(102) Effects of Tuned Mass Dampers to Local Site Dependent Earthquake Ground Motions

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ABSTRACT.

This paper deals with the application of tuned mass dampers (TMD) for earthquake response reduction of multistory structures. Highly resonant response due to the narrow-banded strong ground motion record of the 1985 Mexico earthquake is reduced significantly when TMDs are included into the structures. On the other hand, response to wide-banded strong motion records is reduced only moderately.

GENERAL DESCRIPTION.

The 1985 Mexico earthquake caused collapse or severe damage to many multistory buildings in Mexico City. The double resonance phenomenon (earthquake-ground, groundstructure) is considered as a main reason of the intensity of damage (1). The strong ground motion recorded at SCT station, on the soft soil zone of the city, exhibits strong oscillations with 2-second period. Most of the buildings that collapsed or suffered the greatest damage were 7 to 15 stories tall. During the strong vibration caused by the earthquake, these structures lengthen their period and entered the range of resonance with the ground. This behavior can be identified as a narrow-band problem, in which the response associated with a period of 2 second should be suppressed.

In recent years, several high-rise structures have included TMD systems in their design to reduce oscillations related to a natural mode of vibration (2). The TMD is a device especially suited to improve situations in resonant vibratory systems. John Hancock Tower, Boston Massachusetts in the U.S. has the dual tuned mass damper system with two 300 ton mass blocks. Citicorp Center, New York City in the U.S. has actively controlled tuned mass damper system with 373 ton concrete mass block. These two tuned mass damper systems are designed to surpress first mode response of the high-rise buildings due to wind oscillations (3). Earthquake response of multistory structures is also governed by the first mode, and for a building having a fundamental period similar to that of the ground motion, high response amplitudes will develop. For these cases, addition of a TMD to the structure is expected to make significant reduction of the response.

This paper presents several numerical examples of earthquake response of high rise building models with (and without) a TMD to examine the feasibility of the system.

STRUCTURAL MODEL AND TMD DESIGN.

Fig.1 shows a schematic representation of a multistory structure equipped with a TMD on the top of the building; u_g denotes the ground displacement, and u_i denotes the displacement of mass m_i (story "i") relative to the ground. If displacement response of a TMD relative to the ground is minimized, the spring attached to the TMD always acts to suppress earthquake response of a main building.

For the numerical analysis in this paper, a 15-story frame building is idealized as a shear beam structure, considering one degree-of-freedom per floor as shown in Fig. 2. Mass and stiffness characteristics of the building model used are presented in Table 1. Modal analysis of the building model is carried out and the first four modes are plotted in Fig. 3. It is found that the fundamental period of the model is 1.99 second with the effective mass of 0.619 which is much larger than those of the higher modes. A TMD is simulated as an extra story in the model and designed according to Den Hartog's optimum tuning consideration (4). Several sizes of TMD are analyzed, with different values of total mass ratio R (TMD mass / building's total mass). Modal analysis of the structural model with a TMD of which R=0.03 is also carried out the first four modes are plotted in Fig. 4. The first and second natural period of the model is calculated as 2.46 and 1.76, respectively. The effective mass of the second mode (0.337) is found larger than that of the first mode (0.302). Hence the second mode in which the TMD and a main building is moving toward the opposite direction is expected to be predominant to suppress earthquake response of a main structure.

SEISMIC RESPONSE ANALYSIS.

The response of the building models is computed in the linear range to the EW component of SCT record, Mexico, 1985 (Fig. 5) Structural damping factor for all modes is taken as 2%. The 15th floor displacements relative to the ground, for the original structure and for a structure having a TMD with R=0.03 are shown in Fig. 6. Similar response amplitudes were obtained for other TMD sizes. It is seen that the response is greatly reduced by the effects of a TMD. For practical use of a TMD, travelling distance of it should also be checked. In Fig. 7, TMD displacement relative to the top floor is plotted, and the maximum value is found 3.14m which is larger than structural response without a TMD. When smaller mass of a TMD is used, larger relative displacement is obtained. Hence, large space is needed for travelling of a TMD. However, due to reduced displacement response, member internal forces will also be reduced with increased structural safety.

Global effectiveness of the TMD can be observed in Fig. 8, which shows envelopes of maximum displacement response to SCT record, for the original building and for the building with TMD (two cases: R=0.005 and R=0.03). Concerning the TMD displacement relative to the building, better results are obtained for the case of R=0.03.

