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Errors on bridge vibration data measured by a passing vehicle

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ABSTRACT

This study presents the numerical simulation of VBI (Vehicle-Bridge Interaction) system and compares the bridge and vehicle vibration responses. According to the numerical simulation, bridge frequency tends to be around the natural frequency, regardless of the road profile. On the other hand, the vehicle frequency is dominantly affected by the road profile, and tends to be different from the bridge one.

BACKGROUND

VRA (Vehicle Response Analysis) technology for bridge damage detection is intensively studied. In VRA, sensors are not installed on the bridge, but on a vehicle passing through the monitored bridge, and the bridge damage is estimated by using the vibration data of the vehicle. This technology is inspired by "Indirect Approach", which was proposed by Yang et al., in 2004, and it has been improved by many researchers. In SHM (Structure Health Monitoring) methods using vibration, structural damages are generally estimated by changes of vibration characteristics. Thus, in VRA, the measured vibrations of a passing vehicle must show the sameness with those of the monitored bridge.

This study presents numerical simulation of VBI system and compares the vehicle and bridge vibration. The main purpose of this study is to show the differences between them. Parametric analysis is carried out in order to discover a condition in which they are identical.

NUMERICAL SIMULATION

A rigid body and spring model is adopted as the vehicle, while the bridge is modeled by finite

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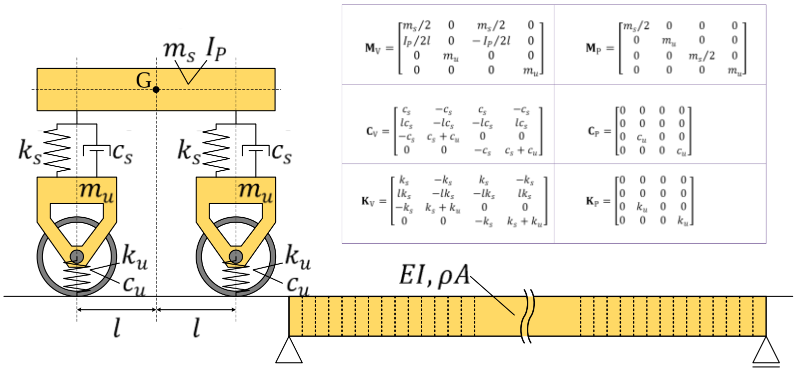


Fig. 1 VBI system

Table 1 The standard parameters of vehicle

Sprung-	Mass	m_s	18,000[kg]
	Stiffness	k_s	1.0×10^6[kg/s^2]
	Damping	c_s	1.0×10^4[kg/s]
	Inertia	I_P	64958[kg m^2]
	Distance	l	1.875[m]
Unsprung-	Mass	m_u	1,100[kg]
	Stiffness	k_u	3.5×10^6[kg/s^2]
	Damping	c_u	3.0×10^4[kg/s]

Table 2 The bridge parameters

Span Length	L	30.0[m]
Flexural Stiffness	EI	1.56×10^{10}[Nm]
Mass per unit length	ρA	3,000[kg/m]
Reyleigh coefficients	α	0.238
	β	0.000

beam elements, as shown in **Fig. 1**. Their parameters are also shown in **Table 1** and **Table 2**. The equation of motion of VBI system is described as

$$\begin{bmatrix} \mathbf{M}_\mathrm{B} & \mathbf{L}(t)\mathbf{M}_\mathrm{P} \\ & \mathbf{M}_\mathrm{V} \end{bmatrix} \begin{Bmatrix} \ddot{\boldsymbol{y}}(t) \\ \ddot{\boldsymbol{z}}(t) \end{Bmatrix} + \begin{bmatrix} \mathbf{C}_\mathrm{B} & \\ -\mathbf{C}_\mathrm{P}\mathbf{U}(t) & \mathbf{C}_\mathrm{V} \end{bmatrix} \begin{Bmatrix} \dot{\boldsymbol{y}}(t) \\ \dot{\boldsymbol{z}}(t) \end{Bmatrix} + \begin{bmatrix} \mathbf{K}_\mathrm{B} & \\ -\mathbf{K}_\mathrm{P}\mathbf{U}(t) & \mathbf{K}_\mathrm{V} \end{bmatrix} \begin{Bmatrix} \boldsymbol{y}(t) \\ \boldsymbol{z}(t) \end{Bmatrix} = \begin{Bmatrix} \mathbf{C}_\mathrm{P}\dot{\boldsymbol{r}}(t) + \mathbf{K}_\mathrm{P}\boldsymbol{r}(t) \\ \mathbf{L}(t)\mathbf{M}_\mathrm{P}g \end{Bmatrix} \quad (1)$$

