RETROFITTING OF REINFORCED CONCRETE FRAME BUILDING USING METALLIC DAMPERS

A DISSERTATION

Submitted in the partial fulfilment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

EARTHQUAKE ENGINEERING

(With specialization in Structural Dynamics)

by

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Dedicated

to

My Parents

CANDIDATE’S DECLARATION

I hereby, declare that the work which is being presented in this dissertation entitled, **“RETROFITTING OF REINFORCED CONCRETE FRAME BUILDING USING METALLIC DAMPERS ”**, being submitted in partial fulfilment of the requirements for the award of degree of Master of Technology in Earthquake Engineering with specialization in Structural Dynamics, to the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee under the supervision of Dr. R.N. Dubey, Associate Professor, Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my own work carried out during the period of June 2018 to June 2019.

I declare that I have not submitted the material embodied in this dissertation for the award of any other degree or diploma.

Place: Roorkee
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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Place: Roorkee
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ABSTRACT

Past studies have revealed that safe handling of earthquake by building structures requires reasonable amount of energy dissipation. The conventional practice is to adopt masonry infills and bracing system as lateral load resisting systems. Seismic behavior of metallic damper in reinforced concrete building is still not fully established. The study focuses on exploring methodology for design of shear yielding dampers and response of reinforced concrete building equipped with dampers, which is actually designed for gravity loads. In addition, this study attempts to explore the ambiguity in selection of stiffness ratio (SR) and response of metallic dampers. The outcome of this will help forward to explore the applicability of SR value in other type of similar building. Hence, it is an initiative towards the incorporation of the overlooked design parameter, which will yield economical use of damper and change in response of building.

The study adopts energy dissipating device (EDD), which is an immediate choice nowadays particularly passive metallic damper with bracing, is currently trending in earthquake engineering community. Shear yielding damper is the recent development and adopted widely. The effectiveness of metallic damper as a device for energy dissipation during earthquake relies on various design parameters namely connection efficiency, stiffness ratio, yield strength of shear and flexure plates. The most equivocal parameter is brace stiffness to device stiffness (B/D) ratio and device stiffness to bare frame stiffness (D/F) ratio. Past studies did not suggest and justified the adoption of SR value. Adopting single value of SR for all storey may not show uniform dispersal of ductility and fully utilize intended inelastic behavior of the damper. The present study tries to explore the reasonable value of SR by adopting given methodology and variety of analysis. Thus, to optimize the dynamic response based on uniform distribution of deformation, different B/D ratio must be adopted.

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A_w	Area of web
τ_{avg}	Average allowable stress
Δ_{roof}	Displacement at the roof
φ	Design Shear Strain of Damper
α	Angle subtended by brace with horizontal
P_{cr}	Buckling load for Brace
V_{cr}	Lateral shear buckling Load for Brace
f_a	Allowable stress for brace
R_{cr}	Maximum Shear Strength of link
$\sigma_{0.2}$	Tensile yield Strength of link
k	Stiffness of system
Δ_{Avg}	Average Storey displacement
D	Depth of Shear link

CHAPTER 1 : INTRODUCTION

1.1 General

In India there are seismically active zones, which had shown its hazard potential in past. The conventional and traditional method of structural design has overlooked the structural safety of many buildings. The concerned design forces in case of earthquake resisting structure are lateral loads. The building structures constructed in earthquake prone areas with the idea that it shows effective performance against dynamic action of earthquake. Numerous building across seismic zone V are standing with zero assurance of its survival during earthquake. In addition, it is also not possible rather a huge task to retrofit all seismically deficient buildings.

The two very basic philosophy to acknowledge earthquake is (a) Design of structure to endure ordinary earthquake that has small structural and nonstructural damage (b) Design for extreme earthquake to avoid structural collapse.

The performance and response of building is shown by multiple parameter, which includes inter storey drift, ductility, strength, floor acceleration and energy dissipation. Energy dissipation is one of the concerned area for reinforced concrete building during earthquake. Adequate lateral load resisting ability of a multi-storey building is high priority and in addition it is required that building show uniform distribution of ductility against earthquake. In India, many of the buildings designed are based on gravity loads and are not efficient to perform against earthquake loads. Many buildings in the cities that lies in zone V are vulnerable to earthquake forces. Therefore, the retrofitting of important structure is the need to safeguard them against future earthquake motion.

A need for a design that controls structural and nonstructural damage is required. Structural systems can significantly enhance the seismic performance of buildings by controlling inelastic deformation demands on the lateral load resisting system. There are multiple options available for general retrofitting of building but it also depends on economics and kind of deficiency.

In this thesis, retrofitting of gravity based designed building has been attempted using shear link and chevron brace assembly. Shear link represents metallic damper whose design parameter and methodology is discussed in details in the following section.

1.2 Need for Study

Retrofitting of RC buildings require judicious choice of stiffness ratio. Adopting single value of stiffness ratio (SR) for all storey may not show uniform dispersal of ductility and fully utilize intended inelastic behavior of the damper. This study tries to explore the reasonable value of SR. Thus, to optimize the dynamic response based on uniform distribution of deformation, different B/D ratio must be adopted. If same value of SR is adopted for all the storey, all the dampers will not be utilized to their full potential hence judicial choice is required in selecting the size and stiffness of dampers along the height of the building.

1.3 Objectives

The main objective of this study is to enhance knowledge and proficiency in earthquake resistant design and seismic retrofitting of existing reinforced concrete structures and to get familiar with modeling and analyses of buildings against earthquake loads. The objectives of this study are:

1. To investigate response of existing building analytically under the effect of earthquake load.
2. To retrofit the deficient RC building and study the behavior of metallic damper in RC structure.
3. To estimate the stiffness ratio and location of damper to reach at the optimum value of SR for given RC building.
4. To study the effect of varying damper width and shape ratios along the height.

1.4 Scope of Study

The present study deals with analysis of seismically deficient building and further retrofitting it using passive energy dissipating device that is metallic damper. The comparative study of the retrofitted building using shear link element and then arriving at particular value of stiffness ratio is part of the study. The analytical study carried out involves nonlinear static analysis and multiple nonlinear dynamic analyses. In addition, comparative study on the response of brace retrofitted building and passive energy device retrofitted building has been done which shows the comparison of initial stiffness. The optimum value of SR obtained by analyzing the result will decide the design stiffness of dampers.

1.5 Organization of Thesis

Chapter 1 talks about the basic outline of the thesis. The objectives, need and scope of study are part of this chapter.

Chapter 2 deals with the literature that involves study around the relevant topics. It discusses about the basic principle of damper and its preference over other alternatives. The chapter also highlights the importance of stiffness ratio. Past studies revealed that various design parameter were not recognized which are equally important shear link braced frame design.

Chapter 3 discusses the analytical modelling and analysis of building structure. The basic assumptions considered, analysis involved in each stage and response of building in different analysis.

Chapter 4 describes stiffness ratio and its importance as design parameter in any building using an example through multiple analysis.

Chapter 5 presents results and discussions that are relevant from building performance point of view.

Chapter 6 Conclusions and future scope.

CHAPTER 2 : LITERATURE REVIEW

2.1 General

Recent studies on the damaged structure especially reinforced concrete structure revealed that inadequate ductility of structure is a major concern in seismic prone areas. The inadequacy of concrete structure to dissipate the seismic energy is the major drawback. Conventional methodology to counter the lateral deficiency of concrete structure is bracing and masonry infills. They are good as far as stiffness enhancement is concerned. However, once they are damaged, their replacement and repair is cumbersome. Shear infill wall has many downside, as it has tendency to fail out of plane. On the other hand, bracing has buckling problem, which causes sudden drop down of stiffness of storey.

2.3 Various Types of Energy Dissipating Devices

(**Tremblay et al. 2003**) examined steel framed building of different storey; two, four, six and eight with self-centric energy dissipative (SCED) bracing members. Comparison of response was done with buckle-restrained braces (BRB). Building subjected to different ground motion corresponding to 50, 10 and 2% in 50-year hazard level. Study demonstrated SCED could be a good alternative to BRB frame construction. Peak storey drifts reduced, and residual deformation nearly eliminated during low hazard earthquake. In addition, system offers better resistance to collapse under MCE ground shaking. The other side of using SCED braces is floor acceleration pulses that may pose damage to other building component which are very stiff and brittle.

