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Vibration Control of Bridge Superstructure Using Tuned Mass Damper (TMD)

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Abstract— *In this article, vibration caused by high speed vehicle in the super structure has been studied. An attempt has been made to control these vibrations using passive Tuned Mass Dampers (TMD). Tuned mass damper consists of a mass, spring and viscous damper which dissipates the vibration energy of the primary structure at the damper of the TMD. In the present paper, concrete box girder bridge superstructure is considered and is modeled using MIDAS software. The bridge is modeled as Euler-Bernoulli beam to study the responses imposed by high speed vehicle. In the present study, comparative study for the responses has been done. The results obtained in this study are based on Indian standard loadings specified in Indian Railways Board (Bridge Rules). A comparative study has been done for the responses of the high speed vehicle with and without Tuned Mass Dampers. The results indicate that there is significant reduction in displacement and acceleration in the bridge superstructure when Tuned Mass Damper is used.*

Keywords: *Bridge Superstructure, High Speed vehicle, Tuned Mass Damper, Vibration control.*

1. INTRODUCTION

The economy of any country is dependent on the transportation facilities they have. The rapid urbanization and space constraints lead to the requirement of more transportation structures like bridges. The study of bridge dynamics is of immense importance considering the comfort of passengers and service life of bridges and its supporting structures. Thus the vibration of a bridge structure due to the passage of vehicles is an important concern in bridge design. To understand the complex interactions between the vehicle and the bridge, a number of researches have been carried out over the past few decades. Many vibration control devices have been used in the bridges to minimize the dynamic responses. A Tuned Mass Damper (TMD) is a vibration absorber system composed usually by a secondary mass suspended by viscous damper and a spring from point on the primary structure, tuned to a particular structural frequency of the bridge. This is done so that it is excited the damper will oscillate out of phase with the bridge motion, i.e., the TMD oscillates in the opposite direction of the primary structure. A TMD is one of the most used passive control devices for different types of structures including bridges. It has two main functions, Firstly it reduces the resonant response of the main structure and secondly, increases the overall damping of the structure through the attached dashpot, providing a supplementary source of energy dissipation[5]. To obtain a god performance and effectiveness of this system, it is required to tune the TMD which is achieved by considering different mass ratio of the TMD to the modal mass of the primary structure. Usually, the mass and stiffness of the TMD are chosen in order to tune its natural frequency to values near the resonant frequency of the main structure to be damped. Nowadays dashpots used in TMDs are either linear or non-viscous dampers.

A passive tuned mass damper doesn't require external power source unlike active tuned mass dampers. Although both possesses the advantages and disadvantages with relation to its use. TMD, a kind of passive type control device, has a variety of merits in that it has permanent service time, and only requires easy management and maintenance efforts and no external power supplying source. TMD is tuned to the first dominant vertical mode and installed in the middle of bridges.

The TMD system is basically a single mode control device. For the case of long span bridges which vibrate in combination of several modes, more than one TMD may be considered. It is well known that the performance of a TMD is sensitive to the frequency ratio between the TMD and the structure. A slight deviation of the frequency ratio from its design value would lead to a drastic deterioration in the TMD's performance.

2. MODELING OF BRIDGE

The modeling of the bridge and the train loads has been done using MIDAS Civil software. Midas Civil is software based on finite element program. The bridge superstructure considered here is of span 30m box girder. The train loading (245.25KN) is based on Indian standard loadings specified in Indian Railways Board (Bridge Rules) as shown in figure 1. Ten numbers of bogies have been taken as dynamic load cases with four axles for each bogie. Time history analysis has been performed for getting the dynamic responses under the passage of the train. The bridge superstructure is divided into 30 elements each of 1m length. The velocity of the train is 200km/hr. The location of train loads on the bridge is time variant. Therefore, the model was simplified and several assumptions were made, as under-

- A bridge is considered as Euler -Bernoulli beam with its ends simply supported.
- In order to understand the dynamic responses of the passenger cars, the train is modeled as a periodic series of planar moving forces.
- It is assumed that the cross-section of the bridge is unchanged during vibration.
- The rail irregularity is negligible.
- The train loads are considered at the centerline of the track.
- Velocity of the vehicle is considered constant while it passes the bridge.

