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Seismic Mitigation and Control in Irregular Buildings with Floating Storey as Tuned Mass Damper

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Abstract
From the past earthquakes, it is seen that irregular buildings are the most vulnerable during the earthquake. However, irregularity cannot be avoided during the construction of buildings. Therefore, it is necessary to determine seismic responses of buildings with irregular configurations. Efforts have led to development of various techniques in controlling seismic responses of structures.The traditional Tuned Mass Damper (TMD) device which is used for controlling seismic responses of structures has some disadvantages. TMDs occupy large valuable space in a building. Space restrictions caused by traditional TMD configurations led to the thought of making use of soft storey at top of the building to act as TMD. This research explores an additional top storey called a floating storey as tuned mass damper in irregular building system for reducing the seismic response of structures and mitigating damage. The main objective is to study the performance of multiple models with different tuning ratios and controlling the drift and displacement of the structure and to design a tuned mass damper for the irregular models. The proposed structural configuration separates the floating storey of the structure to act as the 'tuned' mass which can be a simple, effective, economical and reliable means for decreasing undesirable vibration of structure caused by seismic excitation.

Keywords:*Stiffness irregularity, setback, floating storey, tuned mass damper.*

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I. INTRODUCTION

In structural engineering, the major goal has been maintaining the structural stability against the effect of various forces acting on the structure. Earthquake is one of the important external forces that need to be taken in account while designing a structure, as they can greatly affect stability of structure.From the past earthquakes, it is seen that irregular buildings are the most vulnerable during the earthquake. However, irregularity cannot be avoided in most of the cases during the construction of buildings. Therefore, it is necessary to determine seismic responses of buildings with irregular configurations. Mass and stiffness are two basic parameters to evaluate the dynamic response of a structural system under vibratory motion.

When quick change of stiffness takes place along the height of the structure, stiffness irregularity exists.Mass irregularities are considered to exist where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey.

Efforts have led to development of techniques like base isolation, active control and passive control devices. Base isolation technique is shown to be quite effective and it requires insertion of isolation device at the foundation level, which may require constant maintenance. Active control techniques turn out to be quite costly for buildings, as they need continuous power supply. With the aim of developing such a simple control device, Tuned Mass Damper (TMD) has been proposed in the last decades for controlling seismic responses of structure.

A TMD is a passive energy dissipation device consisting of a mass, and spring that is attached to a structure in order to reduce the dynamic response of the structure. The TMD is designed to have the natural frequency tuned to that of the primary structure. When the particular frequency of the primary structure gets excited, the TMD will resonate out of phase with the structural motion and reduces its response. There are some disadvantages for tuned mass damper.A large mass or a large space is needed for their installation. The effectiveness of a TMD is constrained by the maximum weight that can practically be placed on the top of the structure. Their effectiveness depends on their tuning, but natural frequencies of a structure cannot be predicted with great accuracy.

This research explores an additional top storey called a floating storey as tuned mass damper in mass and stiffness irregular building systems for reducing the seismic response of tall structures and mitigating damage. The proposed structural configuration separates the floating storey of the structure to act as the 'tuned' mass which can be a simple, effective, economical and reliable means for decreasing undesirable vibration of structure caused by seismic excitation.

1.2 Modelling

For the analytical study, a 9-storeyed steel building is modelled. The structure is modelled with box section columns and I-section beams. The section properties are given in Table 1. Fe250 beams and Fe345 columns are used. The floors are composite construction (i.e., steel and concrete).All bays are 7m wide. Height of first storey is 4m and all other stories are 3.6m high.

