect on Heritage Building at Muar, Johor, Malaysia

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Abstract. The vibration produced by road traffic can contribute to the long-term adverse effects on heritage structures. The objectives of this study were to analyze the dynamic response of the heritage building under time-dependent loads caused by traffic vibration by carried out the transient analysis in ANSYS and to determine the level of Vibration Criterion of the heritage building due to traffic vibration by using VSATs in MATLAB software. This research was to predict the traffic vibration effect on the old building of Telecom Muar at Johor, Malaysia. A field testing was carried out using a mobile application, iDynamics, to obtain the vibration signal induced by road traffic. The data obtained were analyzed using ANSYS and MATLAB software. Two types of analysis were carried out using ANSYS, which are modal analysis and transient analysis. MATLAB was used to obtain the vibration criteria plot (VC) for the building. The natural frequency of the fundamental mode shape was 2.57Hz. The natural frequency of the building is acceptable as it is below the human sensitivity frequency range. On the other hand, the level of vibration criteria of the building falls on VC-E, which is the lowest level in the Generic Vibration Criteria Plot implemented by Gordon (1991). In conclusion, both natural frequency and the vibration criteria of the selected building is acceptable according to the results obtained from the analysis conducted.

1. Introduction
Vibration is one of the frequent issues which lead to the failure of buildings. Normally, building structures are exposed to the two most important vibration sources which are the internal and external sources [1]. The internal sources of vibration come from the usage of machinery, elevators, HVAC systems, and the activities of a human inside a building; while the external sources of vibration originate from an earthquake, rail and road traffic, construction activities, and wind [2].

The traffic-induced vibration in Malaysia has increased significantly since the population in Malaysia increased year by year and the amount of newly registered vehicles has also increased drastically in Malaysia [3]. Thus, the vibration produced by road traffic needs to be focused on as it has the possibility to contribute to the long-term adverse effects on historic structures [2]. Traffic vibration is often caused by heavy vehicles that drive at relatively high speed and contact with the uneven road surface. The contact between the wheels of vehicles with the road surface causes a dynamic excitation and creates waves that disperse in the soil. The dispersion of waves will impact the foundations of the surrounding structure [4] and cause unwanted structural damage or also excessive vibration on floor at building [5].
The aim of the study was to predict the effect of traffic vibration on the heritage building, the old building of Telecom Muar at Johor, Malaysia. Software analysis using ANSYS and MATLAB were carried out in this study. The Finite Element Modelling (FEM) software, ANSYS, was used to model the heritage building and carried out the transient analysis. VSATs and ModalV in the MATLAB software were used to obtain the vibration criteria level of the heritage building. The vibration criteria obtained will then be used to compare with the Generic Vibration Criteria guideline implemented by Gordon [6].

2. Generic vibration criteria
In this study, generic vibration criteria were used as the guideline to determine the traffic vibration effect on the heritage building. There is a total of five types of criterion curves, which are curves VC-A through VC-E. The curves are taken from the form of a set of one-third octave band velocity spectra, together with the International Standard Organization (ISO) guidelines of the impact of vibration on people in buildings [6]. Figure 1 shows the graph for the generic vibration criterion curve and table 1 shows the description for the generic vibration curves.

![Generic Vibration Criterion (VC) Curves by Gordon](image)

**Figure 1.** Generic Vibration Criterion (VC) Curves by Gordon [6].
Table 1. Description of Generic Vibration Criterion (VC) Curves [6].

| Criterion curve       | Max Level (μm/ s) | Detail Size (μm) | Description of use                                                                 |
|-----------------------|-------------------|-----------------|------------------------------------------------------------------------------------|
| Workshop (ISO)        | 800               | N/A             | Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas    |
|                       |                   | N/A             | Feedable vibration. Appropriate to offices and non-sensitive areas.               |
| Office (ISO)          | 400               | N/A             | Barely feelable vibration. Appropriate to sleep areas in most instances. Probably |
|                       |                   |                 | adequate for computer equipment, probe test equipment and low-power (to 20X)      |
|                       |                   |                 | microscopes.                                                                      |
| Residential day (ISO) | 200               | 75              | Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most      |
|                       |                   |                 | instances for microscopes to 100X and for other equipment of low sensitivity.     |
|                       |                   |                 | Adequate in most instances for optical microscopes to 400X, microbalances,      |
|                       |                   |                 | optical balances, proximity and projection aligners, etc.                       |
| Operating theatre (ISO)| 100              | 25              | 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. Suitable in most instances for the most demanding equipment         |
|                       |                   |                 | including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to  |
|                       |                   |                 | the limits of their capability.                                                 |
| VC-B                  | 25                | 3               | 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.     |
| VC-C                  | 12.5              | 1               |                                                                                   |
| VC-D                  | 6                 | 0.3             |                                                                                   |
| VC-E                  | 3                 | 0.1             |                                                                                   |

3. Methodology

The old building of Telecom Muar at Johor, Malaysia as shown in figure 2 was selected as the case study location for this study. The in-situ field testing was carried out at the surrounding of the building by using the mobile application, iDynamics. The two-storey old Telecom Muar building was modelled using ANSYS to carry out Finite Element Analysis. Besides, ANSYS was also used to carry out a transient analysis. Vibration criterion analysis was carried out using VSATs and Modal V in MATLAB.