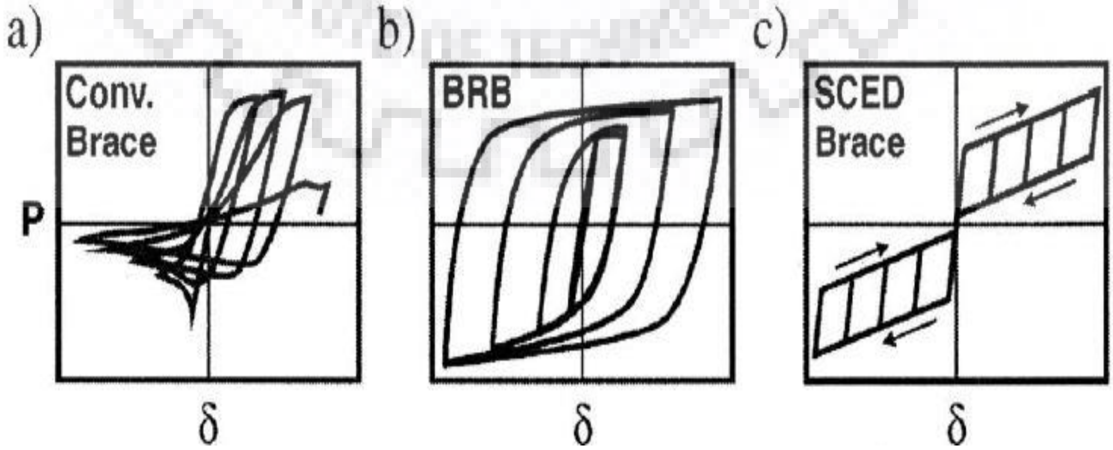


Figure 2.1 *Hysteresis Curve of Brace (a) Conventional (b) Buckling restrained (c) Self Centric*

2.2 Development of Passive Energy Dissipating System

Passive energy dissipating devices are currently one of the most efficient technological advancement in structural earthquake engineering community. Dissipation of energy is the key concern for safe and efficient performance of the structure. They absorb great amount of input energy and brings down the demand for primary structural member. Active and passive energy dissipating devices are preferred as they are economical when compared with other retrofitting option and strengthening procedure.

Base isolation is amazing concept to reduce the demand coming on to the structure. The basic principle underlying is to increase the natural period. This is achieved by absorbing material which acts as intermediate between superstructure and substructure. The shortcoming of active and hybrid energy equipment is that their action relies upon power. They start acting on earthquake excitation. In case there is power loss, they are inefficient to serve desired action. The passive energy devices have wide variety of development. Most of the devices are used termed as 'dampers'. Friction dampers, viscous dampers, liquid dampers and many more. Current ongoing research focusses on optimum performance and incorporation of these passive energy devices. Many industries came up with the devices based on hydraulics. However, they are expensive and not suitable for general building. Easy installation and replacement on damage makes these devices unique unlike other lateral load resisting assembly.

2.4 Metallic Dampers

(Rai and Wallace 1998) performed an experimental study to explore the enhanced behaviour of aluminium link in earthquake force resistance. To study the energy dissipating potential and to transfer the forces to the primary members through yielding in shear.

Low yield strength of aluminium allows using thicker section that result in higher cross-section of web and hence local buckling factor is taken care by the higher thickness. Fast and slow cyclic loading rate test conducted on different two-alloy specimen of aluminium. Aluminium link showed excellent energy dissipation and effect of loading rate was minimal. Hysteresis loop observed until 10% shear strain. Numerous experiments on various specimen were conducted which enabled them to propose aspherical equation.

In design of shear link braced frame, shear link was positioned in between top of the chevron bracing and the girders of floor of that storey. Resulting in yielding of link element before the buckling failure of compression brace.

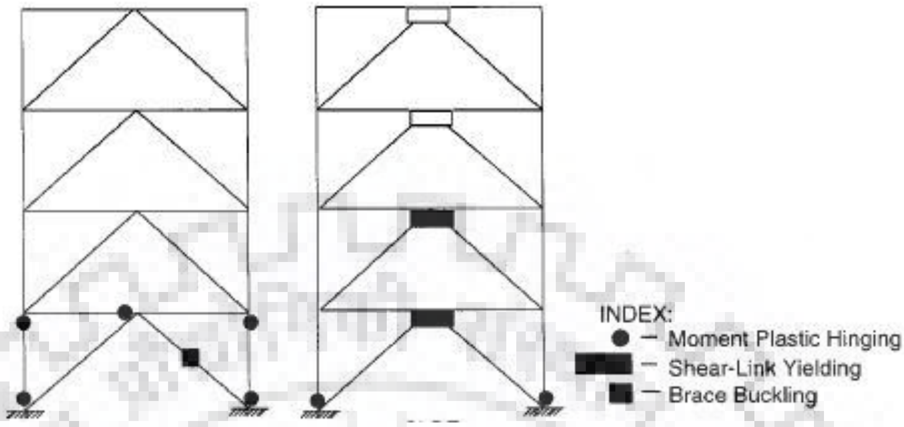


Figure 2.2 *Location of Plastic Hinge Formation in Braced only and Link Braced Frame at Final Collapse*

Finally, the comparison of shear link braced frame and ordinary braced frame was made. It showed that the uniform distribution of storey drift, reduced base shear and more energy dissipation in case of link equipped frame as compared to that of ordinary braced frame.

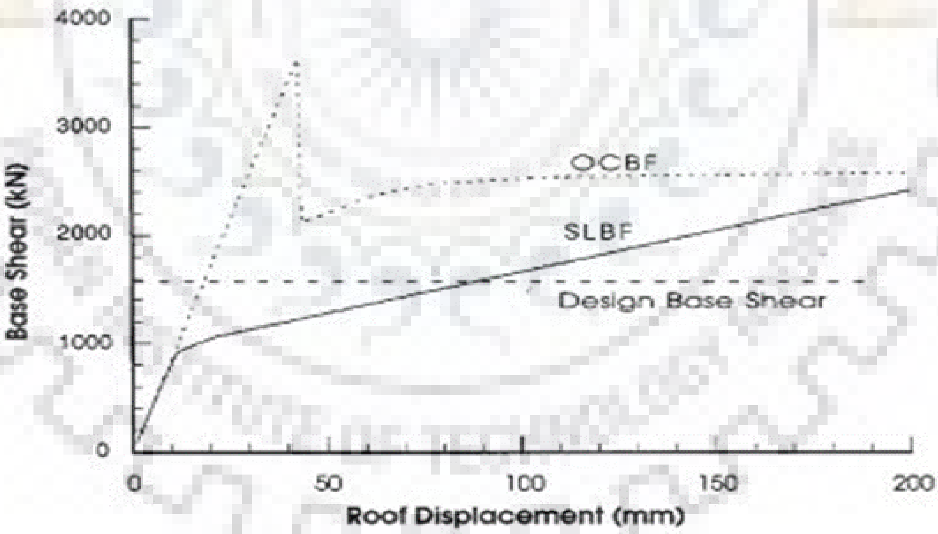


Figure 2.3 *Comparison of Pushover Curve for Link Braced and Braced Frame*

(Khosravian and Hosseini 2012) carried out study on plane shear building of 10 storey using metallic damper triangular added damping added stiffness(TADAS) as passive energy dissipating device using genetic algorithm. Selection of damper parameter and optimum number was explored using genetic algorithm. Non-uniform stiffness of damper considered along the height by adopting different number of damper blades in each storey.

Number of dampers and parameter are decided based on suggested optimisation technique. It involves genetic algorithm to optimise the number of blades in dampers. Response reduction of building using different blades at given location justified through reduced value of base shear by 27% and inter-storey variation narrowed down to uniform value along the height of building depicted in figures given below.

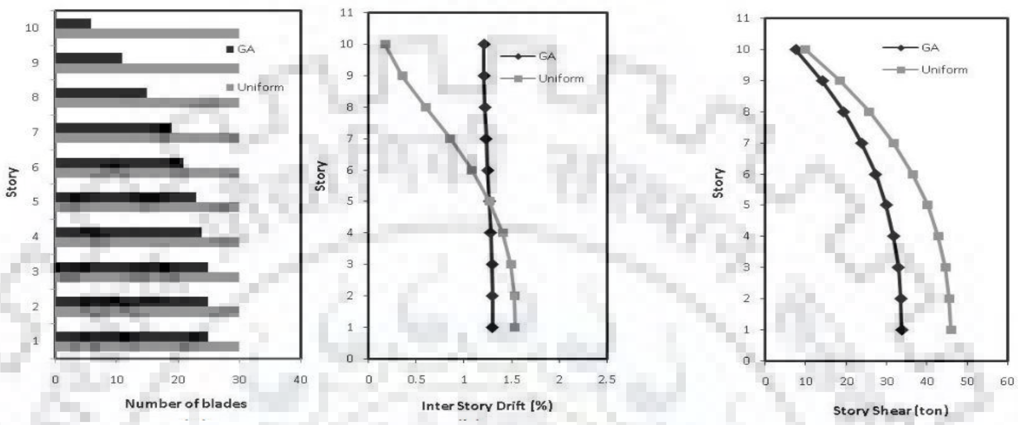


Figure 2.4 (a) *Number of Blades used in Dampers* **(b)** *Variation of Inter-Storey Drift along the Height* **(c)** *Variation of Storey Shear along Height*

(Sahoo et al. 2015) carried out finite element study on cyclic behavior of flexure and shear yielding damper (SAFYD) for prediction of the ultimate resistance and hysteretic response of specimen. The main parameters explored were load-carrying capacity, hysteretic response, dissipation of energy and ductility. End plate of X-configuration was allowed to yield in flexure and web plate of the device was allowed to dissipate energy through shear yielding. Shear and flexure yielding enhances the energy dissipating potential and lateral load resisting capacity when compared to other counterpart ADAS and shear link. Economically also it was found that the proposed assembly SAFYD is superior. The experimental study could be extended by performing finite element analysis to obtain further hysteresis curve.