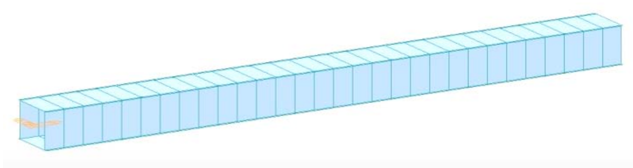

Fig. 1: FEM Model Of Bridge Superstructure (Box Girder)

3. METHODOLOGY

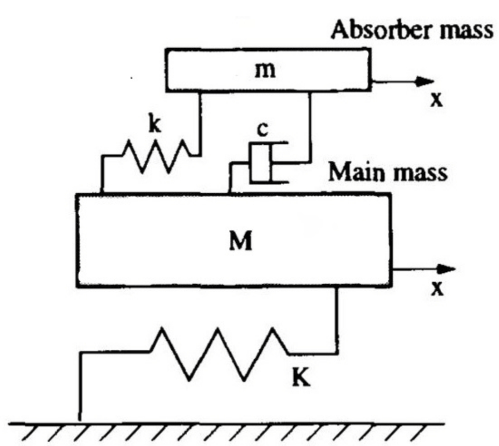

Fig. 2: Representation of SDOF system with single TMD

The equations of motion of the structure and the TMD are given below:

$$M\ddot{X}(t) + KX(t) + \left[C\left\{\dot{x}(t) - \dot{X}(t)\right\} + k_d\{x(t) - X(t)\}\right] = P(t)$$

$$\mathrm{m}\ddot{x}(t) + C_d\left\{\dot{x}(t) - \dot{X}(t)\right\} + k_d\{x(t) - X(t)\} = p(t)$$

where,

M = Mass of structure

m = Mass of TMD

K = Stiffness of structure

K_d= Stiffness of TMD

C_d = Damping of TMD

P (t) = Force acting on structure mass

P (t) =-M$\ddot{x}_g$ (t)

p (t) = Force acting on TMD mass.

$$p(t) = \begin{cases} \frac{m}{M} P(t)\,; & for\ base\ excitation \\ 0\,; & for\ main\ mass\ excitation \end{cases}$$

4. APPLICATION OF TMD

The passage of train over the superstructure induces vibrations both in the bridge and the train. The excessive vibrations may affect the life of the bridge which needs to be controlled. However it is not possible to completely suppress the vibration, it can be reduced to some extent by using dampers. Therefore in order to reduce the bridge vibrations, tuned mass damper has been used. TMD is installed at the mid span of the bridge wherein the dynamic displacement is of maximum. As TMD is designed to control a particular mode of vibration, the first mode is considered to control the vibration of the structure. The selection of proper TMD properties is important considering the detuning effect of TMD. Optimal parameters need to be calculated. Den Hartog gave the following relationships to get the optimum values of the TMD stiffness and damping-

The parameters of are:

Frequency ratio$\left(\boldsymbol{f} = \frac{\boldsymbol{\omega_d}}{\boldsymbol{\omega_s}}\right)$;

It is defined as the ratio of natural frequency of TMD to natural frequency of the structure.

(b) Mass ratio μ =$\left(\frac{\boldsymbol{m_d}}{\boldsymbol{M}}\right)$ and

(c) Damper damping ratio ξ_d = $\left(\frac{\boldsymbol{c_d}}{\boldsymbol{2.\omega_d m_d}}\right)$

Where,

M = Mass of the structure, m_d = mass of damper, c_d= damper damping coefficient, ω_d = Natural frequency of damper, ω_s = Natural frequency of structure.

