ANALYSIS OF NONLINEAR BEHAVIOR OF SHINKANSEN VIADUCT UNDER DOUBLE PASSING LOAD OF SHINKANSEN AND EFFECTIVENESS OF APPLICATION OF MULTI TUNED MASS DAMPERS (MTMD) OF DIFFERENT MASS RATIOS

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1. BACKGROUND

In Japan, Shinkansen is very important because, in modes of transportation, it has a key role. In 1964, first Shinkansen (High-Speed Train) came into service during 1st Tokyo Olympics. Till today, Shinkansen connects almost all major cities of Japan. In 2014, JR reported, that some spans of Shinkansen viaducts have vibration more than Ride Comfort Limit which is equal to 17 mm.

In our lab, Nakasuka et al (2016), started research and observed that the Natural frequency of the healthy concrete of bridge is greater than that which was determined by observing response against excitation frequency. In other words, resonance in the structure was observed at a frequency less than the natural frequency of healthy concrete. He concluded his research with the reason of reduction in the natural frequency (performance) of structure which is; (1) Reduction in Effective Area of Restressed and Reinforced Concrete (PRC) girder due to tension cracks causes a reduction in stiffness of girder (showed a nonlinear trend).

Yamamoto et al (2016) performed Finite Element Model (FEM) analysis of a typical bridge (30m Span) and using 12 cars typical Shinkansen as moving load. He proposed a solution consists of Multi Tuned Mass Dampers (MTMD) System of total mass equal to 1% mass of structure to suppress the excessive vibration in structure. His research concluded with the effectiveness of the application of Multi TMDs to Nonlinear System instead of single TMD but has certain shortcomings which are; (1) model was simulated only for a single passing load of the train but the worst case may be for double passing load, and, (2) Simulation performed were limited.

In this research, Shinkansen viaduct is simulated for analyzing its nonlinear behavior considering double passing loading and effectiveness of Multi Tuned Mass Damping System (MTMD) to reduce excessive vibration against the nonlinear behavior.

2. SIMULATION FOR DOUBLE PASSING LOAD

A Simply Supported bridge of 30 m span is simulated for Double Directional Passing Load of Shinkansen with same speed (worst case), using ABAQUS software as shown in Fig. (1a). The dynamic response for this model was observed and compared with the dynamic response of single direction passing load case. It was observed that the dynamic displacement was quite high in case of double passing load can be seen in Fig. (1b).

The response was observed at various Shinkansen speed to find the resonant speed which corresponds to the resonant frequency/natural frequency of the structure. Fig. (2) shows the variation of maximum amplitude with a change in train speed for both single passing (SP) and double passing (DP) without installation of any controlling devices.

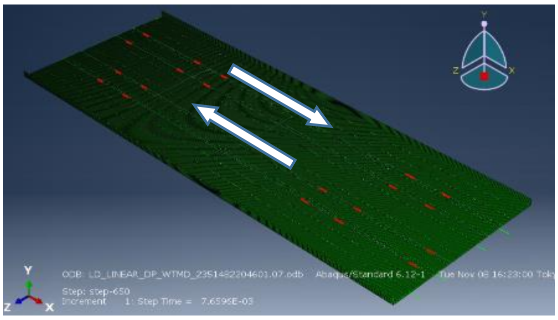

Fig.1a: FEM Double Passing Model

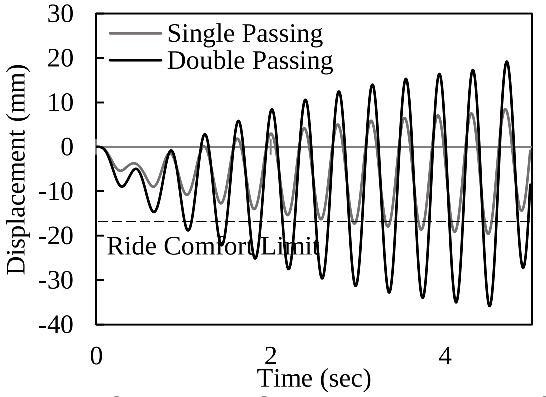

Fig.1b: Max. Displacement Resonant Speed

3. APPLICATION OF MUTI TUNED MASS DAMPERS

As the system is nonlinear so Single TMD can't work effectively because it has narrow frequency bandwidth (Kareem, 1995). So, to overcome excessive vibration a system of Multi Tuned Mass Dampers (TMDs) was developed. A set of five (05) TMDs of various frequencies were proposed using total mass of TMDs equal to 1% of 1st Modal Mass of Structure. The properties of TMDs were obtained using following formulae (Silva, 1999) are shown in the Table (1) and results obtained are shown in Fig. (3).

$$k = \omega^2 m \qquad where, \omega = 2\pi f \tag{1}$$

$$\varsigma = \sqrt{\frac{3\mu}{8(1+\mu)^3}} \qquad where, \mu = mass\ ratio \qquad (2)$$

Table 1: Properties of TMDs Used with 1% mass ratio

	Speed	Excitation Frequency	Stiffness	Damping Coefficient
	Km/hr	Hz	N/m	N-sec/m
TMD1	215	2.44	293100	1065
TMD2	225	2.56	321000	1115
TMD3	235	2.67	350091	1164
TMD4	245	2.78	380600	1239
TMD5	255	2.89	412300	1264

4. MULTI TMDS WITH MASS RATIO OF 1.5% AND 2.0%

The results illustrated in Fig. (3) show that Amplitude displacement at resonant speed / resonant excitation frequency is still beyond ride comfort limit. For checking trend in reduction in vibration with respect to Mass Ratio, TMDs of mass ratio 0.5%, 0.75%, 1.5% and 2.0% were designed using equation (1) and (2). The properties of TMDs and results are shown and Table (2) and Fig. (4) respectively.

