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

The University of Tokyo Student Member ○ Qi Hu
The University of Tokyo Regular Member Di Su
The University of Tokyo Regular Member Tomonori Nagayama

1. INTRODUCTION

The vehicle running stability and safety on the bridge under a strong crosswind have become a hot topic with increasing concern in recent years. The traditional analysis method applied to the vehicle-bridge interaction (VBI) system is complicated and time-consuming and cannot meet the requirement of timely decisions. This study presents a combined method that integrates the FEM (Finite Element Method) and MBS (Multiple Body Simulation) to analyze the VBI system. In this study, a new double-dummy coupling method is used to simulate the vehicle-bridge connection to solve the vehicles' responses accurately and efficiently. Furthermore, to fully utilize the in-situ test data, which is ignored by previous research, a monitoring-based approach is proposed to hybrid the monitoring data and FEM-MBS model to obtain the vehicle response. The Tsukige Bridge in Chiba Prefecture 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 bridge is simulated by FEM software Abaqus and the vehicle is created through MBS software Simpack.

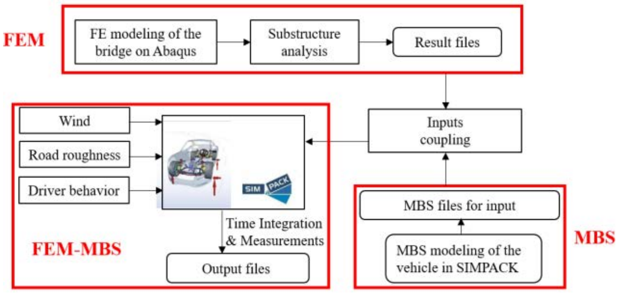

Fig. 1 Procedures of FEM-MBS method

Fig. 1 shows the vehicle-bridge coupling flowchart using the FEM-MBS method. Firstly, bridge is modelled by FEM and then output as a flexible-body substructure. After incooperating the substructure into the SIMPACK, the vehicle model couples with bridge model in the MBS. Finally, other factors like wind, road roughness, and driver behavior can be simulated in the analysis system. Comparing with the FEM method, the 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.

One of the critical points of the VBI coupled vibration is the simulation of the coupling relationship between the vehicle and the bridge in the MBS. He et al., 2017 have achieved the train-track coupling through FEM-MBS based on a single dummy method. It failed when applied to the VBI system with the problems of not well considering the vehicle tire, wind force, and road roughness factors together because the tire lateral nonlinear properties and the excitation due to the roughness cannot be well simulated. In this paper, a new double-dummy method is proposed.

The rigid vehicle body and flexible bridge body are connected by the dummy body 1 based on the Curve-Curve 2D-Contact method in the SIMPACK. A joint connecting the dummy body 2 and the dummy body 1 is created to solve the road roughness problem. The vehicle tire can be well simulated by connecting the rigid vehicle body and dummy body 2. Wind, driver behavior, and monitoring data also can be considered in the model.

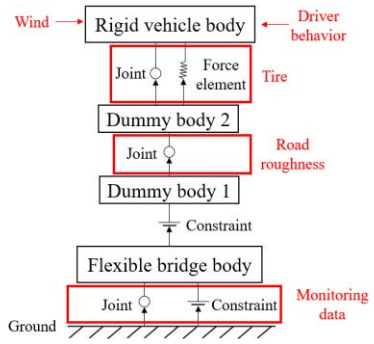

Fig. 2 Double-dummy coupling method

3. METHODOLOGY OF THE MONITORING-BASED APPROACH

The equation of motion of the vehicle model can be expressed as

$$M_v\ddot{q_v} + C_v\dot{q_v} + K_v q_v = F_c \tag{1}$$

where M_v, C_v, K_v are the mass, damping, and stiffness matrices of the vehicle separately. q_v is the vehicle absolute response and F_c is the contact force. The relative response q_{rv} can be obtained from q_v and the bridge absolute response q_b through $q_{rv} = q_v - q_b$. Substitute q_{rv} into equation (1) and transfer the items of q_{rv} to the left side, the undated equation is

$$M_v\ddot{q_{rv}} + C_v^*\dot{q_{rv}} + K_v^* q_{rv} = F_c^* \tag{2}$$

where C_v^*, K_v^* are the updated matrices and F_c^* is the function of the bridge absolute response q_b. If the real-time vibration response of the bridge is known, the q_{rv} can be obtained through solving the Eq. (2) by using numerical integration methods, and q_v can be obtained through $q_v = q_{rv} + q_b$.

Keywords: Vehicle-Bridge-Interaction, FEM, MBS, Monitoring data.
Contact address: 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8856, Japan, Tel: +81-3-5841-4739

In the MBS system, dummy body 1 is created to connect the ground and bridge, and a joint with a moved marker is created to simulate the bridge absolute movement q_b. Also, a constraint that links the bridge test point and ground is generated to ensure the deformation is precisely the same as the real test result. The number and location of bridge test points does affect the result and can be determined by optimal sensor placement method.