Table 1: Section properties

Element	Section property
1st level columns	430 ∗ 430 ∗ 18 mm
2nd–5th level columns	400 ∗ 400 ∗ 15 mm
6th–9th level columns	380 ∗ 380 ∗ 12 mm
1st–5th level beams	500 ∗ 180 ∗ 11 ∗ 16 mm
6th–9th level beams	440 ∗ 150 ∗ 10 ∗ 16 mm

1.3 Non-linear time history analysis

Time-history analysis is a step-by-step analysis of the dynamic response of a structure to a specified loading that may vary with time.In order to examine the exact nonlinear behaviour of structures, nonlinear time history analysis has to be carried out. In this study, the structure is subjected to real ground motion records of El Centro earthquake.

1.4 Methodology

The analysis is carried out to study the seismic responses of 9-storeyed steel building without and with top floating storey as TMD using ETABS 2017. Buildings with single setback, double setback and both direction setback are studied. All these models are considered with TMD of mass ratios 2%, 4% and 6%. Additional top storey called floating storey of 2m height is provided as TMD. Buildings with 3 irregular configurations with TMD are shown in Figure 1, 2 and 3.

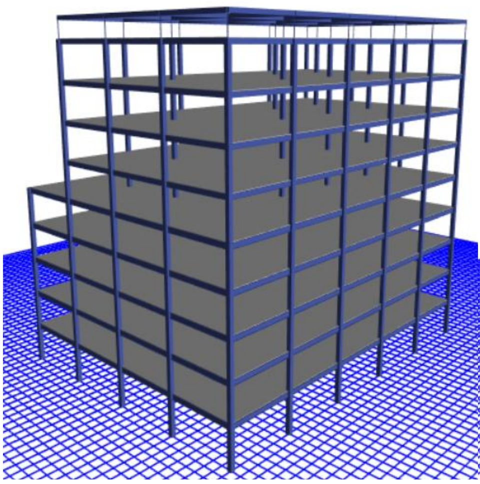

Figure 1:Single setback building with TMD

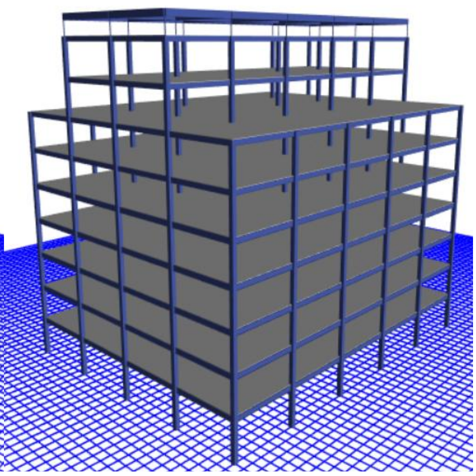

Figure 2:Double setback building with TMD

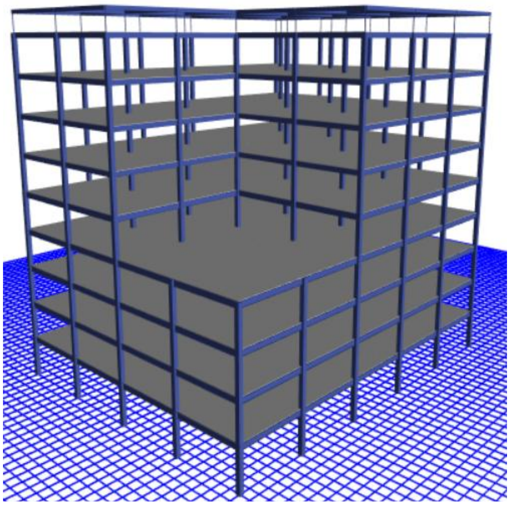

Figure 3:Both direction setback building with TMD

II. RESULT AND DISCUSSION

The results obtained are discussed below.

2.1 Displacement

All the three cases of irregular buildings show decrease in displacement with floating storey TMD.For the single setback building, mass ratio of 2% is effective. For the double setback building, 4% proves to be more effective and for the building with both direction setback, TMD of 4% mass ratio is better. The storey displacement of the three cases are shown in Figure 4, 5 and 6.

