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Dynamic Response of RC Structures with Dampers

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Abstract - Earthquakes are potentially devasting natural events which threaten lives, destroy property and disturpt life-sustaining services. There are various conventional seismic design measures but situations do exist in which the conventional design approach is not applicable. In such cases behaviours of the structures may begin with consideration of distribution of energy within a structure. Structural vibration control device is an advanced technology to implement energy dissipation devices into structures to dissipate energy and reduce excessive structural vibration and prevent catastrophic structural failure due to strong earthquakes. Energy dissipative devices range from passive devices to fully and semi-active systems. Passive devices are largely applied due to their advantages such as low cost, no external power and low maintenance. In this paper performance a 14 storey reinforced concrete structure is modelled in ETABS software with equal area of varying plan configuration. Types of configuration modelled are rectangle plan configuration, L plan configuration and Hexagon plan configuration. After modelling various properties of friction damper and viscous damper in order to model in software were obtained. A nonlinear time history analysis was performed. The structure with dampers showed a greater reduction in displacement and time period when compared with the model without dampers. Friction dampers showed greater reduction of displacement when compared with viscous dampers.

Keywords - Energy dissipating devices, Passive control devices, time history analysis, Friction damper, Viscous damper.

I.INTRODUCTION

Man has always lived with earthquakes which cause major damage to structures (bridges, buildings, etc.) and kill thousands of people. However, for strong earthquakes a large portion of the input energy will be absorbed by hysteretic action i.e., damage to structure. There are many conventional approaches to protect the structures against the effects of earthquakes but many Engineers admits that there is a severe damage to the structure that it is no longer repairable. This has favoured the emergence of several innovative technologies such as the introduction of special damping devices in the structures, which have the immediate effect of increasing the critical damping ratio right up 20–30% and at the same time reducing the stresses and strains generated by earthquakes. This approach, is commonly known as the ‘‘energy dissipation” [A.Ras and N.Boumechra, 2016].

Passive Control Devices are also called as Dampers. They are one of the seismic vibration mitigation systems that dissipate energy. When the dampers are installed to a structure they enhance energy dissipation of a structure. The passive dampers, includes supplemental devices which function on principles such as frictional sliding surfaces (friction dampers), yielding of metals (hysteretic and metallic dampers), phase transformation in metals (shape memory alloys), deformation of Visco-elastic solids (Visco-elastic dampers), and fluid orificing (fluid dampers). This study focuses on only two types of dampers i.e., friction damper and viscous damper.

A. Friction Damper

Friction dampers are permanent passive energy absorbing systems. During severe seismic excitations, the friction devices yield at the predetermined loads and provide dissipation of energy by friction phenomenon while at the same time shifting the structural fundamental mode away of the earthquake resonant frequencies. fig 1.1. shows the Friction damper device by Quaketek manufacturer.

Fig. 1 Taylor device fluid viscous damper

Friction dampers are designed to have moving parts that will slide over each other during an earthquake. It dissipates energy through the friction that develops between two solid bodies sliding to one another to dissipate input energy in form of heat. [Diego lopez-garc et al, 2014].

B. Viscous Dampers

FVD typically consist of a piston head with orifices contained in a cylinder filled with a highly viscous fluid, usually a compound of silicone or a similar type of oil. fig. 1.2 shows the Fluid Viscous Damper device manufactured by Taylor Devices Inc. When the damper is subjected to a compressive force, the fluid volume inside the cylinder is decreased as a result of the piston rod area movement. A decrease in volume results in a restoring force. This undesirable force is prevented by using an accumulator. An accumulator works by collecting the volume of fluid that is displaced by the piston rod and storing it in the makeup area. As the rod retreats, a vacuum that has been created will draw the fluid out. [Diego lopez-garc et al, 2014].

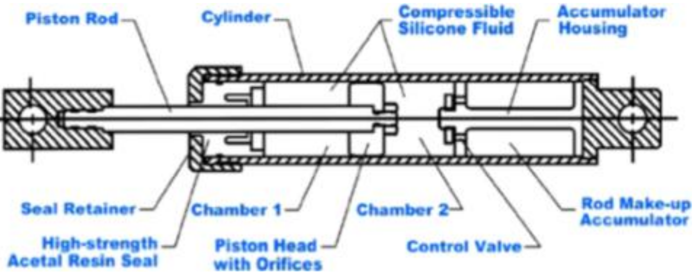

Fig. 2 Taylor device fluid viscous damper

II. DAMPER PROPERTIES

A. Friction Damper

1) Link Properties:

ETABS has many link types for modelling types of dampers. For each deformational degree of freedom you may specify in dependent uniaxial plasticity properties. The plasticity model is based on the hysteretic behaviour proposed by Wen (1976). All internal deformations are in dependent. The yielding at one degree of freedom does not affect the behaviour of the other deformations. If you do not specify non-linear properties for a degree of freedom, that degree of freedom is linear using the effective stiff ness, which may be zero. Hence in order to model friction damper in software PLASTIC (WEN) is used for analysis.

2) Effect of bracing stiffness:

A numerical study was also conducted by many to examine the effect of the flexibility of the brace on which a damper is installed. It was observed that the stiffer the bracing, the higher the damper effectiveness. As a brace is simply another spring in series with the damper, its effect was similar to that of the series spring in the Maxwell model. The numerical results showed that a brace stiffness of about ten times the story stiffness could be considered essentially rigid, but a brace with five times the story stiffness will also be adequate without compromising the damping effectiveness significantly. Stiffness of the bracing can be calculated from

$$K = \frac{AE}{L}$$

Where K = stiffness of bracing
A = area of bracing
E = youngs modulus of steel
L = length of bracing + damper

From steel tables ISHB 350 I section was chosen as Bracing and its sectional properties are shown below:

TABLE 1
SECTION PROPERTIES OF BRACING

Bracing section= ISHB 350	
Weight	724 kN
Area	9221 mm^2
Depth	350mm
Breadth of flange	250mm
Thickness of flange	11.6mm
Thickness of web	10.1mm

3) Non-linear parameters:

Some software allows for the direct input of the hysteretic loop. Slip Load should be equal to 75% of the actual brace's yield strength and 130% of the service loads. The mass of the damper will vary depending on the slip load and travel required. This technology allows new ways to answer architectural and customer constraints. It has been found that this force is below 50% of the story shear but different forces are often selected by the structural designer depending on his/her constraints and objectives. For quick calculations use 1/3 of the story shear, ensuring that the ratio of lateral braces stiffness to total lateral story stiffness (frame + braces) is strictly greater than 0.5 and constant throughout the building height. A damper of 1500kN is chosen as slip load.

