Dynamic Structure Interaction Between Adjoining Shinkansen RC Viaducts

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Abstract

Recent approaches to Structural Health Monitoring (SHM) use changes in mode shapes of structures in detecting and locating damage. In this paper, the phenomenon of dynamic structure interaction between adjoining RC viaducts which significantly affects the actual mode shapes of these structures is discussed. Experimental evidence and finite element model results pointing to the presence of viaduct interaction will be shown.

Introduction

The aging of structures, stricter standards of safety and the lack of resources to build new ones created the need for Structural Health Monitoring (SHM) techniques for checking the structural integrity of existing structures. These structures play an important role in the socio-economic life of a country so that their continued use and preservation is a priority. The Shinkansen RC viaducts built over 40 years ago fall under this category of structures.

At present, impact tests and a limited number of sensors are used to determine a viaduct's natural frequencies. These natural frequencies are used to diagnose the present health of the viaduct. However, research shows that the natural frequency is not a very sensitive parameter for damage detection [4]. Also, although changes in natural frequency may indicate damage, it does not provide spatial information regarding the location of damage.

Recent SHM techniques use changes in mode shapes of structures in detecting and locating damage because it is a more sensitive parameter to damage compared to natural frequency and/or damping [3]. Depending on the spatial distribution of measurement points during experiment or the discreteness of the finite element model, research have shown that changes in mode shapes can accurately locate damage in a structural member. Thus, before any SHM technique utilizing changes in mode shapes can be developed for the Shinkansen RC viaduct, it is important to investigate their actual dynamic behavior in the field.

In this paper, the mode shapes determined from a finite element model of a single viaduct are presented. The analytical model shows that a viaduct has three closely spaced global modes: lateral, longitudinal and torsional modes. The analysis of ambient vibration data acquired using Laser Doppler Vibrometers (LDV) to determine the mode shape of existing Shinkansen RC viaducts will also be discussed. The experimental results hint at the presence of structure interaction between viaducts which significantly affect their mode shapes. Lastly, a series of viaducts were modeled using finite elements in order to simulate actual viaduct interaction in the field.

Finite Element Model

A three-dimensional finite element model of a viaduct was developed using Structural Analysis Program (SAP). The concrete deck of the viaduct was modeled using plate elements, while the connecting beams and columns were modeled using beam-column elements. The pile-supported footings were modeled using lateral, longitudinal and rotational springs. Figure 1 is a photograph of a typical Shinkansen RC viaduct and indicates the location of the experiment measurement points. Table 1 shows the properties and additional loads of the finite element model. Figure 2 shows the three global modes of a viaduct and their corresponding natural frequencies from the finite element analysis.

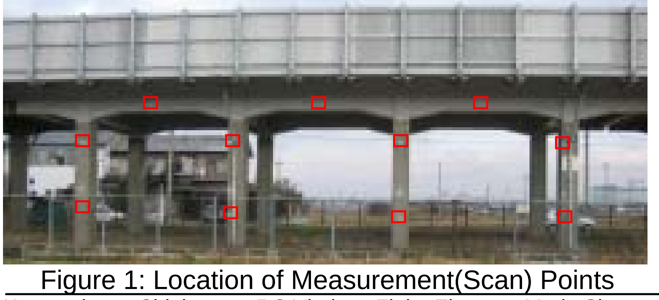

Figure 1: Location of Measurement(Scan) Points

Member Sizes:	Soil Spring stiffnesses:
0.6x0.7m Columns	Kh = 4*[6.262 x 10^8 N/m] Kv = 4*[4.396 x 10^9 N/m] Kr = 4*[6.330 x 10^9 Nm/rad]
0.6x(1.2/0.9/1.2)m doubly tapered longitudinal beams	Additional Masses:
0.6x1.0m lateral beams	Wall: 1.1 kN/m Rail, Sleeper, etc: 5.72 kN/m Gravel ballast: 72.67 kN/m
0.25m thick concrete slab	

Table 1: Structural Properties of FE Model

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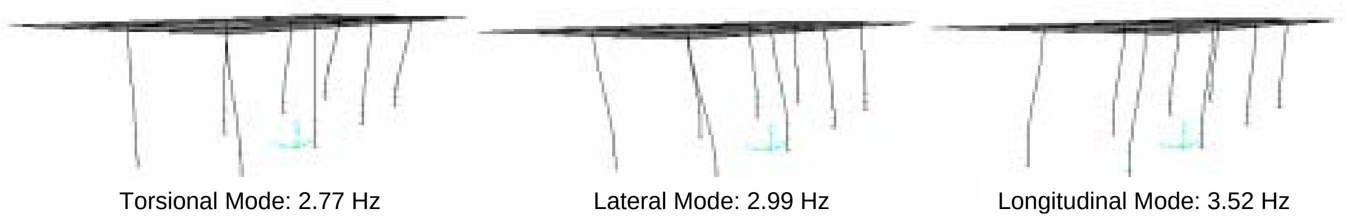

Figure 2: Global Modes of a Viaduct

Experimental Analysis and Results

The experiment was conducted by monitoring three different viaducts out of ten adjoining viaducts. Figure 3 shows the identification process used in determining the actual mode shapes of the viaducts. Using ambient vibration, averaging of the cross spectrum is performed to improve the estimate of the natural frequencies. Figure 4 shows the mode shapes determined from the experiment.