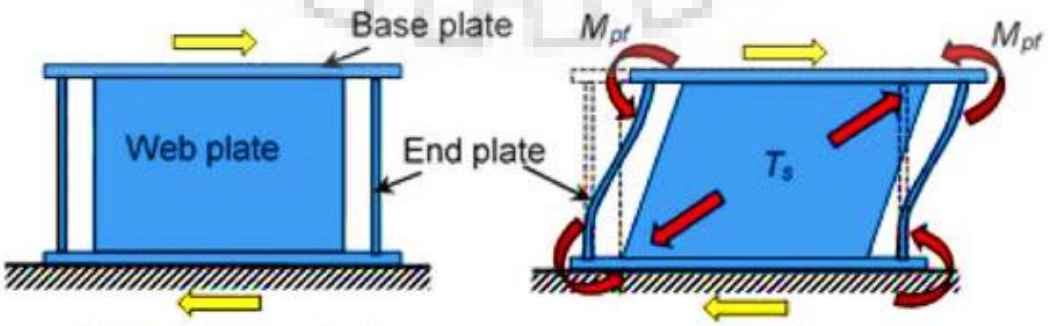


Figure 2.5 *Arrangement of Plate at Initial and Deformed Stage*

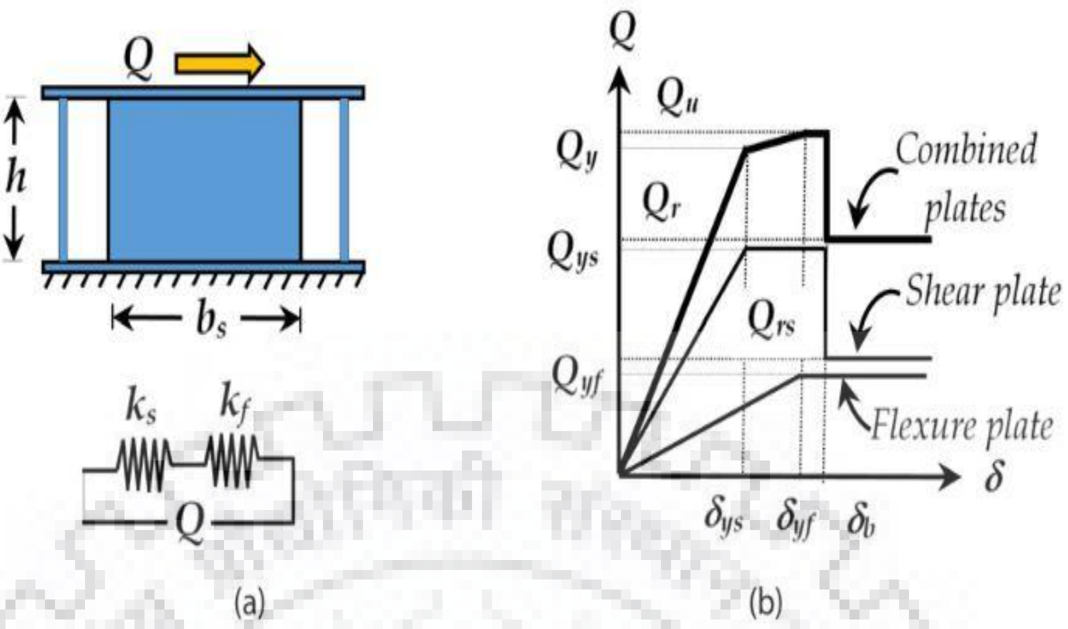


Figure 2.6 (a) *Equivalent Model of Device* **(b)** *Force vs Deformation Curve and Comparison*

(Alehashem et al. 2008) explored the performance of ADAS and TADAS damper in comparison with the traditional lateral load-resisting member that are concentrically braced frame, eccentrically braced frame and chevron braced frame. Three different earthquake motions were used to carry out numerical simulation of multi-storeyed building. First mode period was to be more for metallic dampers as compared to that of conventional braces. Comfort level in building equipped with metallic damper was more as roof acceleration is less as compared to other system. Result suggested that damage are prone to be in damper due to flexure yielding of plate, which ensures that structure is safe under earthquake**.** Inelastic deformation of metallic plate ensures the energy dissipation. Roof acceleration found to be less in case frame equipped with metallic fuse as compared to other load resisting assembly. ADAS and TADAS adoption resulted in increase in fundamental period as compared to other systems.

(Teruna et al. 2015) carried out experimental study to get the performance of metallic damper using different geometrical shapes of flexure plate made of mild steel. Comparative study was performed to evaluate the hysteretic behaviour. Convex shaped plate showed superior energy dissipating characteristics and ductility factor as compared to other types of plate. Deformation vs load curve segmented into Bauschinger, skeleton and elastic unloading zone. Concerned parameter to define behaviour of damper such as elastic stiffness, yield strength and stiffness ratio after yield obtained from skeleton curve. Furthermore, the skeleton curve drawn using experimental result was taken as basis for development of approximate trilinear hysteretic model.

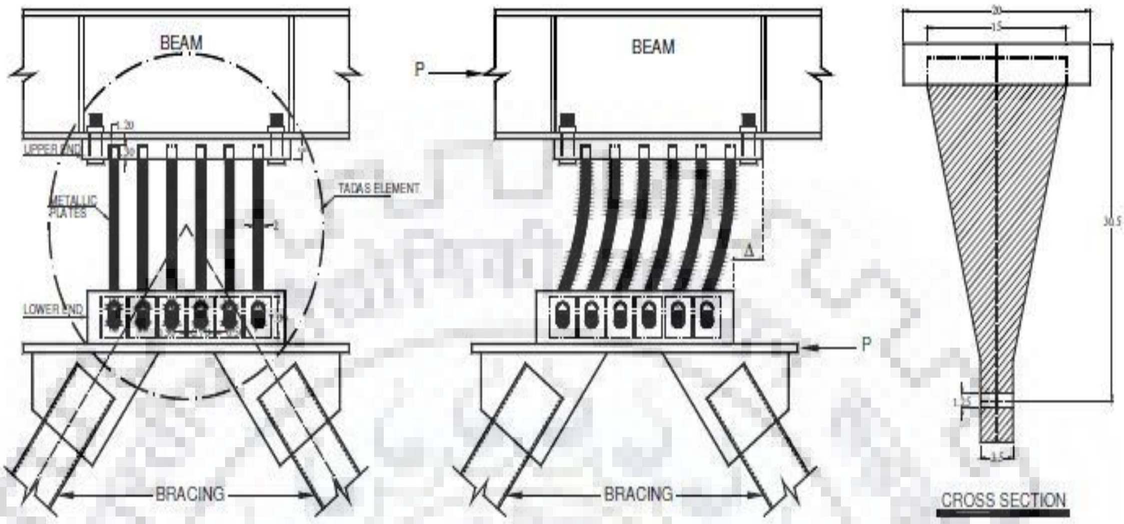


Figure 2.7 *Behavior of Flexure Yielding Damper under Earthquake*

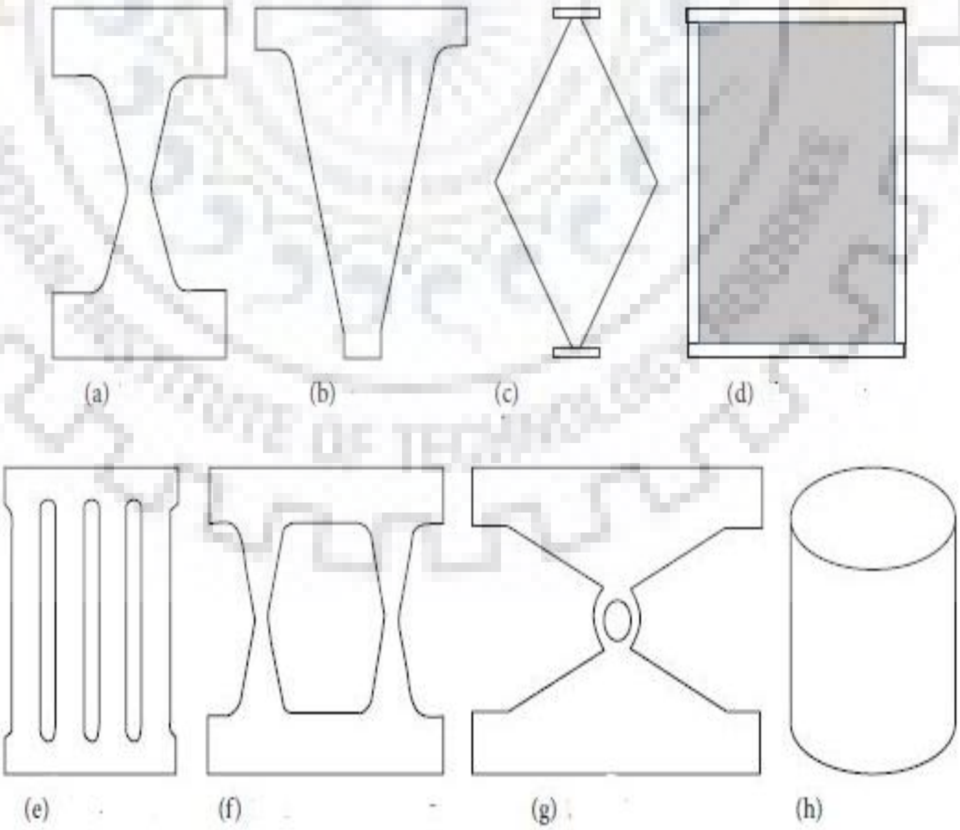


Figure 2.8 *Various Hysteresis Steel Damper* ***(a)*** *XADAS* ***(b)*** *TADAS* ***(c)*** *Rhombic shaped* ***(d)*** *Panel* ***(e)*** *Slit* ***(f)*** *Honeycomb* ***(g)*** *Dual Function Damper* ***(h)*** *Circular Plate*

(Basu and Reddy 2016) carried out an analytical study to show the behaviour of metallic damper that is capable of dissipating energy irrespective of the direction of ground motion excitation. Hourglass added damping added stiffness damper (HADAS) design is similar to that of ADAS except it includes an extra modification in yield load. HADAS damper shows superior performance than ADAS and TADAS damper, as they are capable in resisting one directional earthquake ground motion. It helps in dissipating energy regardless of earthquake direction. Furthermore, it also shows better results for column shear demand and drift. HADAS also proved to be cost effective option when compared to ADAS and aluminium in HADAS system shows better corrosion resistant properties than mild steel in ADAS. Although the major setback in using HADAS is that it hinders the functional requirement, as it requires four adjacent bays for its installation .HADAS system is less prone to failure through neck formation.