where $\mathbf{M}_\mathrm{B}$, $\mathbf{C}_\mathrm{B}$ and $\mathbf{K}_\mathrm{B}$ are the mass, damping and stiffness matrices of bridge, respectively. And, $\mathbf{M}_\mathrm{V}$, $\mathbf{C}_\mathrm{V}$ and $\mathbf{K}_\mathrm{V}$ are also those of the passing vehicle. $\mathbf{M}_\mathrm{P}$ is the mass matrix of the vehicle of the gravity term. $\mathbf{C}_\mathrm{P}$ and $\mathbf{K}_\mathrm{P}$ are the bridge damping and stiffness matrices of the input to the vehicle. $\boldsymbol{y}(t)$ and $\boldsymbol{z}(t)$ denote the response vectors of bridge and vehicle, respectively. $\mathbf{L}(t)$ and $\mathbf{U}(t)$ are the equivalent nodal force distribution matrices, which can be supposed to satisfy $\mathbf{L}(t) = \mathbf{U}^\mathrm{T}(t)$. Newmark-β method is applied to Eq. (1). The first and second undamped natural frequencies of the bridge model are 3.96[Hz] and 15.84[Hz]. The run speed of the vehicle and the road profile are varied. The road profiles are shown in **Fig. 2**.

RESULTS AND DISCUSSION

The effect of vehicle run speed is examined, first. The bridge and vehicle responses,

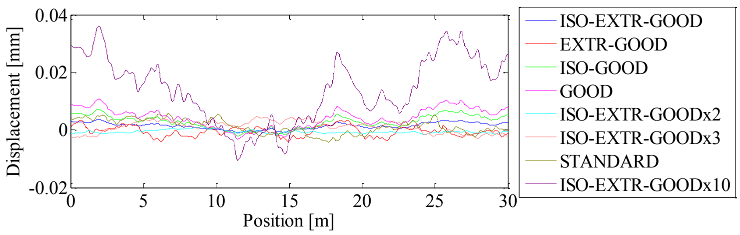
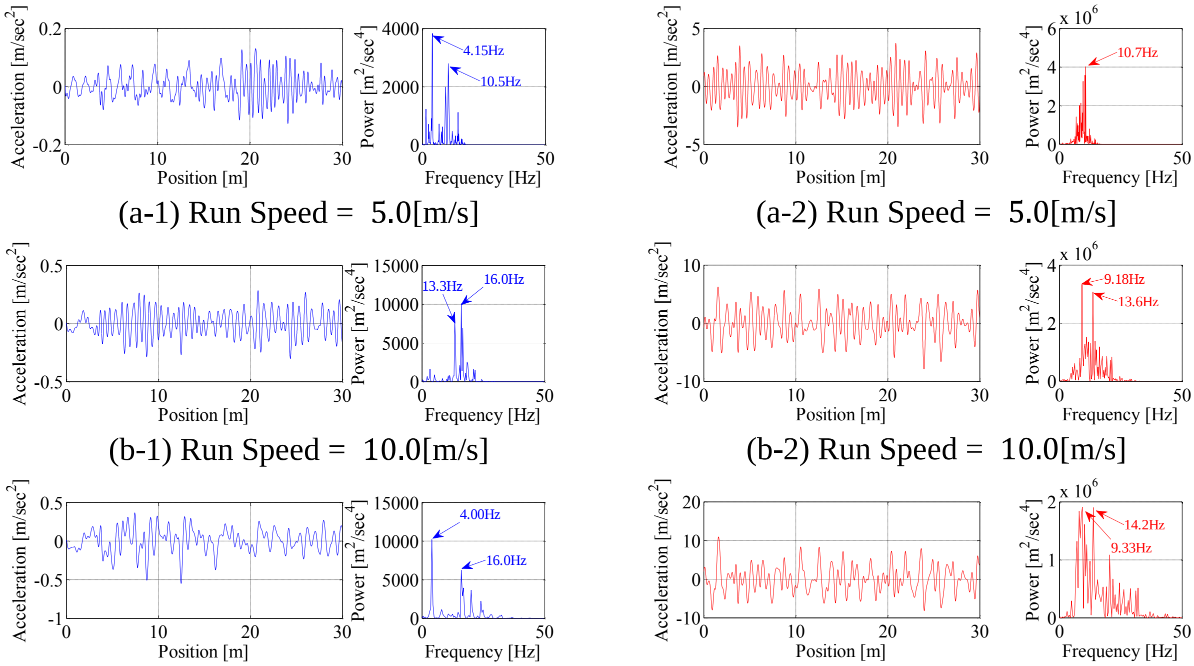


Fig. 2 The road roughness



(a-1) Run Speed = 5.0[m/s] (a-2) Run Speed = 5.0[m/s]

(b-1) Run Speed = 10.0[m/s] (b-2) Run Speed = 10.0[m/s]

(c-1) Run Speed = 15.0[m/s] (c-2) Run Speed = 15.0[m/s]

