Suppression of Bridge Vibrations using Tuned Mass Dampers

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***Abstract*— The importance of bridge vibrations induced by moving vehicles, which act as an oscillators on a bridged as well as time variant forces, has long been recognized. this vibration can amplify the propagation of existing cracks resulting in further damage to the bridge. it has become one of the causes of reduction in long-term serviceability of the bridge, although major bridges failures are not usually caused directly by moving vehicles. It is also a critical factor to bridge structure fatigue and rapid deterioration since, the vehicle-induced vibration is more critical to bridges with medium to small spans it is worthwhile to investigate the possibility of applying tuned mass damper on these bridges. A TMD is a passive control device with variant of merits in that it has permanent service time and only requires easy management and maintenance efforts and no external power supply source. In order to achieve the above objective a general formulation of the vehicle induced bridge vibration controlled with a TMD system is developed here in the present study, which takes into account the road surface conditions. Then, a comprehensive investigation is made to investigate the efficiency of the TMD for suppressing vibrations of bridge under moving load.**

Keywords— Tuned mass dampers; truss bridge; suppressing vibration; moving load

I. INTRODUCTION

Vehicle-bridge interaction is a complex dynamic phenomenon, which is a non-linear problem dependent on many parameters? These parameters include the type of bridge and its natural frequencies of vibration, vehicle characteristics, vehicle speed and traversing path, the number of vehicles and their relative positions on the bridge, roadway surface irregularities, the damping characteristics of bridge and vehicle etc. The first recorded research into bridge vibration appears to be a report published in the 19th century (Willis, 1849),which discussed the reasons for collapse of the Chester Railway Bridge. In the first half of the 20th century, investigations into bridge vibration were mainly concerned with developing analytical solutions for simple cases of moving force (Timoshenko, 1922; Lowan, 1935; Ayreet al1, 1950; Ayre and Jocobsen, 1950) and moving mass (Jeffcott, 1929).

The moving force model is the simplest model whereby researchers can capture the essential dynamic characteristics of a bridge under the action of a moving vehicle, although the interaction between the vehicle and bridge is ignored. Where the inertia of the vehicle camion is regarded as small, a moving mass mode is often adopted instead. However the moving mass model suffers from its inability to consider the bouncing effect of the moving mass, which is significant in the presence of road surface irregularities or for vehicles running at high speeds.

The development of cost-effective analysis methods as well as the clear identification of the important parameters that govern dynamic response will certainly be of great help to better understanding of the true behavior of the entire bridge-vehicle system. This thesis therefore focuses on development of effective methods for analyzing the vibration of various types of bridges including girder bridges, railway bridges, slab bridges and cable-stayed bridges under the action of moving vehicles and trains. The vibration analysis of suspension bridges is excluded from this thesis due to the limitation of study period.

Truss Bridge:

Truss Girders, lattice girders or open web girders are efficient and economical structural systems, since the members experience essentially axial forces and hence the material is fully utilized. Members of the truss girder bridges can be classified as chord members and web members. Generally, the chord members resist overall bending moment in the form of direct tension and compression and web members carry the shear force in the form of direct tension or compression. Due to their efficiency, truss bridges are built over wide range of spans. Truss bridges compete against plate girders for shorter spans, against box girders for medium spans and cable-stayed bridges for long spans.

DAMPERS:

Some vibrations problems are directly related to structural resonances, which are specific frequencies at which dynamic perturbations are, sometimes hugely, amplified. The level of this amplification is inversely proportional to the internal damping of the structure. Hence, in order to reduce vibration problems related to resonances, one will want to increase the structural damping and this can be done by passive (friction joints, viscous material, Tuned Mass Dampers…) or by active means.

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II. OBJECTIVE AND METHODOLOGY

A. *Objectives*

The aim of the study is to evaluate the seismic performance of a bridge with & without TMD.

- To study the feasibility of extraction the fundamental bridge frequency from the dynamic response of a vehicle passing over bridge.
- To study the impact of a speed of vehicle on the structural response of different components of bridges.

B. *Methodology*

TRUSS bridge which is selected for the study is assumed to be located in zone 5 of India, the factors as listed above could be modeled for the study using the finite element analysis the analysis is carried out in SAP 2000. The dynamic analysis would be carried out to study the impact of speed of the vehicles on the structural response of the bridges. The study will be conducted in the form of parametric study so that the studies could result in design chart. The input values to be used in FEM program shall be selected from the literature review initially and then revised based on the values and refined further if possible by conducting theoretical model studies.