Similar analyses are done using wide-banded strong motion records: El Centro NS, 1940 shown in Fig. 9, and Hachinohe NS, 1968 shown in Fig 10. Envelopes of maximum displacement response, for the original building and for the building with the most effective TMD are given in Figs. 11 and 12, respectively. The TMDs in these cases reduce only moderately the response, and this effect is mostly concentrated on the upper floors. When input earthquake motions are wide-banded with limited duration, structural response does not become resonant state but stays at transient response. Therefore, a TMD does not travel much to have small effects on a main structure.

CONCLUSIONS.

From this investigation, TMD systems seem to be effective in reducing earthquake response of structures in resonant conditions (narrow-banded ground motion combined with structures having similar natural periods). Great reduction of response is achieved even with small TMD sizes. When wide-banded records are used, TMD systems are found to be less effective.

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(3) Wiesner, K.B., "The Role of Damping Systems", preprint of Second Century of the Skyscraper, Van Nostrand Reinhold Co., New York, 1986.
(4) Den Hartog, J.P. "Mechanical Vibrations", McGraw-Hill Book Co., 1947.

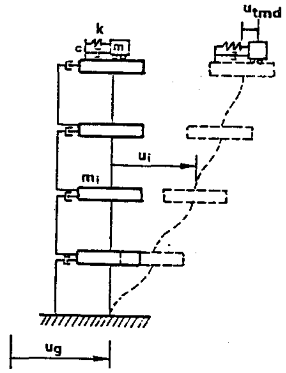

Fig.1. Multistory structure with TMD.

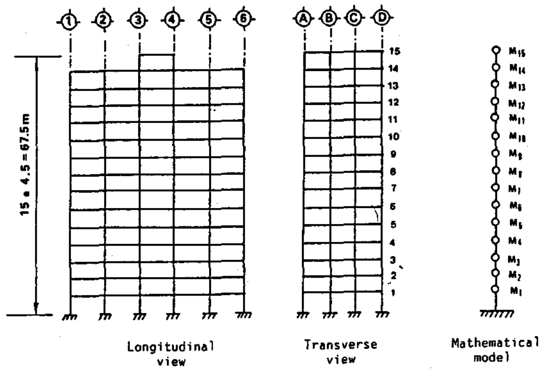

Fig.2 Evaluation views and mathematical model of a building

Table 1 Characteristics of building model

Floor	Weight (ton)	Mass ($ton\text{-}sec^2/m$)	Number of columns	Column cross section (m)
15	140	14.30	8	0.40 x 0.40
11-14	830	84.70	24	0.40 x 0.40
6-10	870	88.78	24	0.55 x 0.55
1- 5	920	93.88	24	0.70 x 0.70

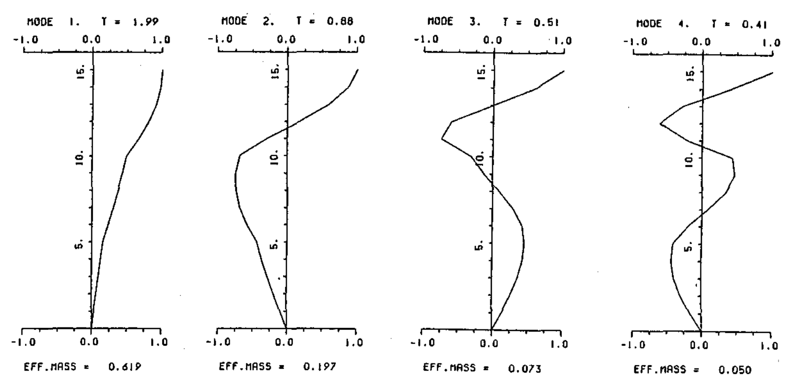

Fig.3 Natural period, effective mass, mode shapes without a damper

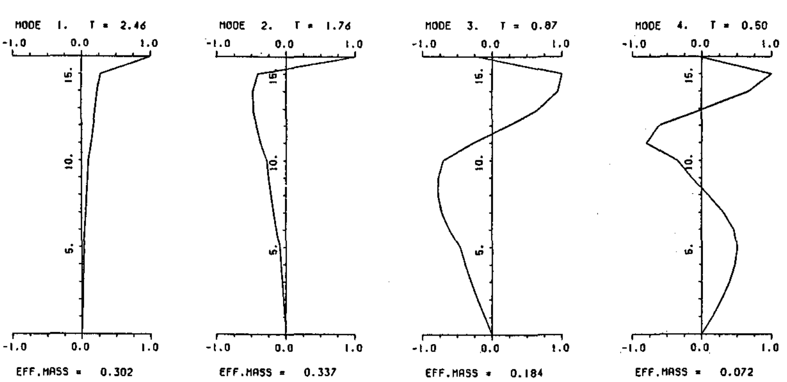

Fig.4 Natural period, effective mass, mode shapes with a damper

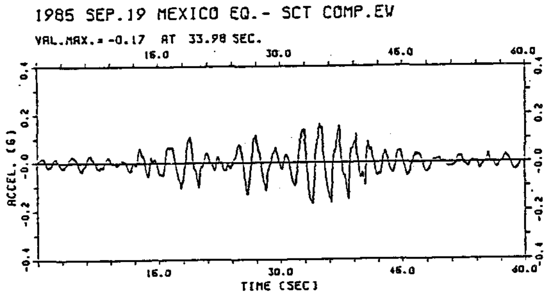

Fig.5 SCT ground motion record used in analysis.

