The Impact Influence of Highway Bridge due to Moving Vehicles

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Abstract. In recent years, rapid urbanization associated with considerable urban population growth has placed significant demands on urban transport infrastructure. As a result, more and more elevated highways, usually long piers, have been erected in urban platforms to ease urban traffic pressures. However, the high traffic volume of such highway bridges can cause significant vibration. To study the effects of vibration caused by bridge traffic, this study monitored the acceleration due to moving vehicles of an isolated bridge for 24 hours. The fast Fourier transform method and the system implementation method are then used to analyse the acceleration measurements and thus to calibrate the system parameters of the bridge and the building. Besides, the displacement from the deck to the pier and the deck acceleration were measured to investigate how vehicle transport affects the structural performance of the deck and pier. The results can be used as a reference for improving vibration problems caused by bridge traffic in the future.

1. Introduction

Earthquake engineering research focuses on the seismic performance of structures, namely structural safety and life safety. With the intensification of urbanization, more and more urban roads and bridges have been developed, reshaping the landscape of large cities. However, the vibrations caused by bridge vehicles may, to some extent, exceed the comfort level of human beings, thus affecting citizens' daily life in the vicinity. Previous bridge vibration studies have focused on three areas: the impact of wind-induced bridge vibration on vehicle ride comfort, the characteristics of bridges under wind excitation, and the failure of expansion joints caused by vehicles [1-2]. Through reference to reviewed research, this study aims to investigate the effects of vehicle-induced bridge vibration on nearby buildings.

2. Methodology

2.1. Root Mean Square (RMS) Acceleration

The obtained three-axis vibration measurements are shown in the direction of bridge traffic, vertical and vertical directions of traffic, respectively, in the X, Y, and Z directions. Analyse the readings of the servo speedometer and determine the floor acceleration using the following function according to ISO 2631-1 [3].
\[ a_w = \left[ \frac{1}{T} \int_0^T a_w^2(t) \, dt \right]^{\frac{1}{2}} \]  

where \( a_w(t) \) is the acceleration measurement \((\text{m/s}^2)\), \( T \) is the measurement period \((\text{s})\) and \( a_w \) is the root mean square (RMS) acceleration \((\text{m/s}^2)\).

2.2. Time-frequency analyses

Time-frequency analyses are typically used to investigate structure vibration responses. To execute the time-frequency transform of the floor acceleration signals, this study employed the discrete fast Fourier transform (FFT) algorithm (Function 2), which was derived from Cooley and Tukey’s FFT algorithm [7].

\[ X(f)_k = \sum_{k=0}^{n-1} x_k e^{-\frac{2\pi i}{n} k j}, j = 0, 1, \cdots, n-1 \]  

3. Case study

Regarding the investigated elevated expressway bridge (Figure 1), the local traffic management department reported the noticeable building vibrations in the adjacent area and the discomfort experienced by the residents due to the bridge traffic. In this case, a specially designed obstacle is embedded in the ground (20 meters deep) between the pier and the adjacent building to reduce the impact of the bridge vibration caused by the vehicle on the adjacent building. In order to evaluate the effect of this vibration isolation implementation, the floor vibration of adjacent residential buildings was monitored and analysed. The target RC frame building is five stories high with a basement above the roof and an additional lightweight sheet metal structure (Figure 2). The distance between the building and the bridge is approximately 25 meters.

![Figure 1. Target elevated expressway bridge.](image-url)
acquire the readings of these servo velocity meters before and after the vibration isolation implementation. The floor vibration was measured following the national standard for measuring the ambient vibration level [8] and the sampling rate was 200 Hz.

**Figure 2.** Allocation of vibration measurement spots in the target building.

### 4. Vibration responses analysis

#### 4.1. Target building

The vibration responses of the target building are depicted in Figure 3. Before the vibration isolation implementation, the acceleration readings exhibited considerable vibration responses from 6:00 to 18:00, and the maximum RMS acceleration in the X, Y, and Z directions were 0.014, 0.013, and 0.015 m/s², respectively. Subsequently, the vibration isolation implementation substantially diminished the building vibration in all three directions: the maximum RMS acceleration in the X, Y, and Z directions were reduced to 0.008, 0.01, and 0.013 m/s², respectively. According to the discrete FFT analysis of the acceleration signal of the first floor, the peak vibration frequency in the X direction was 3.09 Hz (Figure 4), representing the dominant frequency of the building.

**Figure 3.** Floor vibration responses of the target building in 24 hours.
Vehicle type (i.e., sedans, freight vehicles, and trailers) can somehow affect the bridge vibration and thus influence the adjacent buildings; therefore, to assess such effects, this study reckoned the average vehicle volume and trend in 24 hours (Table 1). Table 1 indicates that the daily rash hour of the bridge traffic is from 8:00 to 11:00 and from 14:00 to 17:00, and during these periods, semi-trailers take a large percentage of the total vehicle volume, followed by freight vehicles. On the contrary, the sedan volume peaks at 7:00 and 17:00. According to Figure 5, the building vibration trend was consistent with the total vehicle volume trend. Furthermore, hard floor vibration was significantly associated with trailers driving through the bridge.

