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Design of Metallic Dampers and Analysis Using MATLAB Program

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Abstract

Earthquakes are one of the major natural hazards to life on the earth and have affected countless areas on almost every continent. The damaged caused by earthquakes are mostly seen in man-made structures which are most of the time responsible for most of the causalities. Therefore, it is necessary that design of structures is done to resist earthquake forces, in order to reduce the loss of life. Passive control devices were developed earlier and have been used extensively in practice. Metallic dampers, one of the passive damping devices, dissipate seismic energy through in-elastic deformation of metals. It utilizes the yielding of metals as the dissipative mechanism. In the present study, characterization of ADAS (Added Damping Added Stiffness) type metallic damper is carried analytically and experimentally to understand cyclic behaviour. It is found that response of metallic damper is a function of its geometry and its mechanical characteristics of the metal. The primary factors affecting ADAS element behaviour are device's elastic stiffness, yield strength and yield displacement. Attempt has been made to develop design procedure for ADAS type metallic damper in Indian Scenario. Designed damper behaviour is analysed by programming tool MATLAB obtaining solution of equation of motion for different time history data.

Keywords: Metallic Damper, ADAS, Damper, MATLAB

1. Introduction

Earthquakes, one of the major natural hazards to life and have affected several regions of almost every continent. The damaged caused by earthquakes are mostly seen in man-made structures which are most of the time responsible for most of the causalities. Hundreds of small earthquakes occur around the world every day. Some of them are so minor that humans can't feel them, but seismographs and other sensitive machines can record them. Every year, earthquakes take the lives of thousands of people, and destroy property worth billions. Therefore, it is necessary that structures are designed to resist earthquake forces, in order to reduce the loss of life. Earthquake engineering has gain lots of attention and structural design is done especially considering earthquake precautions since past years, one can design safe structures which can safely withstand earthquakes of reasonable magnitude. Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements and to some structural members in the building. This may cause the building to be non-functional after the earthquake, which should not happen for some structures, like hospitals, fire stations, which need to remain functional after an earthquake.

Passive control devices were developed the earliest and have been used more commonly in practice for seismic design because they require minimum maintenance and need no external power supply to operate. Tracing the roots of the concept of structural control it goes back more than 100 years to John Milne, a professor of engineering in Japan, who built a small house of wood and placed it on ball bearings to demonstrate that a structure could be isolated from earthquake shaking. Energy dissipating systems (EDS) are mainly of 2 types: (i) Hysteretic (ii) Viscoelastic. Hysteretic dissipators shows the yielding of metals or sliding. Viscoelastic system includes viscoelastic solids, viscoelastic fluids. Main benefits of EDSs are low cost, easy inspection and ease of replacement after earthquake. Hysteretic dissipators include fiction dampers and

Metallic dampers. Friction dampers dissipates the energy by sliding force generated by friction between two surfaces. In metallic dampers seismic energy is dissipated through in-elastic deformation of metals. Metallic dampers utilize the yielding of metals as the dissipative mechanism.

The major advantages of metallic dampers are: no complex technology is required in manufacturing process, they can easily be installed in structures, no environmental (temperature, humidity, etc.) factors affect their performance and they show stable behaviour in earthquakes. Metallic dampers can be made of mild steel or other metals to dissipate

