Seismic Performance Analysis of RCC Benchmark Problem with Passive Control System

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***ABSTRACT*- Structures situated in a high Seismic risk area undergo a higher level of dynamic response. Seismic response, reduction through increasing structural stiffness and damping by implementing passive energy dissipation devices is found to be effective in the non-linear response reduction. In Earthquake Engineering, damping is an inherent property of the structure which tends to resist the movement of the structure due to vibration. Higher the damping of the structure quicker it will return to its resting position from the displaced position. This paper presents a performance analysis of various passive dampers, assessing effectiveness of 6 storey RCC Benchmark structure under controlled and uncontrolled condition. Systems of structural control considered are ViscoElastic Damper, Metallic Friction Damper and Viscous Fluid Damper. A multi storey Benchmark building with 6 stories have been modeled using FEMM Software package SAP2000, Nonlinear Time History Analysis was carried out for three earthquake ground motion data namely Elcentro 1940, Imperial valley and Northridge. The response of the Benchmark structure was studied as displacement, interstorey drift and base shear. Viscous Fluid Damper and Friction Damper shows efficient damping performance when compared to other passive energy dissipation systems**..

***Keywords*— Benchmark, SAP2000, Structural Stiffness, Friction Damper, VFD, VED.**

I. INTRODUCTION

An Earthquake is one major hazards experienced by the whole world for past few decades where some countries experience seismic activities frequently. This results in increased structural damages, collapse and loss of human life. Control of Seismic response by using a structural design approach has been nowadays widely followed to reduce the structural vibration. Conventional method of seismic energy dissipation involves an addition of an alternate load path which sustain the structure from collapse, but it makes the structure to be non-functional after the earthquake. To overcome these disadvantages modern energy dissipation methods have been adopted through various control systems and it involves a Passive control system, Active control systems and Semi Active control systems. This paper presents the analysis of seismic behavior of the RCC benchmark building adopted with the passive dampers involves Friction Damper, viscoelastic dampers, Viscous Fluid Damper and analyzed by THA using FEMM software package SAP2000 for three earthquake excitation such as Elcentro 1940, Imperial Valley and Northridge.

Structural control action can be achieved through various mechanisms and this paper focus on the passive control techniques. The passive dissipation device uses the mechanical property of the some materials, namely rubber, lead, steel to reduce the inelastic deformation. Viscous Fluid damper is a type of passive energy dissipation device dissipated energy by converting mechanical energy into heat when the piston deforms the highly viscous silicone gel (Symans and Constantinou, 1998). Stiffness and Damping coefficient of the VFD play a major role in energy dissipation, but the structural potential increment can be achieved through structural VFD dampers without a greater increase in stiffness of the structure (Abdelouahab Ras et al 2014). Passive control device use steel to dissipate energy includes various bracing and also Friction Damper. Friction Damper dissipated energy through slippage. (Rosario Montuori et al 2014). Total energy dissipated is equal to the product of slip load, for very high slip load energy dissipation will be zero and for low slip load the energy dissipation will be negligible. (A. Filiatrault et al 1990). Friction damper works efficient, when it is designed for optimum slip load.(A.V Baskararao et al 2006).

Passive control system using rubber material to dissipate energy involves base isolation bearings and Viscoelastic damper. Viscoelastic dampers are frequency dependent damper and depends on the mechanical property of the material used. Damping property of the friction damper depends on the storage modulus and loss modulus of the polymer material used. . (R. Lewandowski et al 2012). Passive control system is well know accepted system for the application of structural control by enhancing strength, stiffness and damping of the structure. (Soong et al, 2002). Comparison among Friction damper, Viscous fluid damper and Viscoelatic Damper has done for the same force capacity and analysed for the reduction in seismic response of the structure when subjected to the three earthquake ground motion. VFD are designed as the exponent damping in software analysis. Damping exponent of the Viscous fluid damper depends varies from 0.3 to 2. Damper produces a force to resist the lateral displacement of the structure.(D.P Taylor et al 2004).