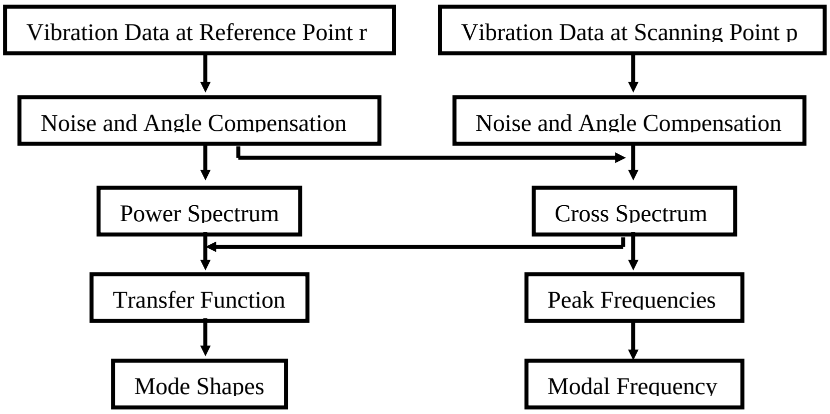

Figure 3: Identification Process

One observes that the derived mode shape having a frequency near 2.83 Hz does not agree with the torsional mode shape predicted by the finite element model. This mode shape and the one with a frequency near 2.93 Hz is a combination of the lateral and torsional modes predicted by the FE model. This is only possible if interaction between viaducts occur in the field, which is reasonable because of the continuity of the rail tracks of the train.

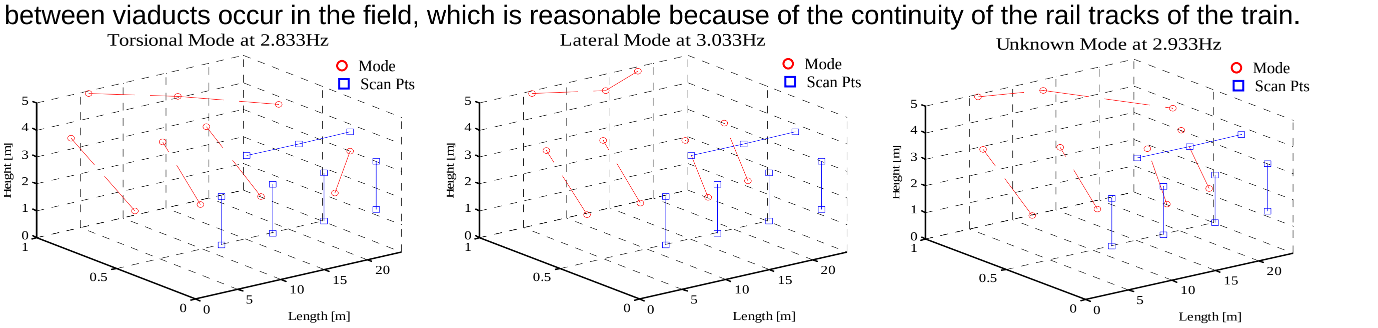

Figure 4: Global Modes of Viaduct from Experiment

FE Model of Adjoining Viaducts

In order to simulate interaction between viaducts, a three-dimensional FE model of the ten adjoining RC viaducts was developed, connected using linear springs. Figure 5 shows a portion of the top view of the mode shapes.

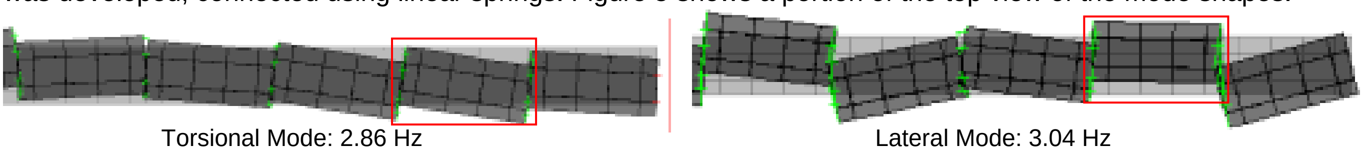

Figure 5: Top View of FE Model of Adjoining Viaducts

The viaduct with mode shapes derived above is marked with a red box. It can be seen from the top view of the FE model that the predicted mode shapes agree with the derived mode shapes if viaduct interaction is accounted for.

Conclusion

This paper discussed the presence of structure interaction between Shinkansen viaducts in the field. Experimental and FE model mode shapes show good agreement if structure interaction between viaducts is taken into account. Awareness of this phenomenon will be useful in developing an SHM technique for detecting and locating damage.

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