Dynamic Response of RC Building Using Metallic Dampers

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Abstract—The supplementary energy dissipation represents an efficient technique for the seismic protection of structural system. Metallic damper such as X – plate is among energy dissipating devices that have been using in the new generation of earthquake resisting building. In this paper, the performance of building with X – plate damper made of Steel and Aluminum are investigated to check effectiveness of damper material. For this purpose ground acceleration records, Loma Pieta is used as the disturbing ground motion for time history analysis and entire analysis is carried out by using SAP2000. The results shows comparison of X – plate damper with Steel and Aluminum and seismic responses of the building with and without XPD are also discussed and compared.

Keyword—X-Plate Dampers, energy dissipating devices, Time History

I. INTRODUCTION

Structures shows the inelastic non-linear behavior under severe cyclic loads associated with natural activities like earthquakes and winds, which imparts the external seismic energy to the them, consuming in the lateral movement of structures such movement may be responsible for the failure or collapse of these structures, in order to prevent such a collapse it is necessary to recognize the non-linear behavior of structure and adopt an suitable mechanism to control the response of them and this is possible by dissipating the input seismic energy which imparts on it. It is generally expedient and economical to retrofit the structures instead of constructing them a new. One of the popular seismic retrofitting measures is the installation of supplemental dampers. Several different types of dampers are available, such as, viscous, visco-elastic, friction, metallic yielding, etc. These devices act as energy sinks to dissipate the input seismic energy thereby reducing the seismic demand on the structural members. However, an indiscriminate spatial distribution of dissipation devices in the structure may not necessarily lead to a substantial reduction in the seismic response. The effectiveness of a damper in reducing the structural response depends on the extent of its participation in response of structure to the external excitation. Keeping in view the damper costs and its effectiveness in reducing the response of structure, it is necessary to optimize the damper location and their numbers to improve the seismic performance of the structure.

In this study, the performance of building with X – plate damper made of Steel and Aluminum are investigated to check effectiveness of damper and also focuses on the application of a genetic algorithm for identifying optimal locations of Metallic dampers that will provide the largest structural response reduction of a 7-story RC frame subjected to seismic loading. The distribution of the Metallic dampers within the buildings is optimized under the constraint that the number of dampers and their properties are known parameters. The search space of the optimization is the possible stories in which dampers can be placed. An integer optimization is therefore utilized within the genetic algorithm process. A linear combination of maximum inter-storey drift and maximum base shear of the structure with XPD normalized by their respective structure without XPD counterparts as an objective function is considered in the optimization process such that the optimal locations of damper are dependent on the dynamic characteristics of both the building and ground motions. Simulation results of the nonlinear building model subjected to earthquakes are presented.
which illustrate the effectiveness of each damper distribution strategy, also depending on the objective function used.

Hosseini (2005) examined the application of genetic algorithms for the optimal number of damper’s plate distribution in each story. Among those who have examined the application of genetic algorithms for damper location selection, Kokil and Shrikhande (2007) attempted to identify a suitable distribution of dampers for vibration control of a 10-story building with arbitrary degree of complexity in configuration has been proposed while Shukla and Datta (1999) determined Optimal locations of passive VEDs with the help of a controllability index, which is obtained with the help of the root-mean-square value of the interstory drift. Wu and Soong (1997) demonstrated optimal placement problem when applied to structures where both translational and torsional responses are of major concern.

II. X-PLATE METALLIC DAMPER (XPD)

An XPD is a device that is capable of sustaining many cycles of stable yielding deformation resulting in a high level of energy dissipation or damping, its energy dissipation depends primarily on relative displacement within the device and not on the relative velocities. It consist of an assembly that holds either single or multiple components of ‘X’ shape plates, the number of plate depends on the requisite of system to dissipates the external input seismic energy.

