PREDICTION OF TRAFFIC-INDUCED VIBRATION USING 3D BRIDGE MODEL AND CONSIDERATION ON INFLUENCE OF BRIDGE STRUCTURAL PROPERTIES ON RESPONSE

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INTRODUCTION

A new trend in bridge structures is to employ 2-girder span and rubber bearings instead of traditional multi-girder bridge with steel bearings. However, this results in higher susceptibility of the bridge structural members, e.g. slab and girders, to traffic-vibration in both global and local and may cause acoustic emission. To handle such problems, it is incumbent to prognosticate the traffic-induced vibration 3-dimensionally. In this study, the analysis on traffic-induced vibration is performed using 3D bridge model. Simulation results are compared to experimental results. Finally, consideration on influence of bridge structural characteristics, i.e. bearing and slab stiffness, on response is also conducted.

EXPERIMENT

The sample bridge used in this study is Hibakaridaira Bridge, constructed by *Japan Highway*. The bridge is located in *Toukaihokuriku Highway* in Gifu Prefecture. It comprises of 4 spans with total length of 193.00 m. (47.4m+48.5m+48.5m+47.0m), The structure consists of concrete slab and 2 continuous steel girders. During experiment, vehicle was smoved on 3 different routes, i.e. C1, C2, C3 as illustrated in Fig. 1 at constant speed of 30 km/h. Routes

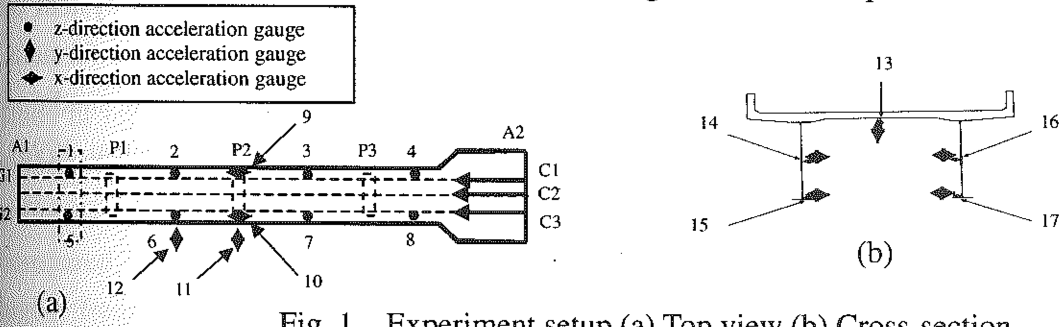

Fig. 1 Experiment setup (a) Top view (b) Cross-section

C1, C2 and C3 were set as routes of passage over girder 1 (G1), centerline and girder 2 (G2) respectively. Acceleration gauges were located at several points on the slab and on the girders as shown in Fig. 1.

MODELING OF VEHICLE-BRIDGE SYSTEM

The bridge was modeled by Finite Element Method 3-dimensionally and eigen value analysis was carried out in order to find natural frequencies and mode shapes. Displacement of the bridge $\mathbf{u} = \{u_x\ u_y\ u_z\}^T$ at any arbitrary point $\mathbf{x} = \{x\ y\ z\}^T$ can be written in modal form as:

$$\mathbf{u}(\mathbf{x},t) = \Sigma\, \Phi_n(\mathbf{x})q_n(t) \tag{1}$$

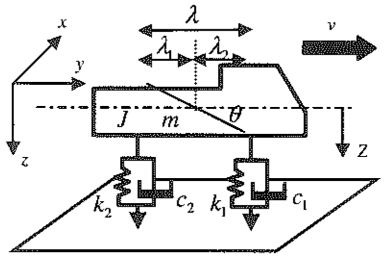

Fig. 2 Vehicle-bridge model

where $\Phi_n = \{\phi_n^x\ \ \phi_n^y\ \ \phi_n^z\}^T$ and q_n denote the n-th 3D mode shape and the corresponding generalized coordinate respectively. By assuming proportional damping, the equation of motion of the bridge in generalized coordinates is:

$$\ddot{q}_n(t) + 2\xi_n\omega_n\dot{q}_n(t) + \omega_n{}^2 q_n(t) = \frac{1}{m_n}\{\phi_n^z(\mathbf{x}_1)P_1(t) + \phi_n^z(\mathbf{x}_2)P_2(t)\} \tag{2}$$