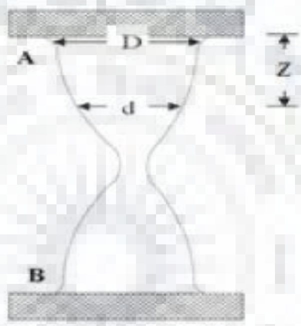


Figure 2.9 *Profile of Hourglass ADAS*

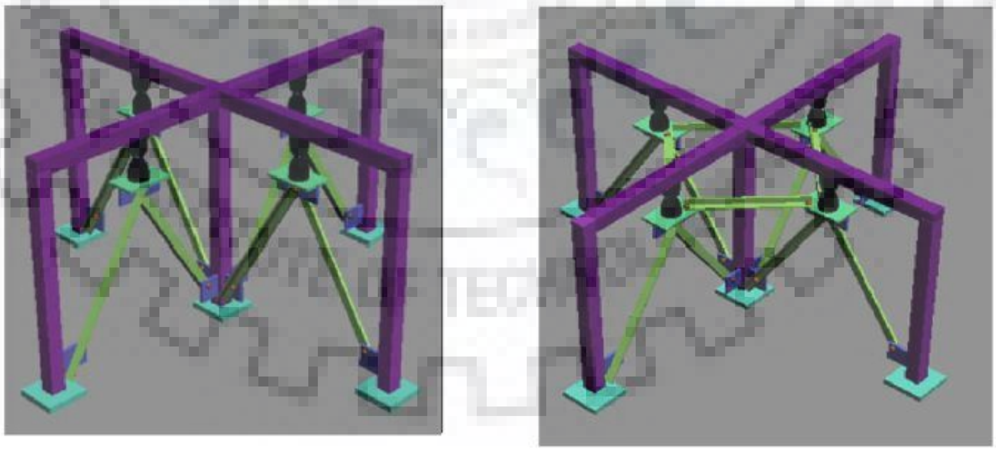


Figure 2.10 (a) *Conventional System of Brace and Device* **(b)** *Proposed 3D Bracing Damper System*

(Bayat and Abdollahzade 2011) carried out study to compare the response of structure having ADAS as energy dissipating device. Concentrically braced frame with and without ADAS damper in five, ten, fifteen storey three bays building is analysed. PERFORM 3D software was adopted to carry out nonlinear analysis for three different earthquake ground motion. Higher ratio of plastic energy to input energy shows better performance of ADAS device in contrast with that of CBF. Maximum total input energy is utilised in exploring the response of structure. Furthermore, the ratio of hysteretic to input energy for an ADAS device is more than that for CBF.

2.4.1 Flexure yielding and shear yielding damper

The type of deformation decides the extent of efficiency of damper. If damper has yielding phenomenon in flexure it is called (Added Damping Added Stiffness) and it resist small load and offers comparatively smaller stiffness. If damper has yielding phenomenon in shear, it is called as shear-yielding damper and it offers significant stiffness and post yield deformation. Combined metallic damper is new advancement, which incorporates both types of yielding.

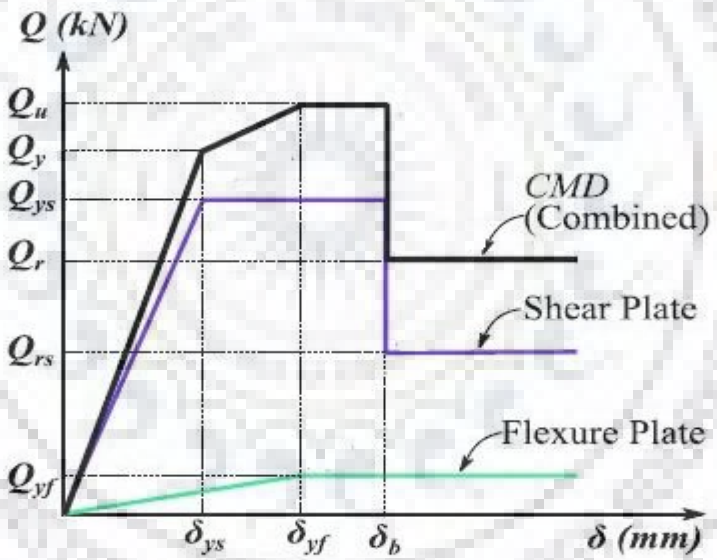


Figure 2.11 *Backbone Curve of Combined Metallic Damper*

2.4.2 Preference for metallic damper

Every lateral load resisting system has its unique merit and demerit. The simplified design methodology and its easy installation makes it unique. The admiring add on is that it can be easily replaced once it fails. The supporting bracing always keep the damper proactive. Temperature and humidity has minimal effect on metallic damper. Energy is absorbed at concentrated part and it acts as fuse dissipating earthquake energy. Shear yielding metallic damper offers reasonably high stiffness and damping.

2.4.3 Principle of metallic dampers

Inelastic deformation of material is the best effective technique to dissipate energy. Dynamics of structure is concerned with dissipation of energy. The hysteresis behavior during the yielding process is the basis of safe energy dissipation. In earthquake engineering, structural design is dependent on post yield ductility of frame element. The yielding of metals can provide dissipation of considerable amount of energy.

The principle behind the action of dampers installed with building structure is storey drift. Under earthquake load, storey drift tend to initiate the deformation process in metallic damper that are actually below the beams. Relative movement in upper and lower plates produces resisting action in damper. When it reaches in inelastic stage it is activated as energy dissipater. The point of energy absorber is metallic damper also pronounced as fuse element. It helps in preventing yielding of primary frame member which otherwise be responsible for energy dissipation.

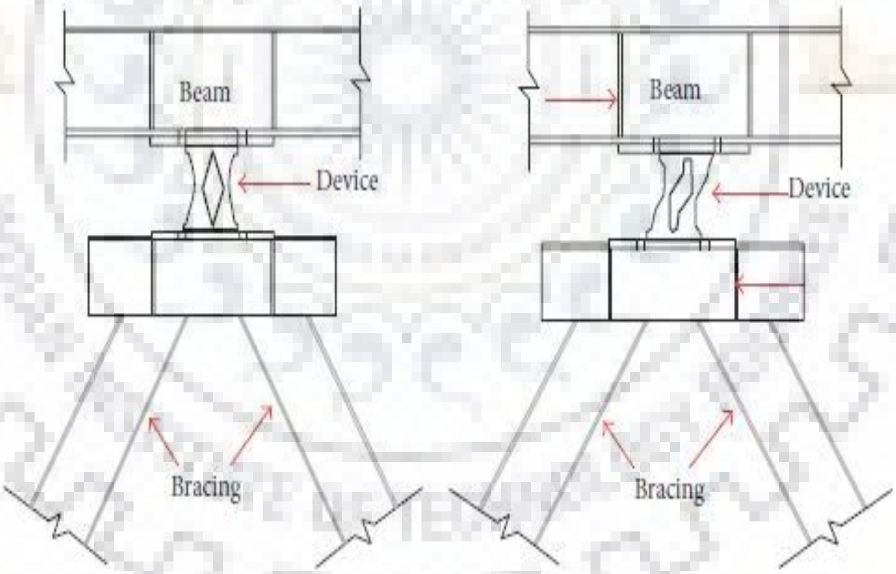


Figure 2.12 *Configuration and Action of Damper and Inverted Bracing*

2.5 Stiffness Ratio

(**Moreschi and Singh 2003)** suggested the optimal design of yielding damper and friction damper using genetic algorithm. Both the assembly act as fuse with high nonlinearity and have different parameter, which control their seismic behavior. Based on required performance objective different parameter are decided optimally. The concerned design parameter were yield force, brace stiffness and damper stiffness. Multiple examples presented using suggested optimization technique for desired performance objective.

