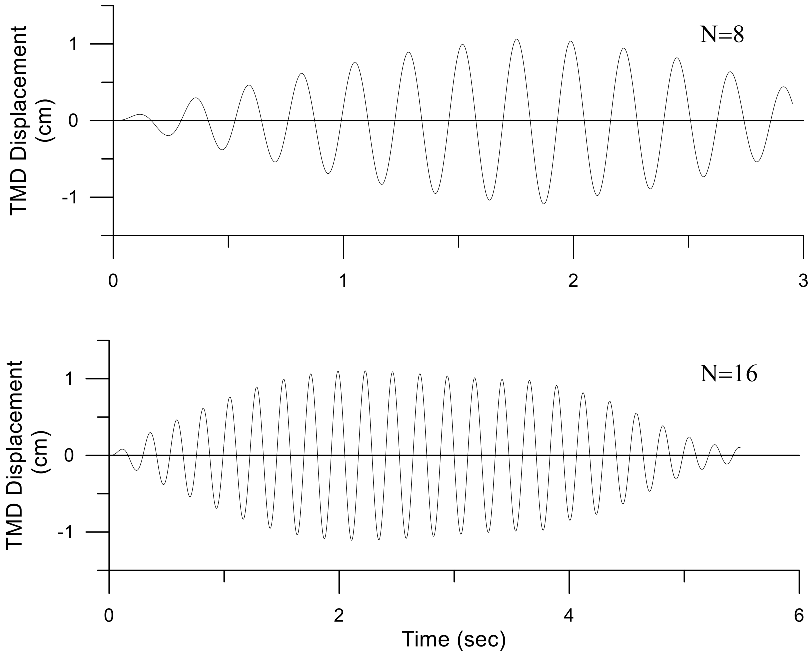

Fig. 11. Displacement of the tuned mass damper installed at the railway bridge.

Fig. 10 shows the mid-span deflection of the bridge under SKS train at a resonance speed of 266 km/h. It can be seen from Fig. 10 that the bridge resonates with the train as the train is operated at resonance speed, and the bridge deflection increases with increasing number of cars (N) of the train. With the installation of a tuned mass damper at mid-span, the deflection response is reduced significantly. Although the maximum operating speed of 300 km/h is not a resonant speed for the current train (SKS) and bridge configuration, it may be useful if bridge vibration is a concern for other types of train-bridge assembly, or the train is operated near the resonance speeds. Fig. 11 shows the displacement time history of the tuned mass damper. It can be seen from Fig. 11 that the displacement of the tuned mass damper is relatively small, in both N=8 and N=16 cases. This is an important characteristic since the space inside the bridge cell is usually confined, which makes tuned mass dampers quite suitable for railway bridge applications. The tuned mass damper is therefore considered a feasible and effective damper device for suppressing bridge vibration caused by high-speed trains.

4. CONCLUSION

In this paper, a case study of a railway bridge under train's moving load is conducted. The paper uses a simple approach to model the railway bridge under high speed trains, aiming at reducing the complexity in the modeling process and obtaining promptly the bridge responses under train loads. Dynamic analysis of a representative simply supported railway bridge under SKS and TGV trains at varied speeds are conducted. Simple finite element modeling using consistent mass beam element is also conducted, with a goal of verifying the response given by the analytic model. Results from the simple model indicated that the bridge response can be readily obtained with sufficient accuracy, and at current maximum operating speed of 300 km/h, bridge vibration caused by either SKS and TGV trains are well within the acceptable limits and no resonance effect is observed. A tuned mass damper is attached to the mid-span of the bridge to test the feasibility of adding such damping system to reduce the vibration induced by high-speed trains. Results indicate that the installation of an optimized tuned mass damper can reduce the bridge vibration effectively when the bridge resonates with the train.

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REFERENCES

Editorial Office (2004), *Design code for railway bridges*, Ministry of Transportation and Communication, Taipei, Taiwan.

Kwasniewski, L., Li, H., Wekezer, J. and Malachowski, F. (2006), “Finite element analysis of vehicle-bridge interaction”, *Finite Elements in Analysis and Design*, **42**(22), 950-959.

Lee, C.L., Chen, Y.T., Chung L.L. and Wang, Y.P. (2006), “Optimal design theories and applications of tuned mass dampers”, *Engineering Structures*, **28**, 43-53.

Lee, Y.S., Hwang, F.J. and Zheng, S.H. (1998), *Design parameters and analysis of vertical vibration and longitudinal forces of railway bridges for high-speed trains.* R-ST-98-02, Sinotech Engineering Consultant, Taipei, Taiwan.

Liu, K., De Roeck, G. and Lombaert, G. (2009), “The effect of dynamic train-bridge interaction on the bridge response during a train passage”, *Journal of Sound and Vibration*, **325**, 240–251.

Salcher, P. and Adam, C. (2015), “Modeling of dynamic train–bridge interaction in high-speed railways”, *Acta Mechanica*, **226**, 2473–2495.

Yang, Y.B. and Yau, J.D. (1997), “Vehicle-bridge Interaction element for dynamic analysis,” *Journal of Structural Engineering, ASCE,* **123**, 1512–1518.

Yau, J.D. and Fryba, L. (2015), “A quasi-vehicle/bridge interaction model for high speed railways”, *Journal of Mechanics,* **31**(2), 217-225.

Yan, J.D. and Yang, Y.B. (2000), *Theory of high-speed train-bridge interaction*, Zetech, Taipei, Taiwan.

Zhang, N., Xia, H. and Guo, W.W. (2008), “Vehicle-bridge interaction analysis under high speed trains”, *Journal of Sound and Vibration*, **309**, 407–425.

Zhang N., Xia H., Guo W.W., De Roeck G. (2010), “A vehicle–bridge linear interaction model and its validation”, *International Journal of Structural Stability and Dynamics*, **10**(2), 335–361.

Zhong, H., Yang, M. and Gao, Z. (2015), “Dynamic responses of prestressed bridge and vehicle through bridge-vehicle interaction analysis”, *Engineering Structures*, **87**, 116-125.