Table 2: TMD Properties for 1.5% and 2.0% mass Ratio

	Mass Ratio = 1.5%		**Mass Ratio = 2.0%**	
	Stiffness	Damping Coefficient	Stiffness	Damping Coefficient
	N/m	N-Sec/m	N/m	N-Sec/m
TMD 1	439700	1954	586200	3005
TMD 2	481550	2046	642100	3145
TMD 3	545300	2136	700400	3284
TMD 4	570950	2227	761200	3424
TMD 5	618500	2318	824700	3564

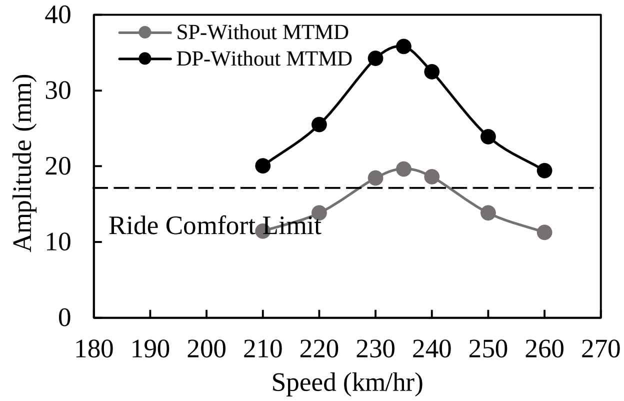

Fig. 2: variation of Max. Amplitude with Speed

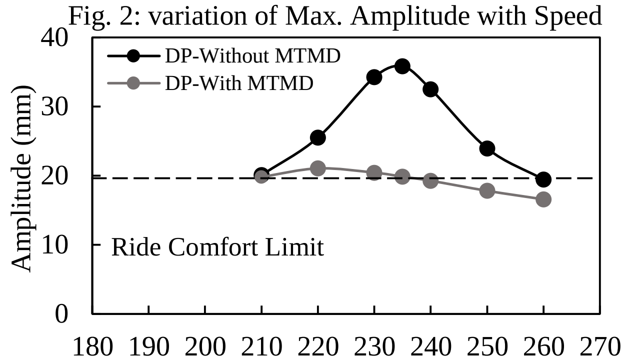

Fig. 3: Max Amplitude Response after MTMD of μ = 1%

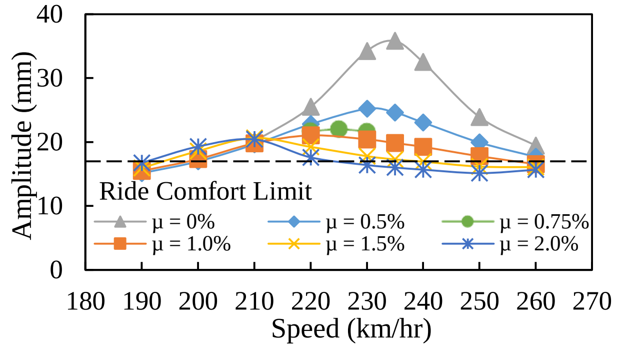

Fig. 4: Max Amplitude Response for μ 0.5 to 2%

5. CONCLUSION

The effect of Multi TMDs of different Mass Ratios (μ) on reduction in excessive vibration in bridge behaving nonlinearly is studied and it is concluded that for Double Passing Load case, MTMDs of Mass Ratio 1% suppressed amplitude displacement significantly which is close to Ride Comfort Limit. As the rate of occurrence of Double Passing Load with the same speed of the train (Worst Case) is also very small so this system can work effectively in such worst scenarios. According to previous research, for normal case i.e. a nonlinear system with Single Passing Load, the MTMD system is very effective (Yamamoto et al, 2016).

In this research, calculation of damping ratio (ς) is done using equation (2), which give optimized value for linear systems but as the system is nonlinear, so by finding more optimized other parameters i.e. Damping Ratio, Stiffness, Frequency Range and Location of Dampers, we may further control amplitude displacement.

References

- Kareem Ahsan, Kline Samuel: Performance of Multiple Mass Dampers Under Random Loading. Journal of Structural Engineering, ASCE, 121-2, 1995, pp. 348 – 361
- Silva, C.W.: Vibration: Foundation and Practice, United States, 1960, pp. 797-798
- J. Nakasuka et al., “Analysis of Large Amplitude Vibration Mechanism of High-speed Train PRC Girder Bridges Based on Vibration Measurement,” Proceedings of EASEC-14, Ho Chi Minh City, Viet Nam, Jan. 2016, pp. 805-813.
- 山本悠人ら：新幹線走行に伴うPRC 橋の共振現象のTMD による振動制御効果の検証，土木学会第71回年次学術講演会講演概要集，Vol.71，No. I-204，2016，pp.407-408.