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the input energy which can sustain no. of cycles of hysteretic yielding behaviour. A wide variety of different types of devices have been developed that utilizes flexural, shear or longitudinal deformation modes into the plastic range. Inelastic deformation of metals is a one of the effective mechanisms for the dissipation of input energy from a structure of an earthquake. These dampers will increase damping and stiffness of structures and increase its energy dissipation capacity. Addition of metallic dampers in the structures causes concentric energy dissipation in the structure. These metallic dampers can easily be replaced or installed for strengthening of structure after an earthquake for future earthquakes. Using steel plates as distorting element and dissipating energy was firstly introduced in nuclear installation. A number of devices have been given in the literatures. The 1st idea of utilizing added metallic energy dissipators within a structure to absorb a large portion of the seismic energy given by the work of J. M. Kelly in 1972 [1], in which they tested X-shaped energy dissipaters in a 3-storey building on the earthquake simulator at the University of California at Berkeley. Whittaker et al. 1989[2], conducted a more elaborated test for this kind of dampers at University of California at Berkeley. Xia et al. 1992 [3], studied various characteristics of X-shaped (ADAS) dampers by numerical simulations. Tsai et al. 1993[4], have conducted some numerical and laboratory tests on TADAS dampers. Considering the promising outcomes in using these dampers, the Bechtel's Added Damping and Stiffness (ADAS) [5] and Triangular-plate Added Damping And Stiffness (TADAS) [6] dampers have been found extremely acceptable for the retrofitting of existing structures as well as in the construction of new structures. ADAS elements consist of multiple X-shaped mild steel plates, configured in parallel between top and bottom boundary element which is design in a building such that the storey drift causes top of the device to move horizontally relative to the bottom. ADAS device can be easily replaced after earthquake.

The response of metallic damper is a function of its geometry and its mechanical characteristics of the metal from it is manufactured. The primary factors affecting ADAS element behaviour is; device elastic stiffness, yield strength and yield displacement. For effective inclusion of these metallic damper devices in the design of an actual structure, one must be able to characterize their expected hysteretic behaviour under arbitrary cyclic loading. Usually, metallic devices dissipate energy through a mechanism that is independent of the rate of load frequency, number of load cycles or variation in temperature. In addition, hysteresis devices have high resistance to fatigue. Metallic dampers utilize the yielding of metals as the dissipative mechanism. The steel-plate added damping and stiffness (ADAS) device is a mechanism of steel plates to designed for installation in a building frame such that the relative story drift causes the top of the device to move horizontally relative to the bottom, due to yielding of steel plates, the ADAS device can dissipate energy during an earthquake. Figure 1 show the combination of a yielding metallic element and the bracing members that support the device is called as the device-brace assembly.

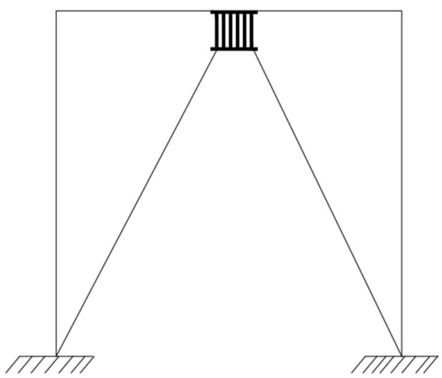

Fig. 1 Device Brace Assembly

2. General Design of Dampers

Like many other structural design procedures, it is in general and iterative process. First, an analysis of the structure without added dampers should be carried out. For new buildings, this may be for some code-reduced lateral forces and desired displacement limits and for existing structure it will be more of an improvement of actual condition of structure to desired or required safe limits or conditions without increments in forces in original structural elements. Hence required damping ratio and required drift reduction and energy dissipation becomes primary requirement and design parameter for addition of damper to the any structure. Firstly, design earthquake force as per earthquake zone from codal provision is calculated and analysis is done for the same structure under the effect of forces. From analysis result required damping ratio is calculated and from that damper design is done further. General design steps or flow for any type of dampers are as shown in fig 2. below.[1]