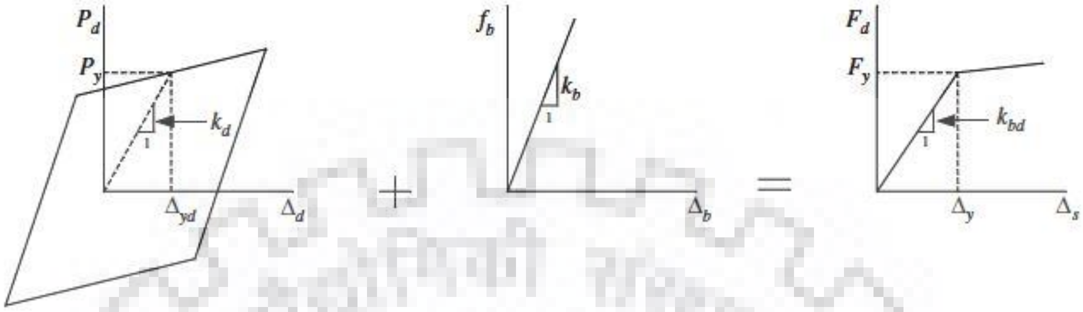


Figure 2.13 *Combination of Load Displacement Curve of Brace and Device*

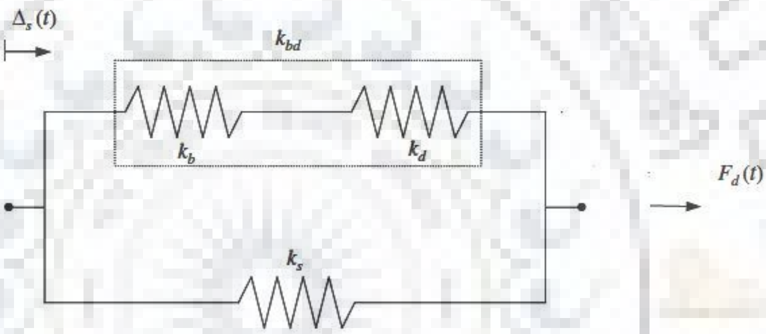


Figure 2.14 *Representative Stiffness of Assembly and Storey*

Optimal solution suggested using algorithm based on concerned performance criteria. Two index was used as for directing the algorithm. The two index used was based on maximum storey drift and roof acceleration. They have considered values of stiffness ratio in between zero to ten and B/D ratio in between one to ten. Improved performance index for higher number of variable indicated the enhanced flexibility in achieving objective. Study reveals that the types of dampers adopted are highly nonlinear in nature so multiple sequential time history analysis would be an appropriate choice to arrive at optimal value of design parameter.

(Chaudhury and Singh 2014) suggested a step-by-step methodology for designing a reinforced concrete building using passive energy dissipating devices based on performance based design. Authors talked about steps required to arrive at design forces for dampers. Study also talks about the variation of axial forces and shear forces in the critical column. In addition, different stiffness ratio values adopted and multiple analysis conducted to arrive at the effect of this parameter on the response of building. The study reveals that the adoption of passive dampers results in decrease roof displacement and increase in axial forces and increase enhanced seismic performance.

(Teruna and Wijaya 2018) studied about the vulnerability of building considering stiffness ratio as concerned parameter for design. They tried to explore the effect of stiffness ratio on the seismic response of structure under multiple dynamic excitation. Under the influence of strong earthquake, not all dampers may reach inelastic range. Therefore, adoption of higher stiffness ratio does not necessarily beneficial. They have considered stiffness ratio in the range of two to six. In addition, they have taken B/D as two. For weak earthquake and required structural performance below immediate occupancy, higher stiffness damper may not show hysteresis behavior. Damper yield limit should be less than the allowed storey drift in order to activate it and utilize its nonlinearity.

2.6 Braced Frame Behavior

(Moghaddam et al. 2005) suggested a methodology to optimize the response of building based on concept of uniform displacement. It involves great deal of multiple dynamic analysis. It is an iterative method to achieve a uniform deformation along the height. The redistribution of stiffness was done based on the roof displacement in each of the iterative step. The storey that has higher inter-storey drift is made stiffer multiplying by appropriate factor to resisting system and similarly system stiffness is reduced for the storey that has lower drift. It resulted in proper utilization of lateral load resisting systems. They intended to arrange the bracing system in such a manner to minimize the maximum inter-storey drift.

$$(K_i)_{n+1} = (K_i)_n \left[\frac{\Delta_i}{\Delta_{avg}} \right]^{\alpha} \quad (1)$$

α is coefficient of convergence that is 0.2 and K is the bracing stiffness for particular storey at particular iteration.

Comparative analysis of optimized braced frame and conventional frame is done. The structural response of optimized structural frame prone to less damage as compared to the conventional frame.

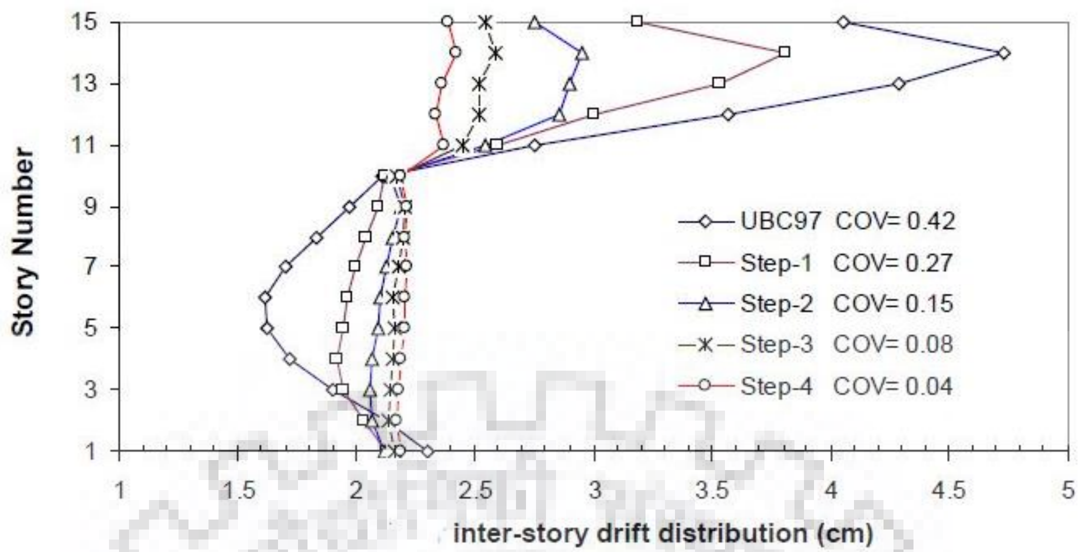


Figure 2.15 *Storey Drift Distribution from UBC97 Designed Model towards Final Design*

(Vijayanarayanan et al. 2017) discussed about the seven different types of method to calculate approximate storey stiffness. Three of them are simply involves basic equation and obtained manually and rest four methods are based on analysis output from software. They concluded fundamental transitional mode shape procedure is the most appropriate as it involves the dynamic response of structure involving modal analysis. In addition, it involves minimal simplifying assumption. It takes into account axial, shear deformation and flexibility of column beam joint. Results are indeed readily available and it is most practical way to counter the cumbersome conventional methods to calculate storey stiffness.

$$\left\{K_1;........;K_{j-1};K_j\right\}^T = \left\{\left[\frac{\omega^2\sum_{i=1}^{j} m_i\phi_i}{\phi_1}\right];..........\left[\frac{\omega^2\sum_{i=j-1}^{j} m_i\phi_i}{\phi_{j-1}-\phi_{j-2}}\right];\left[\frac{\omega^2 m_j\phi_j}{\phi_j-\phi_{j-1}}\right]\right\}^T \quad (2)$$

(Sahoo and Rai 2010) conducted an experimental study to compare the behavior of strengthened non-ductile reinforced concrete frame and link braced frame. Unique energy dissipation capacity and damping capability of shear link enhanced lateral response of frame and the level of damage reduced up to significant drift level. Shear link dissipated approximately 67% of total energy and equivalent damping enhanced to twice in case of strengthened frame to that of bare frame. Until 3.5% of storey drift column member was able to sustain lateral loads and enhanced damping reduced lateral demand

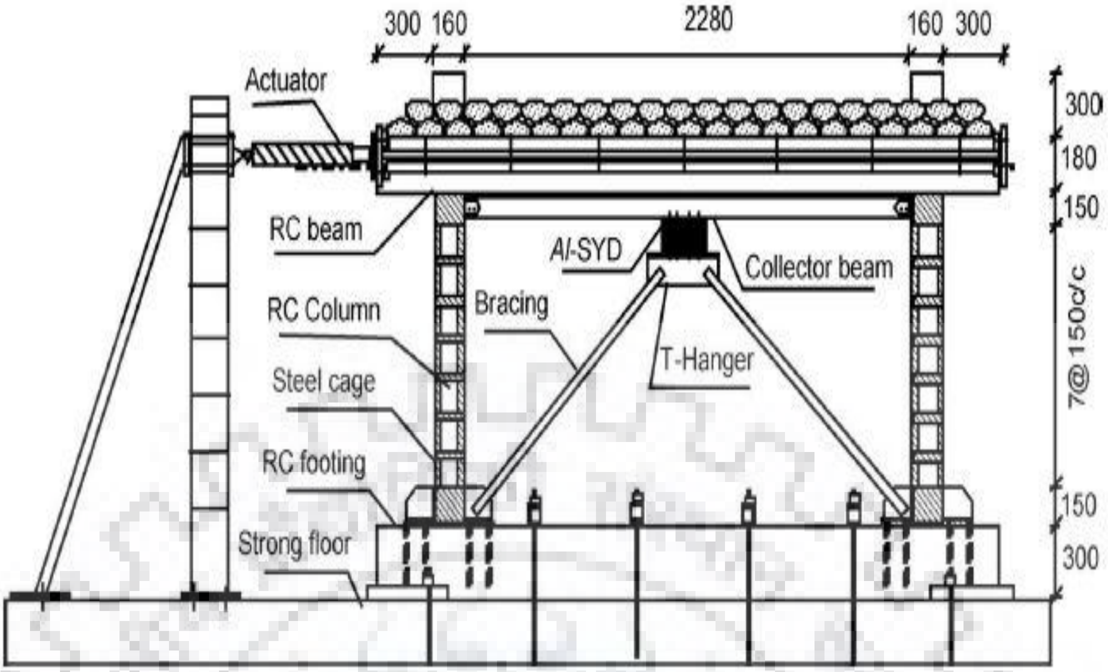


Figure 2.16 *Experimental Setup of Strengthened RC frame*

(Durucan and Dicleli 2010) proposed a methodology to enhance the performance of deficient structure under earthquake. The steel frame is retrofitted using infill frame and chevron brace. The method mentioned involves equalization of dissipated energy of building. The response spectrum analysis and pushover analysis is integrated and their energy difference is obtained to get the design parameter for lateral load resisting system. Efficiency of proposed methodology is compared at various level of performance. The methodology enhanced the ductility of structure unlike the conventional methods of retrofitting at collapse prevention.

