Optimal Positioning of X Plate Damper in Concrete Frame Building

Arjun K Bose[1], Dr. C.K. Prasad Varma Thampan[2]

[1]PG Student, Department of Civil Engineering, NSS College of Engineering, Palakkad,
[2]Professor, Department of Civil Engineering, NSS College of Engineering, Palakkad.

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Abstract - *Earthquakes are the most dangerous natural disaster as they occur with no warnings. Earthquakes can impart large amount of energy to structures and can cause large deformations and vibrations resulting in their imminent failure. So there is a need for the earthquake energy to be dissipated from the structure. One of the most effective mechanism to dissipate energy in a vibrating system is by the inelastic strain of supplemental metallic elements with plastic deforming characteristics. An X- plate damper (XPD) is one such metallic device that can endure many cycles of stable yielding deformation resulting in a high level of energy dissipation or damping. In this paper the behavior of 3 bay 10 storey concrete framed buildings equipped with XPDs subjected to real time earthquake motions is simulated and optimal configuration of dampers at various storeys is investigated and a parametric study on XPDs is conducted on the optimal configuration. The most optimal damper placement locations are selected by conducting a sequential optimization procedure based on a controllability index. Nonlinear Time History analysis using structural analysis package SAP2000 is used for analyzing frames.*

Key Words: SAP, Modal time history analysis, Concrete frames, optimization, XPD, controllability index

1. INTRODUCTION

Earthquakes are the most dangerous and feared upon natural disaster as they occur with no warnings. Earthquakes can impart large amount of energy to structures and can cause large deformations and vibrations resulting in their imminent failure. So there is a need for the earthquake energy to be dissipated from the structure. To this day a large number of fatalities has occurred due to the collapse of manmade structures subjected to earthquakes. A huge amount of energy is imparted to the structure at a very short duration of time making earthquake design very complex. Conventional design philosophy is based on preventing collapse by allowing structural members to absorb and dissipate the absorbed earthquake energy by allowing structural members to absorb and dissipate the absorbed earthquake energy by inelastic cyclic deformations in specially detailed regions which means that building is allowed to deform and get damaged to an irreparable extent but total collapse may not occur. In the last couple of decades, special protective systems have been developed to increase safety and reduce damage to structures during earthquakes thereby eliminating fatalities to life and reducing damage cost. These unconventional methods aim to control the structural seismic response and energy dissipation demand on the structural members by modifying the dynamic properties of the system.

Most structures are subjected to vibrations arising from wind forces, earthquake excitation, machine vibrations, or many other sources. Sometimes, especially under strong earthquake excitations, these vibrations can cause structural damage or even structural collapse. Higher the inherent or natural damping in structures, lower will be the likelihood of damage. However, for structures subjected to strong vibrations, the inherent damping in the structure is not sufficient to mitigate the structural response. In earthquake prone regions, supplemental damping is required to control the response of these structures. About this subject, many researchers have studied, developed and tested different supplemental damping techniques. The basic supplemental damping systems used in structures are passive, active and semi-active systems.

2. X- PLATE DAMPER

X-plate damper (XPD) is a passive metallic damper which can endure many cycles of stable yielding deformations during cyclic loading. It consists of thin metallic plates which dissipates energy by flexural inelastic yielding. The 'X' shape assures a constant strain variation over its entire height and ensures simultaneous and uniform yielding. During cyclic loading the metal plates are subjected to hysteretic mechanism and the plasticization of these plates absorbs and dissipates a large fraction of vibration energy imparted to the structure. Also, the additional stiffness introduced by the metallic elements increase the lateral strength of the building, resulting in subsequent reduction in deformations and damage in the main structural members. The cyclic response of yielding metallic devices is strongly nonlinear supplemented by changes in element stiffness due to the loading, unloading and reloading of yielded elements. The introduction of these devices in a structure will render it to behave nonlinearly, even if the other structural elements are designed to remain linear. It was assumed that the structural elements and the braces that support these devices remain linear when they are subjected to the real earthquake ground motions. Fig-1 represents the sectional details of a XPD.