II. DESIGN OF MODEL BUILDING

The building considered for this study is RCC Benchmark building. Six Storey (6storey) Benchmark structure is 15m (49.2ft) by 18m (59.04ft) in elevation. Lateral load resisting system of the building is comprised of 3 bays, 6 storey high reinforced concrete frame in a building designed in accordance with provisions of the Argentine code IC103. In this study since it is 2D analysis x translation and z translation are represented and rotational component θ is ignored.

TABLE 1

DIMENSION DETAIL OF RCC BUILDING

SI.NO	**DESIGN DATA OF 6 STOREY BUILDING**	
1.	Structure	RCC
2.	Number of Storey	G+5
3.	Storey Height	3m
4.	Grade of Concrete	M_{30}
5.	Grade of steel	Fe415
6.	Beam Size	0.25m x 0.45m
7.	Column 1 Size (Exterior)	0.60m x 0.60m
8.	Column 2 Size (Exterior)	0.55m x 0.55m
9.	Column 3 Size (Exterior)	0.50m x 0.50m
10.	Column 4 Size (Interior)	0.65m x 0.65m

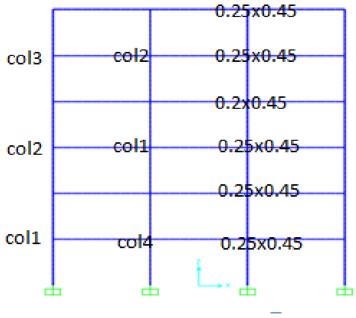
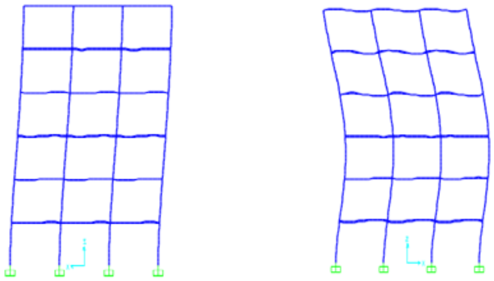


Fig 1. Schematic Diagram of 6 storey benchmark building



Mode1(2.285Hz) Mode2(7.694Hz)

Fig 2. Mode shape of 6 Storey Building

III. PASSIVE CONTROL SYSTEM

The passive control system involves the passive mechanism. This paper presents the modeling and comparative numerical analysis of passive energy dissipation devices such as VED, Friction damper and VFD. Damping Properties dependency on the structure response are less, so passive control devices do not require any external source for its operation. The energy dissipation approach is same as that of ductile detailing of the structure both aims towards developing of non linear deformation mechanism to dissipate large amounts of seismic energy dissipation and in this paper each damper is modelled for the same damping force and the comparison has been done. Passive dampers are placed in the center bay along the height of the structure which is found to be optimal position for the 6 storey Rcc building.

Table II

THREE GROUND MOTION RECORDS

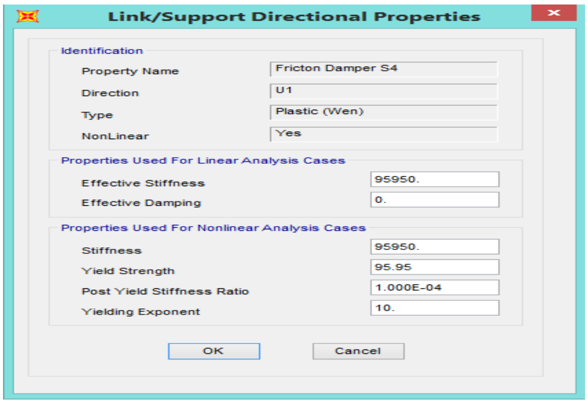
S.NO	EARTHQUAKE	MAGNITUDE
1	ELcentro	6.9Mw
2	Imperial valley	6.4Mw
3	Northridge	6.7Mw

A. Friction Damper

Friction Damper dissipates energy through columb friction when solid surfaces sliding relative to one another. During the times of severe earthquake device slips at the predetermined load know to be slip load. When the device attains its slip point it shift the structural fundamental load away from the earthquake resonant frequency. Various forms of friction damper are chevron braced, X braced, diagonal braced damper. For each earthquake slip load will be 30% of the building weight. Damper should be designed for optimum slip load, in case of its higher or lower slip load condition structure response will be vigorous. Slip load of the structure is designed based on THA results before and after earthquake displacement condition. Shear force undertaken by the frame will be equal to the energy dissipation capacity of the frame which means the slip load will be optimum under that condition.