1. The truss bridge is adopted as a design example for a study.
2. It is 40m, 60m and 80m long & 12m wide truss bridge with two lanes bridge of traffic.
3. A span of 40m, 60m and 80m between two piers is chosen for study.
4. The span is considered to be as simply supported.
5. The systematic parameters like natural frequency, time period, displacements, acceleration, velocity, model damping energy, kinetic energy are studied.
6. The vibrations of systematic parameters of bridge with and without TMDs are studied considering Bhuj earthquake data.
7. The impacts of speed of vehicles on bridge are studied.

Dynamic Equilibrium Equation of Structure

The dynamic response of a structure at any instant of time t under an excitation force is defined by its displacement u(t), velocity u̇(t) and acceleration ü(t). The total force acting on a structure is resisted by its inertia F(t)I, damping F(t)D and stiffness F(t)S component of reactive force. The force equilibrium equation of a structure at any instant of time of t, subjected to dynamic load F(t) can be expressed by the following equation.

F(t)I + F(t)D + F(t)S = F(t)
Where, F(t)I = m.ü(t)
F(t)D= c.u̇(t)
F(t)S = k. u(t)
Where, m= mass of the system.
c = damping of the system
k= stiffness of the system

For multi degree of freedom system corresponding equation of motion become
[M]+ [C]+[K]U(t)={F(t)} (3.11))(tUtU)
Where, [M] = The global mass matrix of structure.
[C] = The global damping matrix of the structure.
[K] = The global stiffness matrix of the structure.
U(t) = Absolute nodal displacement.
U̇(t) = Absolute nodal velocity.
Ü(t) = Absolute nodal acceleration.
F(t) = Force vector. (For earthquake loading F(t)=-[M].Üg(t))
Üg(t)= Ground acceleration due to earthquake.
The effect of TMD can be considered by adding extra opposite nature force to forcing function.

C. *Parameters considered for the study*

Table.1 parameters considered

1.	Type of bridge	TRUSS BRIDGE
2.	Grade of concrete	M 30
3.	Number of lanes	2
4.	Lane width	4m
5.	Length of bridge	40m, 60m and 80m
6.	Yield strength	250Mpa
7.	Youngs modulus, E	5000√fck
8.	FRAME SECTION: 1. Box section 2. Bracings (I-section) 3. Floor beam 4. Cross beam 5. Stringer 6. Portal	
9.	Deck slab	300mm

III. MODELS

In the present study 3-dimensional truss bridge models of different span of 40m, 60m and 80m with fixed base, with and without tuned mass dampers of different mass ratio is made using SAP2000

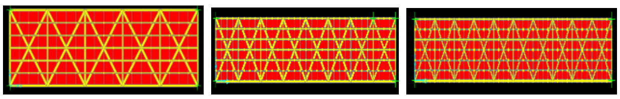

Fig. 1. Plans of 40m, 60m and 80m span

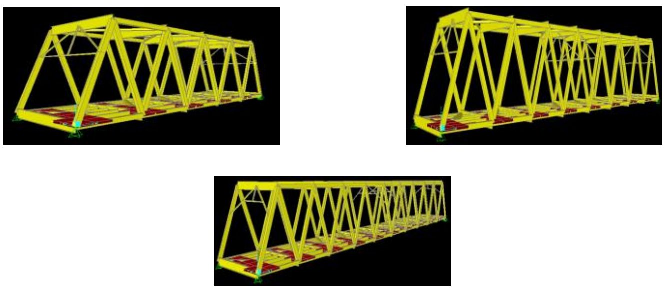

Fig. 2. Elevation of 40m, 60m and 80m span without TMD

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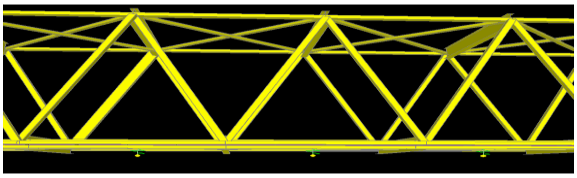
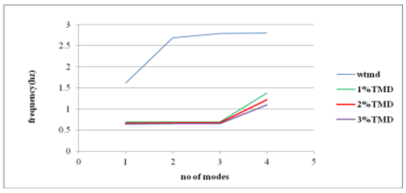


Fig. 3. Elevation with TMD

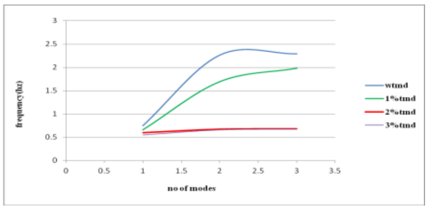
IV. RESULTS AND DISCUSSION

In the present study 3-dimensional truss bridge models of different span with fixed base, with and without tuned mass dampers of different mass ratio subjected to acceleration v/s time period of Bhuj earthquake is studied. Tuned mass damper is modeled with elastic spring properties. The variation in frequency and the structural responses like Base shear, Displacement and Acceleration for time history data is presented.

