Behaviour of the water tank staging with aluminum and steel X-plate damper.

G. Nirmala[1], *Atulkumar* Manchalwar[2]

[1]Associate Professor, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India
[2]M-Tech Scholar, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India

Abstract: - Many water tanks are pull-down during post-earthquake due to failure of water tank staging and this occurs because of the dynamic behaviour of the water tank staging that leads to collapse of water tank. These are important elements during post-earthquake that must be in service. In this study to reduce the damage of water tank staging by installation of additional dissipation devices known as dampers made up of X-plate steel and aluminum and these are effective in reduction of damage of structures, gives the additional damping and additional stiffness to the structure. For this study water tank staging's with different heights are modeled in SAP-2000 and performed nonlinear dynamic analysis under four real ground motions with and without damper. After the analysis the results obtained is, Displacement, shear force, amount of energy dissipation, maximum axial force and bending moment compared with and without damper and significantly reduced.

1. Introduction:

Earthquake is an unexpected tragic event that produces some energy in the form of waves due to this ground starts shaking. The structure existing on the ground behaves like a dynamic loading on the structure. If any inelastic behaviour of the structures gets damaged.

In general water is an essential for every human beings life. For that the storage of water tanks are constructing, that may be ground supported, underground and elevated water tanks. In this paper describing about elevated water tanks, these tanks plays an important role in municipality services. The tanks may be shaft supported and frame supported apart from this frame supported tanks are efficient in retrofitting purpose. Many water tanks are week against seismic forces but rapid growth of population the importance of water tanks increases day by day.

During post-earthquake elevated water tanks plays main role in water distribution purpose and should be in service. But many water tanks are pull down during earthquake for example Bhuj earthquake (2001), the forces from the earthquake to the structure is dynamic and the structure starts moves horizontally, behaves like nonlinear inelastic. This may be the reason for the damage of the structure. Reduction of seismic damage by retrofitting is tough task and requires expertise work man ship. It can be reduced by introducing effective technique that may be the dissipation of seismic energy. Dissipation of energy can be attained by introducing control device. Now days there is different types of dampers are available. In this paper displacement control dampers are used which controls the displacement, gives the additional stiffness to the structure and dissipates the seismic energy.

According many authors studied the effectiveness of dampers on water tanks. Studied the performance of double variable frequency pendulum isolators of four different combinations, different geometry and coefficient of friction on liquid storage slender and broad tanks. it`s concluded initial stiffness was more on top sliding surfaces compared to bottom sliding surfaces, Soni.et.al [1]. Seismic performance of the liquid storage steel tank isolated with variable friction pendulum system as compared with conventional friction pendulum investigated under trigonometric cycloidal pulses Panchal and Jangid [2]. The behaviour of the water tanks isolated with curved surface sliding bearings and it is affective in reduction of responsive quantity of base shear Abali and Uckan [3]. Water tank is designed according to Eurocode 8, performed response spectra analysis and observed the responsive quantities. Malhotra.et.al [4]. The performance of the water tank is isolated with fluid structure interaction by Housner; this isolation is effective in small capacity tank in reduction of responsive quantities Shenton.et.al [5]. Frame staging of frame members are decided is based on the ductility factor and response reduction factors Lakhade.et.al. [6]. Some of the authors worked on the various dampers, seismic response RC structure and effectiveness of the damper when equipped with X-plate damper and it is effective in reducing the responsive quantities. Manchalwar and Bakre [7]. The behaviour of the fluid viscous damper and steel yielding devices discussed by Terenzi.et.al [8]. To determine the seismic response of the structure five advanced placement methods were used Williams. Et.al [9}Study the behaviour of the two types of metallic dampers that is X-plate and accordion metallic dampers and discussed about optimal placement of damper by Manchalwar and Bakre [10]. Effectiveness of X-plate damper equipped in elevated water tank staging discussed by Nirmala.G.et.al [11]. In this paper damage states were determined by using Ang and park indices Kumar.R.et.al [12]. The behaviour of the structure when subjected to tuned metallic damper at top base of the storey and the damper is effective in minimize the seismic response of the structure Manchalwar and Bakre [13].