TABLE III
OPTIMUM SLIP LOAD

STOREY (G+5)	**OPTIMUM SLIP LOAD**
Fifth Floor	86.38KN
Fourth Floor	86.38KN
Third Floor	91.21KN
Second Floor	91.21KN
First Floor	95.95KN
Ground Floor	95.95KN



Identification
Property Name: Fricton Damper S4
Direction: U1
Type: Plastic (Wen)
NonLinear: Yes

Properties Used For Linear Analysis Cases
Effective Stiffness: 95950.
Effective Damping: 0.

Properties Used For Nonlinear Analysis Cases
Stiffness: 95950.
Yield Strength: 95.95
Post Yield Stiffness Ratio: 1.000E-04
Yielding Exponent: 10.

Fig 3 Modelling of Friction damper in SAP2000

B. *VISCOELASTIC DAMPER*

Viscoelastic damper is a viscoelastic material slab sandwiched between two steel plates. VE damper energy dissipation capacity depends on its tan delta of damping material. Material with highest tan delta shows the effect of greater phase shift up to 90 degrees. The tan delta is an indication of material effectiveness in damping capabilities. The tan delta is also know to be a loss factor depends on the value of the shear storage modulus and shear loss modulus of the VE material. VE damper is modelled as the size of 400mm x 400mm x 15mm is shown in fig 3. VE damper properties will depend on the shear deformation and frequency of the structure after the Time History Analysis and modeled for 5% damping.

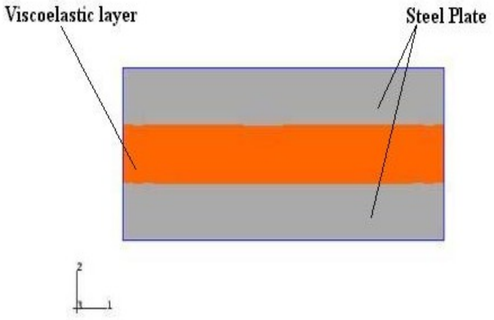


Fig.4 Model of Visco Elastic Damper

VE Materials used for the modelling of VE damper are Sorbothane @Duro50. Damping properties are computed using the shear storage modulus and loss factor for the first modal frequency of the structure. Shear stiffness are defined in terms of storage modulus

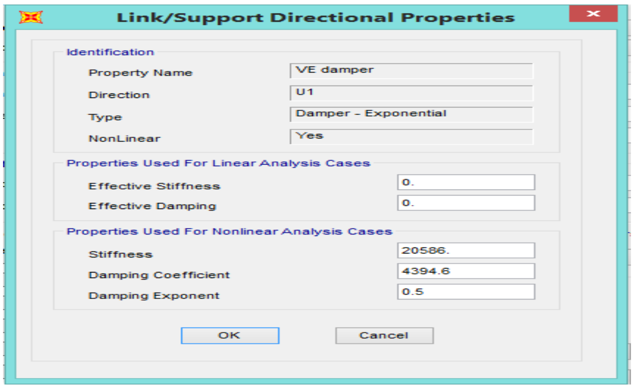
$$K' = G' A_b / t; \quad \eta = G'' / G'$$

G' is storage modulus, A_b and t represents the bonded area and thickness of VE damper. Damping coefficient C is represented in terms of G", Damping coefficient can be varied up to 10,000KN.s/m.

$$C = G'' A_b / \omega t;$$

Table IV
VE DAMPER PROPERTIES

Parameters	Value
Area	0.4m x 0.4m
Stiffness	20586KN/m
Damping coeffecient	4394.5KN.s/m



Link/Support Directional Properties

Identification
Property Name: VE damper
Direction: U1
Type: Damper - Exponential
NonLinear: Yes

Properties Used For Linear Analysis Cases
Effective Stiffness: 0.
Effective Damping: 0.