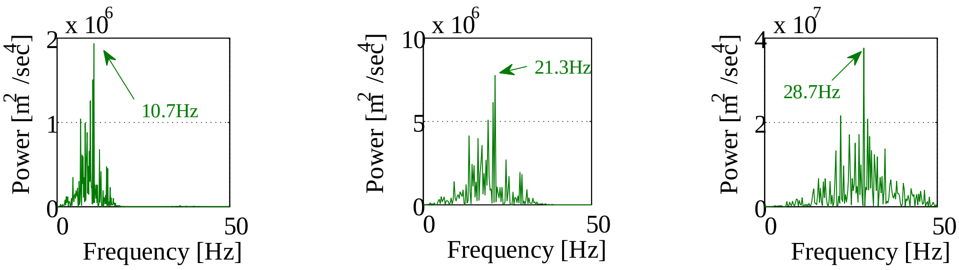
(1) Bridge (at the position of 10[m]) **(2)** Vehicle (at the unsprung-mass)

Fig. 3 The response features of different vehicle run speeds (Road Profile: ISO-GOOD)

when the road profile is categorized into ISO-GOOD, are shown in **Fig. 3**. The blue lines denote the acceleration responses and power spectra of the bridge. The red ones do those of the vehicle. The observation position of the bridge is located on $L/3$ (= 10[m]), so that the first and second mode appear. The predominant frequencies (4.00[Hz] and 16.0[Hz]) in the case of the run speed at 15.0[m/s] are close to the first and second undamped natural frequencies of the bridge (3.96[Hz] and 15.84[Hz]), respectively. Those in the case of 5.0[m/s] and 10.0[m/s], however, are different from the bridge natural frequencies. **Fig. 5** shows the acceleration inputs of the travelling vehicle system due to the road unevenness. According to these figures, the road profile as the input of VBI system dominantly affects bridge response as the outputs.

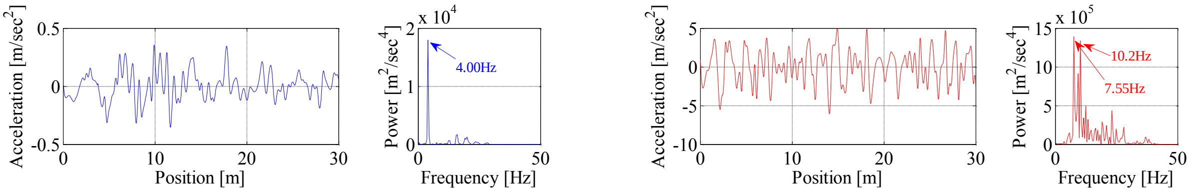
On the other hand, the vehicle responses shown in the right side of **Fig. 3**. have similarity to the bridge responses only around the dominant frequency of the road profile. It means that the vehicle response usually does not match the characteristic of the bridge vibration.

Examples of the bridge and vehicle responses in different road profiles are also shown

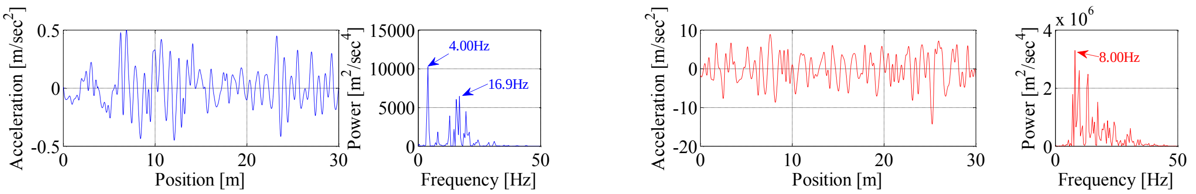


(a) 5.0[m/s] (b) 10.0[m/s] (c) 15.0[m/s]

Fig. 5 The acceleration inputs due to the road profile



(a-1) Road Profile: ISO-EXTR-GOODx2 (a-2) Road Profile: ISO-EXTR-GOODx2



(b-1) Road Profile: ISO-GOOD (b-2) Road Profile: ISO-GOOD

(1) Bridge (at the position of 10 [m]) **(2)** Vehicle (at the -mass)

Fig. 6 The response features of different vehicle run speeds (Run Speed = 15.0[m/s])

in **Fig. 6**. The bridge vibrates mainly around its natural frequencies, regardless of the road profile, while the vehicle reacts depending to the road profile. It is shown that the bridge frequencies due to the traffic loading tends to be around its natural frequencies, while the vehicle frequencies depend on the road profile and tend to be different from the bridge natural frequencies. Thus, it is difficult to apply a simple frequency domain analysis to VRA for bridge damage detection.

CONCLUSION

This study presents the numerical simulation of VBI system and it is cleared that the bridge predominant frequencies tend to appear around the natural frequencies. The vehicle frequencies, however, are affected dominantly and directly by the road profile and could not be around the bridge natural frequencies.

REFERENCE

Yang, Y.-B. et al : Extracting bridge frequency from the dynamic response of a passing vehicle, *J. of Sound and Vibration*, Vol.272, pp.471-493, 2004.