(Maniyar and Paul 2012) carried out analytical study on seismic response of metallic damper. The study was conducted in two stages (a) Retrofitting of RC structure using link element and (b) Response of structure and its behavior under dynamic load. Design of lateral load resisting system is based on the energy principle. The amount of excess energy left that is not sufficiently dissipated by the deficient structure is the basis of design. The distribution of brace and damper assembly is following the principle of equal energy distribution. Although this is valid, only for the structure having small period. As the period is high, equal displacement principle must be used.

CHAPTER 3 : MODELLING AND ANALYSIS

The configuration of building selected is representative commercial RC building commonly located in Indian seismic zone V as per **IS 1893 (Part- 1)-2016** constructed on soft soil. To avoid the complex interpretation of irregular building, a six-storey building having regular symmetric floor plan and equal height of floor level has been adopted. The inadequacy to cater dynamic earthquake load makes the building seismically deficient. Building is retrofitted using passive energy device. The building is designed for gravity loading as per **IS 456-2000.** The deficient building is inadequate to cater the earthquake loads.

3.1 Building Description

Table 3.1 *Technical Parameters adopted and Loading on Commercial Building*

Live load	4.0 kN/m^2 at all floor
Floor finish	1.0 kN/m
Terrace finish	1.0 kN/m^2
Wind load	Not considered
Earthquake load	As per IS 1893 (Part 1)-2016
Seismic zone	V
Type of soil	Type III, Soft soil as per IS:1893(Part 1)-2016
Importance Factor	1.5
Response Reduction Factor	5
Allowable bearing pressure	200 kN/m^2
Storey height	Typical floor: 5 m
Floors	Ground floor + 5 upper floors
Walls	230 mm thick brick masonry walls
Material Properties:	
Concrete	M25 grade all unless specified
Steel	HYSD Fe 415 used throughout

Table 3.2 *Details of Commercial Reinforced Building*

Details	Dimensions	Remark
Floor plan dimensions	22.5m x 22.5m	Each bay of 7.5m
Height of building	30.0m	Floor height of 5m
Members dimensions		
Concrete column	Periphery 500mm x 500mm Middle 550mm x 550mm	M25
Concrete beam	600mm x 300mm	M25
Concrete slab	150mm	M25
Masonry walls	230mm	

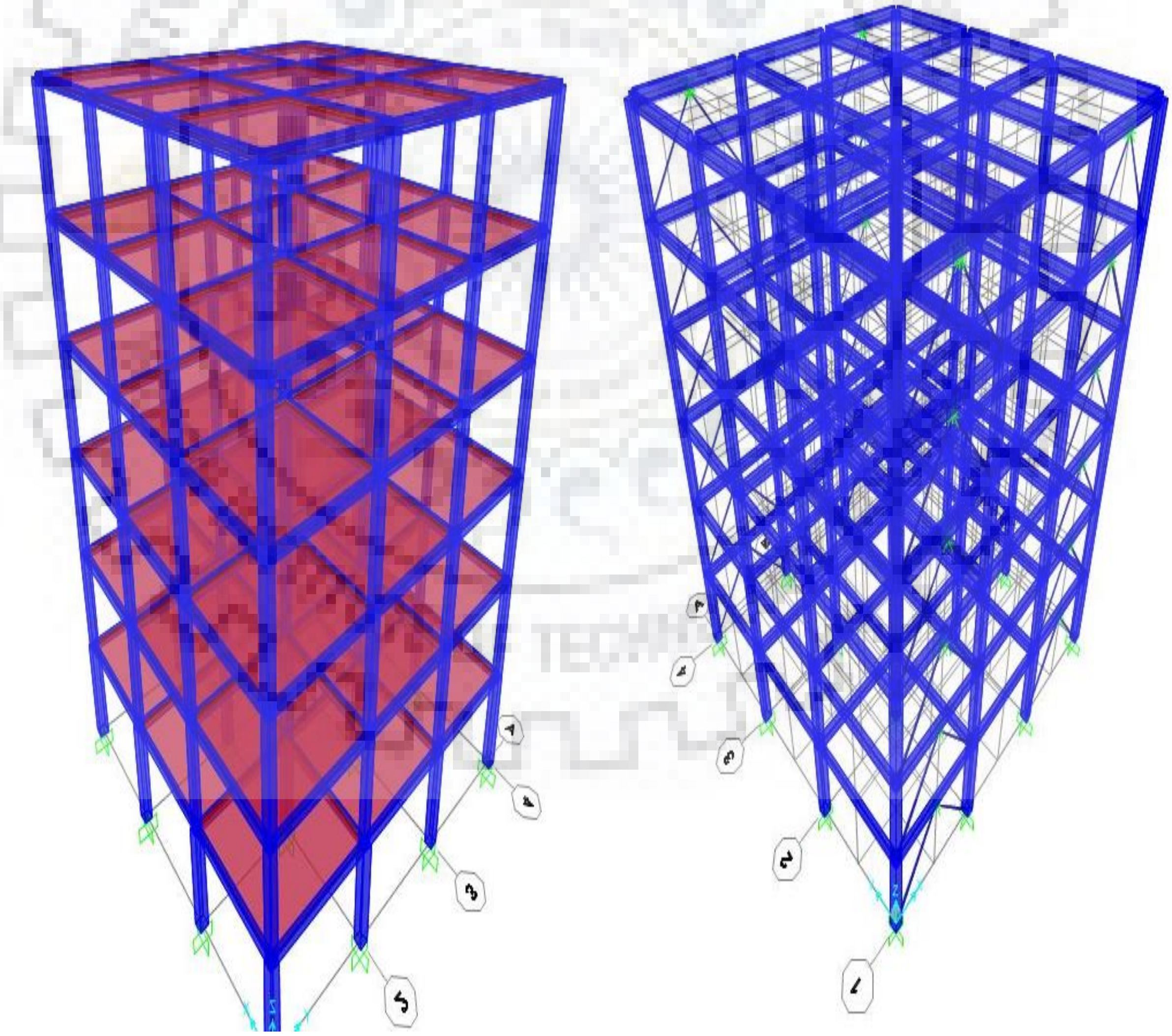


Figure 3.1 *3D Modelling of Building without Dampers and with Dampers*

3.2 Analytical Modelling

(**SAP2000 2019)** v20.1.0 is general-purpose software program used for dynamic nonlinear analysis of 3D space frame. Formulation of program is based on the member-to- member modelling approach. It involves design of beams, columns, braces and shear link etc.

3.2.1 Modelling of frame elements

Columns and beams have been modelled with six degree of freedom at each node using line frame elements. Modification factor has been used for cracked section stiffness. Flexure rigidity and shear rigidity both are respectively modified by factor 0.5 and 0.4. (ASCE-41). The in plane rigidity can be ensured by assigning diaphragm constraint at each storey level. IS 456-2000 has been incorporated for design of the members. Beams are designed as rectangular to distribute the moments to axial frame member on conservative side.

The base of the building was assumed to be completely restraint neglecting the effect of soil structure interaction.

3.2.2 Modelling of shear damper with chevron brace

Chevron bracings have been modelled using 'inverted brace' tool. The hollow pipe sections has been taken as it has greater fracture life and ductility as compared to that of other available section.

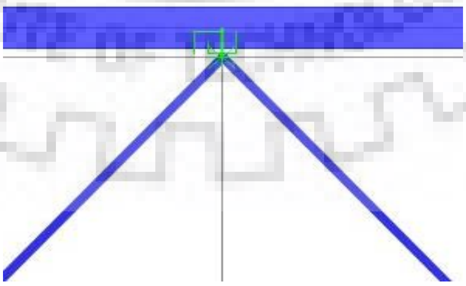


Figure 3.2 *Link Element Representative Model*

Link element assigned in SAP2000 incorporates the features of Rai and Wallace (1998) experimental work on aluminium shear link. Two joint shear link element assigned under the category of plastic wen type. It has an elastoplastic hysteresis curve of shear force displacement. Using the idealised bilinear curve all the parameters can be obtained and yield shear force calculated by multiplying average shear stress to web shear area (A_g). The depth of link is taken as per the past literature that is 1/12th of storey height. In the present work, it has been taken as 440mm that comes out 1/11.4th times floor height.