The basis for Den Hartog method is to minimize the responses to sinusoidal loading which is for an undamped 2-DOF system result in the following parameters:

$$f = \frac{1}{1+\mu}$$

$$\xi = \sqrt{\frac{3\mu}{8(1+\mu)}}$$

After numerous studies on the applicability of TMDs for seismic applications were carried out by Villaverde, Villaverde and Koyama (1993), and Villaverde and Martin (1995) where it was found that TMD performed best when the first two complex modes of vibration of the combined structure and damper have approximately the same damping ratio as the average of the damping ratios of the structure and TMD. To achieved this, Villaverde [10] found that the TMD should be in resonance with the main structure (f =1) and its damping ratio be

$$\xi = \beta + \Phi\sqrt{\mu}$$

Where,

β = damping ratio of structure,

μ = mass ratio of TMD mass to the mass of structure,

Φ = amplitude of the mode shape at the TMD location.

4.1.Optimum TMD parameters

The mass ratio is computed as the ratio of the TMD mass to the generalized mass for the fundamental mode for a unit modal participation factor.

$$\mu = \frac{m}{\phi^T[M]\phi}$$

Where [M] is the mass matrix and $\boldsymbol{\phi}$ is the fundamental mode shape normalized to have a unit participation factor.

The TMD damping ratio is also found to correspond approximately to the damping ratio computed for a 2-DOF TMD system multiplied by Φ. The equation for the damping

For MDOF structures, the practical parameters of the optimal TMD stiffness and the optimal damping coefficient can be thus derived:

$$K_d \text{ opt} = f_d \text{ opt2 } \Omega^2 m$$

$$C_d \text{ opt} = 2\, \xi_d\, f_d \text{ opt } \Omega\, m$$

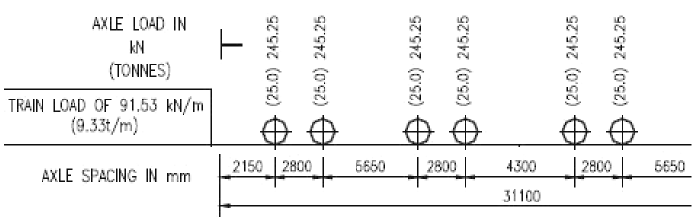

Fig. 3: 25tonne loading pattern of an Indian Railway locomotive

5. RESULTS

The dynamic effect due to the passage of the train is reduced by use of TMD which is shown in the fig.4 and fig.5. The reduction in dynamic responses i.e., displacement and acceleration at the various nodes can be seen in the figures mentioned by comparing the responses considering with and without TMD.

In fig4, it is seen that displacement is maximum at the mid span of the structure. This is mainly due to the fact that response is primarily influenced by the first mode shape. As it is already mentioned that the TMD has been designed considering the first mode shape. Thus it observed that there is some amount of reduction in the dynamic responses.

However in case of acceleration response as shown in fig5, acceleration peaks can be observed at other locations too. This can be explained due to the higher mode effect. The comparison of the responses with and without TMD has been plotted and the response reduction is achieved.