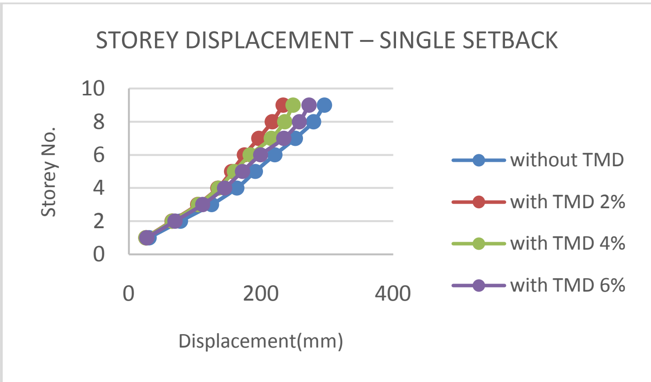

Figure 4: Storey displacement graph of single setback case

Figure 5: Storey displacement graph of double setback case

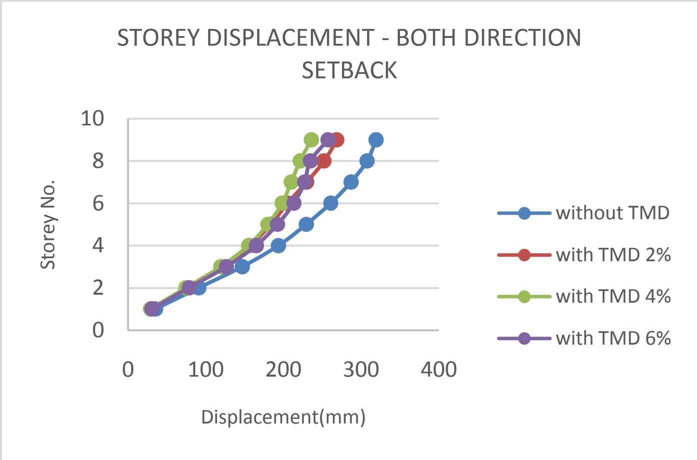

Figure 6: Storey displacement graph of both direction setback case

2.2 Drift

All the three cases of irregular buildings show decrease in drift with floating storey TMD. For the single setback building, mass ratio of 2% is effective. For the double setback building, 4% proves to be more effective and for the building with both direction setback, TMD of 4% mass ratio is better. The storey drift of the three cases are shown in Figure 7, 8 and 9.