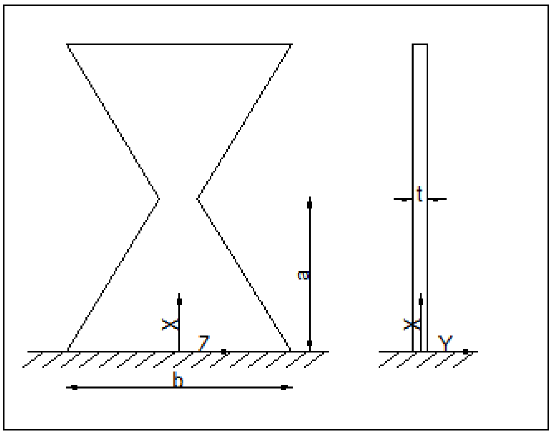


Fig -1: A typical XPD sectional details

Using beam theory, the properties of XPD are expressed as:

$$K_d = \frac{Ebt^3}{12a^3} n \qquad (1)$$

$$F_y = \frac{\sigma_y bt^2}{6a} n \qquad (2)$$

$$q = \frac{2\sigma_y a^2}{Et} \qquad (3)$$

where, K_d is the initial stiffness, F_y is the yield load and q is the yield displacement of the XPD. E and σ_y are elastic modulus and yield stress of the damper material, respectively; a, b and t are height, width and thickness of the XPD as shown in Fig-1.

3. MODELLING

The structure considered in the present study is a three bay ten storey concrete frame. The structure was modelled in SAP2000. Beams and columns were modelled as frame elements.

The XPDs were modelled as Plastic-Wen link elements. The Bouc-Wen model is a model that is often used to describe non-linear hysteretic systems. It was introduced by Bouc [1967] and extended by Wen [1989], who demonstrated its versatility by producing a variety of hysteretic patterns [21]. An especially attractive feature of the Bouc–Wen's model is that the same equation governs the behavior in the different stages of the inelastic cyclic response of the device. Moreover, since this model is in the form of a differential equation, it can be conveniently coupled with the equations that describe the motion of the building structure. The elevation of the frame is shown in Fig-2. The ground motion selected for analysis was Altadena(0.32g).

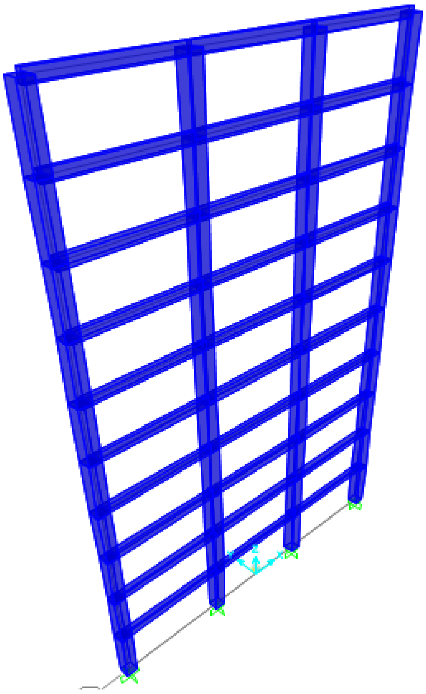


Fig-2: Elevation of concrete frame

Table-1: Size of concrete sections used

size (in mm)	beam	column
	230x500	600x600

3. OPTIMISATION OF LOCATIONS OF THE XPD

Based on the literatures reviewed a suitable method for optimisation was selected which is discussed in the below sections.

