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CORRELATION OF STRUCTURE-BORNE NOISE AND VIBRATION ALONG RAILWAY VIADUCT

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ABSTRACT
Some typical data from real time frequency analyzer were obtained for the structure-borne noise and vibration excited by the train traffic on viaduct. Relationship between the structure-borne noise and vibration in terms of transfer function, coherence, velocity, frequency and train speed were evaluated. They showed that the dominant frequency range for the noise and vibration is between 40 Hz and 100 Hz, the resonance frequencies are 42.5 Hz and 57.5 Hz and have significant tonal noise characteristics. On the other hand, the frequency is constant as the trains pass through but the magnitude of vibration varies. Therefore, it will be more related to the structural resonance frequency of the viaduct, which does not depend on the train parameters. Calculations are made on the resonance frequency of concrete structures and the calculated frequency agrees with experimental results.

1 - INTRODUCTION
In Hong Kong, the extension of the railway system is an obvious trend to cope with the growing demand for public transportation. At the same time, the elevated structures through residential area are developed rapidly and the speed of trains will be increased to improve the railway service. Therefore, noise and vibration from railway lines running on the viaduct through residential area is one of the significant problems we are facing now. In order to protect nearby buildings in residential areas, vibration and structure-borne noise from railway traffic should be subjected to certain requirement. However, there is no official code released for vibration or structure-borne noise from railway in Hong Kong.
Many investigations of structure-borne sound from rail traffic, both theoretical and experimental, exist in the literature. However, no investigations for the correlation of structure-borne noise and vibration along the railway system have been conducted. A number of research papers have only examined the effect of the structure-borne noise and vibration individually or used an in-situ measurement and a theoretical model to predict the effect of the structure-borne noise.
This paper shows the contribution of structure-borne noise and vibration at the bottom of the concrete viaduct and at the column. In this case, the viaduct itself screens the rolling noise, so large portion of the measured noise level come from the vibrating viaduct structure. Its data is used to determine the relationship of vibration and structure-borne noise and their characteristics.

2 - METHODOLOGY
A measurement experiment was carried out in order to determine the level of noise and vibration generated by running trains. The measurement points shown in Figure 1 were taken at the bottom and 4.8 m below the viaduct of the Airport Express Lines. All of the measurement data were recorded by the Sony MD walkman-digital recording and the data at location 1 were measured by the HP 3569A Real-time Frequency Analyzer simultaneously. Both of the measurement points are under the viaduct in order to determine the contribution from the bridge itself (i.e. structure-borne sound of the viaduct). The signals were registered using the narrow-band with a resolution of 200 lines in the frequency range from 2.5 Hz to 403 Hz for the period of the train passing, the time recording and observation of the Airport Express Rail were also been taken simultaneously.

3 - RESULTS

When cars run on rails, the vibrating motion of the rails is communicated to the supporting structures such as tracks and concrete structures (bridges). The frequencies of the structure-borne sound excited by train traffic are generally lower than those of the rolling noise, according to [1], the dominant frequency range is between 40 Hz and 100 Hz. From Figure 1, the magnitude of sound pressure levels below 125 Hz is relatively higher, that implies frequencies above 125 Hz are less significant for the structure-borne noise.

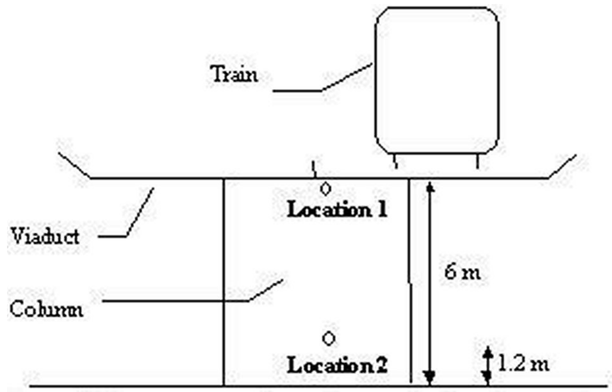

Figure 1: Measurement locations of vibration and noise measurement of the concrete railway viaduct.

According to ref. [2], the critical frequency (f_c) and resonance frequency (f_{11}) of the concrete viaduct section are calculated from the formula presented below:

$$f_c = \frac{c^2}{1.8t}\sqrt{\rho_m/E}$$
$$f_{11} = 0.48\sqrt{Et^3/M}\left(\frac{1}{a^2}+\frac{1}{b^2}\right)$$

where

- f_c = critical frequency, Hz
- E = Young's modulus of the plate, N/m^2
- c = speed of sound, m/s
- M = mass surface density of plate, kg/m^2
- t = plate thickness, m
- a = length of plate, m
- ρ_m = density of the material, kg/m^3
- b = width of plate, m

For the concrete viaduct shown in Figure 2, E=19.6 $\times 10^9$ N/m^2, ρ_m=1700 kg/m^3, t=0.15 m, a=2.1 m and b=20 m. From the above equations, the critical frequency is 120 Hz and resonance frequency is 56 Hz. They are closed to the experimental results of 102.5 Hz and 42.5 Hz.