Properties Used For Nonlinear Analysis Cases
Stiffness: 20586.
Damping Coefficient: 4394.6
Damping Exponent: 0.5

Fig 5 Modelling of VED in SAP2000

C. *VISCOUS FLUID DAMPER*

Viscous Dampers are designed to protect structures from earthquake through the movement of the piston through the cylinder filled with the silicone oil. During earthquake Rcc structure under failure, viscous damper provides an alternative to structural yielding as a way to absorb seismic energy. For the resistance of structural motion viscous damper produces a force and the force is proportional to the relative velocity between the ends of the damper. Viscous damper is manufactured by Taylor devices Inc.

Viscous Damper in SAP2000 is modeled as the two link joint exponent damper. Since the VFD do not resist static loads, linear properties of the analysis is to zero. Damping coefficient is calculated as per Taylor device manufacture. In the viscous damping model, output is

$$F=CV^{\alpha}$$

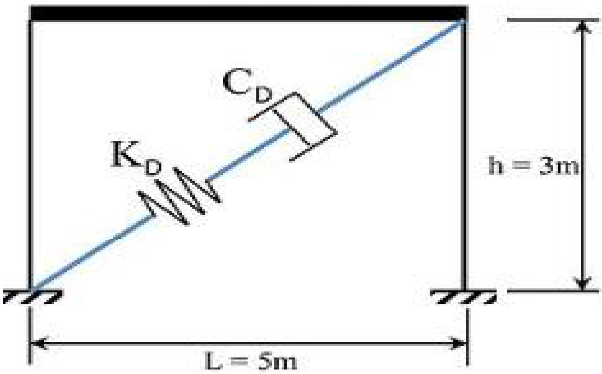
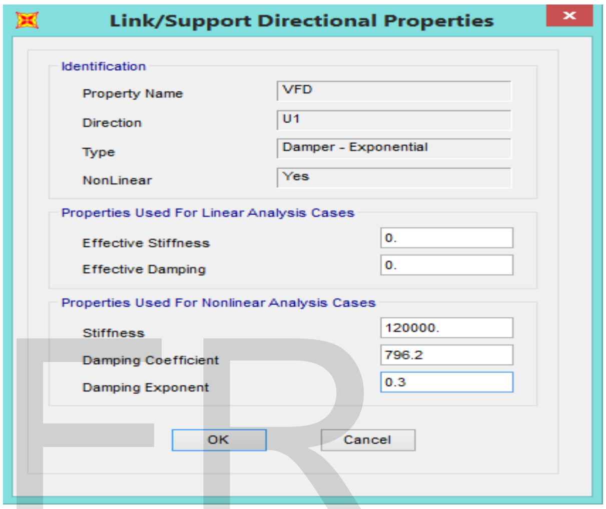


Fig.6 Model of Viscous Fluid Damper

F= Force of damper,
C=Damping coefficient
α = Damping exponent.

TABLE V
VF DAMPER PROPERTIES

Parameters	Values
Stiffness	120000KN/m
Damping Coeff	796.2KN. s/m
Damping exponent	0.5



Link/Support Directional Properties

Identification
Property Name: VFD
Direction: U1
Type: Damper - Exponential
NonLinear: Yes

Properties Used For Linear Analysis Cases
Effective Stiffness: 0.
Effective Damping: 0.

Properties Used For Nonlinear Analysis Cases
Stiffness: 120000.
Damping Coefficient: 796.2
Damping Exponent: 0.3

Fig.7 Model of Viscous Fluid Damper

IV. RESULTS AND DISCUSSION

The Six storey benchmark building with different damper such as Friction Damper, VED and VFD subjected to real earthquake ground motion is investigated. Different earthquake ground details are given in table 2. In this paper comparative study between the Building without damper, with Friction damper, VFD, VED has been done for seismic response such as Displacement, Interstorey drift, and Base shear.Effectiveness of dampers is evaluated by the behavior of the building.