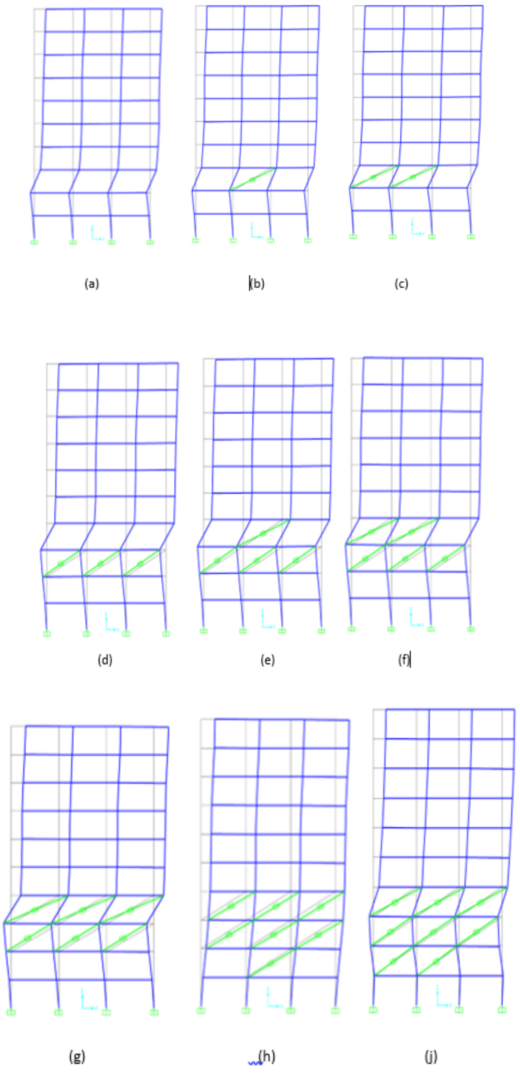
3.1. PROCEDURE FOR OPTIMISATION

Zhang [1992] was the first to propose a procedure for sequential optimisation of viscous dampers in a steel frame building based on a concept of controllability and verified it experimentally [27]. Pujari [2011] studied the optimum placement of steel XPDs on square shaped buildings subjected to earthquake motions using a sequential optimisation procedure. To seek the optimal location of dampers, a linear combination of maxi-mum inter-storey drift and maximum base shear of the damped structure normalized by their respective un-damped counterparts has been taken as the objective function. He also conducted a parametric study on effect of variations in geometrical properties of XPDs at optimal location

The optimization process in this study involves the search for the best location of XPD in the structure shown in Figure 2. The best position for the first damper is found from the uncontrolled response, which was found to be the floor with the maximum inter-story drift. After adding damper to that location, the procedure is repeated by taking into account the added stiffness and damping of the first damper in the original structure (i.e. modified structure) to determine the optimal location of the next damper. This procedure is repeated until the inter-storey drift can't be further reduced. Following these guidelines, a 2-D frame structure having ten storey-three bay configuration as shown in Fig-2 is chosen for the study.

3.2 SAMPLE PROBLEM

A sample problem using the same frame and optimization procedure mentioned in the above section is shown below. The XPD used here has a single plate, b =20mm, a=20mm and t=2mm. The figures 3 (a to k) shows the sequential optimization procedure. Ground motion used Altadena (0.33g).



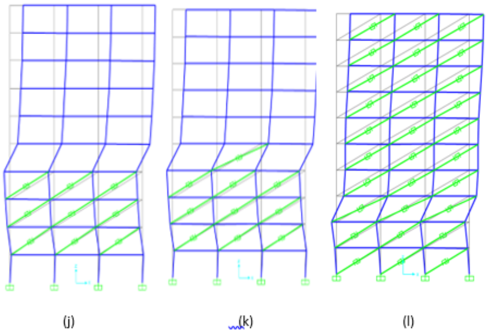


Fig-3: Sequential optimisation procedure

The maximum inter-storey drift of the bare frame without any dampers (Fig-3 (a)) was found to be 77.9mm. By performing a sequential optimisation the minimum inter storey drift was found to be 19.9mm (Fig-3 (h)) using 7 XPDs. By increasing the number of dampers no further reduction in inter storey drift was achieved.

4. NUMERICAL STUDY

A parametric study was conducted by varying the geometric dimensions of the XPD and the effect of varying dimensions was observed. The parameters varied were:

(a) Base width, b – 20mm, 40mm, 60mm, 80mm, 100mm

(b) Half height, h – 20mm, 40mm

(c) Thickness, t – 2mm, 3mm, 4mm

The effective stiffness and yield strength of the dampers studied are given below in tables 2 and 3 respectively.

Table-2: Effective Stiffness (kN/m)

b a	20	40	60	80	100
	For	t=2mm			
20	323.33	646.67	970.00	1293.33	1616.67
40	40.42	80.83	121.25	161.67	202.08
	For	t=3mm			
20	1091.25	2182.50	3273.75	4365.00	5456.25
40	136.41	272.81	409.22	545.63	682.03
	For	t=4mm			
20	2586.7	5173.3	7760	10346.6	12933.
40	323.33	646.67	970.00	1293.33	1616.67

Table-3: Yield strength (kN)

b a	20	40	60	80	100
	for	t=2mm			
20	0.16	0.31	0.47	0.63	0.78
40	0.08	0.16	0.24	0.31	0.39
	for	t=3mm			
20	0.35	0.71	1.06	1.41	1.76
40	0.18	0.35	0.53	0.70	0.88
	for	t=4mm			
20	0.63	1.25	1.88	2.50	3.13
40	0.31	0.63	0.94	1.25	1.56

5. RESULTS

The bare frame without any dampers was analysed using non-linear time history. The maximum inter-storey observed was 77.9mm. Then optimization was done using XPDs of varying dimensions and thicknesses. The results obtained by following the optimization procedure mentioned above are tabulated below.