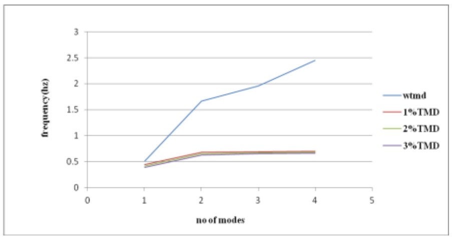
A. VARIATION IN FREQUENCY



40m SPAN

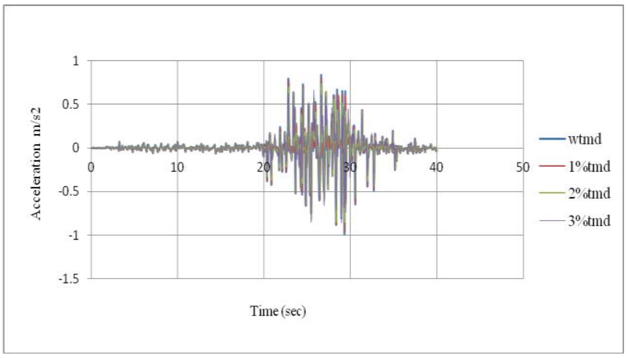


60m SPAN

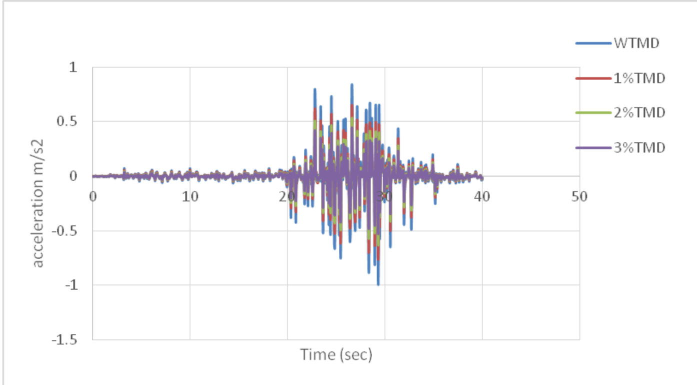


80m SPAN

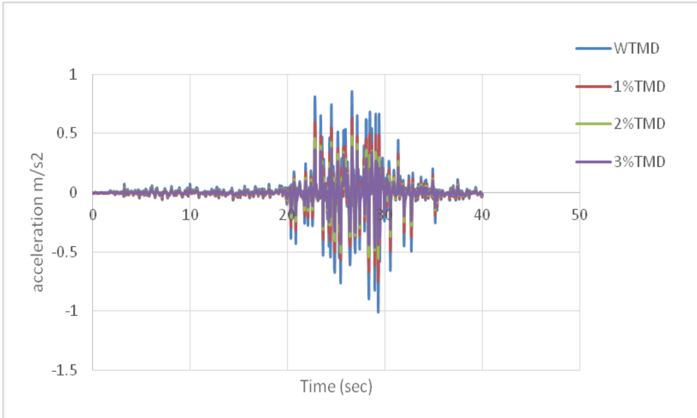
B. VARIATION IN ACCELERATION:



40m SPAN



60m SPAN



80m SPAN

C. VARIATION IN VERTICAL DISLACEMENT:

Table.2. 40m SPAN

Node at midspan	Maximum Vertical Displacement (m)		
	Without TMD	With TMD	% Reduction
106	0.00189	0.00121	35.97884
106	0.00189	0.00104	44.97354
106	0.00189	0.00085	55.02646

Table.3. 60m SPAN

Node at midspan	Maximum Vertical Displacement (m)		
	Without TMD	With TMD	% Reduction
263	0.00295	0.00186	36.94915
263	0.00295	0.00104	64.74576
263	0.00295	0.00094	68.13559

Table.4. 80m SPAN

Node at midspan	Maximum Vertical Displacement (m)		
	Without TMD	With TMD	% Reduction
263	0.00423	0.0039	7.801418
263	0.00423	0.00369	12.76596
263	0.00423	0.00335	20.80378

CONCLUSION

1. Since Frequency decreases, vibration reduces with the increase in mass ratio that is 3% and maximum variation is found in 80m span Steel Truss bridge.
2. Joint Displacement of a structure increases with increase in span and after the implementation of TMD there is a substantial decrease in Joint Displacement maximum decrease is observed in case of mass ratio 3%.
3. Joint Acceleration of a structure increases with increase in span and after the implementation of TMD there is a substantial decrease in Joint Acceleration maximum decrease is observed in case of mass ratio 3%.

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