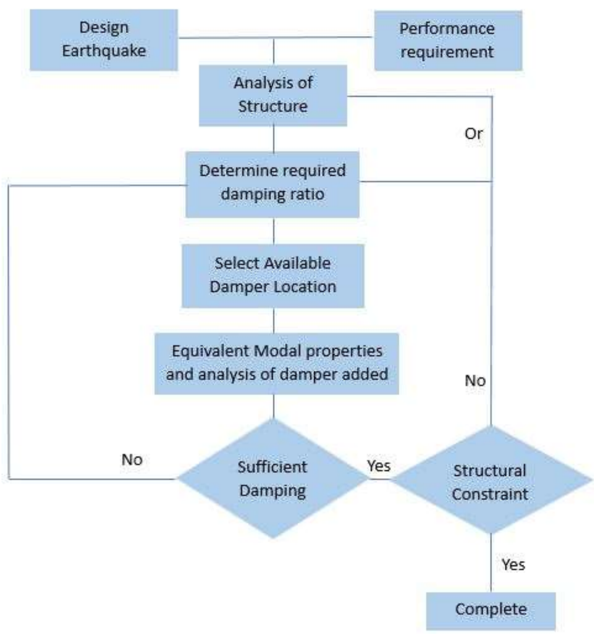

Fig. 2 Flow Chart For design of Dampers

2.1 Design Equations for ADAS Metallic Dampers

Parameters such as yield load, yield displacement and stiffness are calculated from derived equation for different types of dampers like X-Plate Metallic Dampers and Triangulated Plate Added Damping Added Stiffness Metallic Dampers (TADAS). For every shape of damper Equations or relations of properties remains same just multiplying numerical values or factors changes. Equations for those parameters as per type of dampers are as follows.

2.1.1 TADAS Damper

Basic mechanical characteristics of TADAS Device are stiffness (K_d), yield load (P_{yd}), yield displacement (Δ_{yd}), Plastic Load (P_p) and Yield rotational angle (γ_p). The equation of this properties are as follows:

$$K_d = \frac{N \times E \times B_d \times t^3}{6 \times {H_d}^3} \tag{1}$$

$$P_{yd} = \frac{f_y \times N \times B_d \times t^2}{6 \times H_d} \tag{2}$$

$$\Delta_{yd} = \frac{f_y \times {H_d}^2}{E \times t} \tag{3}$$

2.1.2 X-Plate ADAS Damper

For X-Plate Metallic Damper equations are as follows:

$$K_d = \frac{2 \times N \times E \times B_d \times t^3}{3 \times {H_d}^2 \times L} \tag{4}$$

$$P_{yd} = \frac{f_y \times N \times B_d \times t^2}{3 \times H_d} \tag{5}$$

$$\Delta_{yd} = \frac{f_y \times {H_d}^2}{2 \times E \times t} \tag{6}$$

Where,
B_d = Width of Damper
H_d = Height of Damper
N = No. of plates in damper
t = Thickness of each plate respectively.

From this equation we can fix dimensions of the damper like Height, Width, and No. of Plates [7].

2.2 Design Steps for ADAS Damper

General design steps for designing ADAS metallic dampers are as follows [7]:

1. Material is chosen for the ADAS damper.
2. Yield stress, young's modulus and poison's ratio is obtained.
3. The dimensions of ADAS damper is obtained from yield load and yield displacement.
4. Thickness of the plate is assumed. H/B ratio is generally assumed as 2 or less than 2.
5. No. of plates required for the ADAS damper is calculated considering the required yield force.