Table-4: Results of Optimisation for plate thickness = 2mm

S.No.	A	b	Inter storey drift	No. of XPDs
1	20	20	19.9	7
2	40	20	20.4	7
3	20	40	18.7	7
4	40	40	19.1	7
5	20	60	15.1	9
6	40	60	19.2	7
7	20	80	19.1	7
8	40	80	14.6	9
9	20	100	15	9
10	40	100	18.1	7

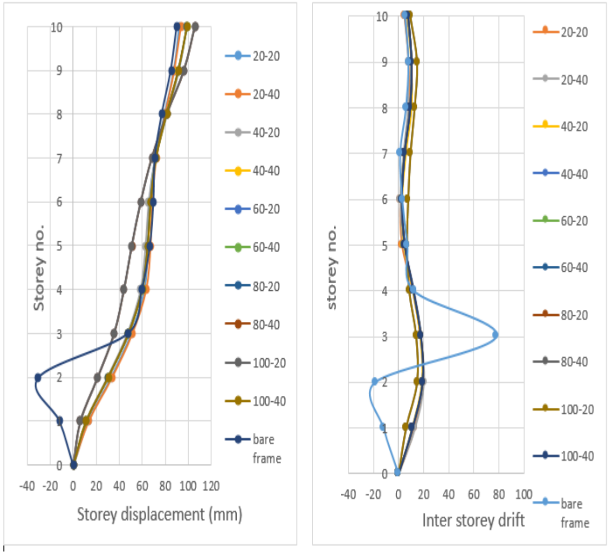
Table-5: Results of Optimisation for plate thickness =3mm

S.No.	A	b	Inter storey drift	No. of XPDs
1	20	20	15.2	7
2	40	20	12.1	9
3	20	40	15.2	7
4	40	40	12	9
5	20	60	13.5	9
6	40	60	19.1	7
7	20	80	11.9	12
8	40	80	17.2	7
9	20	100	11.9	9
10	40	100	18.2	7

Table-6: Results of Optimisation for plate thickness =4mm

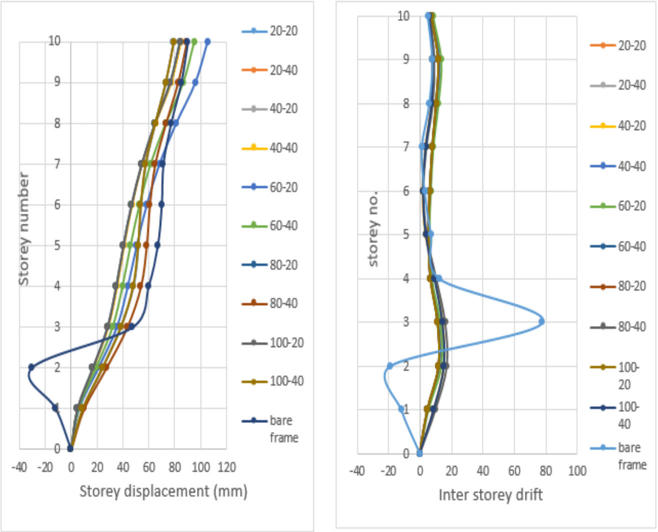
S.No.	A	b	Inter storey drift	No. of XPDs
1	20	20	11.3	9
2	40	20	14.3	12
3	20	40	11.2	12
4	40	40	11.8	9
5	20	60	11	9
6	40	60	11.4	9
7	20	80	10	9
8	40	80	11.1	12
9	20	100	9	9
10	40	100	9.5	12

Table 4, 5, 6 shows the optimum number of dampers which were required to minimize the maximum inter-storey drift in the structure. Any addition of extra dampers was proved to be ineffective in reducing the drift. Plot between inter-storey drift and storey levels are shown in charts 3, 4 and 5.