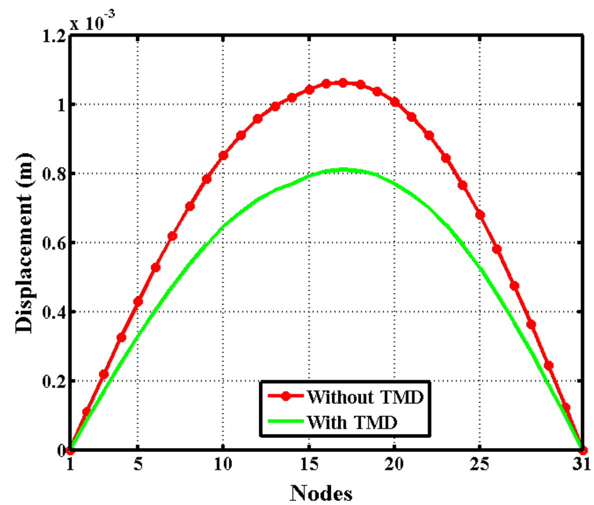

Fig. 4: Comparison of dynamic displacement with and without TMD

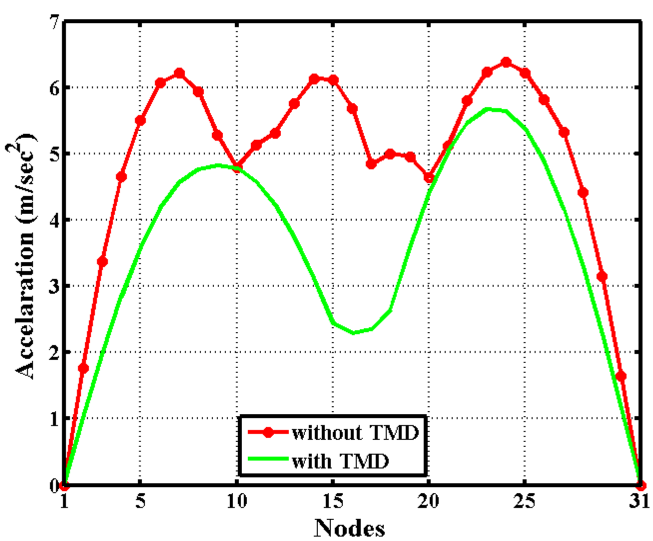

Fig. 5: Comparison of dynamic acceleration with and without TMD

6. CONCLUSION

Thus it is seen that TMD is effective in reducing the dynamic responses of the bridge superstructure when its parameters are properly chosen. The vibration control of the main structure achieved by use of passive TMD is economic and requires less maintenance. Den Hartog's optimal criterion has been discussed and this can be used for computing the TMD mass, stiffness and damping with minor errors when the damping of the structure is small. It can be said that the TMD is a useful device in mitigating the vibrations induced on the bridge by the passage of the train.

REFERENCES

[1] Abe, M., Fujino, Y., "Dynamic characterization of multiple tuned mass dampers and some design formulas". Struct. Dyn., 23, 813-835,1994
[2] Akin, J. E., Mofid, M., "Numerical solution for response of beams with moving mass." J. Struct Engg., 115(1), 120-131, 1989
[3] Wang J.F., "Vibration control of structures with multiple tuned mass dampers considering system interaction effect."PhD Thesis, Dept. of Civil Engineering, National Chung-Hsing University, Tai-Chung, Taiwan. 2001
[4] Yang Y. B., J. D. and Hsu, L. C.,"Vibration of simple beams due to train movement at high speeds." Eng Struct. 19(11), 936-944, 1997
[5] Karaoumi, R. "Response of Cable Stayed and Suspension Bridges to Moving Vehicles, Analysis Methods and Practical Modeling Techniques."1998
[6] Wang, J.F., Lin, C.C., Chen, B.L."Vibration suppression for high speed railway bridges using tuned mass dampers." International Journal of Solids and Structures, 40(2),465-491. 2003
[7] Lin, C.C., "Vibration suppression for high speed railway bridges using tuned mass dampers."International Journal of Solids and Structures, 42(24-25),6520-6521, 2005a
[8] Lin, C.C., Wang, J.F., Chen, B.L."Train-Induced Vibration Control of High Speed Railway Bridges Equipped with Multiple Tuned Mass Dampers." Journal of Bridge Engineering, 10(4), 398-414, 2005b
[9] Rana, R., Soong. T.T., "Parametric study and simplified design of tuned mass dampers." Engineering Structures, 20(3), 193-204, 1998
[10] R. Villaverde, Reduction in seismic response with heavily damped vibration absorber, Earthquake Eng. Structure Dynamic. Vol. 13, pp. 33-42, 1985