3.1. Modal analysis

Vibration characteristics in terms of natural frequencies and mode shape of the structure can be determined through modal analysis. The parameter and the geometry of the building were defined in the analysis. The building consists of two-storey buildings with a dimension of 32.9m x 22.8m, and a height of 7.5m. The frame structure of the building includes a reinforced concrete frame system and also a timber concrete composite slab structure for the first-floor slab.
Figure 2. Front view of the old building of Telecom Muar.

Table 2 shows the properties of the building structure and table 3 shows the sizes of beams and thickness of a slab for each floor of the building. The concrete graded at 40 N/mm² was assumed to be used for the concrete structure.

| Materials       | Density (kg/m³) | Elastic Modulus (GPa) | Poisson Ratio |
|-----------------|----------------|-----------------------|---------------|
| Reinforced concrete | 2500           | 38                    | 0.2           |
| Concrete        | 2400           | 38                    | 0.2           |
| Timber          | 1000           | 10                    | 0.2           |

Table 3. Sizes of beam and thickness of the slab.

| Floor          | Beam size (mm) | Slab Thickness (mm) |
|----------------|----------------|---------------------|
| Ground Floor   | Primary beam   | 300 x 600           | 300            |
|                | Secondary beam | 300 x 500           |                |
| First Floor    | Primary beam   | 300 x 600           | 130            |
|                | Secondary beam | 300 x 500           |                |
|                | Timber joist   | 43 x 400 @ 750mm c/c|                |
| Roof           | Primary beam   | 200 x 600           | 125            |

3.2. Transient analysis
Transient dynamic analysis is a technique used to determine the time history dynamic response of a structure to arbitrary forces varying in time. This analysis provides the displacement, stress, strain, and force-time history response of a structure to any other combination of harmonic or transient loads [7].

3.3. Vibration criteria analysis
Vibration criteria analysis was carried out using VSATs and ModalV in MATLAB. The results generated using VSATs analyses were performed and characterized by colors. The results obtained from
ModalV were formed as a plotted graph, then were compared with the Generic Vibration Criterion (VC) curve by Gordon [6].

4. Results and Discussion
The results obtained from the modal analysis, transient analysis and vibration criteria analysis were presented and discussed in this section. For all the analysis, the ground floor was not be taken in the analysis. The ground floor was assumed to be fixed to the ground; while the upper floor was set to be free. Besides, only vertical displacement (z-axis) of the floor structure was investigated. The horizontal displacement was not considered in this study.

4.1. Result for modal analysis
The result of the modal analysis was generated through ANSYS, where the result shows that the natural frequency of the fundamental mode shape of the building was 2.57 Hz. According to Siddika et al. [8], the first mode for free vibration is considered critical and has a high risk to cause resonance to occur. The other modes of free vibration can be critical for high-rise structures and assumed as less critical than the natural period for low-rise structures. Hence, the fundamental mode obtained from the modal analysis is the most important mode to reflect the behavior of the building.

According to the ISO base curve, as shown in figure 3, the human sensitivity is at its maximum when the frequencies are between 4Hz to 8Hz; after that, the sensitivity will decrease as the frequency increases [9]. Hence, the natural frequency for the first mode shape can be accepted as it is below the range between 4Hz to 8Hz. The mode shape and natural frequencies for the first ten-mode are shown in table 4. Green color indicates that the model does not undergo any displacement; blue color means that only minimum displacement is faced by the model; yellow color shows the model has moderate displacement, and red color means the model is under its maximum displacement.

![Figure 3: ISO base curve [9].](image-url)
Table 4. Model of the first ten modes and their natural frequencies.

| Mode Shape (ANSYS) | Mode 1, 2.57 Hz | Mode 2, 3.20 Hz | Mode 3, 3.36 Hz | Mode 4, 3.89 Hz | Mode 5, 4.14 Hz | Mode 6, 4.42 Hz | Mode 7, 5.75 Hz | Mode 8, 5.80 Hz | Mode 9, 6.89 Hz | Mode 10, 7.51 Hz |
|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
4.2. Result for transient analysis