2. X-plate damper:-

XPD is used to resist the displacement of the inelastic behaviour of the select structure gives the additional stiffness to the structure and dissipates the input seismic energy of the structure. The configuration of the damper is X so it is called as X-plate damper, the size of the single X-plate damper is these are made up of steel and aluminum. The numerous authors investigated on the X-plate damper and observed the performance of the damper. Manchalwar and Bakre [7] worked on the two metallic dampers steel and aluminum and many numbers of tests were performed in BARK and IIT in Mumbai.

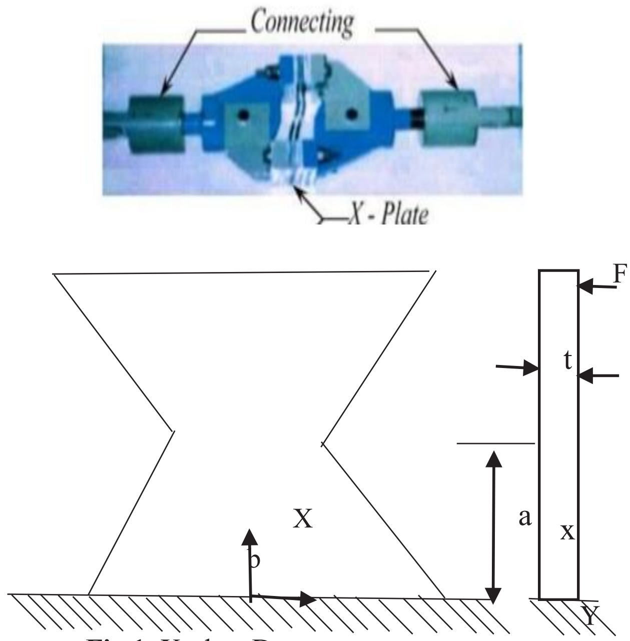

Fig.1. X-plate Damper

This is taken from Manchalwar et.al.(2019), Manchalwar and Bakre (2019).

XPD parameters:-

$$F_y = \frac{\sigma_y b t^2}{6a} n$$

$$q = \frac{2\sigma_y a^2}{Et}$$

$$K_d = \frac{F_y}{q}$$

$$K_d = \frac{Ebt^3}{12a^3} n$$

Where,

a is height of the damper, b is the width of the damper and t is the thickness of the damper,40, 60 and 4mm respectively. F_Y is the yield force and σ_y young's modulus and yield stress of the damper;

3. Problem statement:-

To determine the seismic response of the structure with steel and aluminum damper for this study 12 column 20m staging height and 24 column 24m staging height has been considered and modeled and time story analysis has been performed under four real ground motions in SAP-2000 as shown in table -1. The plan and elevation of the water tank staging as shown in Fig.2 &3. Taken from the Lakhade et.al

As per Indian standards the grade of the concrete and yield strength of the steel M20 and Fe500 has been considered respectively. The size of the frame members has been considered based on the elastic flexibility criteria as shown in table -2, dead load live load for design taken as per IS 875-1983 of part 1&2 respectively.

Table 1 Real earthquakes:-

Earthquake names	station	PGA (g)
Imperial valley 1940	EL Centro	0.35
Kern county 1952	Toft Lincoln tunnel	0.16
Loma prieta 1989	Oakland outer harbor	0.27
Northridge 1994	Symlar county hospital	0.604

Table 2 Sectional properties:-

Supporting structure	Tank capacity (ML)	Tank diameter (m)	Size of the column (mm×mm)	Size of the Bottom Beam (mm×mm)	Size of the Brace Beam (mm×mm)
12 column	0.6	11.38	400×400	350×700	300×550
24 column	1.7	18.35	400×400	300×550	400×700
36 column	2.6	22.77	400×400	400×650	300×500