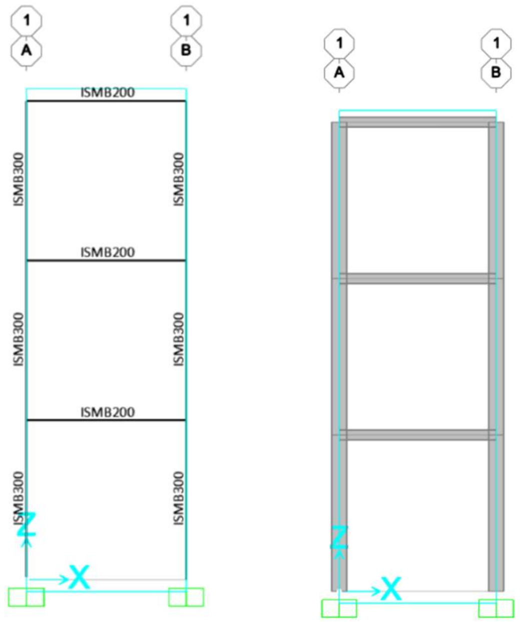

Fig. 3 Considered MDOF system

General parameters for ADAS type of metallic dampers are: 1. Stiffness Ratio 2. B/D Ratio. 3. Ratio of Restoring Forces. All this Parameters are assumed in between 1.5 to 2 generally. Stiffness ratio (SR) is ratio of Stiffness of structure (K_s) and combined stiffness of Bracing and Damper. B/D ratio is ratio of stiffness of damper and bracing.

$$P_{yd} = SR \times K_s[1 + \frac{1}{\frac{B}{D}}] \times \Delta_{yd} \tag{7}$$

3. Damper Design for MDOF System

Here for MDOF system 3 storey portal frames is considered and sections used are as beam section of ISMB200 and column sections of ISMB300. Hinge locations and type are also same for each storey at beam column junction. Below figure shows the SAP2000 model of this considered MDOF frame.
Pushover analysis has been performed to get the yielding properties of the structure. From pushover results yield displacement of this frame is 0.0195 m.

Table 3.1 Design of Metallic Damper

Inputs		
Yield Displacement of Structure	0.0195	
Ratio of restoring Force of storeys	2	
Yeild Displacement of Bracing	0.005	
Yield Displacement	0.003	m
Stiffness Ratio (SR)	1.5	
B/D Ratio	2	
Stiffness of Storey	15295288	N/m
Modules of Elasticity	200000	N/mm2
Thickness Of Plate (t)	20	mm

Yield Strength	250	N/mm2
H_d/B_d Ratio	2	
Process		
Height of Damper (H_d)	288.7	mm
Width of Damper (B_d)	144.3	mm
Stiffness of Damper	34414400	N/m
No. of Plates Required	5.38	
Yield Force	89686.01	N

Now Calculating Design properties of the damper as per height and width values considered from the required values.

Table 3.2 Design of Metallic Damper

Input		
Stiffness Ratio (SR)	1.5	
B/D Ratio	2	
Stiffness of Structure	15295288.89	N/m
Modules of Elasticity	200000	N/mm2
Thickness of Plate (t)	20	mm
Yield Strength	250	N/mm2
H_d/B_d Ratio	2	
Height of Damper	300	mm
Width of Damper	150	mm
No. of Plates	6	
Output		
Stiffness of Damper	35555555.56	N/m
Yield Force	100000	N
Yield Displacement	0.0028125	m
Stiffness of Bracing	71111111.11	N/m

Now as per designed values total weight of the damper is also calculated as shown in below Table.

Table 3.3 Design of Metallic Damper

Inputs		
Density of Material	7850	kg/m3
Height of Damper	300	mm
Width of Damper	150	mm
Thickness of Flange	20	mm
Width of flange	200	mm
Thickness of Plates	20	mm
Spacing of Plates	40	mm
Edge Distance of plates	40	mm
No. of Plates	6	
Outputs		
Length of the Damper	400	mm
Weight of the Damper	67.51	kg

Design drawings of this damper as shown in the below figures.

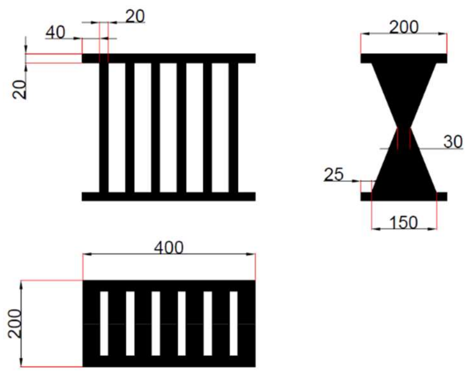

Fig. 4 Design Drawing of ADAS Damper

4. Analysis and results

Now when additional damping is introduced in system some additional damping quantity is added in equation of motion and it can be written as [8]:

$$m\ddot{u}(t) + (c + c_{eq})\dot{u}(t) + (k_s)u(t) = -ml\ddot{u_g}(t) \quad (8)$$

where, c_{eq} is additional equivalent viscous damping added in system. Whatever type of damping is added in system, for simplicity in analysis equivalent viscous damping is found out of applied damping value with an experiment or some of the methods like energy method etc.