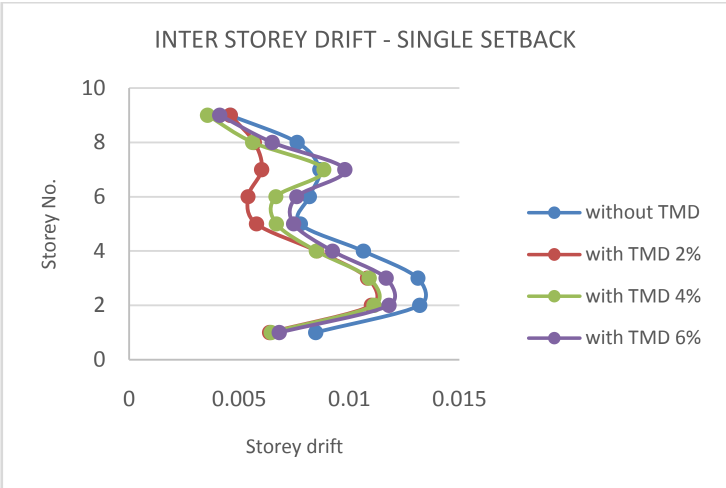

Figure 7:Storey drift graph of single setback case

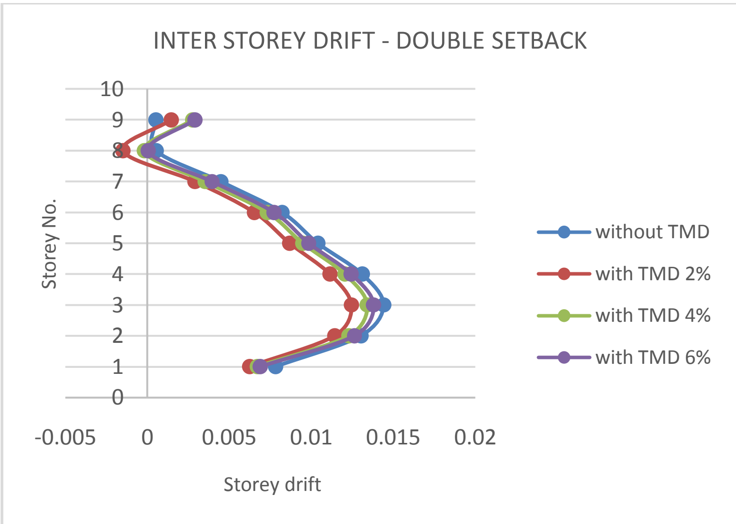

Figure 8: Storey drift graph of double setback case

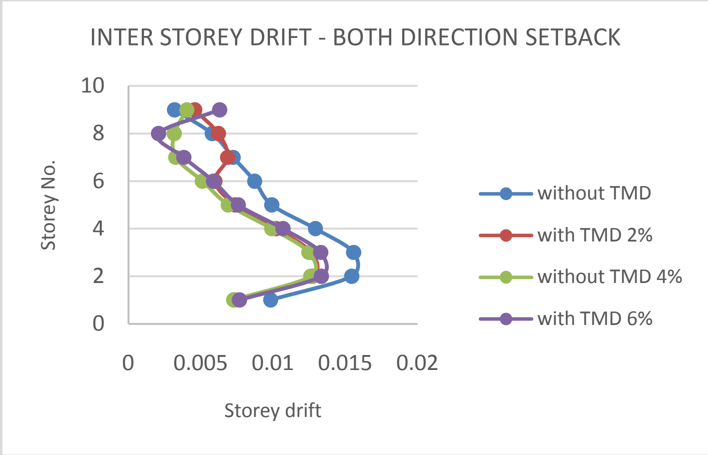

Figure 9:Storey drift graph of both direction setback case

2.3 Base shear

- Base shear in single setback irregular building without floating storey TMD is 15479.27kN. In this case, 2% TMD results in maximum decrease in base shear compared to other mass ratios. Base shear is reduced to 14703.92kN.
- Base shear in double setback irregular building without floating storey TMD is 11607.06kN. In this case, 2% TMD results in maximum decrease in base shear compared to other mass ratios. Base shear is reduced to 11098.26kN.
- Base shear in both direction setback irregular building without floating storey TMD is 13929.63kN. In this case, 2% TMD results in maximum decrease in base shear compared to other mass ratios. Base shear is reduced to 13152.45kN.

III. CONCLUSION

The efficiency of floating storey TMD in reducing the response of steel buildings to earthquake has been studied. Based on the analysis done on stiffness irregular buildings with 3 setback conditions without and with floating storey TMDs of various mass ratios, following conclusions can be made.

- In single setback case, TMD of 2% mass ratio proves to perform better with 22% reduction in top storey displacement,17% reduction in drift and 6% reduction in base shear.
- In double setback case, TMD of 4% mass ratio proves to be better with 7% reduction in top storey displacement, 15% reduction in drift and 4% reduction in base shear.
- In both direction setback case, TMD of 4% mass ratio proves to be better with 26% reduction in top storey displacement, 20% reduction in drift and 6% reduction in base shear.
- On comparing the 3 cases of stiffness irregular building, floating storey TMD shows better performance in the building with both direction setback with 26% reduction in displacement, 20% reduction in drift and 6% reduction in base shear.
- Altogether, 4% proves to be the effective mass ratio for TMD in the case of stiffness irregular building.

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