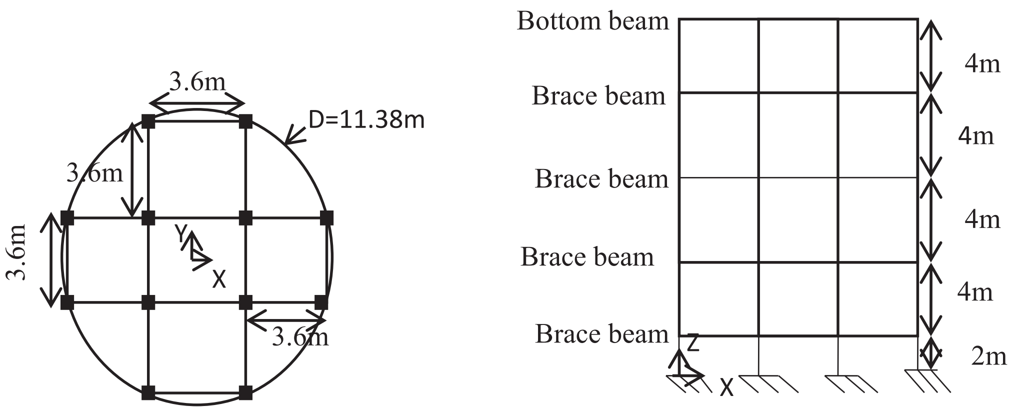

Fig.2. 12 column 20m staging height of water tank plan and elevation.

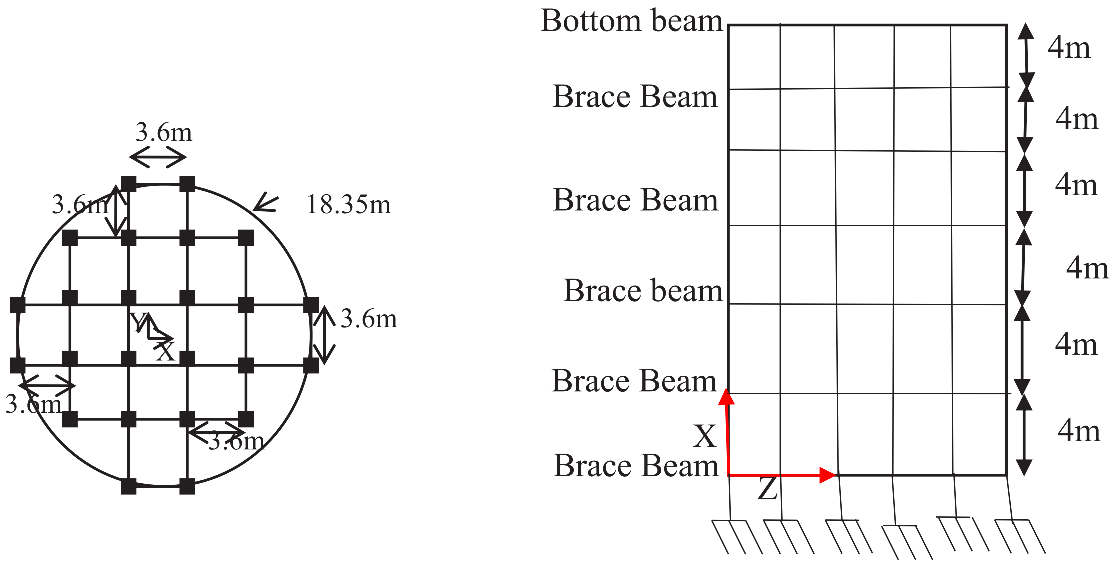

Fig.3. 24 column 24 meter staging height of water tank plan and elevation.

4. Behaviour of the structure:-

To examine the efficiency of the X-plate steel and aluminum damper for this study time history analysis has been performed under four real ground motions in Sap-2000 as shown in table-2. The yield strength and stiffness of steel damper 0.96kN and 960kN/m respectively, for aluminum damper yield strength and stiffness is 1.16437kN and 1164.37 kN/m respectively.

4.1 Shear, Axial and Bending moment comparison:-

From the experimental analysis the responsive quantities of shear, axial and bending moment of two elevated water tank staging as shown in table 3&4.From the results it is noted that axial force gradually increases and shear force and bending moment significantly reduces as compared without damper case.