A. *COMPARISON OF STOREY DISPLACEMENT*

The important parameter to evaluate the damper effectiveness in seismic analysis is displacement.

Displacement reduction for the benchmark building is achieved by different passive dampers. Friction damper and VFD show a reduction of 73% and 84% respectively for the chosen Benchmark problem.

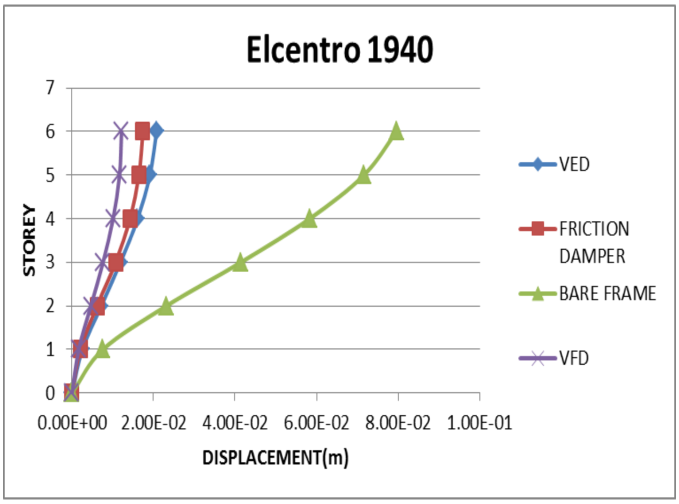


Fig 8 Variations of Displacement with Elcentro input

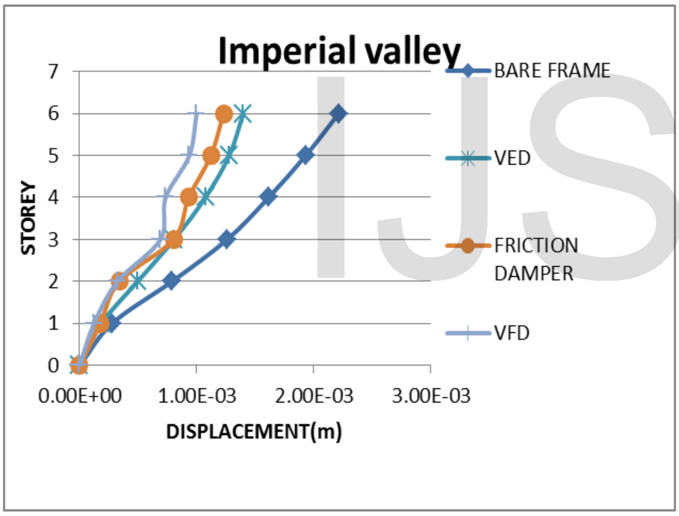


Fig 9 Variations of Displacement with Imperial valley input

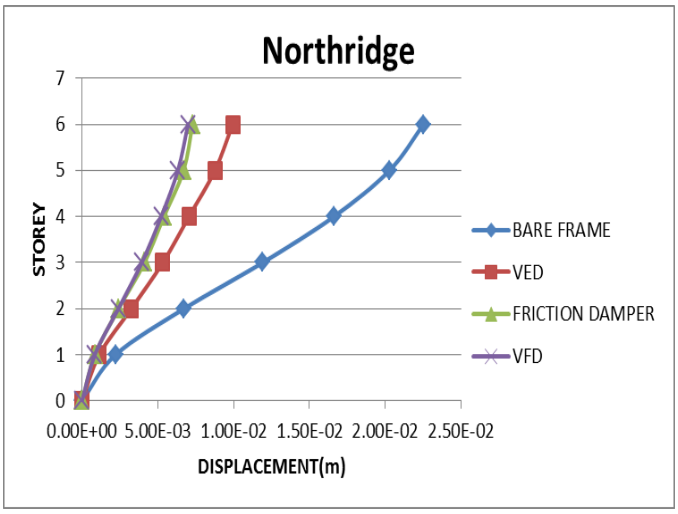


Fig 10 Variations of Displacement with Northridge input

B. *COMPARISON OF INTERSTOREY DRIFT*

As the number of storeys increases the Inter storey drift increases and it plays as an important parameter to evaluate the building response when subjected to the earthquakes. Drift reduction is achieved through both Friction damper and the VFD.