Table 3.3 *Parameters for Wen Link Element Model of Resulting Idealized Elastoplastic Curve*

Parameter	**Values**	**Remark**
Initial stiffness (K_1)	R_y / Δ_Y	Elastic range
Average shear stress	0.722fy	at 0.002 strain
Yield stress	35.2 MPa	
Post elastic stiffness (K_2)	$(R_{max} - R_y) / (\Delta_U - \Delta_y)$	Allowable strain=0.2
Post yield ratio	0.0128	K_2/K_1
Yielding exponent	2	Transition at yield
Yield shear force		

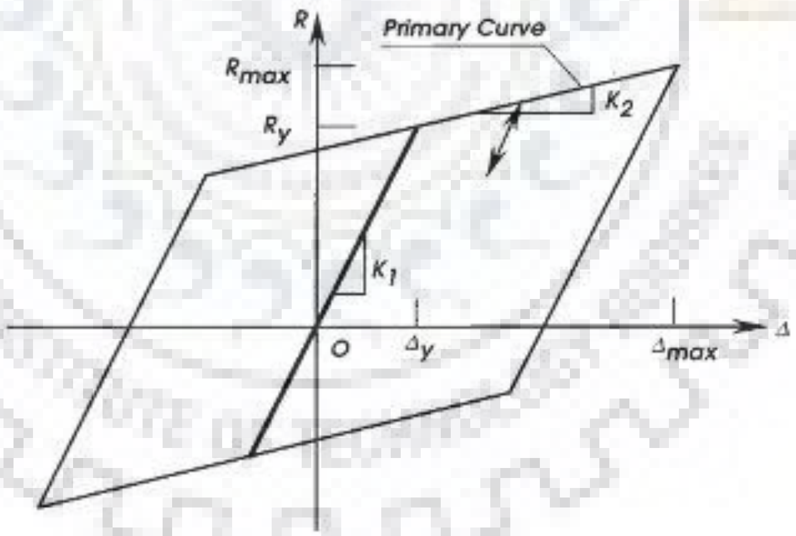


Figure 3.3 *Idealised Hysteresis Curve for Shear Link*

3.2.3 Assigning non linearity to frame element

To carry out nonlinear analysis using pushover method we need to take in account the nonlinear characteristics of frame. Nonlinear behaviour shall be ideally incorporated by assigning user-defined hinge as per the code followed in designing. However, SAP facilitates auto hinge option as per FEMA 356, which is useful for assigning hinges. The hinge property is based on capacity of given member.

In case of beams, nonlinearity is considered by assigning flexure hinge (M3) and in case of column, flexure hinge is assigned as (P-M2-M3) at both ends. On other hand in braces, nonlinearity assigned using axial hinge at middle of brace element. Factor of 1.25 and 1.5 were used for modification of expected strength of steel and concrete respectively to align it with (**ASCE-41 2017**), which is basis for default hinges.

3.3 Analysis

The building found to be safe in static gravity analysis, however it is unable to sustain lateral load caused due to earthquake in seismic prone area (zone V).

Seismic analysis of given deficient building involves dynamic linear analysis and nonlinear static analysis. Further, using link brace assembly in deficient building the same analysis is performed again to compare the results.

3.3.1 Response spectrum analysis

Response spectrum analysis was performed to evaluate the seismic response of original building as per IS 1893 (Part-1)-2016. In original building, modal analysis also considers response in vertical direction. The scale factor is considered and modification done with reference to the analysis done using static load method. Scale factor obtained using the ratio of base shear obtained from static earthquake loading to the base shear obtained by response spectrum in each direction. Although dynamic linear analysis is insufficient to show the actual response of the building and for further interpretation, nonlinear static (Pushover) and nonlinear dynamic analyses is performed.

Table 3.4 Output of Response Spectrum Analysis

Frame Type	Fundamental Time period (sec)	RSA Base shear (kN)	Maximum roof Displacement (mm)	Stiffness (kN/m)
Original Structure	2.3	440.27	35.05	12561.3
Braced Frame	0.67	782.27	16.80	46572.0
Link Braced frame	1.70	854.51	15.70	54354.9

3.3.2 Nonlinear Static Analysis

Pushover analysis is performed by subjecting the building to a monotonically increasing lateral loads representing inertial force, which will be experienced, by building during actual dynamic action. As load increases sequential yielding occurs via formation of hinges, energy is dissipated, and stiffness of building decreases as each step progress. The curve obtained represents the base shear force and deformation variation, which gives the idea about the behavior of structure.

3.3.3 Nonlinear Dynamic Analysis

For nonlinear dynamic analysis, eleven earthquake ground motions, mentioned in Table **3.5** were extracted from the Strong Motion Database of Pacific Earthquake Engineering Research Center (PEERC https://peer.berkeley.edu/). The extracted raw ground motion record have been scaled to compatible response spectrum as per IS 1893(Part-1)-2016 corresponding to 5% damping for soft soil. The amplitude scaling is done using Seismosignal software for the suggested time range as per ASCE-7.

Table 3.5 *Earthquake Ground Motion Used in Study*

S.No.	RSN	Earthquake	Year	Magnitude	PGA(g)
1	169	Imperial Valley-06	1979	6.53	0.69
2	737	Loma Prieta	1989	6.93	0.72
3	900	Landers	1992	7.28	0.59
4	1115	Kobe_ Japan	1995	6.9	0.56
5	1158	Kocaeli_ Turkey	1999	7.51	1.07
6	1496	Chi-Chi_ Taiwan	1999	7.62	0.50
7	1762	Hector Mine	1999	7.13	0.56
8	3748	Cape Mendocino	1992	7.01	1.02
9	4847	Chuetsu-oki_ Japan	2007	6.8	0.73
10	5832	El Mayor-Cucapah Mexico	2010	7.2	0.92
11	6969	Darfield_New Zealand	2010	7.0	0.57