Table 3 Axial, Shear force and bending moment comparison for 12c 20m:-

Column number	Time histories	Axial Force(kN)		Shear force(kN)		Bending moment (kN m)	
		Without damper	Al	Without damper	Al	Without damper	Al
38	Imperial valley	27.70	386.476	150.26	104.623	319.9083	261.056
	Kern county	11.987	152.57	54.154	40.808	107.173	84.00
	Loma prieta	33.919	335.55	157.665	90.536	337.67	209.9598
	North Ridge	107.27	1490.5	463.39	382.81	1236.604	910.6
50	Imperial valley	626.48	780.18	110.099	71.91	224.269	172.5
	Kern county	207.14	219.66	39.495	27.281	75.08	54.71
	Loma prieta	631.04	670.118	114.935	61.437	237.2912	138.442
	North Ridge	2239.74	2513.81	339.838	261.53	876.85	604.5421

Column number	Time histories	Axial Force(k N)		Shear force(kN)		Bending moment (kN m)	
		Without damper	Steel	Without damper	Steel	Without damper	Steel
38	Imperial valley	27.70	345.727	150.26	111.72	319.9083	272.496
	Kern county	11.987	129.52	54.154	40.34	107.173	84.4494
	Loma prieta	33.919	314.812	157.665	99.52	337.67	227.0203
	North Ridge	107.27	1277.58	463.39	391.38	1236.604	978.8099
50	Imperial valley	626.48	771.25	110.099	77.718	224.269	182.617
	Kern county	207.14	210.665	39.495	27.328	75.08	55.87
	Loma prieta	631.04	655.558	114.935	68.452	237.2912	151.5174
	North Ridge	2239.74	2478.387	339.838	270.25	876.85	657.2164

Table 4. Axial, Shear force and bending moment comparison for 24c 24m:-

Colum n number	Time histories	Axial Force(kN)		Shear force(N)		Bending moment (kN m)	
		Without damper	Al	Without damper	Al	Without damper	Al
16	Imperial valley	712.3	878.43	207.065	183.79	267.7239	291.25
	Kern county	375.43	458.45	123.82	84.606	171.32	119.93
	Loma prieta	1232.45	1375.4	320.14	291.554	422.975	401.8144
	North Ridge	3685.608	3854.43	891.465	914.105	1075.01	1180.15

128	Imperial valley	511.231	682.34	95.638	75.219	161.122	155.866
	Kern county	322.45	390,23	56.77	34.715	105.5045	63.6208
	Loma prieta	147.07	1203.3	147.07	121.332	259.2949	217.2951
	North Ridge	1844.307	2955.7	408.122	377.13	640.03	586.45

Column number	Time histories	Axial Force(kN)		Shear force(N)		Bending moment (kN m)	
		Without damper	Steel	Without damper	Steel	Without damper	Steel
16	Imperial valley	712.3	833.283	207.065	183.901	267.7239	284.836
	Kern county	375.43	413.89	123.82	88.221	171.32	122.59
	Loma prieta	1232.45	1341.42	320.14	296.699	422.975	405.496
	North Ridge	3685.608	3696.84	891.465	913.773	1075.01	1099.91
128	Imperial valley	511.231	564.23	95.638	76.719	161.122	156.523
	Kern county	322.45	354.35	56.77	36.904	105.5045	66.9368
	Loma prieta	147.07	1166.43	147.07	125.67	259.2949	225.185
	North Ridge	1844.307	2788.94	408.122	384.331	640.03	594.58

4.2 Displacement comparison:-

From the Fig.4 it is noted that 32-35% of the displacement gradually decreases Al-6063 as compared with no damper case. Fig.5 shows the steel damper 35-38% displacement decreases as compared to the without damper case for the 12 column 20m staging.

Fig.6 shows the 32-40% of displacement is decreases gradually for the 24 column 24m staging equipped with Al-6063 damper compared with no damper case, by steel damper it is decreases 35-38% displacement.