Where m_n , ξ_n and ω_n represent n-th modal mass, damping ratio and frequency respectively. $P_i(t)$ denotes the vertical force exerted at point $\mathbf{x}_1$ $(i=1,2)$ on the bridge. The equation of motion of vehicle is

$$m\ddot{Z} + \sum_{i=1}^{2} V_i = 0 \quad , \quad J\ddot{\theta} - \sum_{i=1}^{2} (-1)^i \lambda_i V_i = 0 \tag{3a, 3b}$$

$$V_i = (k_i + c_i \frac{d}{dt})\{Z - (-1)^i \lambda_i \theta - u_z(\mathbf{x}_i) - r_i\} \tag{4}$$

where, r_i represents surface roughness at the i-th contacting point. $P_i(t)$ in equation (2) and in the vehicle model, is defined by

$$P_i(t) = mg(\lambda - \lambda_i)/\lambda - V_i \tag{5}$$

Physical properties of the vehicle are given as follow: m = 37570 kg, J = 150900 kgm^2, k_i = 738600 N/m, c_i = 13518 N/m/s, $\lambda_i = \lambda/2$ = 2.41 m (i = 1, 2). Equations (2), (3) and (4) form vehicle-bridge interaction (VBI) equations, which is a time dependent, coupled system of equations. Power spectral densities of surface roughness adopted can be obtained by formula, $S_{zo}(\Omega) = A/(\Omega^2 + \alpha^2)$. Parameter A and α are selected to match good pavement condition and are set as $A = 10^{-7}$ m^{2}m^{-1} and α = 0.05 m^{-1}, respectively (Kawatani and Komatsu, 1998).

COMPUTATIONAL RESULTS

Responses are obtained by integrating equation (2) using finite difference method. Due to shortage of space allowed here, only results from case of C1 are shown. Responses from calculation and experiment at points 1, 9 and 14 (Fig. 1) are shown in Fig. 3. Fourier spectral densities (FSD) at the corresponding points are compared in Fig. 4.