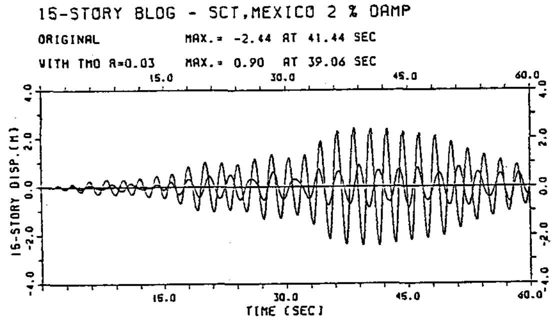

Fig.6 Displacement response of story 15.

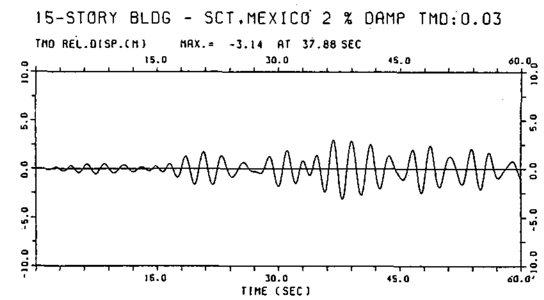

Fig.7 TMD displacement response relative to the building

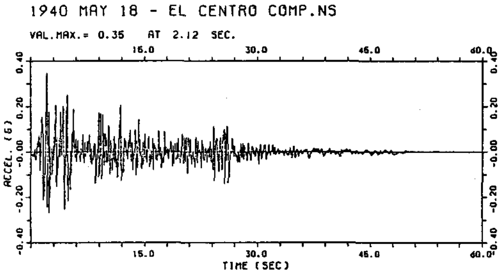

Fig.9 El Centro NS component (1940)

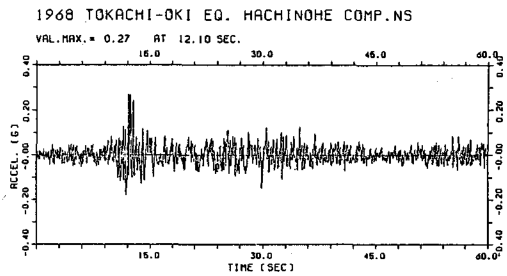

Fig.10 Hachinohe NS component (1968)

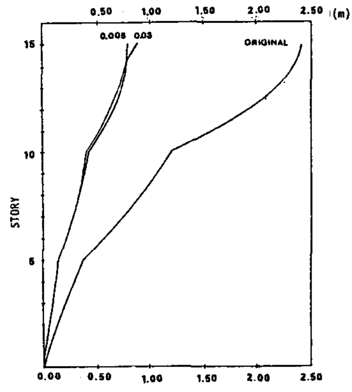

Fig.8 Envelope of maximum displacements, for original building and for building with TMD, R=0.005 and R=0.03, SCT record.

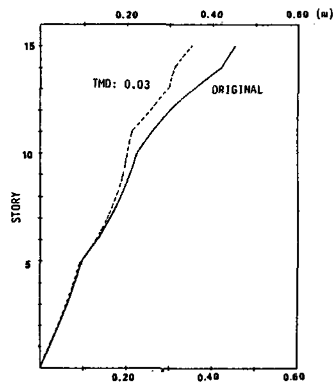

Fig.11 Envelope of maximum displacements for original building and for building with TMD, R=0.03, El Centro record.

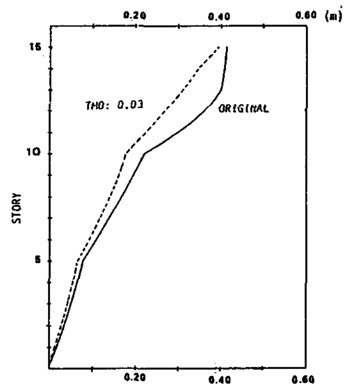

Fig.12 Envelope of maximum displacements, for original building and for building with TMD, R=0.03, Hachinohe record.