MONITORING-BASED FEM-MBS ANALYSIS SCHEME FOR VEHICLE-BRIDGE INTERACTION SYSTEM

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1. INTRODUCTION

The vehicle running stability and safety on the bridge under strong crosswind has become a hot topic with increasing concern in recent years. Previous researchers focused on Finite Element Method (FEM) method to obtain vehicle characteristics without fully utilized the on-site monitoring data of bridge responses. To solve wind-bridge-vehicle interaction, this paper is to solve two fundamental issues. Firstly, it presents a new scheme of Vehicle-Bridge-Interaction (VBI) system by combining the FEM and Multiple Body Simulation (MBS) to be more convenient and comprehensive to analyze the system. Then regarding the limit number of measurement sensors, Perturbed Force (PF) method is used for obtaining responses of unmeasured parts and combine with the model to avoid the complicate fluid-structure interaction analysis. The Tsukige Bridge in Chiba Prefecture in Japan is taken for the case study.

2. FEM-MBS COMBINE METHOD

MBS is carried out to study the kinetic and kinematic behavior of mechanisms. In this research, the MBS software Simpack and FEM software Abaqus are used for analysis.

2.1 Procedures of the combined method

Fig. 1 shows the vehicle-bridge coupling flowchart using FEM-MBS method. Firstly, FEM software Abaqus is used for bridge modeling and substructure analysis to generate a flexible body input file (*.fbi). Then the file is imported into Simpack. After that, the vehicle and bridge model are combined by Dummy Body Coupling method (Ji et al. 2018). Finally, system analysis is conducted. Comparing with FEM method, FEM-MBS method has significant advantages, such as no need to decouple the system and easy to implement to complicated bridge models even considering the structure details.

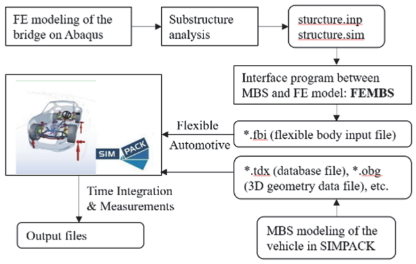


Fig. 1 Procedures of FEM-MBS method

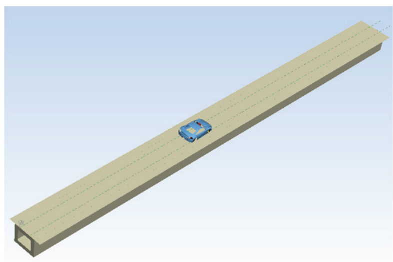
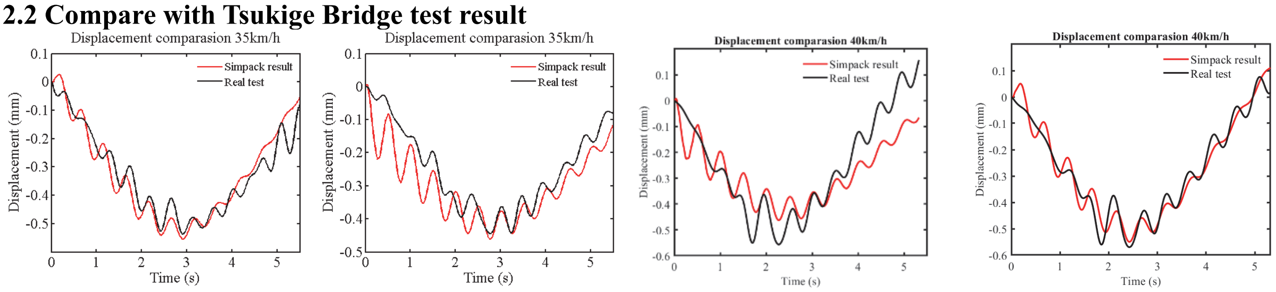


Fig. 2 Tsukige Bridge model

2.2 Compare with Tsukige Bridge test result



(a) (b) (c) (d)

Fig. 3 Displacement comparison (a) 35km/h at midpoint; (b) 35km/h at quarter point; (c), (d) 40km/h at midpoint

Tsukige Bridge is a simply supported bridge with a length of 59m located in Chiba Prefecture, Japan. The vehicle parameters in the FEM-MBS model, which is shown in Fig. 2 can be found from the previous research (Wang et al. 2018). Fig. 3 shows the vertical displacement comparison between the FEM-MBS method and field test data at the different locations of the bridge with different vehicle speeds.

As is shown in the above, the general trend of the result matches well. There is still a difference that influenced by many factors, such as road roughness and vehicular parameters. Moreover, the tire model in the MBS plays an essential role in the simulation. Fig. 3(c) shows displacement result using the vertical spring tire model, in which large difference generates at the speed 40km/h. By changing the tire model to the Pacejka tire model, which is a more accurate simulation of actual tires, the accuracy is significantly increased in the same case, as shown in Fig. 3(d).