TABLE 2
PROPERTIES OF FRICTION DAMPER

PROPERTIES OF FRICTION DAMPER	
LINK TYPE	Plastic(wen)
MASS(Brace + Damper)	468.827kg
WEIGHT(Brace + Damper)	4.6162kN
STIFFNESS (Brace)	215948.4778N/mm 316329.331N/mm
YEILD STRENGTH(slip load)	1500kN
POST YEILD STIFFNESS RATIO	0.0001
YEILDING EXPONENT	10

B. Viscous Damper

Taylor Devices Fluid Viscous Dampers are applicable to both fixed and base isolated structures, including buildings, bridges, and lifeline equipment. Diagonal brace dampers are available in output levels of 2,000 pounds to 2,000,000 pounds forces, with strokes of up to 6 inches. Standard output for both product lines is linear, where force is proportional to velocity. This allows damping levels as high as 50% of critical, offering truly dramatic seismic stress reduction in any structure. Optional output functions are available, including low damping exponents from 0.3 to 0.9, and relief valve damping offering an essentially flat response above a specified velocity limit. Viscous Dampers literally soak up the energy of earthquake induced motion, preventing structural damage. Compact, yet powerful, Fluid Viscous Dampers increase structural damping levels to as much as 50% of critical, the results being truly dramatic stress and deflection reduction.

1) Link type:

This element is very well suited for modelling viscous dampers that have a non-linear force-velocity relationship. For simple linear damping, you may instead want to use the coupled linear Link Support Property. The linear property does not re quire the series spring used by the exponential Maxwell damper, and it does allow you to consider a parallel spring. For the exponential damper, you can specify in dependent damping properties for each deformational degree of freedom. The damping proper ties are based on the Maxwell model of viscoelasticity having an exponential viscous damper in series with a linear spring. If you do not specify non-Linear proper ties for a degree of freedom, that degree of freedom is linear using the effective stiffness, which may be zero. Hence viscous damper is modelled in software as DAMPER EXPONENTIAL.

2) Total mass and weight:

The mass and weight input are estimated values for the dampers and the steel braces that are used to attach them to the structure. Since these items will add a very small amount of weight to the overall structure, they will have a small impact on the performance of the building. Attached are drawings of typical dampers and a drawing showing how our dampers are installed in diagonal bracing elements. You can select the damper weight from the drawing of the damper size that works for your project. You will also have to calculate the weight of the extender based on the size of tube that you select and the length of the entire damper/brace assembly.

3) Nonlinear properties:

The following equation illustrates the relationship of the damping coefficient and exponent to the stroking velocity of the damper:

$$F=CV\alpha$$

where F is the damping force
C is the damping constant (damping coefficient)
α is the velocity exponent.

Dampers are available with α in the range of 0.3 to 1.0. We can make just about any damping constant that is desired. Damper Force F = 1500kN from fig 3.5 is chosen and V = 0.7m/s is taken from the brochure of Taylor devices inc., and α chosen as 0.3 therefore for these values, damping coefficient is found to be 2619.78kN*s/m.
Stiffness of bracing is same as for friction damper since bracing section ISHB 350 is same for both dampers.

TABLE 3
PROPERTIES OF VISCOUS DAMPER

PROPERTIES OF VISCOUS DAMPER	
LINK TYPE	Damping Exponential
MASS(Brace + Damper)	433.827kg
WEIGHT(Brace + Damper)	4.254kN
STIFFNESS (Brace)	215948.4778N/mm 316329.331N/mm
DAMPING COEFFICIENT	2619.78kN*s/m
DAMPING EXPONENT	0.3

III. MODELLING AND ANALYSIS

A. Modelling in ETABS

A 14 storey Reinforced concrete structure was modelled in ETABS software with each storey height 3m and specifications of section properties and material properties are show in table 4;

TABLE 4
BUILDING SPECIFICATIONS

SPECIFICATION	SIZE
Area	1600sq.m
Grade of concrete	40N/mm^2
Grade of steel	500N/mm^2
Beam	230mm*450mm
Column	450mm*600mm
Slab thickness	150mm
Total Height of building	42m
No. of storey	14 nos

Three types of plan configuration modelled in ETABS with equal are of 1600sq. m are

- Rectangle plan configuration
- L plan configuration
- Hexagon plan configuration

TABLE 5
BUILDING DIMENSION FOR ALL CONFIGURATIONS

PLAN CONFIGURATION	DIMENSION
Rectangle	L = 64m B = 25m
L shape	L = 50m B = 50m
Hexagon	Each side = 25m

Table 6 shows dead, live and seismic load considerations.

TABLE 6

LOAD CONSIDERATIONS

Type of load	Loads
Dead load	Floor finish-1.5kN/m^2 230mm wall-12kN/m
Live load	3 kN/m^2 (as per IS 875-part II,1987)
Seismic load	By using equivalent static load method (as per IS 1893-2016)

Figures 3.1, 3.2 and 3.3 show the plan and 3D view of the Rectangle, L, and Hexagon plan configuration respectively.