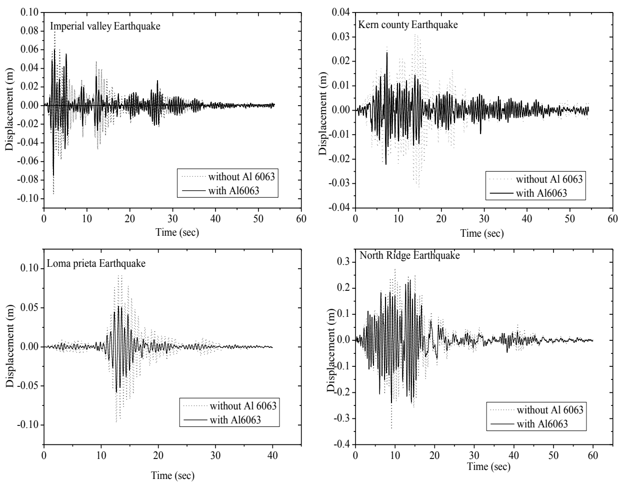

Fig.4. Top Displacement versus Time of Al-6063 Damper for 12 columns 20m

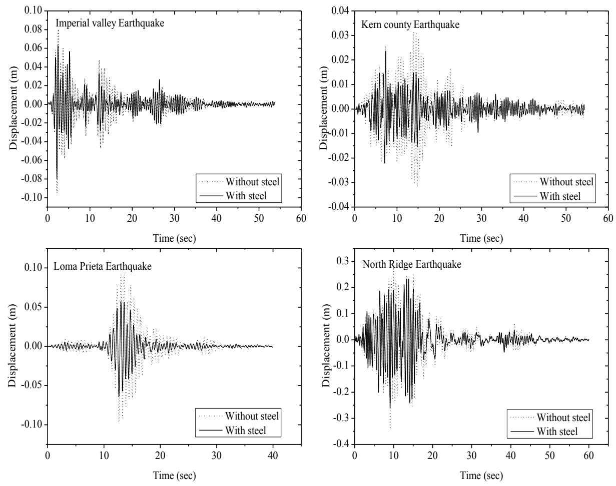

Fig.5. Top Displacement versus Time of Steel Damper for 12 columns 20 meters.

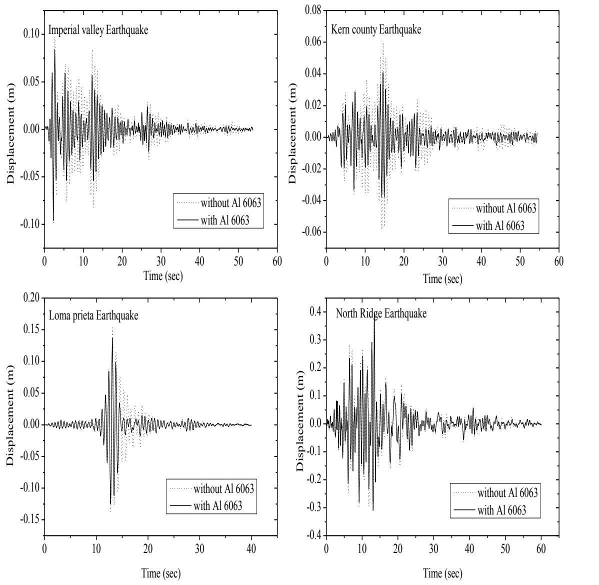

Fig.6. Top Displacement versus Time of Al-6063 Damper for 24 columns 24 meter

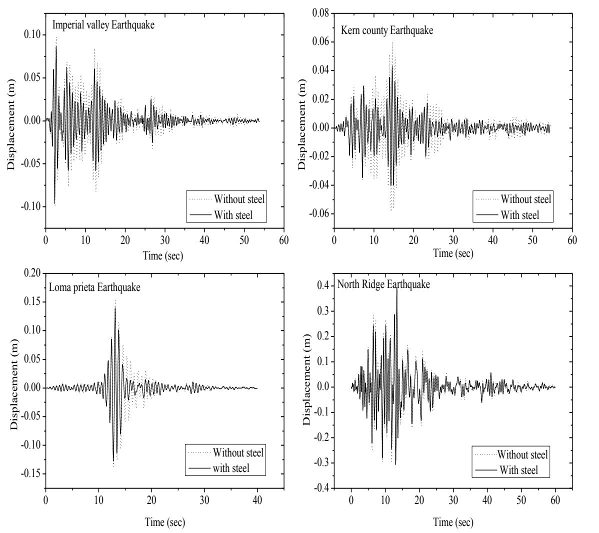

Fig.7. Top Displacement versus Time of steel Damper for 24 columns 24 meter

4.3 Hysteresis loop:-

To control the vibration of elevated water tank many devices are available to dissipate the seismic energy in early ages. X-plate damper is belonging to this category. Hysteresis loop is a Displacement Vs force relationship represents the energy disig.11sipation Fig.8 &.9 shows the dissipation of both Al-6063 and Steel damper have been same for the 12 column 20m staging.Fig.10 & Fig.11 represents the hysteresis loop of 24 column 24m staging of Al-6063 & steel damper respectively. Two dampers have same capacity significantly in dissipation of energy.

