TRAFFIC-INDUCED VIBRATIONS OF STEEL TWO-GIRDER BRIDGE WITH RESPECT TO BEARING TYPES AND END-CROSS BEAM REINFORCEMENT

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1. PURPOSE: The wider girder spacing and more simplified structural system of two-girder bridges than conventional multi-girder bridges make two-girder bridges to be easily vibrated due to external dynamic loads like wind, vehicle loads, etc. Moreover adopting the elastomeric bearing can make bridges more easily vibrated under moving vehicles. Thus, the effect of bearing types on vibration of steel two-girder bridges is investigated. In order to enhance the vibration serviceability of steel two-girder bridges, the end-cross beam reinforcement[1, 2] is applied as a countermeasure against traffic-induced vibration, and analytical investigations are carried out in this study. The effect of removing bumps at expansion joints, so called a layover bump, on reducing the traffic-induced vibration is also investigated.

2. ANALYTICAL PROCEDURES: The finite element (FE) method, modal analysis and Lagrange equation of motion are adopted for modeling and analyzing a bridge and to develop governing dynamic differential equations for the bridge-vehicle interaction system. Newmark-β method is the direct integration method applied to solve the derived system governing equations. Vertical accelerations are estimated by superposing up to 120th modes.

3. ANALYTICAL MODELS: **3.1 Bridge** The two-span continuous steel two-girder bridge in service with total longitudinal length of 106m is adopted for an analytical example. The damping constant of the bridge is assumed to have 0.7 % for the first and second modes based on field test results. Typical cross section and reinforced section of the bridge are shown in **Fig. 1**. The deck slab is made of a prestressed concrete of 31cm thick, and is assumed to act compositely with main girders. The symbols WO and WR in **Fig. 1** indicate the sections in accordance with existence of reinforcement at the cross beams at A1 and A2 abutment and at the pier P1; WO is the section before reinforcing; WR, the section after reinforcing with thickness of 50cm. The reinforced concrete blocks at the cross beams located at abutments A1 and A2 and the pier P1 are assumed to completely link with deck slabs. The FE model of the bridge in **Fig. 2** consists of 231 nodes, 192 flat elements and 159 (163 for the bridge model with WR section) beam elements. The properties of elastomeric bearings in the supports are shown in **Table 1**.

3.2 Vehicle A rear-tandem dump truck idealized as 8DOF model with gross weight of 196kN is adopted as a heavy vehicle running on the bridge. Details of the vehicle model are in **Table 2**.

3.3 Roadway roughness Roadway surface profiles are obtained by Monte-Carlo simulation method based on the power spectral density (PSD) function to fit the measured PSD of Meishin expressway in Japan. Measured bump heights of the expansion joint at A1 abutment under the vehicle path are considered; 16mm and 14mm with 780mm width for left and right wheel path, respectively.

4. ANALYTICAL RESULTS: **4.1 Natural frequencies** Natural frequencies taken from the field test for the first and second bending modes are 2.26-2.30Hz and 3.38-3.42Hz, respectively. Those analytical frequencies are 2.26Hz and 3.37Hz for the 1st and 2nd bending modes, respectively. For the 1st torsional mode, the experimental and analytical results are 3.38-3.42Hz and 3.37Hz, respectively. It indicates the validity of the bridge modelling for dynamic response analysis.

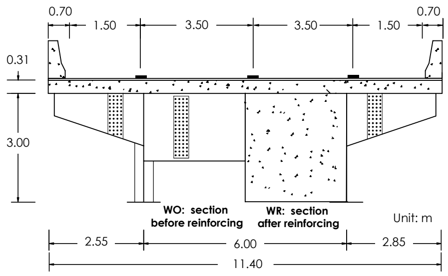

Fig. 1 Cross section of two-girder bridge

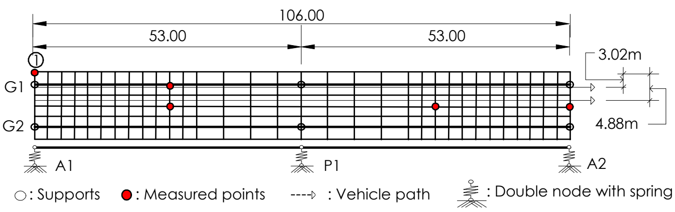

Fig. 2 FE model of two-girder bridge

Table 1 Spring constants of elastomeric bearing (KN/m)

	A1	P1	A2
Longitudinal	4.4718E+02	9.8067E+02	4.4718 E+02
Transverse	6.4332 E+02	7.3746 E+02	6.0409 E+02
Vertical	1.4834 E+06	1.0564E+07	5.5547 E+06

Table 2 Details of vehicle model

Total Weight (KN)	Axle weight (KN)		Tread (m)	Axle distance(m)		Natural frequency(Hz)	
	Front	Rear		Front rear	Tandem	Front axle	Rear axle
196.03	42.95	153.08	1.86	3.86	1.30	2.20	3.40