Now for this study of Metallic dampers, an additional stiffness quantity is added in system due to additional stiffness of damper as well as bracings used for placement of dampers. These quantities are required to be added in equation of motion for getting accurate results actual mathematical equation representing actual scenario of the system. For metallic damping problem simple equation of motion is modified as [8]:

$$m\ddot{u}(t) + (c + c_{eq})\dot{u}(t) + (k_s + Bk_a)u(t) = -ml\ddot{u_g}(t) \quad (9)$$

Where,

m, ks, and c are the mass, stiffness and damping matrices of the building respectively.

u = The vector of the relative displacements of the floors of the building.

l = Influence vector.

K_a = Brace-Damper Combined Stiffness

$\ddot{u_g}$ = The earthquake acceleration excitation.

B = The matrix derived based on placement of passive devices in the building.

c_{eq} = Matrix determine by the equivalent viscous damping contribution

4.1 Method of solving this equation

The Newmark Beta integration method is also based on the two parameters β and γ. These parameters can be changed to suit the requirements of a particular problem. The parameter β and γ indicate how much the acceleration enters into the velocity and displacement equations at the end of time interval. Therefore, β and γ are chosen to obtain the desired integration accuracy and stability. When $\beta = 1=6$ and $\gamma = 1=2$, it corresponds to the linear acceleration method [8]. When $\gamma = 1=2$ and $\beta = 0$, The acceleration is constant from beginning and then changes to the value at $t + \Delta t$ in the middle of the time interval. $\beta = 1=4$ and $\gamma = 1=2$ corresponds to the assumption that the acceleration remains constant at an average value. One of the features of this method is that for linear systems the amplitude is conserved and the response is unconditionally stable, provided that $\gamma \geq 1=2$ and $\beta \geq 1=4(\beta + 1=2)^2$. If $\gamma \geq 1=2$, there is a pseudo damping introduced, proportional to $(\gamma - 1=2)$. If $\gamma = 0$, a negative damping occurs and it involves a self-excited vibration arising solely from the numerical procedure [9].

4.2 Data Considered for analysis

Table 4.1 Data Considered for analysis

Name	Magnitude	Duration (s)	Interval (s)
El Centro	6.9	53.73	0.005
Bhuj	7.6	133.53	0.005
Chile	8.2	281.99	0.01
Kobe	6.9	47.98	0.02
New Zealand	7.8	163.78	0.02
Uttarkashi	7.0	39.9	0.02
Landers	7.3	49.28	0.004

4.3 Results of Analysis

Mass of System, Stiffness of System, Damping in System, Time duration of Time History and Time interval of readings are used as input to MATLAB program. Mass of metallic damper was calculated from its dimension's height, width and length. Length of this damper is calculated from assuming spacing of plates as 50 mm [7] and end edge distance was considered as 50 mm. Outputs of this system with dampers is shown in form of a displacement plots as comparison with original displacement plots of MDOF Portal frame. From the fig.5 it can be seen that for El Centro Earthquake peak displacement of MDOF System without ADAS Metallic Damper = 10.2 mm and peak displacement of MDOF System with Metallic Damper = 5.09 mm.