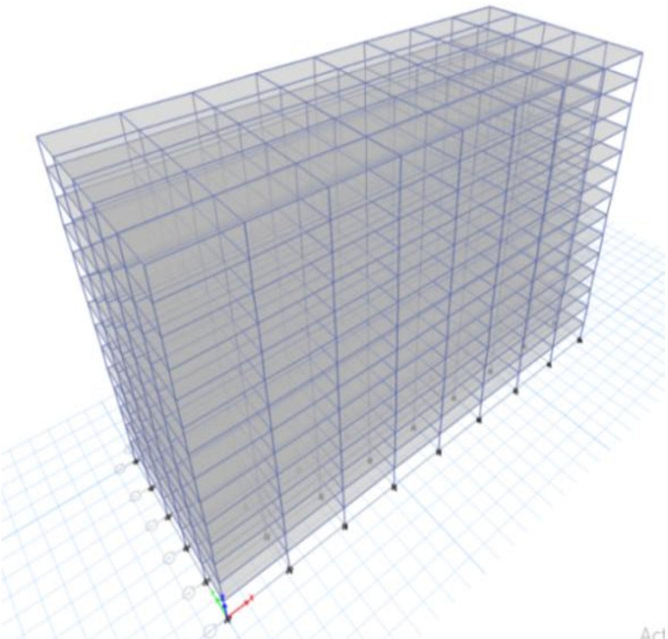

Fig. 3 3D view of Rectangle plan configuration

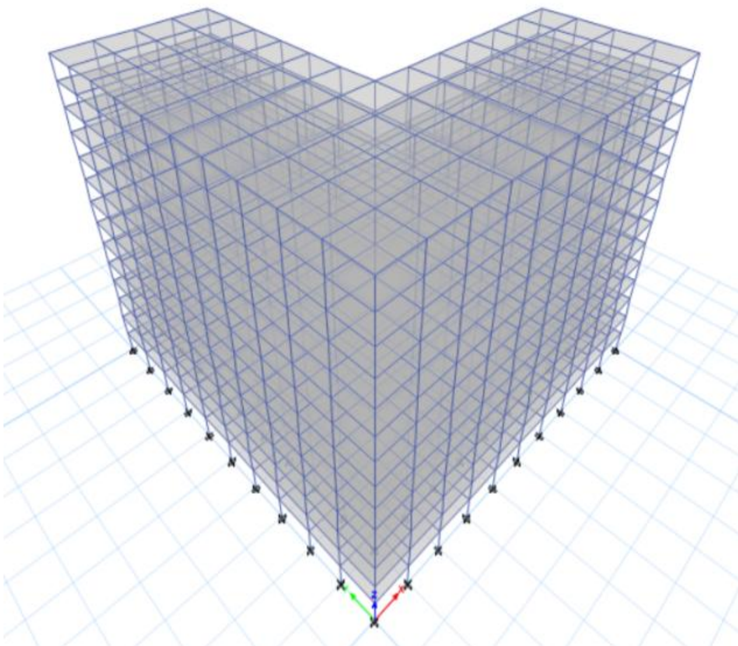

Fig. 4 3D view of L configuration

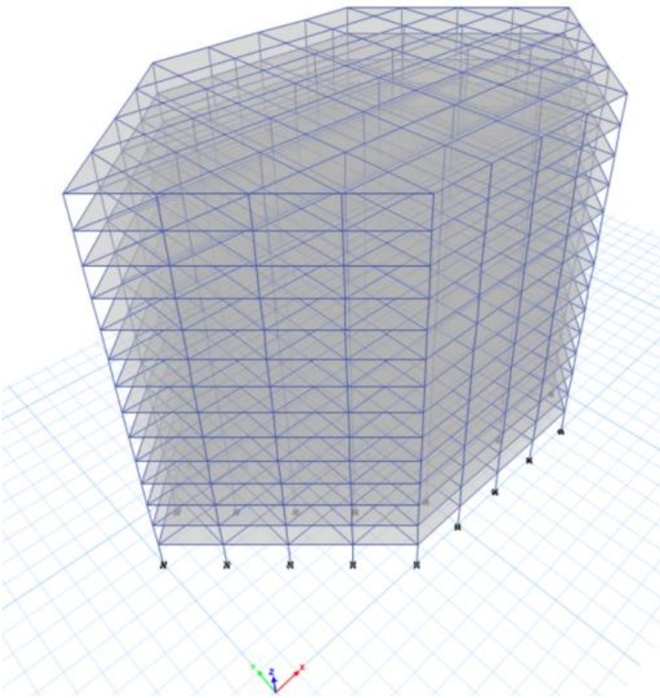

Fig. 5 3D view of hexagon configuration

After applying loads to the structure dead, live and seismic load cases are assigned and static analysis was analysed. From literature 30% of storey was taken as damper force. After finding damping force it was divided by single damper capacity and thus total number of dampers for each plan configuration was found. Table 7 shows the total number of dampers for each plan configurations.

TABLE 7
TOTAL NUMBER OF DAMPERS

S.No	Plan Configuration	Total No of Dampers
1	Rectangle plan configuration	312
2	L plan configuration	360
3	Hexagon plan configuration	231

After finding total number of dampers, both friction damper and viscous damper are separately installed to the structures. Figures 3.4, 3.5 and 3.6 show 3D view of Rectangle, L and Hexagon plan configuration installed with dampers.