2.1 Mechanism of XPD in Structure

X-plate dampers consist of one or multiple X-shaped steel plates, each plate having a double curvature and arranged in parallel; this number of plate depends upon required amount of energy wants to be dissipates in the given system. Material used for manufacturing of X-plate may possibly be any metal which allow large deformation such as mild steel, although sometimes lead or more exotic metal alloy are employed. In order to reduce the response of structure by dissipating the input seismic energy such damper can be used with an appropriate supporting system, intrinsically in building structure combination of bracing and XPDs can be used and such a assembly known as device-brace assembly. When such system experiences the lateral forces like earthquake, high winds, etc., then input seismic energy dissipates through their flexural yielding deformation. They can sustain many cycles of stable yielding deformation, resulting in high level of energy dissipation or damping. The aim behind the use of X-shape of damper is it will have a constant strain variation over its height, thus ensuring that yielding occur simultaneously and uniformly over the full height of the damper. XPDs allow it to behave nonlinearly but restrict behavior of the structure up to the linear elastic range.

A series of experimental tests were conducted at Babha Atomic Research Center (BARC) and IIT Bombay to study the behavior of these XPDs by Parulekar et al. (2003). Bakre et al. (2006) also studied the behavior of XPDs and observed the subsequent results (i) it exhibits smoothly nonlinear hysteretic loops under plastic deformation; (ii) it can sustain a large number of yielding reversals; (iii) there is no significant stiffness or strength degradation and (iv) it can accurately modeled by Wen’s hysteretic model or as a bilinear elasto-plastic material. A typical XPD with holding device used in the present work as shown in figure 1.
Using beam theory the properties of XPD are expressed as,

\[ F_y = \frac{\sigma_y b t^2}{6a} n \]  \hspace{1cm} (1.1)

\[ q = \frac{2\sigma_y a^2}{Et} \]  \hspace{1cm} (1.2)

\[ K_d = \frac{F_y}{q} \]

\[ K_d = \frac{Ebt^3}{12a^3} n \]  \hspace{1cm} (1.3)

Where, \( K_d \) is the initial stiffness, \( F_y \) is the yield load and \( q \) is the yield displacement of the XPD. \( E \) is the elastic modulus and \( \sigma_y \) is yield stress of the damper material, respectively; \( a, b \) and \( t \) are height, width and thickness of the XPD as shown in figure 1.

The properties of the plastically deformed XPD are expressed as

\[ P = \frac{\sigma_y b}{12Ed} \left\{ \left( 4y_0^2 - 3t^2 \right) (H - E) + \frac{Ht^3}{y_0} \right\} \]  \hspace{1cm} (1.4)

Where, \( P \) is the plastic force in XPD due to given displacement \( d \); \( H \) is the rate of strain hardening and strain hardening and \( y_0 \) is the elastic depth given by

\[ y_0 = \frac{\sigma_y a^2}{Ed} \]  \hspace{1cm} (1.5)

It is to be noted here that using above equation, the properties of XPD, \( K_d, F_y, q \) and \( a \) could be obtained for a particular combination of \( a, b \) and \( t \) of an XPD. These properties are required in Wen’s hysteretic model.
III. ANALYSIS OF STEEL AND ALUMINIUM X-PLATE DAMPERS

This study comprehensively investigates the seismic response of 7 storey RC structures with X plate dampers. For the same damping mechanism the effects of two different damper materials were investigated. The first damping material is steel; the second damping material is Aluminium. For this purpose ground acceleration records, Loma Prieta October 17, 1989 is used as the disturbing ground motion. The acceleration time history and response spectrums of the model input earthquake are shown in Fig. 2.

![Fig. 2 Input earthquake acceleration time history and response spectrum](image)

3.1. Description of the Investigated Structures

The data assumed for the problem to be analysing in SAP 2000 are as follows:

<table>
<thead>
<tr>
<th>Table 1. Section Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns Designation</td>
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<td>C1</td>
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<tr>
<td>C2</td>
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<tr>
<td>C3</td>
</tr>
</tbody>
</table>

1. Building = (G + 7) storey
2. Slab thickness  = 150 mm
3. Live Load  = 3 kN/m², (no live load at roof)
4. Floor Finish = 1 kN/m²
5. Software Used = SAP 2000 v14.2.4
6. Method of Analysis = Nonlinear Time History Analysis
7. Earthquake used = Loma Prieta Earthquake - "OCTOBER 17, 1989,
Elevation

3 m

3 m

3 m

3 m

3 m

3 m

3 m

3 m

3 m
3.2 Properties of XPD:

Height of triangular portion (a) = 40mm
Breadth of triangular portion (b) = 60mm
Thickness of plate (t) = 4mm
Number of X- Plates Used (n) = 2, 4 and 6
3.3 Materials