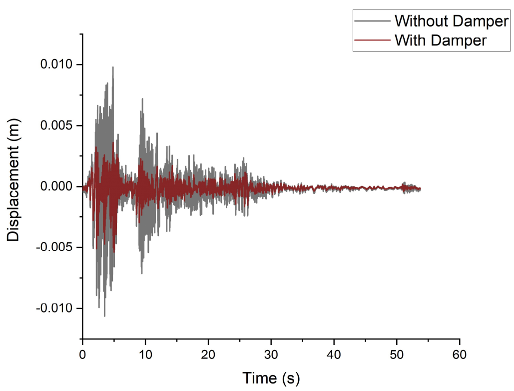

Fig 5. Displacement Plots of MATLAB outputs of El Centro Earthquake with and without damper MDOF system

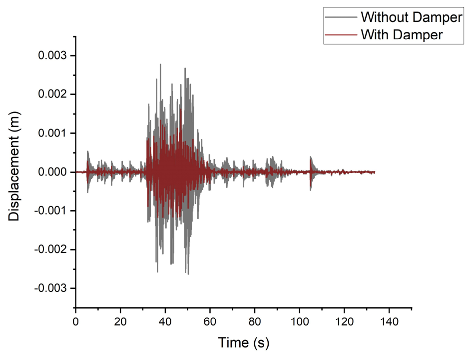

Fig.6 Displacement Plots of MATLAB outputs of Bhuj Earthquake with and without damper MDOF system

From the fig.6 it can be seen that for Bhuj earthquake peak displacement of MDOF System without ADAS Metallic Damper = 2.9 mm and peak displacement of MDOF System with Metallic Damper = 1.8 mm

From the fig.7 it can be seen that for Chile earthquake peak displacement of MDOF System without ADAS Metallic Damper = 9.5 mm and peak displacement of MDOF System with Metallic Damper = 5 mm.

From the fig.8 it can be seen that for Kobe earthquake peak displacement of MDOF System without ADAS Metallic Damper = 12.1 mm peak displacement of MDOF System with Metallic Damper = 8 mm

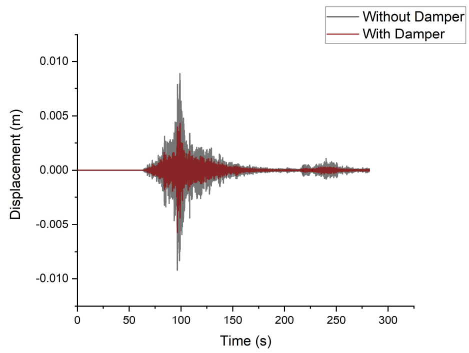

Fig.7 Displacement Plots of MATLAB outputs of Chile Earthquake with and without damper MDOF system

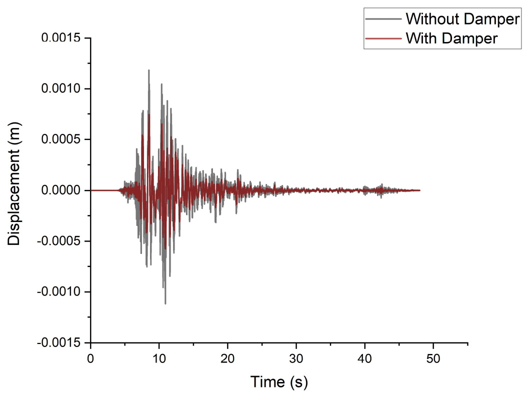

Fig.8 Displacement Plots of MATLAB outputs of Kobe Earthquake with and without damper MDOF system

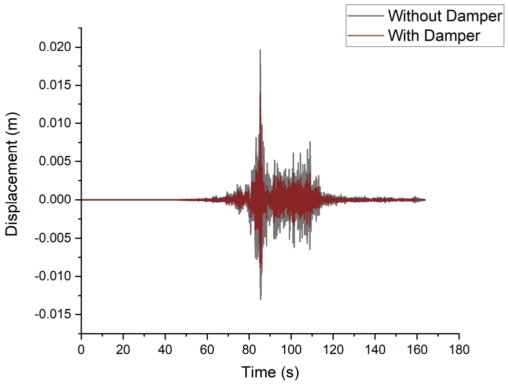

Fig.9 Displacement Plots of MATLAB outputs of New Zealand Earthquake with and without damper MDOF system