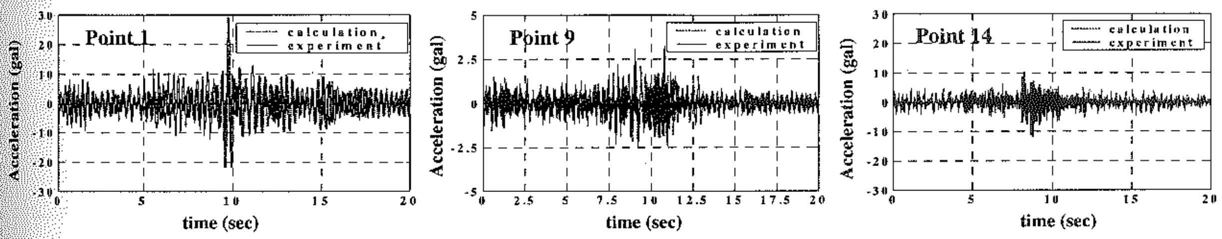

Fig. 3 Acceleration responses at point 1, 9 and 14

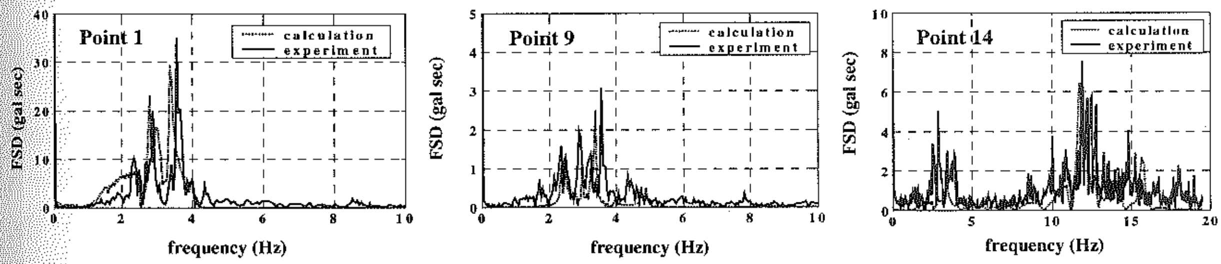

Fig. 4 Fourier spectral densities at point 1, 9 and 14

Points 1 and 9 are on the slab and excited modes in both positions lie in the range of 2-4 Hz. On the other hand, FSD of point 14 on G1, shows peaks not only in the range of 2-4 Hz, but also in the range of 10-15 Hz. Thus, it can be deduced that global vibration generated in Hibakaridaira bridge is a result of 2-4 Hz modes vibration, whereas 10-14 Hz modes provoke local vibration in the girder. Fig. 5 shows the comparison of the standard deviation (SD) of the response, introduced as representative vibration amplitude measure, at several measurement points from this figure. From Fig. 4 and 5, good agreement between experiment and computation can be observed.

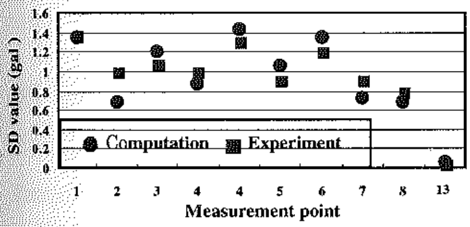

Fig. 5 Comparison of experimental and calculation results

PARAMETRIC STUDY OF INFLUENCE OF STRUCTURAL PROPERTIES ON RESPONSE

Study of influence of structural characteristics on response is conducted parametrically for 4 models, i.e. 1) rubber bearing (reference model) 2) fixed bearing 3) rubber bearing 5 times stiffer 4) rubber bearing, 80% slab thickness. FSD at point 1 (Fig. 1) for 4 models are compared in Fig. 6. It can be deduced from this figure that stiffer structure vibrates with higher frequency but smaller amplitude in term of magnitude of FSD. In the other words, making structure more flexible results in larger response. The same trend can be found in SD value proportions, i.e. $\sigma_2 = 0.6\sigma_1$, $\sigma_3 = 0.8\sigma_1$, $\sigma_3 = 1.2\sigma_1$, where σ_i stands for SD value of response at point 1 in case of the *i*-th model.

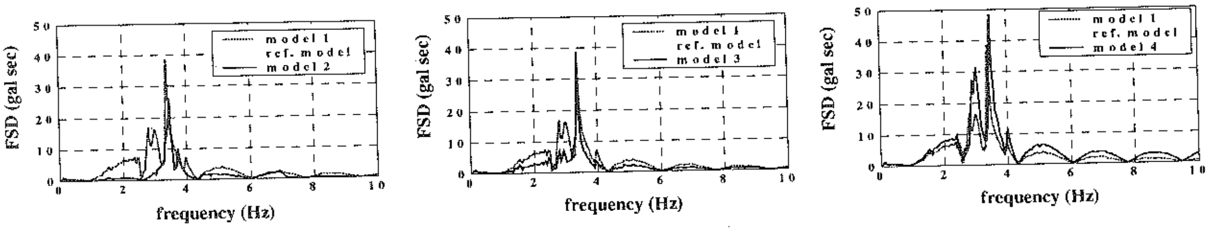

Fig. 6 Fourier spectral densities at point 1 under different structural properties

CONCLUSIONS

In this study 3D bridge model is introduced and employed in the prediction of traffic-induced vibration problem. Vibration is analyzed in both global and local scale. Global vibration is provoked in range of 2-4 Hz, whereas those of local vibration lie among 10-14 Hz. Experimental results are compared to computational results and good agreement is found. In the second part of this study, parametric study of the influence of structural parameters on response is conducted. It can be concluded that increasing stiffness of the bearings by 5 times causes curtailment of approximately 20% in the response, whereas using fixed bearings reduces the response by about 40%. On the other hand, decreasing the slab thickness to 80%, results in 20% increment in the obtained response.

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