Keywords: End-cross beam reinforcement, Traffic-induced vibration, Twin-girder bridge, Vibration reduction
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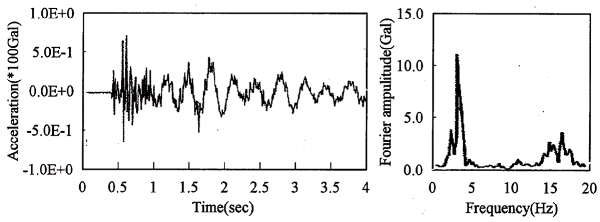
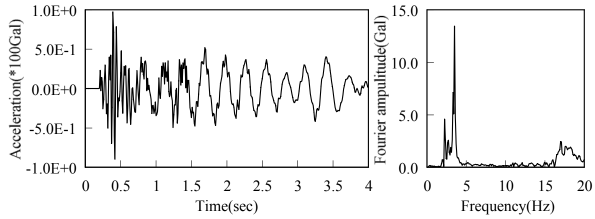
4.2 Acceleration response Acceleration responses and those Fourier spectra of the deck slab at the centre of the 1st span (between A1 and P1) taken from experiment and analysis are shown in **Fig. 3**, which show the resemblance of the wave profile and Fourier spectrum between experimental result and analytical one. Acceleration responses of the deck with respect to end-cross beam reinforcement and bearing types can be observed in **Figs. 4** and **5**. It indicates that the acceleration response of deck near the elatomeric bearing is more amplified by moving vehicle than that of deck near the steel bearing. The vibration reduction effect due to end-cross beam reinforcement can be expected regardless of the bearing types.

4.3 Vibration level To assess the reduction effect quantitatively, the vibration level (VL) is considered as a measure. All pass vibration level with respect to countermeasures against vibration at each node is summarized in **Fig. 6**, which indicates that the bridge with elastomeric bearings (87dB~92dB without any reinforcement, etc.) is more easily vibrated than the bridge with steel bearings (84dB~88dB without any reinforcement, etc.). The interesting results in **Fig. 6** are that, for bridge with steel bearing, the dominated vibration level occurs at the members near span centre. On the other hand, for bridge with elastomeric bearing, the dominated vibration level occurs at the members near the expansion joint. **Figure 6** also demonstrates that the end-cross beam reinforcement is more effective on reducing vibrations of the bridge with steel bearings than those of elastomeric bearings. It can also be observed that removing bumps, if possible, at the joint can guarantee vibration reduction regardless of bearing types of bridges. The symbol B indicates the results considering measured bumps in dynamic response analysis, on the other hand NB means the result without the bumps.

It is noteworthy that, for a node at cantilevered part near the reinforcement as well as dynamic reactions at the reinforced joint, the reinforcement of the bridge with elastomeric bearings will not always guarantee the reduction effect because of the inertia effect due to additional mass at the end-cross beam. **Figure 7** demonstrates the vibration level beyond 10Hz will increase according to reinforcement (see WO-B and WR-B). Moreover, in **Fig. 8**, it can be observed that, when vehicle is running over bumps at the joint, the peak dynamic reaction due to inertia effect of the bridge increases according to reinforcement, even though RMS values of the reaction tend to decrease after reinforcing the end-cross beam.

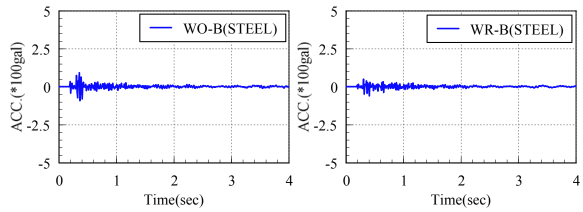


a)　Field test results



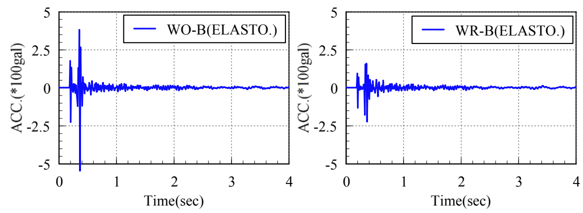
b) Analytical results

Fig. 3 Accelerations; slab center at the center of 1st span



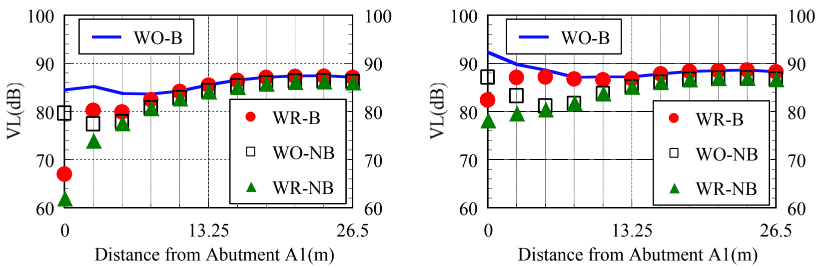
a) before reinforcing　　b) after reinforcing

Fig. 4 Accelerations of slab center at 2.65m from A1; steel bearing; v=100km/hr



a) before reinforcing　　b) after reinforcing

Fig. 5 Accelerations of slab center at 2.65m from A1; elastomeric bearing; v=100km/hr



a) Steel bearing　　b) Elastomeric bearing

Fig. 6 All pass VL w.r.t. countermeasures against vibration at each node; v=100km/hr

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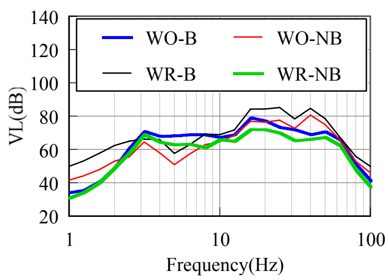

Fig. 7 1/3 Octave band spectrum; node 1 (Fig. 2) on A1 joint with elastomeric bearings

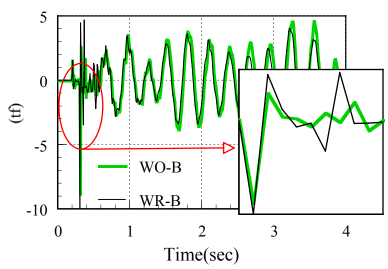

Fig. 8 Dynamic reaction of the elastomeric bearing at G1 girder of the A1 joint