Vibration measurement of RC viaducts under high-speed trains

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1. Introduction

High speed train is considered as a means of mass transit between major cities in modern society. In Japan to meet the needs of passenger transportation, higher speed of the train has become the necessitous demand in the near future. Therefore railway RC viaducts undertake increasing intensive service loads. These structures will play a more important role in the socio-economic life of a country so that their continued use and preservation is a priority. Thus it is important to investigate the actual dynamic behavior of railway structures under high-speed train passage. Based on the thorough understanding of the vibration property, the performance of viaducts under high-speed train loads can be elucidated.

In this paper, the train-induced vibration measurement results of railway RC viaducts are presented. The comparison of vibration measurements in the three directions, i.e. longitudinal, vertical and lateral directions, shows the vibration is not much different from each other. The results also show that the vibration has become large in longitudinal direction before the train reaches the viaducts. This phenomenon predicates the continuous rail track between two viaducts provides enough axial stiffness to transfer vibration energy in this direction. Lastly, the relationship between the vibration level and the train speed is discussed.

2. Filed Measurement

For measuring three-dimensional train-induced vibrations (in longitudinal, vertical and lateral directions), uniaxial velocimeters were attached to the columns and the girders of the RC viaducts respectively. Totally five viaducts were measured at the same time, which have the same or very similar structure from the design figures. A total of 47 trains passed the viaduct with different speeds including both downtrains and up-trains.

2.1 Vibration in three directions

In the previous research about the train-induced vibration, more attention was paid into the vibration in vertical direction, which is affected by the impact train load directly. The vibrations in the longitudinal and lateral direction have not been considered in some simple 2D analysis models. Table 1 gives a typical velocity Root Mean Square (RMS) value of measured velocity in the longitudinal, vertical and lateral directions in the column and girder points. The train speed was about 240km/h. From this comparison, the vibrations in longitudinal and lateral directions are as large as that in the vertical direction. The analysis results from a numerical simulation model [1] also show this phenomenon. Longitudinal and lateral vibrations in addition to vertical vibration, therefore, need to be well considered.

Table 1 Typical velocity RMS values of three directions (mm/s)

Direction		Longitudinal	Vertical	Lateral
Column	Downtrain	1.2964	1.0834	1.1148
	Up-train	0.8759	0.5554	0.9408
Girder	Downtrain	0.7181	2.3387	1.1055
	Up-train	0.5914	1.6049	1.3054

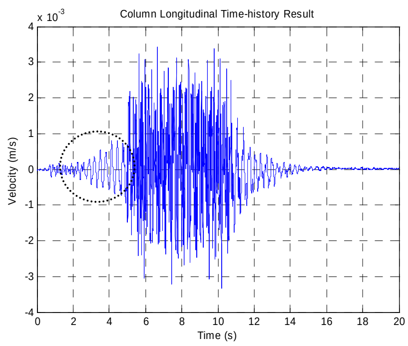

Figure 1. Vibration before train reaches viaduct

Keyword: Train-induced vibration; Railway RC Viaduct; Field measurement; Dynamic response
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2.2 Connection between viaducts and their vibration

For railway viaducts, the train load is always on the eccentric location of the structure. The longitudinal direction is excited by the torsional movement of the structure. Viaducts were built independent of each other. There is not anything (e.g., an elastomeric material) to connect adjoining viaducts. But in the measurement pretty large vibration was observed in longitudinal direction before the train reached the viaduct. Figure 1 shows the typical time-history measurement record. The frequency analysis is explored to check the vibration resource of this vibration. In figure 2, train-induced vibration measured while the train is passing the viaduct shows three clear spectrum peaks. The peaks of the vibration before the train reached the viaduct accord well with these train-induced peaks; train induced vibration is observed even before train reaches the viaduct. Previous research [2] showed that even a weak axial connection between adjacent viaducts have nonnegligible effects and can reduce the shear force at the pile bottom in the longitudinal direction. The continuous rail track can work as a weak axial connection and transfer the vibration energy to adjacent viaduct. Moreover, this result also indicates that extra axial links or dampers between the viaducts may be installed to reduce vibrations in longitudinal direction. This small modification of the viaduct potentially reduces vibrations of viaducts.

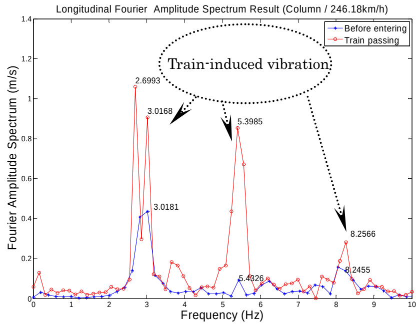

Figure 2. Frequency component analysis

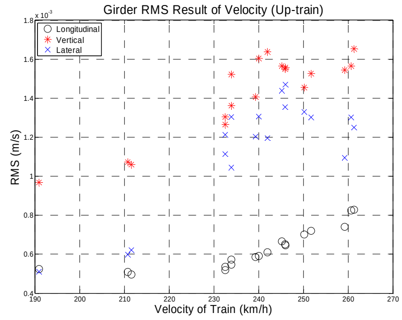

Figure 3. Structural response level and train speed

2.3 The train speed and vibration level

Viaduct vibration responses induced by trains running at various speed levels were measured. Figure 3 shows the clear relationship between the structural response levels in three directions and train speed. The increase in response levels is observed as the train speed increase. Especially the lateral vibration level shows large velocity dependency in the measured train speed range. This observation emphasizes the importance of structural vibration consideration when change in train operating speed is scheduled. In order to investigate structural vibration of railway bridges, a delicate model of the train-bridge interaction analysis system has been developed [1]. Once the model is calibrated with the measurement results, this system can be used to predict the train-induced vibration in various situations.

3. Conclusion and future work

In this paper the results from the train-induced vibration measurement of railway RC viaducts are investigated and discussed. From the results, the vibration in longitudinal and the lateral direction should be taken into account for high-speed railway. The transfer of vibration between viaducts in the longitudinal direction also reveals that installing extra axial link or dampers may be an effective way to decrease the train-induced vibration. The measured vibration level exhibited train speed dependency. At present it is necessary to predict vibration properties of the viaducts accurately by numerical simulation system to prepare for train operations at higher speeds in the future.

Reference

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[2] S.H. Ju and H.T. Lin, Resonance characteristics of high-speed trains passing simply supported bridges, Journal of Sound and Vibration, 2003, 267(5): 1127-1141.