Figure 4. Discrete FFT analysis of the X-direction vibration responses of the first floor

Figure 5. Building responses in respect to the bridge vehicle volume before and after the vibration isolation implementation.
Table 1. Vehicle volume in 24 hours.

| Time   | Sedan | Freight Vehicle | Trailer | Total Vehicles |
|--------|-------|-----------------|---------|---------------|
| 00:00  | 11    | 6               | 14      | 31            |
| 01:00  | 7     | 12              | 24      | 43            |
| 02:00  | 6     | 3               | 8       | 17            |
| 03:00  | 9     | 4               | 8       | 21            |
| 04:00  | 6     | 10              | 7       | 23            |
| 05:00  | 9     | 8               | 18      | 35            |
| 06:00  | 44    | 45              | 89      | 178           |
| 07:00  | 203   | 112             | 76      | 391           |
| 08:00  | 163   | 119             | 199     | 481           |
| 09:00  | 98    | 157             | 299     | 554           |
| 10:00  | 104   | 124             | 251     | 479           |
| 11:00  | 77    | 123             | 252     | 452           |
| 12:00  | 71    | 83              | 144     | 298           |
| 13:00  | 74    | 132             | 228     | 434           |
| 14:00  | 79    | 116             | 243     | 438           |
| 15:00  | 107   | 141             | 239     | 487           |
| 16:00  | 130   | 124             | 207     | 461           |
| 17:00  | 198   | 98              | 124     | 420           |
| 18:00  | 157   | 108             | 96      | 361           |
| 19:00  | 110   | 66              | 84      | 260           |
| 20:00  | 39    | 43              | 75      | 157           |
| 21:00  | 39    | 27              | 43      | 109           |
| 22:00  | 26    | 24              | 30      | 80            |
| 23:00  | 19    | 11              | 16      | 46            |

A comparison of the floor vibration responses in all three directions before and after the vibration isolation implementation is presented in Figure 6. The comparison indicated that the vibration acceleration of all three measured floors was lowered by approximately 20% due to the improvement implementation.

Moreover, after the implementation, the first-floor vibration responses in all three directions did not exceed the human vibration comfort threshold prescribed in the JIS standards (refer JIS Z8735 [4], JIS C1510 [5], JIS C1513 [6]). As to the fourth floor, despite the vibration in the Y direction, the acceleration in the other two directions was lower than the JIS threshold. The three-direction acceleration of the fifth floor also decreased, and the X- and Z-direction acceleration approached the JIS threshold.

4.2. Bridge vibration

Observing the analysis results, as shown in Figure 7, the measurement of the vibration in five different locations are set up in the vertical direction. Discussing the traffic flow in the rush hour, the vibration is generated at the center of the bridge and has gradually passed to the pier. The response of the span center is approximate to 78 dB. The response of the pier bottom is approximate to 59 dB, and the pier top is
approximate to 58 dB, where the vibration of the top and bottom of the pier is similar to each other. The diaphragm is approximated to 71 dB, and the building base is approximate to 47 dB. The attenuation ratio is 9% of the diaphragm, 25% of the pier top, 24% of the pier bottom and 39% of the building base.

![Figure 6](image6.jpg)

**Figure 6.** Comparison of the floor vibration responses before and after the vibration isolation implementation.

![Figure 7](image7.jpg)

**Figure 7.** Bridge responses in respect to the bridge vehicle volume.

5. **Conclusions**
The vibration analyses of the target residential building revealed that during the period from 6:00 to 21:00, the vibration of all three monitored floors (i.e., the first, fourth, and fifth floors) exhibited significant vibration responses. As to the first-floor vibration, the vibration responses in the Z direction were more significant than those in the other two directions with the maximum RMS acceleration was
0.021 m/s² and the ISO RMS acceleration was 86.3 dB. In contrast, for the fourth and fifth floors, the Y direction vibration had more intense responses than the other two directions, and the maximum RMS acceleration was 0.063 and 0.079 m/s², respectively, and the ISO RMS acceleration was 96.0 and 97.9 dB, respectively. The FFT analyses suggested that the vibration frequency of the first floor in the Z direction (= 3.4 Hz) and the fifth floor in the Y direction (= 3.02 Hz) approximated the dominant frequency of the building.

6. References

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Acknowledgments
I am very grateful for the cooperation of Professor Kuo-Chun Chang and research fellow Fang-Yao Yeh who took part in this phase of the study. This research was supported by CECI, an engineering consultant, Inc., Taiwan.