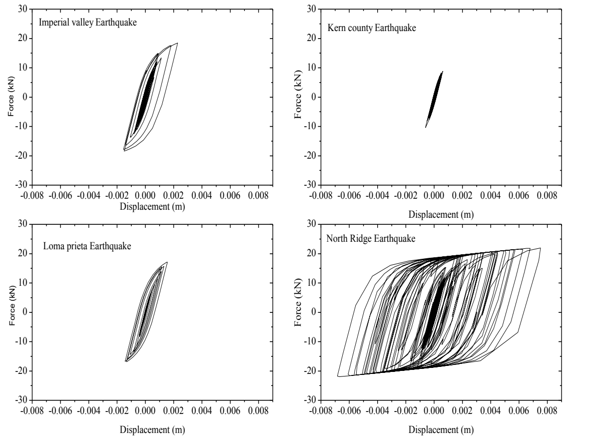

Fig.8. Hysteresis loop for 12c 20m Force versus Displacement of Al-6063

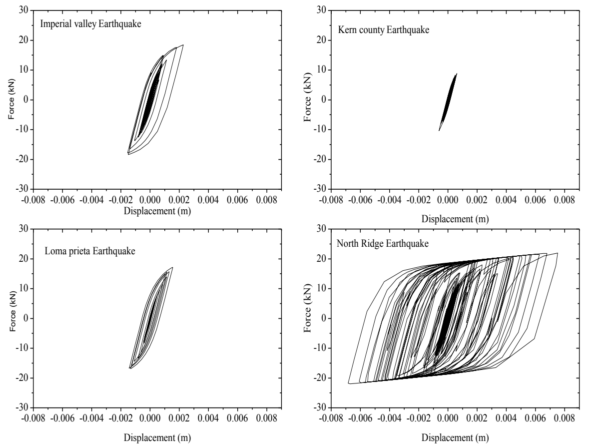

Fig.9. Hysteresis Loop for 24 column 24m Force versus Displacement of steel

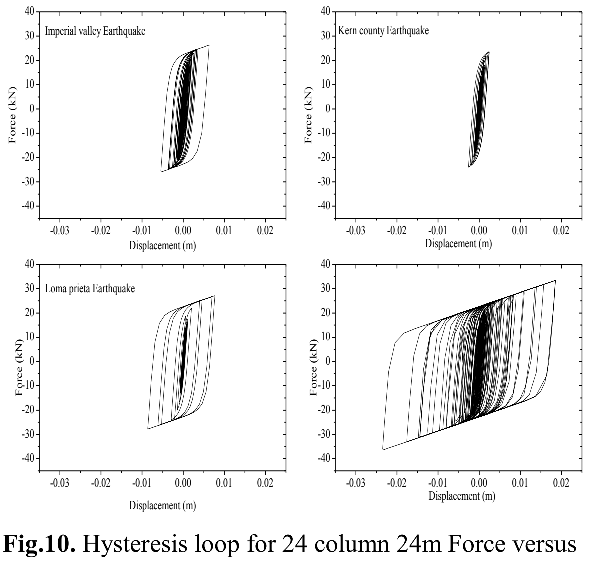

Fig.10. Hysteresis loop for 24 column 24m Force versus Displacement of Al-6063.

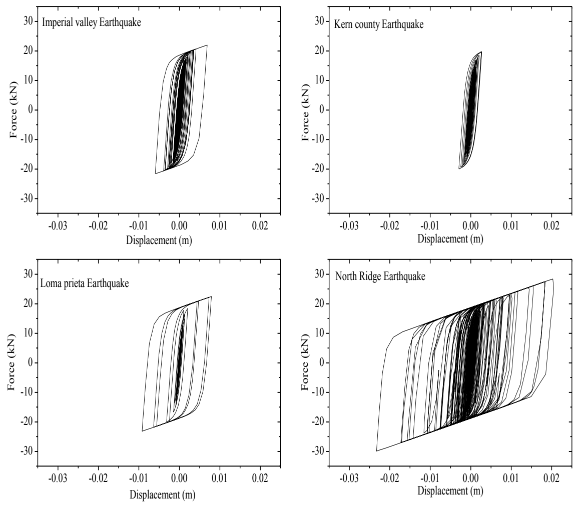

Fig.11. Hysteresis Loop for 24c 24m Force versus Displacement of steel damper

5. Conclusion:-

In this study seismic response of the structure is analysed by using steel and Al-6063 damper. For this study 12 column 20m staging and 24 column 20m staging is modeled and performed time history analysis under four time histories in SAP2000.The resultant quantities Displacement, Axial force, Shear force, bending moment and energy dissipation observed.