4. EXPERIMENTAL VALIDATION BASED ON TSUKIGE BRIDGE

4.1 Experiment Overview

The experiment is conducted on the Tsukige Bridge, a simply supported bridge with a length of 59m located in Chiba Prefecture, as shown in Fig.3. The bridge road profile is obtained through the previous experiment data (Wang et al., 2017). The vehicle speed in each case keeps constant, and 6 repeatability tests are conducted under each speed. Acceleration can be obtained by accelerometers installed on the bridge and tires. The vehicle model in the FEM-MBS is simulated as a full-car and parameters can be found from the previous research (Wang et al., 2018). The FEM-MBS model is shown in Fig.4.

Fig. 3. Tsukige Bridge

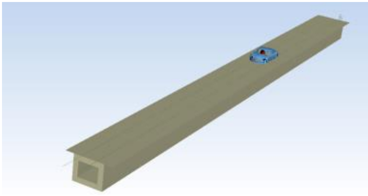

Fig. 4. Tsukige Bridge FEM-MBS model

4.2 FEM-MBS Results and Validation

Fig. 5 shows comparisons of the vertical displacement at the midpoint of the bridge between the FEM-MBS method and field test data. The result of bridge response matches well due to the more realistic Pacejka tire model is applied to the model, which not used in the previous VBI system. The tire model and road roughness in the MBS plays an essential role in the simulation. The Time Response Assurance Criterion (TRAC) obtained from Eq. (3) for the time history is 0.96, which shows the high accuracy of the FEM-MBS method.

$$TRAC = \frac{[(y_{test})^T (y_{simu})]^2}{[(y_{test})^T (y_{test})][(y_{simu})^T (y_{simu})]} \tag{3}$$

where y_{test} and y_{simu} represent the real test response and simulation result separately.

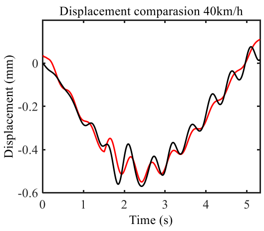

Fig. 5 Bridge displacement results comparison of midspan

4.3 Monitoring Based Results and Validation

The traditional VBI method is challenging to be verified, and the bridge vibration induced by the wind is hard to investigate. The monitoring-based approach can avoid the complicated fluid-structure coupling and make full use of on-site data. The bridge response obtained in the real test, which red points show in Fig. 6, are used as import signals. The locations of input signals are determined by the GA method. The acceleration obtained from the FEM-MBS model at sensor 14 and the vehicle is compared with actual test data, as shown in Fig. 7. The TRAC values are 0.92 and 0.83, which show the high accuracy of the monitoring-based method. When applying a low-pass filter on the vehicle response, the TRAC value will be increase to 0.88, and it is sufficient for vehicular safety and ride comfort analysis in the future.

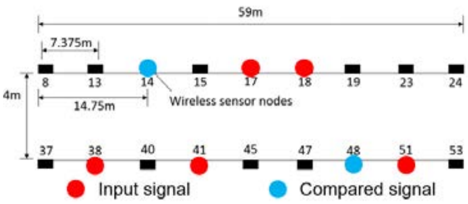

Figure 6. Sensor layout

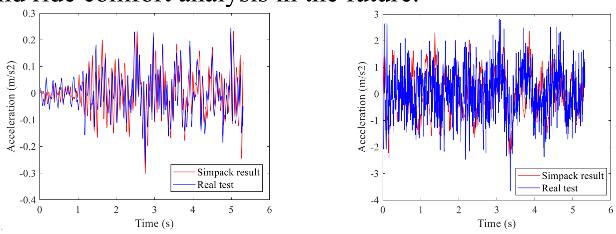

Figure 7. Acceleration comparison (a) sensor 14; (b) vehicle

5. CONCLUSIONS

A novel monitoring-based FEM-MBS analysis scheme for vehicle-bridge interaction analysis is presented in this paper. This new validated FEM-MBS method can also be used for timely and reliable information for stability and safety analysis of vehicles running on bridges under the strong wind in the future.

ACKNOWLEDGE

This work was partially supported by R&D Grant (KyoCho No.12) of Japan Bridge Association.

REFERENCES

He, Gai, and Wu: Simulation of train–bridge interaction under wind loads: a rigid-flexible coupling approach. DEStech Transactions on Engineering and Technology Research. 6-3, 2017, pp. 163-182.

Wang, Nagayama: Extraction of bridge fundamental frequency from estimated vehicle excitation through a particle filter approach, Journal of Sound and Vibration, 428-18, 2018, pp. 44-58.

Wang, Nagayama, Zhao, and Su: Identification of moving vehicle parameters using bridge responses and estimated bridge pavement roughness. Engineering Structures, 153, 2017, pp. 57-70.