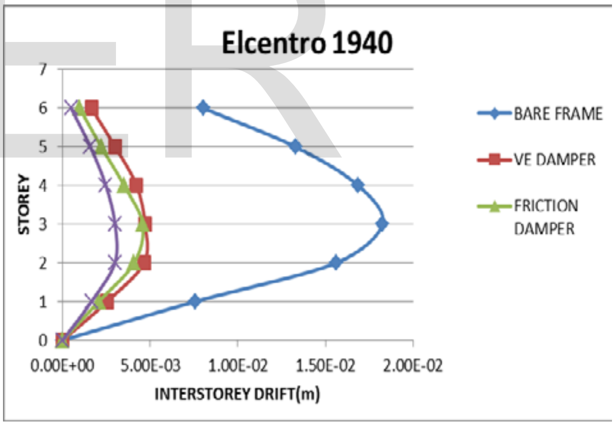


Fig 11 Variations of Interstorey Drift with Elcentro input

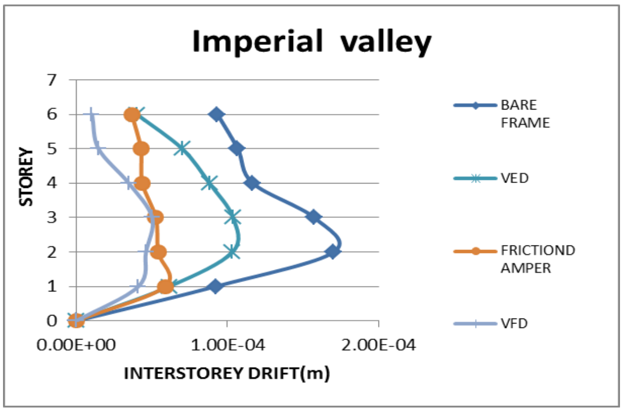


Fig 12 Variations of Interstorey Drift with Imperial valley input

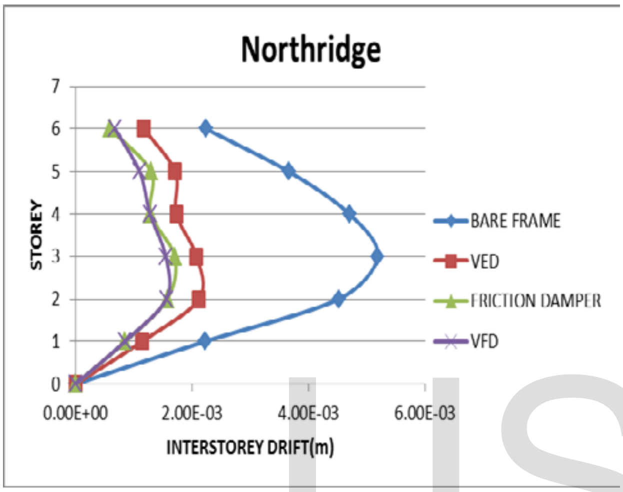


Fig 13 Variations of Interstorey Drift with Northridge input

C. *COMPARISON OF BASE SHEAR*

Base shear reduction occurs when VED and VFD are connected to the benchmark problem. Friction Damper shows a higher level of base shear.