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Al 6063-T6</th>
<th>Al 1100-O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of Elasticity (E) N/mm²</td>
<td>1.922E+05</td>
<td>69E+03</td>
<td>69E+03</td>
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<tr>
<td>Yield Stress (σy) in N/mm²</td>
<td>235</td>
<td>240</td>
<td>99</td>
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3.4. Result and Observation

3.4.1. Displacements and Inter-Storey Drift with Steel XPD

<table>
<thead>
<tr>
<th>FLOOR</th>
<th>DISPLACEMENT (mm) WITHOUT XPD</th>
<th>STORY DRIFT (mm) WITHOUT XPD</th>
<th>% REDUCTION USING XPD</th>
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<tbody>
<tr>
<td></td>
<td>WITH XPD</td>
<td>WITH XPD</td>
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</tr>
<tr>
<td>GF</td>
<td>29.287</td>
<td>26.279</td>
<td>12.54</td>
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<tr>
<td>1st</td>
<td>70.948</td>
<td>64.276</td>
<td>13.07</td>
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<tr>
<td>2nd</td>
<td>116.837</td>
<td>108.793</td>
<td>6.88</td>
</tr>
<tr>
<td>3rd</td>
<td>166.71</td>
<td>153.511</td>
<td>7.92</td>
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<tr>
<td>4th</td>
<td>210.863</td>
<td>191.092</td>
<td>14.88</td>
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<tr>
<td>5th</td>
<td>242.143</td>
<td>215.837</td>
<td>20.89</td>
</tr>
<tr>
<td>6th</td>
<td>257.364</td>
<td>226.974</td>
<td>26.83</td>
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<tr>
<td>6th</td>
<td>257.364</td>
<td>213.652</td>
<td>36.28</td>
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</tbody>
</table>

Table 2. Displacements and Inter-Storey Drift Comparison for (n=2, 4 and 6), Loma Prieta Earthquake.
Fig. 4 Displacements and Inter-Storey Drift Comparison for (n=2, 4 and 6), Loma Prieta Earthquake
3.4.2. Displacements and Inter-Storey Drift Comparison between Steel and Aluminium

![Graphs showing Displacements and Inter-Storey Drift Comparison](image)

**Fig. 5.** Displacements and Inter-Storey Drift Comparison for Steel, Al 6063-T6 and Al 1100-O (n=2, 4 and 6), Loma Prieta Earthquake
3.4.3. Axial Force, Shear Force and Bending Moment Comparison

Fig. 6. Axial force, shear force & bending moment Comparison for Steel, Al 6063-T6 and Al 1100-O

Hysteresis Loop of Steel XPD

Fig. 7. Hysteresis Loop of Steel XPD for n = 2, 4 and 6
Hysteresis Loop of Al 6063-T6 XPD

Fig. 8. Hysteresis Loop of Al 6063-T6 XPD for n = 2, 4 and 6

Hysteresis Loop of Al 1100-O XPD

Fig. 9. Hysteresis Loop of Al 1100-O XPD for n = 2, 4 and 6

With increasing number of X-plates, displacement and inter-story drift at various floors shows significant reduction. For X-plate up to 2 (n=2), the axial force in all columns at top storey is increasing as compare to building without XPD, but for number of X-plate more than 2, XPD shows its efficiency to reduce the axial force significantly. With XPD (n=6), shear force and bending moment of all columns can reduce up to (35-55)%. Reduction in axial force is very small as compared to reduction in shear force and bending moment in all columns at top storey. From hysteresis loops it can be observed that with increase in number of X-plate, dissipation of energy is also increasing.

The responses observed in all three different materials steel, Aluminium 6063-T6 and Al1100-O is of same nature but different magnitude with very less difference. If Aluminium XPD used with more numbers of plate it gives response nearer to steel XPD.

IV. CONCLUSION

With increasing number of X-plates, displacement and inter-story drift at various floors shows significant reduction. For X-plate up to 2 (n=2), the axial force in all columns at top storey is increasing as compare to building without XPD, but for number of X-plate more than 2, XPD shows its efficiency to reduce the axial force significantly. With XPD (n=6), shear force and bending
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REFERENCES