Transient analysis, also known as time history analysis, was conducted using ANSYS software. This analysis was used to determine the dynamic response of the building under the time-dependent loads. The vibration input location in ANSYS is shown in figure 4. The results obtained from the transient analysis were greatly affected by the distance of the vibration input location in ANSYS and signal input obtained from iDynamics. The vibration input location in ANSYS was set in the middle of the building, while the vibration signal was obtained outside of the building (point 1 and point 2). The dynamic soil-structure interaction caused the vibration wave to be dissipated when transferring through the soil structure to the building structure [10]. This was shown in the result obtained in this analysis. The vibration waves received by the building structure decrease to 0 m/s$^2$ when it reaches the middle of the building. Figure 4 indicated the location of the Point 1 and Point 2 from the main road. From the results obtained, it can be concluded that the traffic-induced vibration which acts onto the building was negligible as the acceleration for the first floor was 0 m/s$^2$. Table 5 shows the result obtained from the transient analysis.

![Figure 4. Vibration input location in ANSYS.](image)

**Table 5. Results of transient analysis for traffic-induced vibration.**

|                        | Input (from iDynamics) | Output (from ANSYS) |
|------------------------|------------------------|---------------------|
| **Point 1**            | Acceleration           | 0.150 m/s$^2$       | 0 m/s$^2$           |
| **Point 2**            | Acceleration           | 0.151 m/s$^2$       | 0 m/s$^2$           |
4.3. Result for vibration criteria analysis
Vibration criteria analysis was carried out using VSATs and ModalV in MATLAB. In this analysis, the vibration input location was the same as the transient analysis. The vibration criterion level of the building fell on curve VC-E for both of the analyses. Further discussion will be carried out as follows.

4.3.1. Vibration serviceability assessment tools (VSATs). By using this tool, the vibration criterion for the overall structure can be obtained. The level of vibration response is being characterized by the color pattern as shown in figure 5. The vibration criteria analysis carried out using VSATs in MATLAB shows that the first-floor structure was categorized under VC-E. According to Gordon (1991), a building structure under the VC-E category is assumed to be suitable for placing sensitive equipment and also other systems which require extra dynamic stability [6]. Hence, the traffic vibration around the old building of Telecom Muar did not give any significant effect on the building structure. Table 6 shows the results obtained from VSATs.

![Figure 5. Characteristic of color pattern for vibration response for VC plot.](image)

Table 6. Vibration criteria analysis for first-floor structure of the old building of Telecom Muar with vibration input from Point 1 and Point 2

| Vibration input | Vibration response |
|-----------------|--------------------|
| ![Vibration input for Point 1](image) | ![Vibration input for Point 2](image) |

4.3.2. ModalV. The vibration criteria plot obtained from the analysis shows that the vibration level of the old building of Telecom Muar was 0 μm/s. It can be assumed that the vibration level of the building
drops at the lowest level (VC-E) according to the generic vibration criteria plot implemented by Gordon [6]. Hence, it can be said that this building did not undergo any significant effect on traffic vibration that occurs around the building. Table 7 shows the result obtained from ModalIV.

| Table 7. Vibration criteria plot for the input data from Point 1 and Point 2 |
|-----------------------------|-----------------------------|
| Input data | Vibration Criteria Plot |
| Point 1 | ![Graph1](D:/TNCT_2020/PSM2JESSIE/Matlab/MODAL121_JMWB_TNCT/muar11 ch 2 frame 1) |
| Point 2 | ![Graph2](D:/TNCT_2020/PSM2JESSIE/Matlab/MODAL121_JMWB_TNCT/muar11 ch 2 frame 1) |

5. Conclusion
In conclusion, both objectives have been achieved by the researcher at the end of this study. Overall, the displacement of the floor structure for the first ten-mode shape can be accepted. The natural frequency of the building is acceptable as the frequency of the fundamental mode shape, 2.57Hz, falls below the range as stated in the ISO base curve. On the other hand, the output acceleration obtained from the transient analysis in ANSYS was 0 m/s². This result indicates that the traffic-induced vibration which acts onto the old building of Telecom Muar was negligible.

For the vibration criteria analysis, the level of vibration of the old building of Telecom Muar fell on VC-E, the lowest level in the Generic Vibration Criteria Plot implemented by Gordon [6]. This has shown that the traffic-induced vibration does not show any significant effect on the building structure of the old Telecom Muar building. Hence, it can be concluded that the old building of Telecom Muar was not affected by the traffic vibration that occurs around the building.

There are some suggestions provided as follows to enhance the quality of the research:

i. The accelerometer is recommended to be used to determine the traffic-induced vibration. In order to obtain the vibration signal more accurately compared to the mobile applications.

ii. Besides, further checking needs to be carried out to determine the accuracy of the vibration measurement using mobile applications.

iii. The road condition, type of vehicles passing and the distance from the main road to the building are also important factors to be included in the research.
iv. Lastly, the type of soil around the building should also be taken into consideration as the propagation of vibration waves will be affected by the type of soil.

6. References

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