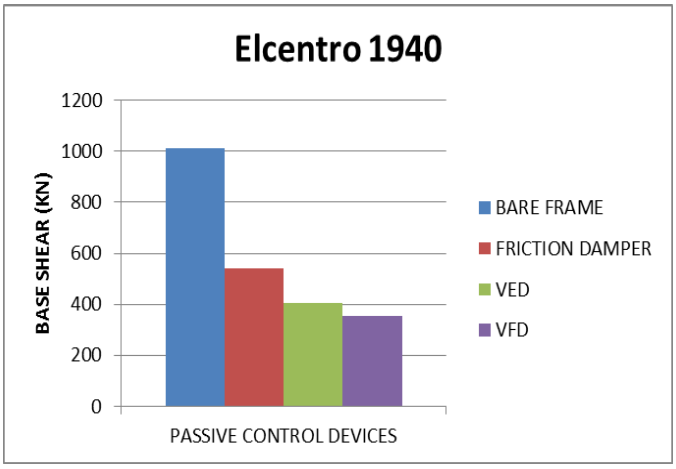


Fig 14 Variations of Base shear with Elcentro 1940 input

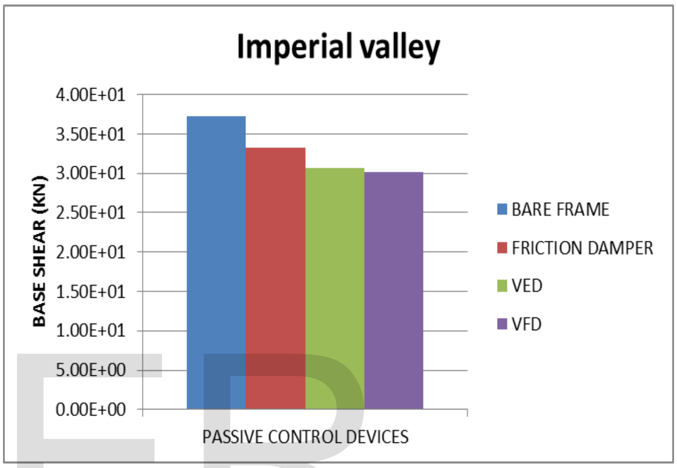


Fig. 15 Variations of Base Shear with Imperial valley input

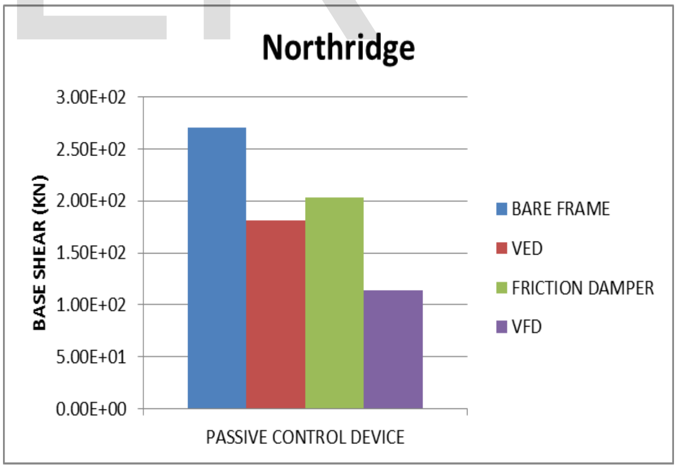


Fig. 16 Variations of Base Shear with Imperial valley inpuT

V. CONCLUSION

In this study the seismic response of the building is analyzed when it is connected with various passive damper and subjected to earthquake. 6

Storey benchmark building is modelled and analyzed using SAP2000 V19. Time History Analysis method is used for dynamic analysis. After the analysis results for passive dampers are obtained and compared and the results are as follows.

1. The Bare frame model is analyzed without damper and its displacements are 79.6mm, 22.5mm and 22.1mm when subjected to Elcentro 1940, Northridge and Imperial valley.
2. The Displacement results obtained after the connection of dampers shows 55%, 73%, 79% displacement reduction for VED, Friction damper, VFD respectively.
3. InterStorey drifts are within the permissible limit for all the passive dampers.
4. Base shear for the Friction damper is higher when compared to the Viscous Fluid damper, Viscoelastic damper.

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