From the fig.9 it can be seen that for New Zealand earthquake peak displacement of MDOF System without ADAS Metallic Damper = 21 mm and peak displacement of MDOF System with Metallic Damper = 15 mm

From the fig.10 it can be seen that for Uttarkashi earthquake peak displacement of MDOF System without ADAS Metallic Damper = 7 mm and peak displacement of MDOF System with Metallic Damper = 3.2 mm

From the fig.11 it can be seen that for Landers earthquake peak displacement of MDOF System without ADAS Metallic Damper = 44 mm peak displacement of MDOF System with Metallic Damper = 22 mm

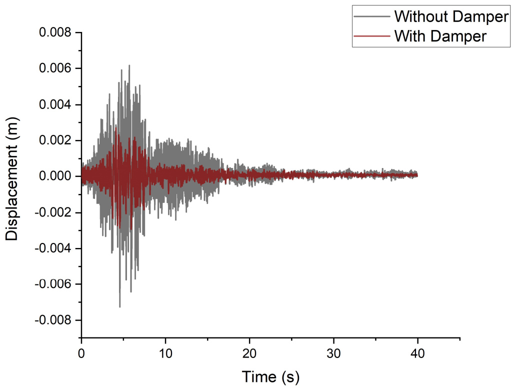

Fig.10 Displacement Plots of MATLAB outputs of Uttarkashi Earthquake with and without damper MDOF system

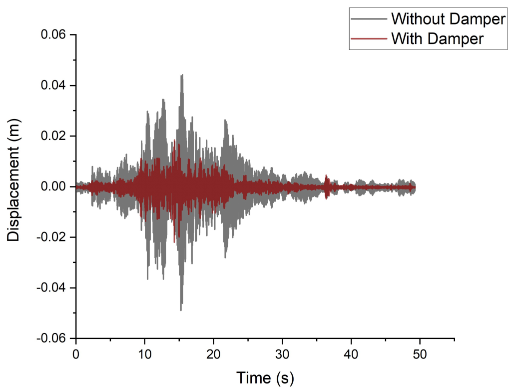

Fig.11 Displacement Plots of MATLAB outputs of Landers Earthquake with and without damper MDOF system

5. Conclusions

It has been observed that by implementation of X-plate ADAS Metallic Damper into system response reduces notably by average of 40 to 45%.

It can be justified that this reduction is occurring due to added damping property and addition to the overall stiffness of the structure due to implementation of the X-Plate ADAS Metallic Damper to the system.

Further analysis can be done to observe the responses of system by changing material properties and shapes of damper element.

Disclosures

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6. References

[1] R. Hanson and T. Soong, Seismic Design with Supplemental Energy Dissipation Devices, Earthquake Engineering Research Institute, 2001.

[2] I. D. Aiken, D. K. Nims, A. S. Whittaker, and J. M. Kelly, Testing of Passive Energy Dissipation Systems Ian D. Aiken, Douglas K. Nims, Andrew S. Whittaker, and James M. Kelly, vol. 9, no. 3, 1993.

[3] A. Whittaker, Earthquake Simulator Testing of Steel Plate Added Damping and Stiffness Elements, 1989.

[4] C. Xia & R. D. Hanson, Influence of adas element parameters on building seismic response., Journal of Structural Engineering, (Vol:118), July 1992.

[5] K. Tsai, Design of Steel Triangular Plate Energy Absorbers for Seismic Resistant Construction, 1993.

[7] D. Basu and P. R. M. Reddy, A New Metallic Damper for Seismic Resilience: Analytical Feasibility Study, Structures, vol. 7, pp. 165-183, Aug. 2016.

[8] A. K. Chopra. Dynamics of structures. theory and application to earthquake engineering. Pearson Education, Inc., 2007.

[9] N. M. Newmark. A method of computation for structural dynamics. ASCE Journal of Engineering Mechanics Division, (Vol:85), 1959