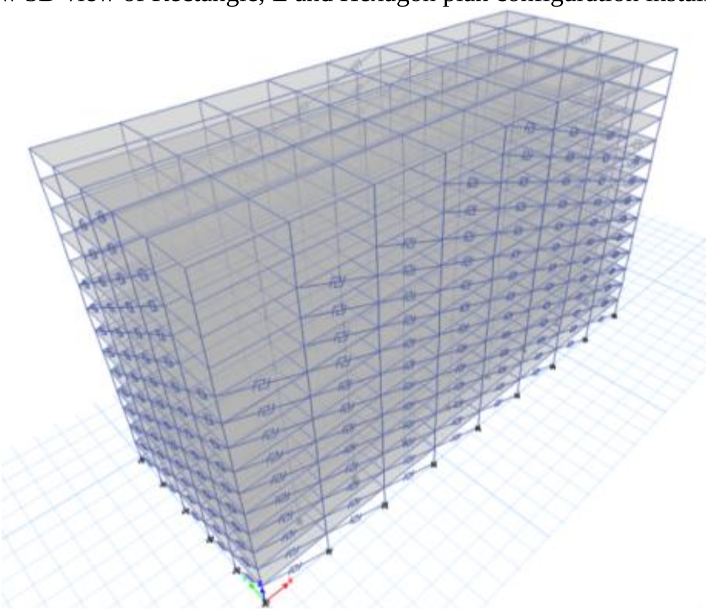

Fig. 6 3D view of rectangle configuration with dampers

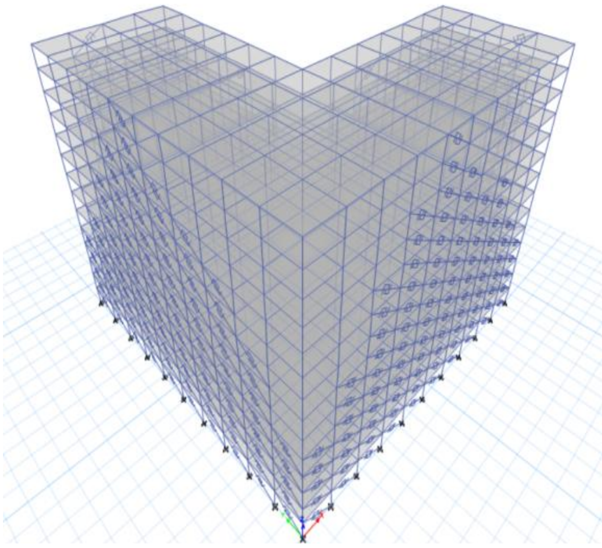

Fig. 7 3D view of L configuration with dampers

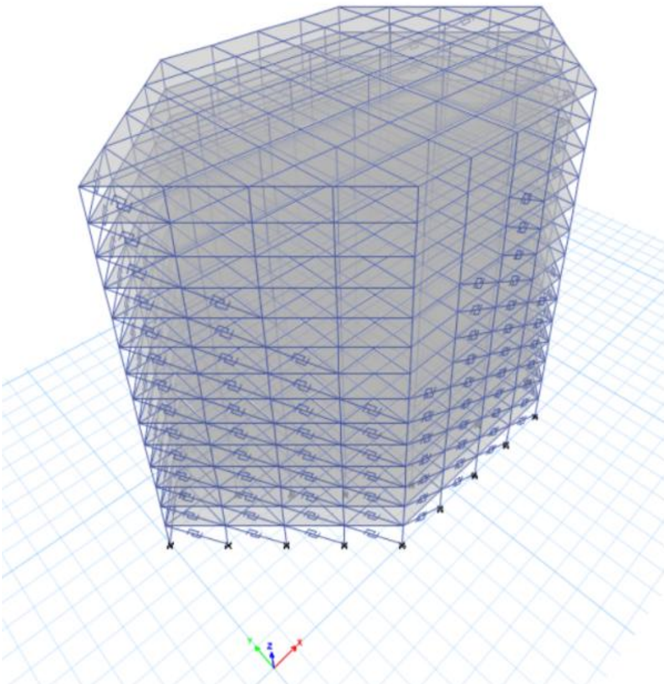

Fig. 8 3D view of Hexagon configuration with dampers

IV. **ANALYSIS**

A. Time History Analysis

Time-history analysis is a dynamic-nonlinear technique which may involve either the FNA or the direct-integration method. FNA is a modal application, whereas with direct integration, the equations of motion are integrated at a series of time steps to characterize dynamic response and inelastic behaviour. Loading is time-dependent, and therefore suitable for the application of a ground-motion record. Time-history analysis may account for both material nonlinearity and P-Delta effects. Nonlinear dynamic analysis is undoubtedly the most realistic and accurate analysis method available. It is also referred as “nonlinear time history analysis”.

1) El centro earthquake:

The 1940 El Centro earthquake (or 1940 Imperial Valley earthquake) occurred at Pacific Standard Time on May 18 (05:35 UTC on May 19) in the Imperial Valley in south eastern Southern California near the international border of the United States and Mexico. It had a moment magnitude of 6.9 and a maximum perceived intensity of X (Extreme) on the Mercalli intensity scale. It was the first major earthquake to be recorded by a strong-motion seismograph located next to a fault rupture. The earthquake was characterized as a typical moderate-sized destructive event with a complex energy release signature. It was the strongest recorded earthquake to hit the Imperial Valley, and caused widespread damage to irrigation systems.

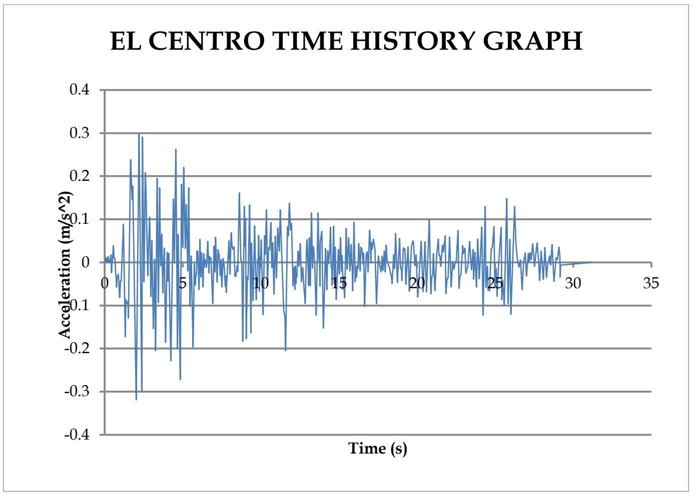

Fig. 9 time history graph of El centro

V. RESULT AND DISCUSSIONS

A. Time history plots

Time history response plots are compared for both time history response on displacement and time history response on acceleration. These time history response graphs of displacement and acceleration are compared between structure without damper and structure with viscous damper and structure with friction damper for both El centro and the results are shown below.

1) Time vs Displacement graphs:

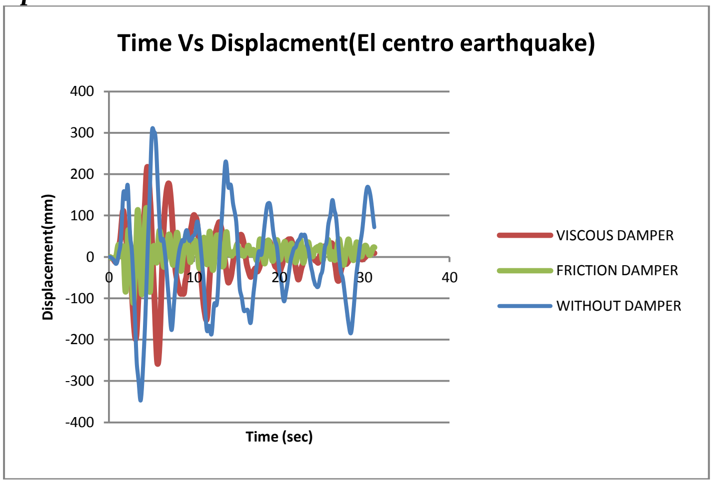

Fig. 10 Time vs Displacement time history graph for el centro earthquake of rectangle plan configuration

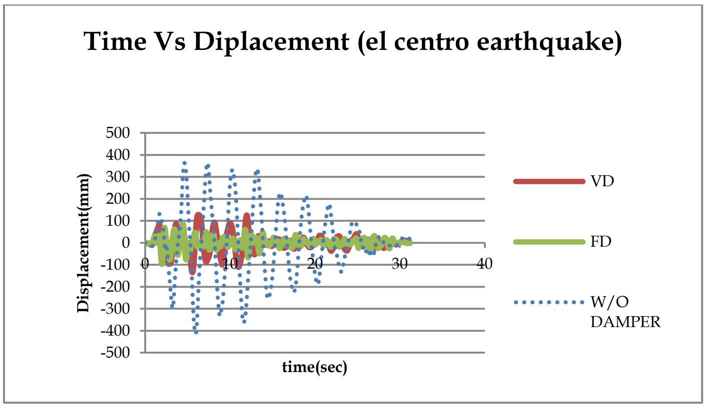

Fig. 11 time vs Displacement time history response of El centro earthquake of L plan configuration

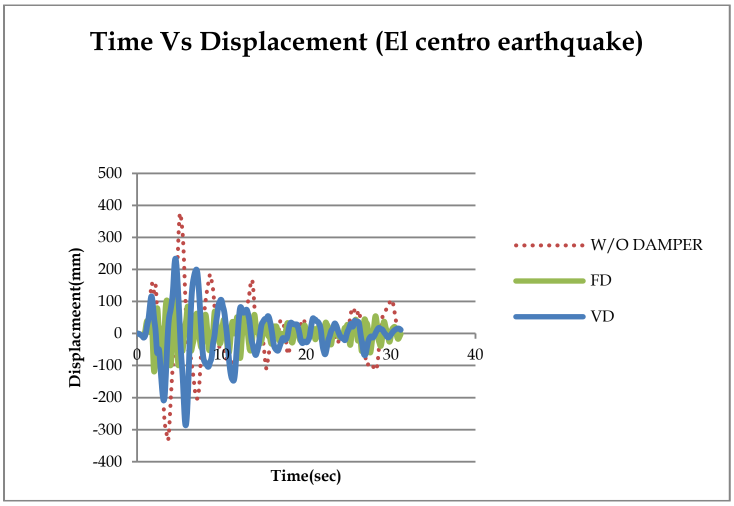

Fig. 12 Time vs Displacement time history response under el centro earthquake of Hexagon configuration