1. Dampers are effective in increase the axial force, decrease the shear force and bending moment significantly in models.
2. In 12 column 20m staging top story displacement is reduced by 30-35% in two dampers.
3. 30-40% top storey displacement reduction is observed in 24 column 24m staging in both Al-6063 and steel damper.
4. From the results dissipation of energy is same in Al-6063 and steel damper.

From the responsive parameters it is concluded that geometry of the structure and dampers decides their effectiveness.

References:-

1. D.P Soni, B.B. Mistry, V.R. Panchal, Double variable frequency pendulum isolator for seismic isolation of liquid storage tanks, *Nuclear Engineering and Design, hysteresis loop*, **Vol. 241**, pp. 700-713, (2011).
2. V.R Panchal, R.S.Jangid, Variable friction pendulum system for seismic isolation of liquid storage tank, *Nuclear Engineering and Design*, **Vol. 238**, pp.1304-1315, (2008).
3. E.Abali, E.Uckan, Parametric analysis of liquid storage tanks base isolated by curved surface sidings bearings, *Soil Dynamics and Earthquake Engineering,* **Vol. 30**, pp. 21-31,(2010)
4. P.K Malhotra, T.Wenk, M.Wieland, Simple procedure for Seismic Analysis of Liquid-storage Tanks. *Structural Engineering International*, **Vol.3**, pp.197-201, (2000).
5. Anchula Nagarjuna, T. Suresh Kumar, B.Yogeswara Reddy, M.Udaykiran, International Journal of Innovative Technology and Exploring Engineering, Vol. 8 no. 11, pp: 640-645, (2019).
6. O.Lakhade, Ratnesh Kumar, O.R. Jaiswal, Estimation of response reduction factor of RC frame staging in elevated water tanks using the nonlinear static procedure, *Structural Engineering and Mechanics*,**Vol.62,** pp. 209-224, (2017).
7. A.Manchalwar, S.V. Bakre, Performance of RC Structures Equipped with Steel and Aluminum X-plate Dampers, *J.Inst. Eng. India ser*, **Vol.97**, pp.415-425, (2016).
8. S.Sorace, G.Terenzi, C.Mori, Passive Energy dissipation-based retrofit strategies for R/C frame Water towers*, Engineering Structures,* **Vol. 106**, pp.385-398, (2016).
9. Naspuri Arun Raju, T. Suresh Kumar, International Journal of Innovative Technology and Exploring Engineering, Vol. 8 no. 11, pp: 3860-3864, (2019)
10. A.Manchalwar, S.V.Bakre, Optimization of Metallic Damper Location for Seismic Response Control. Journal of Vibration Engineering & Technologies, **Vol.7**, pp.261-275, (2019).
11. G. Nirmala, A.Manchalwar, S.Manchalwar, Vibration Control of water tank Staging Equipped X-plate Damper, *International Journal of Recent Technology and Engineering,* **Vol.8**, pp. 5551-5554, (2019).
12. O.Lakhade, Ratnesh Kumar, O.R. Jaiswal, Estimation of drift limits for different seismic damage states of RC frame staging in elevated water tanks using Park and Ang damage index. *Earthquake & Engg Vib*, **Vol.19**, pp.161-177, (2020)
13. A.Manchalwar, S.V. Bakre, Vibration control of structure by top base isolated storey as tuned damper. *International Journal of Dynamics and Control*, (2020).
14. IS 875 (Part 1)-1987. Code of practice for design loads (other than earthquake) for

https://doi.org/10.1051/e3sconf/202018401078

buildings and structures (second revision). BIS, New Delhi, India.

15. IS 875 (Part 2)-1987. Code of practice for design loads (other than earthquake) for buildings and structures (second revision). BIS, New Delhi, India.
16. IS 1893 (Part 2) (2014) Criteria for earthquake resistant design of Structures, Part 2 Liquid retaining tanks (second revision). BIS, New Delhi, India.