Keywords: Vehicle-Bridge-Interaction, MBS, FEM, monitoring
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3. DATA EXPANSION BASED ON ON-SITE MONITORING DATA

3.1 PF method

PF method (Chen 2012) is an approach for expanding mode shapes by introducing a perturbed force vector in order to include the modeling errors which can be obtained from modal data measurements and then applies it to predict the unmeasured part response as shown in Eq. (1).

$$\phi = \begin{Bmatrix} \phi_t^a \\ \phi^u \end{Bmatrix} = T^i \phi_t^a, \quad T^i = \begin{bmatrix} I \\ \sum_{t=1}^{NC} \dfrac{\phi_f^u \phi_f^T S_i^+}{\omega_f^2 - \omega_t^2} \end{bmatrix}, \quad S_i = \sum_{t=1}^{NC} \frac{\phi_t^a \phi_f^T}{\omega_f^2 - \omega_t^2} \qquad (1)$$

where ω and ϕ are the natural frequency and the corresponding mode shape, subscript f and t represent the FE model and test case. Subscripts a and u denote the measured and unmeasured DOFs, respectively. T is the transformation matrix, and S^+ is Moore–Penrose pseudoinverse of sensitivity coefficient matrix S.

3.2 Experiment verification

Nine sensors are placed in Tsukige Bridge as shown in Fig. 4. Response at six blue locations is compared with the result from PF method based on three red sensors. The model shape values are obtained by using Covariance-Driven Stochastic Subspace Identification method and compared with FE result as shown in Table 1. The vertical acceleration comparison can be found in Fig. 5.

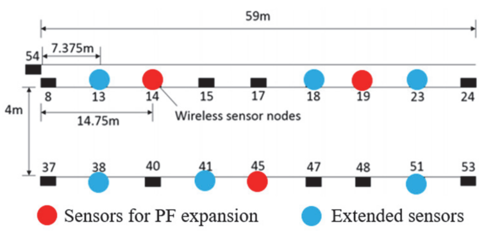

Table 1 Model shape value comparison

Model	Sensor	1st Bending	2nd Bending	3rd Bending
FE mode	014	0.453	1	-1
	019	0.849	-0.990	-0.728
	045	1	0.264	1
Test mode	014	0.665	1	-0.797
	019	0.700	-0.922	-0.840
	045	1	0.185	0.927

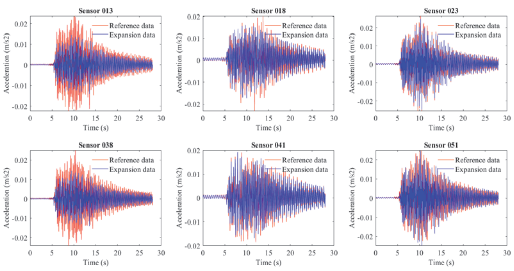

Fig. 5 Acceleration comparison

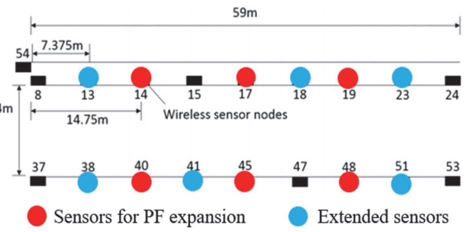

Fig. 6 Sensor layout (Case 2)

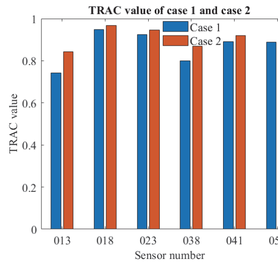

Fig. 7 TRAC value

As is shown in the above, the acceleration of most sensors can be expanded by PF method. Comparing with other sensors, sensor 014 shows a large difference value in Table 1, which results in the inaccuracy in the transformation matrix T. That is the reason why the sensor results of 013 and 038 shows less accuracy compare with others. Moreover, higher measurement noise in sensor 014 is another reason. PF method could consider the modeling errors compared with other methods, while significant errors and noise also lead to the inaccuracy expansion result. The accuracy of the expansion result can be improved by sensor placement. As is shown in Fig. 6, 6 sensors are used for PF expansion in case 2, and the quality indicator -Time Response Assurance Criterion (TRAC) is higher than the result of case 1, which can be found in Fig.7. Notice that all locations TRAC higher than 85% which indicates good correlation of expanded data with measured.

4. CONCLUSIONS

This research presents a FEM-MBS method that combined with on-site monitoring data to analysis the VBI system. This new method can fully take advantage of measurement results to avoid complicate analysis such as fluid-structure interaction simulation comparing with previous methods.

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