(a) (b)

Chart-1: (a) storey displacements (b) Inter-storey drift for t=2mm



(a) (b)

Chart-2: (a) storey displacements (b) Inter-storey drift for t=3mm

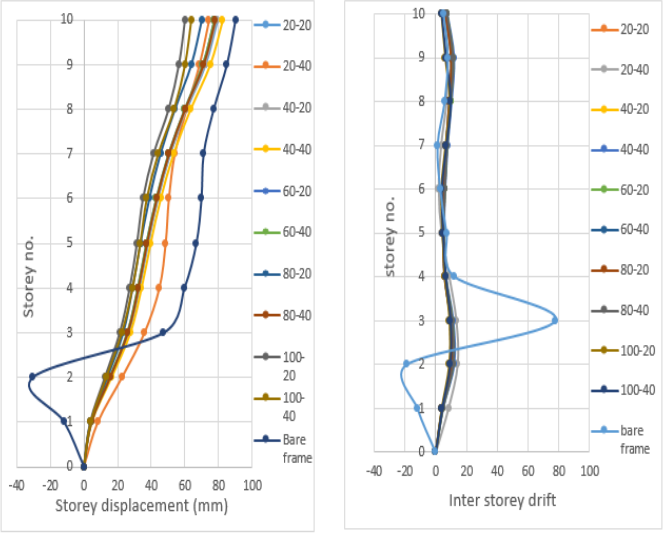


Chart-3: (a) storey displacements (b) Inter-storey drift for t=4mm

The most optimum configurations obtained for which the inter-storey drift obtained were less than 12mm, which is the limit for maximum inter-storey drift are shown in figure 3.

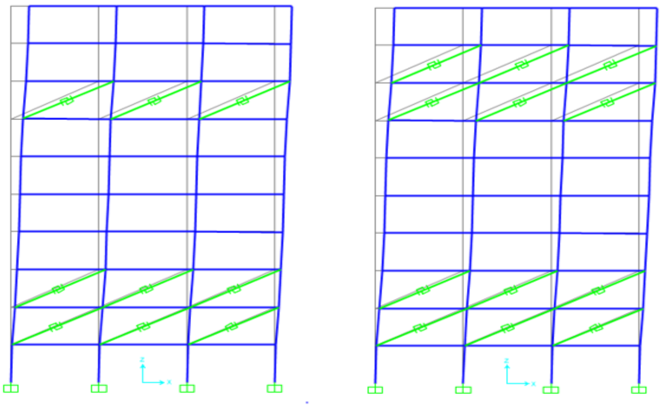


Fig-4: Optimal position for the XPDs obtained from analysis

From table 4 it can be noted that the XPDs with thickness 2mm were not able to reduce the maximum inter storey drifts to the Indian code prescribed level of 12mm (0.004 times the height of the storey). The least value of maximum inter-storey drift obtained by using least number of XPDs was 15mm (a=20mm, b=100mm). From table 5 it can be noted that the XPDs with thickness 3mm were able to reduce the maximum inter storey drifts to the Indian code prescribed level. The least values of maximum inter-storey drift obtained by using least number of XPDs were 11.9mm for dampers with different geometrical configuration (a=20mm, b=80mm and a=20mm, b=100mm). From table 6 it can be noted that the XPDs with thickness 4mm were able to reduce the maximum inter storey drifts to the Indian code prescribed level. The least values of maximum inter-storey drift obtained by using least number of XPDs were 9mm for dampers with different geometrical configuration (a=20mm, b=100mm). From the tables 4, 5 and 6 it can be noted that for the XPDs having same 't' and 'b', ones with lesser half height ('a') value are more effective in reducing storey drift compared to ones with larger 'a' value.

6. CONCLUSIONS

Based on the study of XPD, following conclusions are made:

i. Bouc-Wen's model can be adopted to represent amount of energy dissipated by XPD.
ii. XPD is effective in reducing the seismic response of building.
iii. Placing dampers on all the bays does not always ensure a minimum inter-storey drift.
iv. The energy dissipated in the building is dependent on the thickness of the XPD and input ground motion. As thickness increases the amount of energy dissipated by XPD increases.
v. The percentage of energy dissipated by the XPD in buildings is higher for XPDs having lower values

of 'a' (half the height of XPD) and higher value of 'b' (width of XPD).

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