2) Time vs Acceleration graphs:

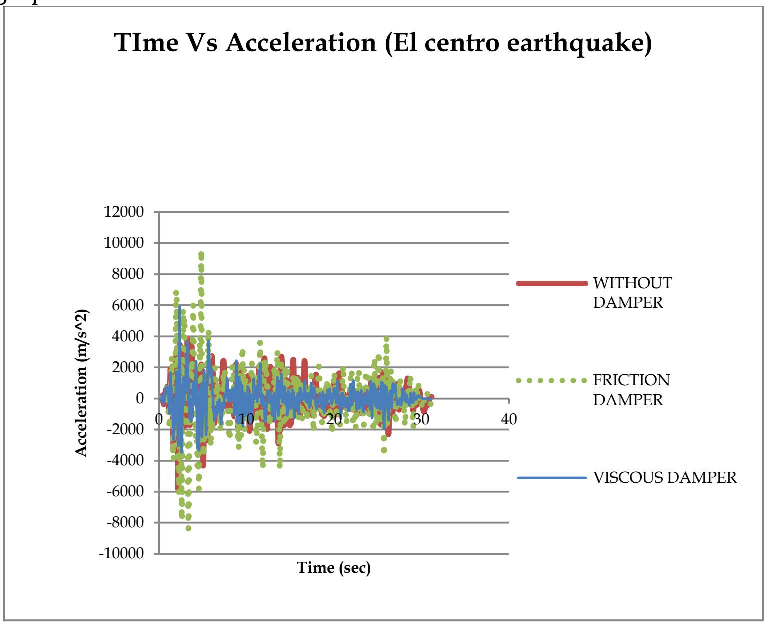

Fig. 13 Time vs Acceleration time history graph for el centro earthquake of Rectangle plan configuration

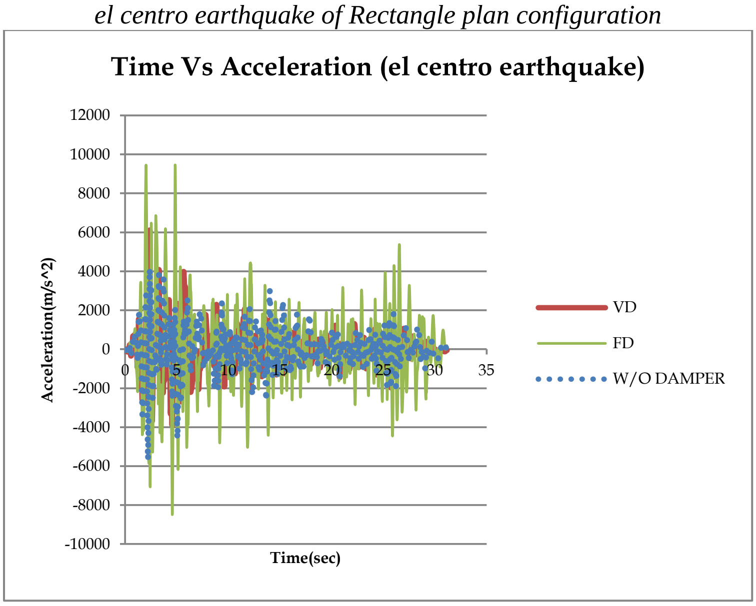

Fig. 14 Time vs Acceleration time history response of El centro earthquake of L plan configuration

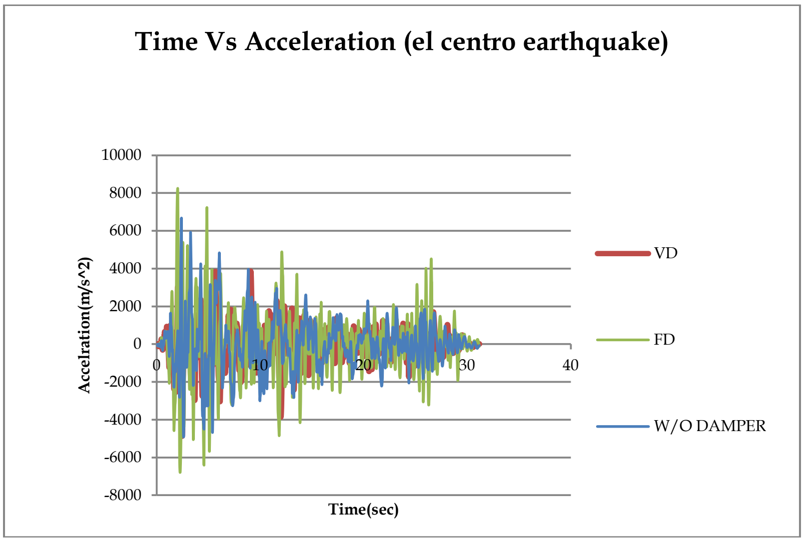

Fig. 14 Time vs Acceleration time history response under el centro earthquake of Hexagon plan configuration

3) Maximum storey drift:

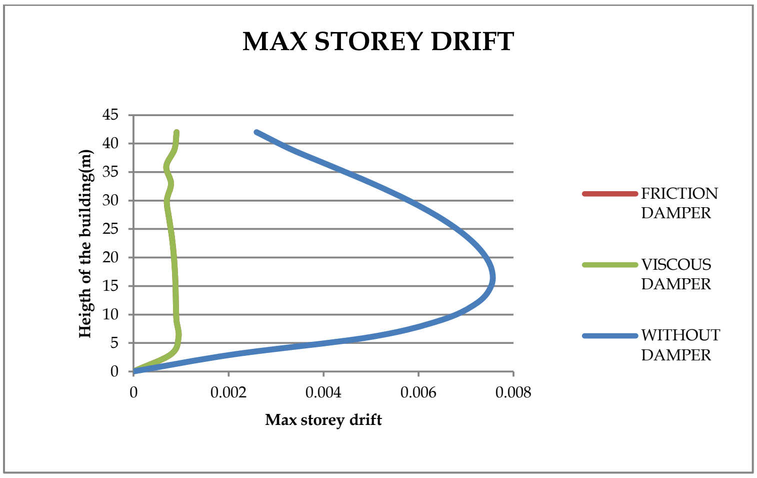

Fig. 15 Maximum storey drift of rectangle configuration

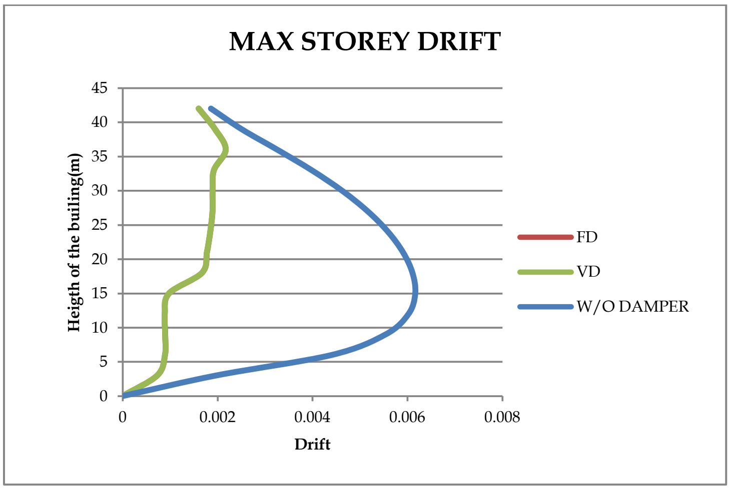

Fig. 16 Maximum storey drift of L plan configuration

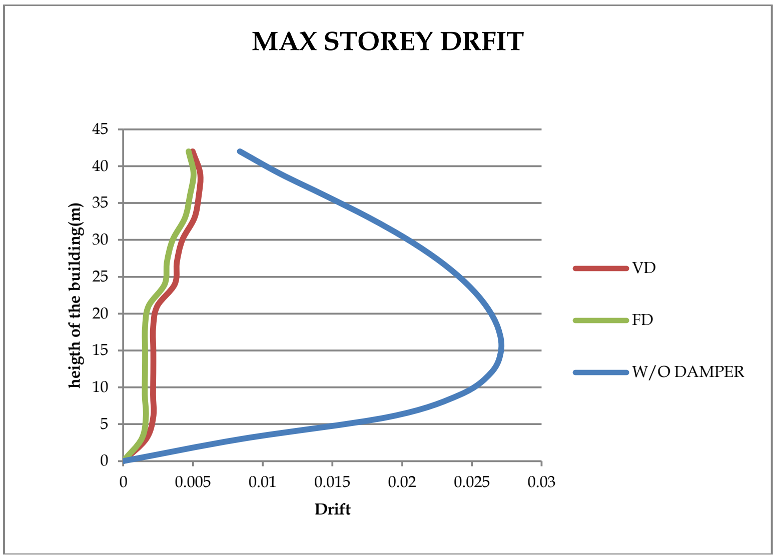

Fig. 17 Maximum Storey drift of hexagon plan configuration

4) Hysteresis behaviour of dampers:

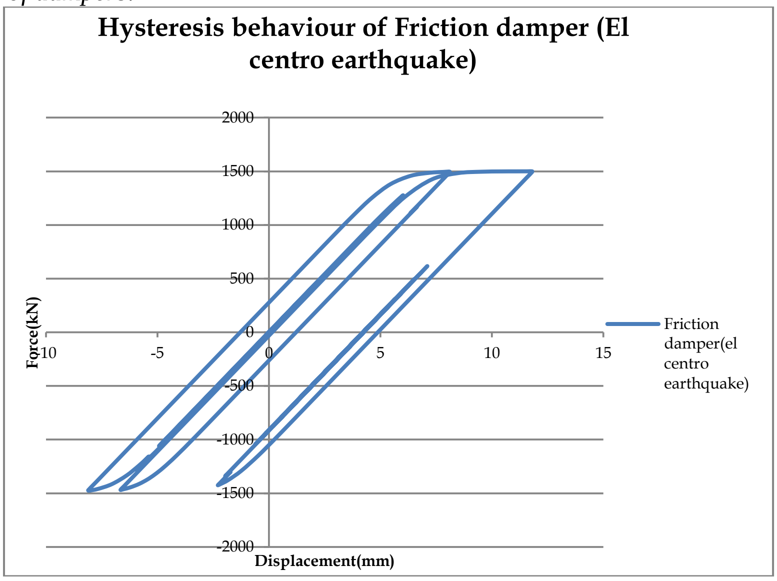

Fig. 18 Hysteresis behaviour of friction damper under El centro earthquake of rectangle plan

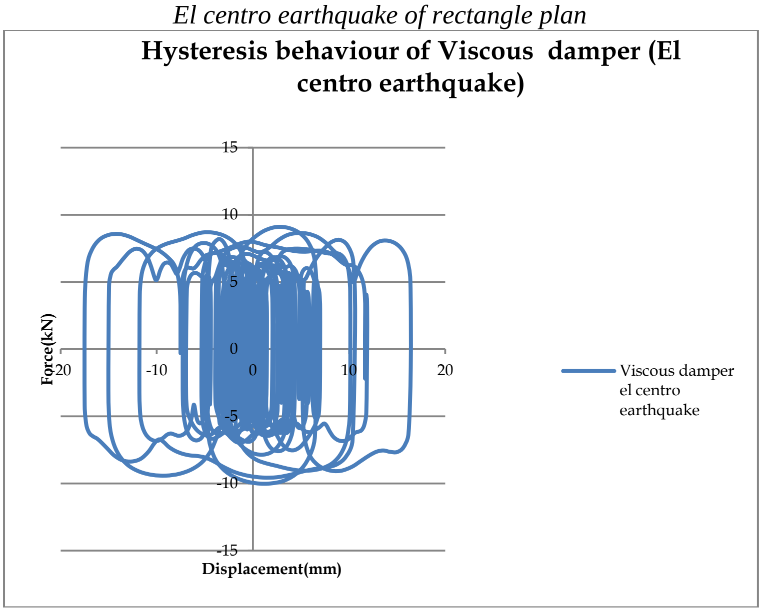

Fig. 19 force deformation curve of Viscous damper under El centro earthquake rectangle plan