Some typical data of real time frequency analyzer were obtained for the structure-borne noise and vibration excited by the train traffic on viaduct. Relationship of the structure-borne noise and vibration in terms of transfer function, coherence, velocity, frequency and speed of train were evaluated. In this case the rolling noise is screened by the bridge itself, noise level under the bridge is the contribution from the bridge, which may represent the structure-borne sound. As the train travels at 140 km/h, the dominant frequency range for the noise and vibration is between 40 Hz and 100 Hz and has significant tonal noise characteristics. From Figures 3 to 7, the acoustics resonance includes 102.5 Hz, 147.5 Hz. For vibration resonance, it encompasses 42.5 Hz and 57.5 Hz separately as they have peak response for the acceleration and velocity of vibration. It should be noted that SPL at 42.5 Hz and 57.5 Hz is higher than that at 102.5 Hz. Accordingly, the amplification of the vibration at 42.5 Hz and 57.5 Hz band

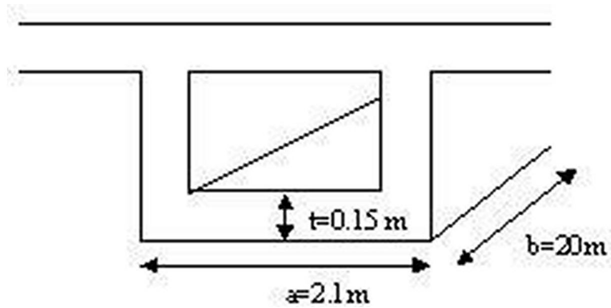

Figure 2: Dimensions of the concrete railway viaduct.

is influenced by resonance of the combination of viaduct and train, and the vibration response can be caused by wave motion propagating upon the concrete elevated structure. In several measurement data, the resonance frequencies are the same for different trains. This may implies that the train parameters are not the dominant component to affect the resonance frequency of the system.

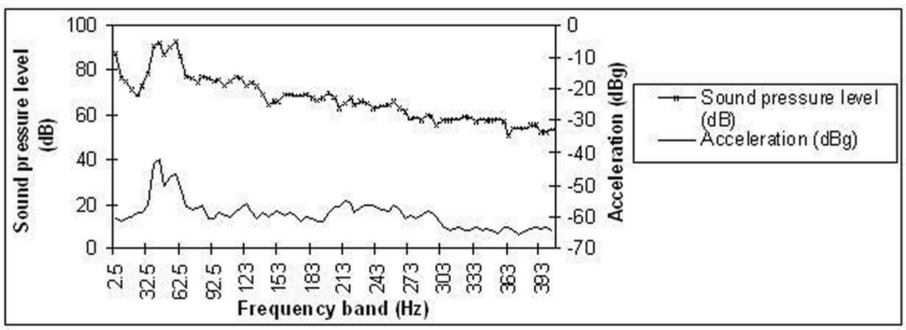

Figure 3: Magnitude of sound pressure level and acceleration (airport).

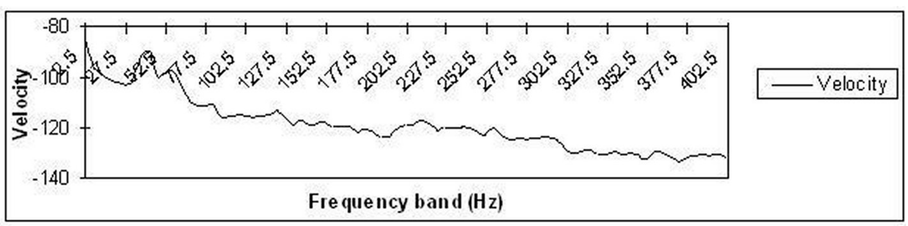

Figure 4: Velocity (airport).

4 - CONCLUSIONS

From the measurement data, the resonance and critical frequencies of concrete structures agree with the calculated results. The SPL due to vibration resonance is the dominant frequency band in the structure-borne noise. The dominant frequency range of structure-borne noise is between 40 Hz and 100 Hz.

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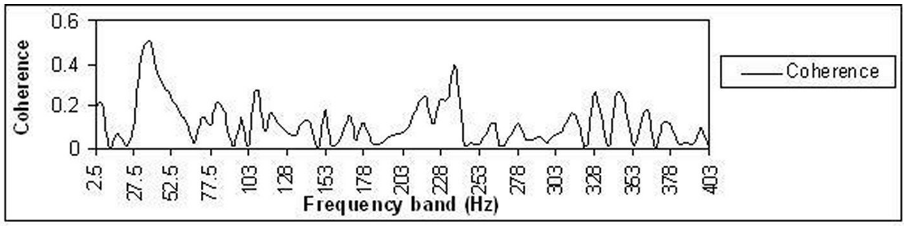

Figure 5: Coherence (airport).

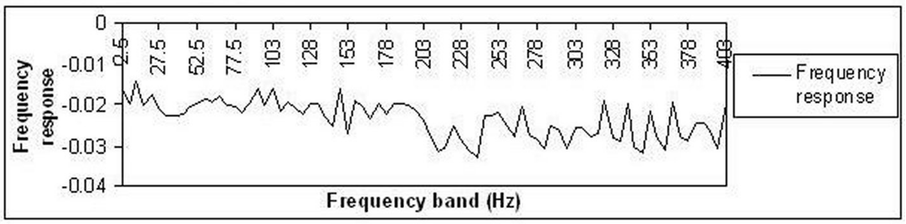

Figure 6: Frequency response (airport).

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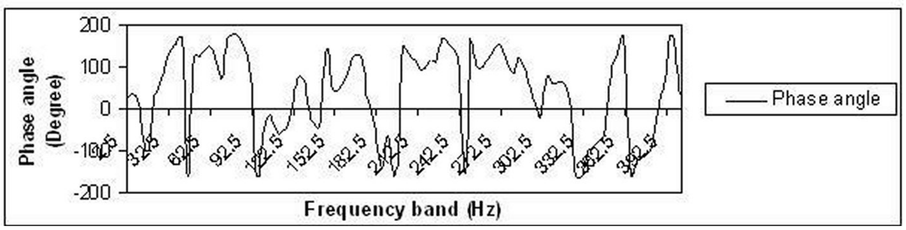

Figure 7: Phase angle (airport).