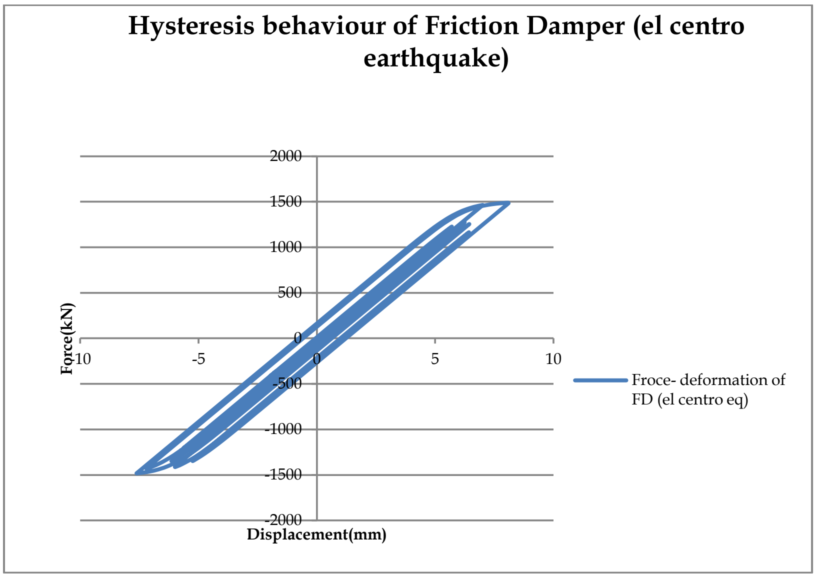

Fig. 20 Hysteresis behaviour of Friction damepr under el centro earthquake of L plan

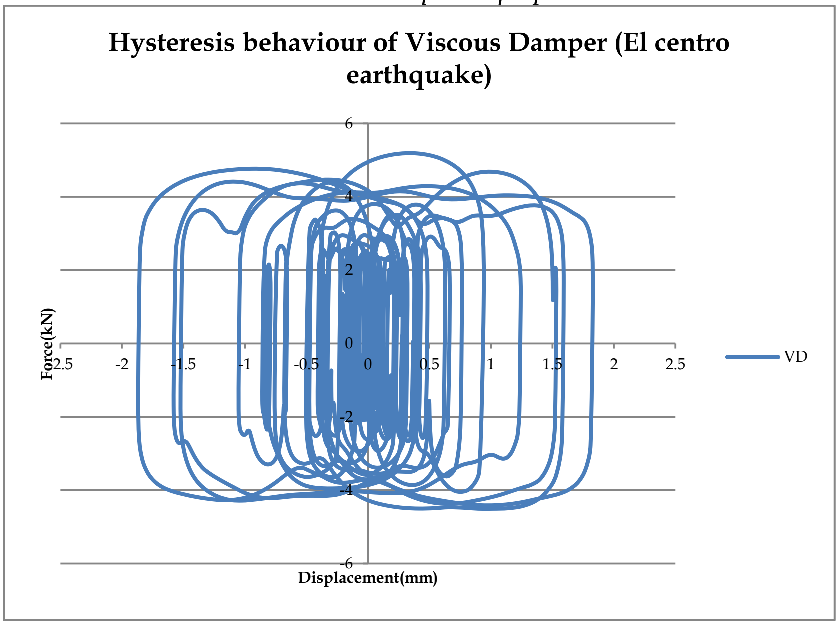

Fig. 21 force deformation curve of Viscous damper under el centro earthquake of L plan

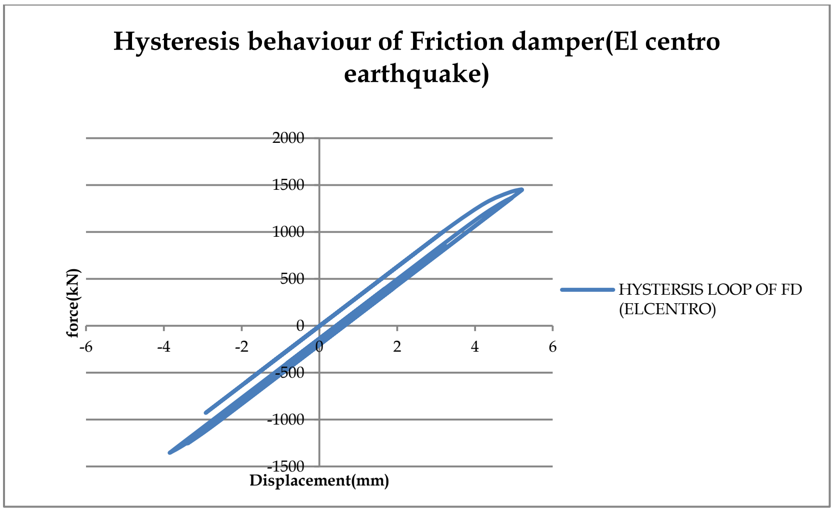

Fig. 22 Hysteresis behaviour of Friction Damper under Elcentro earthquake of Hexagon plan

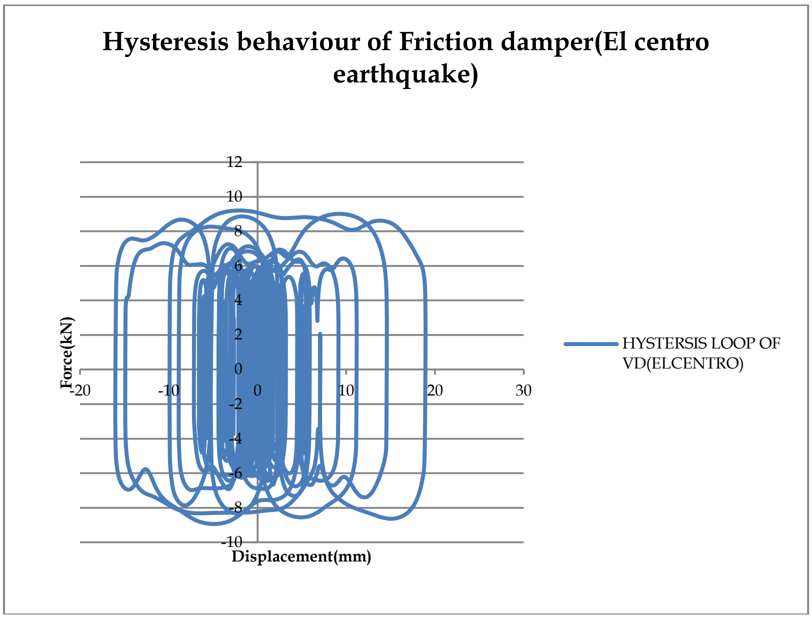

Fig. 23 Hysteresis behaviour of Viscous Damper under el centro earthquake of hexagon plan

5) Base reaction and Time period:

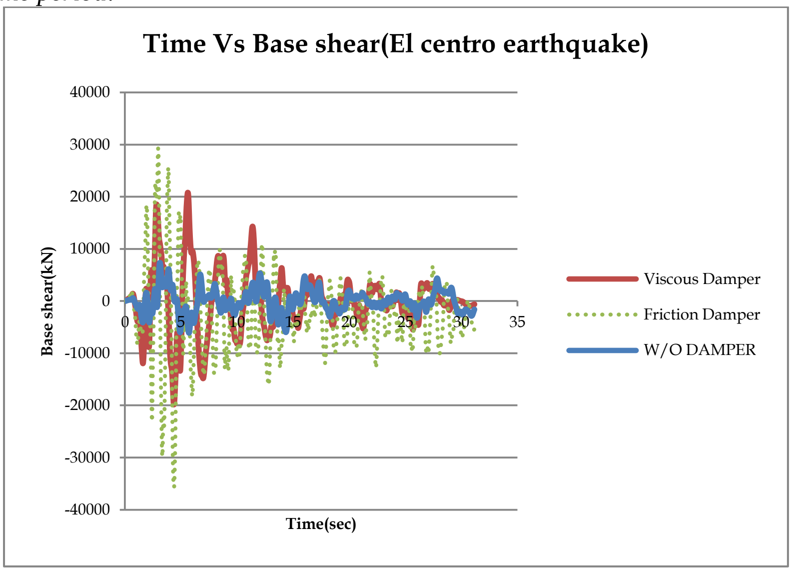

Fig. 5.14 Base shear response under El centro earthquake of Rectangle plan

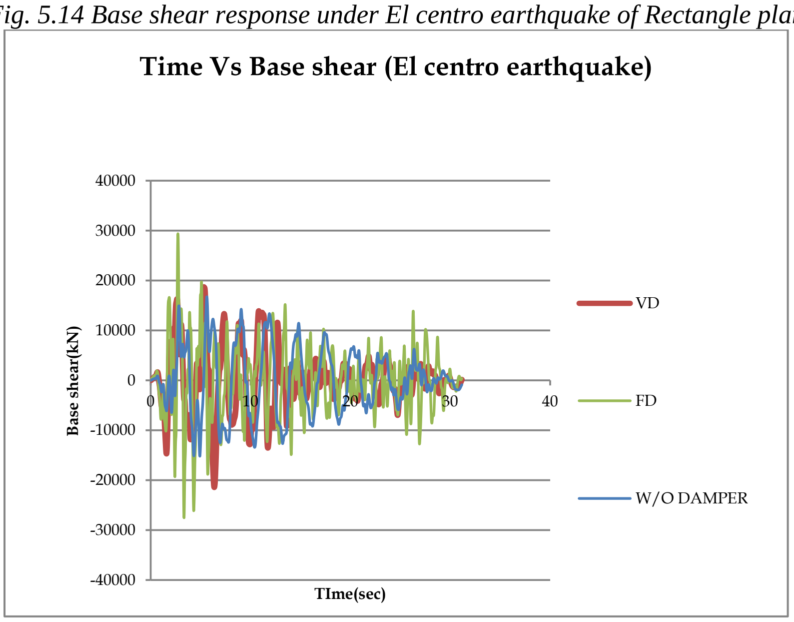

Fig. 5.15 Time Vs Base shear response under El centro earthquake of L plan

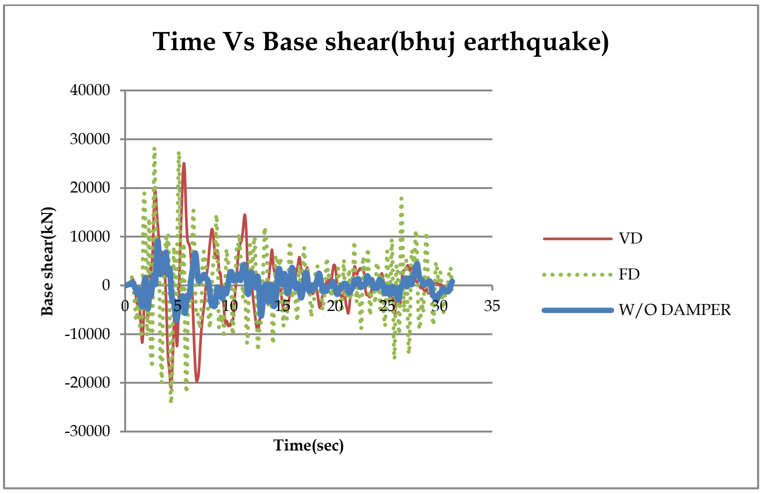

Fig. 5.16 Time Vs base shear response under El centro earthquake of Hexagon plan

TABLE 8
TIME PERIOD VALUES OF RECTANGLE CONFIGURATION

MODEL	TIME PERIOD
Without damper	4.173
Friction damper	1.258
Viscous damper	1.258

TABLE 9
TIME PERIOD VALUE OF L PLAN CONFIGURATION

MODEL	TIME PERIOD
Without damper	3.048
Friction damper	1.284
Viscous damper	1.153

TABLE 10
TIME PERIOD OF HEXAGON PLAN CONFIGURATION

MODEL	TIME PERIOD
Without damper	4.044
Friction damper	1.389
Viscous damper	1.582

VI. CONCLUSION

Nonlinear time history analysis carried out on all three plan configuration and compared between structure modelled without damper with structure with Friction damper and structure with Viscous damper. And following results were obtained:

The force displacement curve was plotted for all three plan configuration by comparing structure without dampers and structure with friction damper and viscous damper.

Friction dampers are activated with total load of the damper initially, whereas Viscous damper does not utilize total capacity of the damper instead it uses certain desirable load as per deformations.
Maximum storey drift values of rectangle configuration are nearly zero when dampers are installed to the structure.
Storey drift values were reduced to 65%,14% and 44% for damped structure compared with undamped structure for Rectangle, L and Hexagon configurations.
When time history response of displacement was compared, friction dampers had higher displacement reduction when compared with viscous dampers.
When the displacement of undamped structure is maximum correspondingly the displacement of damped structure where very minimum and displacement values are reduced immediately.
Time history acceleration response of all three models without damper and with friction and viscous damper was simillar, this means that the increase of structure stiffness with addition of dampers does not increase its acceleration response.
Viscous dampers reduced the acceleration response more than that of friction damped structure. VD reduces the acceleration response comparatively more since it has greater acceleration at the beginning.
Time period of rectangle configuration has higher period of 4.173 comparatively and reduced to 1.258 when dampers are installed.
And hexagon configuration had time period of 4.044 for structure without damper and period reduced to 1.359 and 1.582 when dampers were incorporated.
Whereas though L configuration has lesser time period of 3.048 its reduction is less 1.284 and 1.153 when dampers are incorporated to the structure compared to other configuration.
The installation of damper reduces the displacement, acceleration and time period but in case of base shear, dampers increases the base shear.
Since increase of stiffness in structure, the base shear increases relatively in damped structures.
But Viscous dampers were comparatively had greater reduction in base shear than friction damper.
It was found that both dissipate systems led to substantial improvement in performance of building.

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