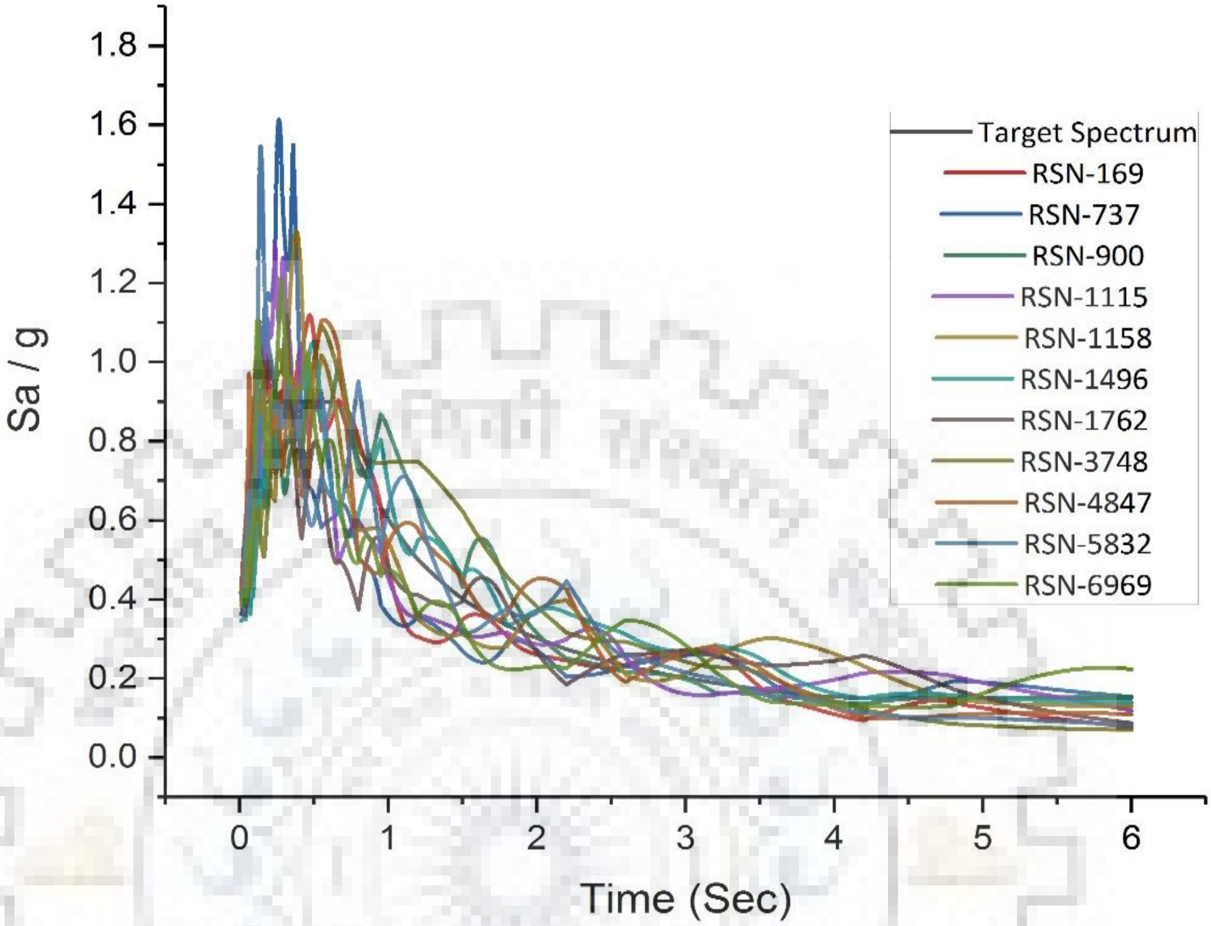
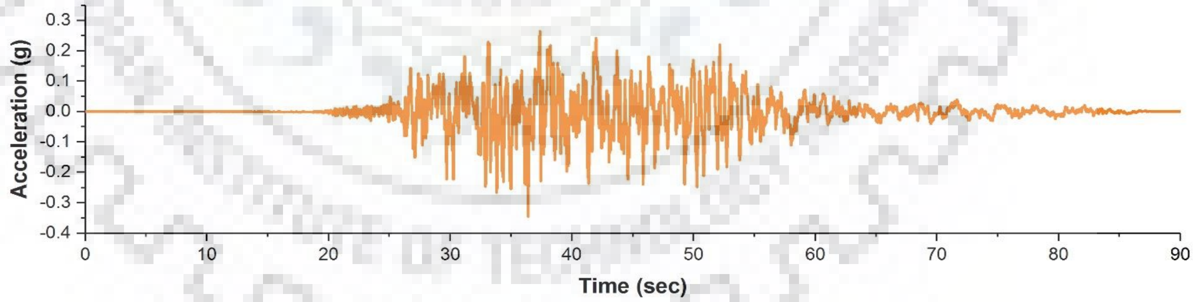
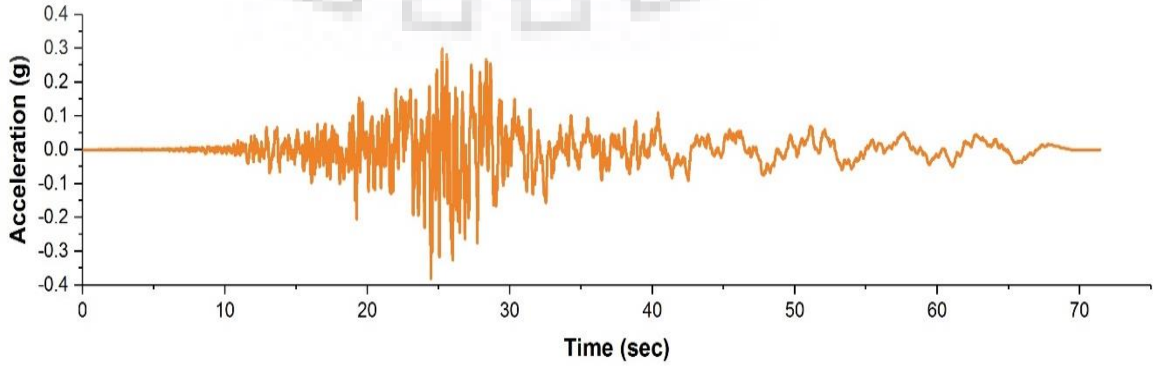
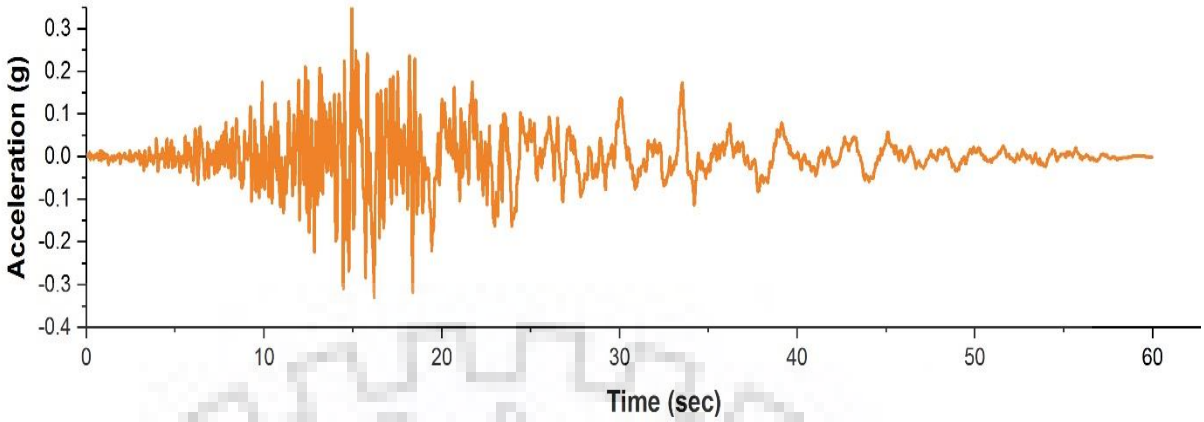
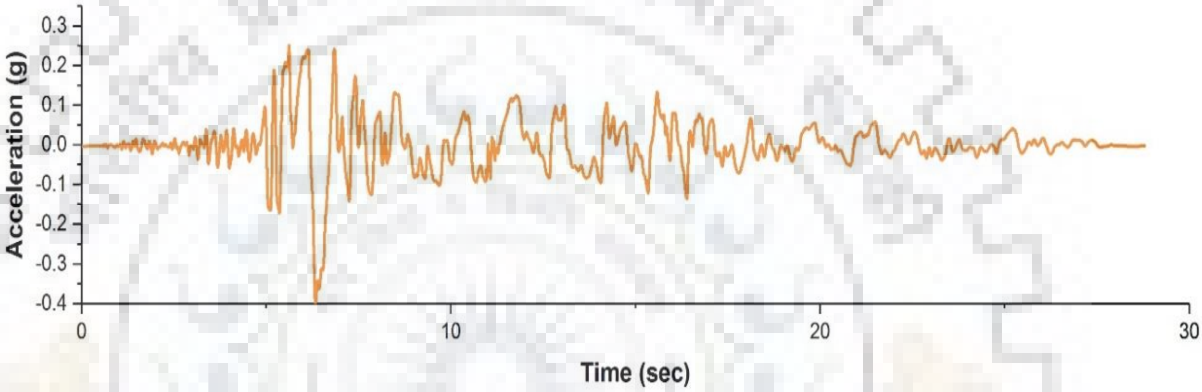


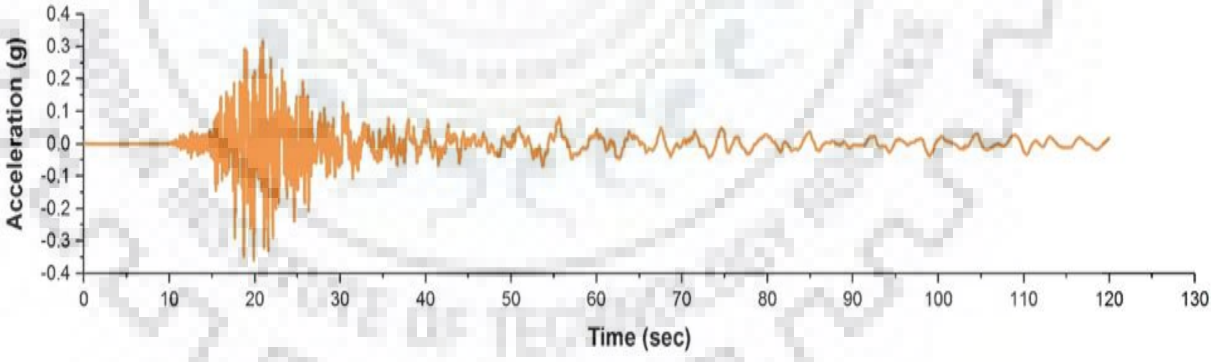
Figure 3.4 *Spectrum Compatible Time History Matching*






Acceleration (g)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
Time (sec)


Acceleration (g)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
Time (sec)


Acceleration (g)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
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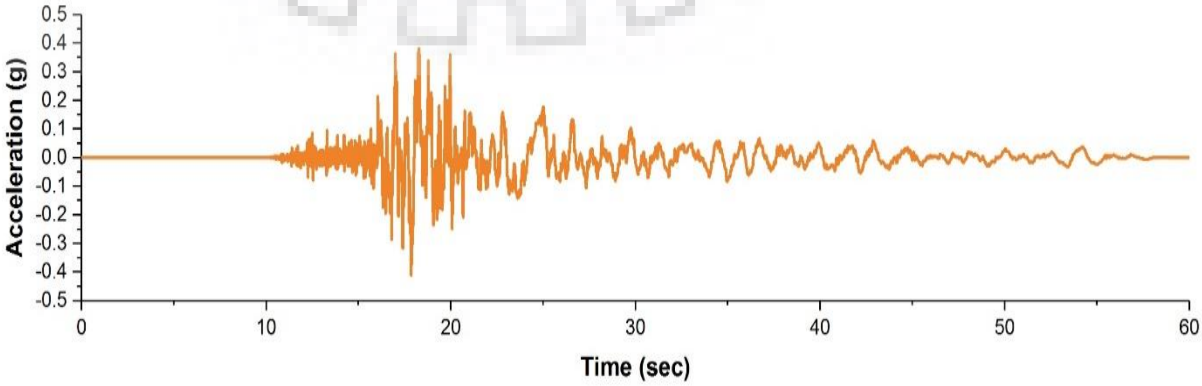
40
50
60
70
80
90
100
110
120
130
Time (sec)


Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
10
20
30
40
50
60
Time (sec)

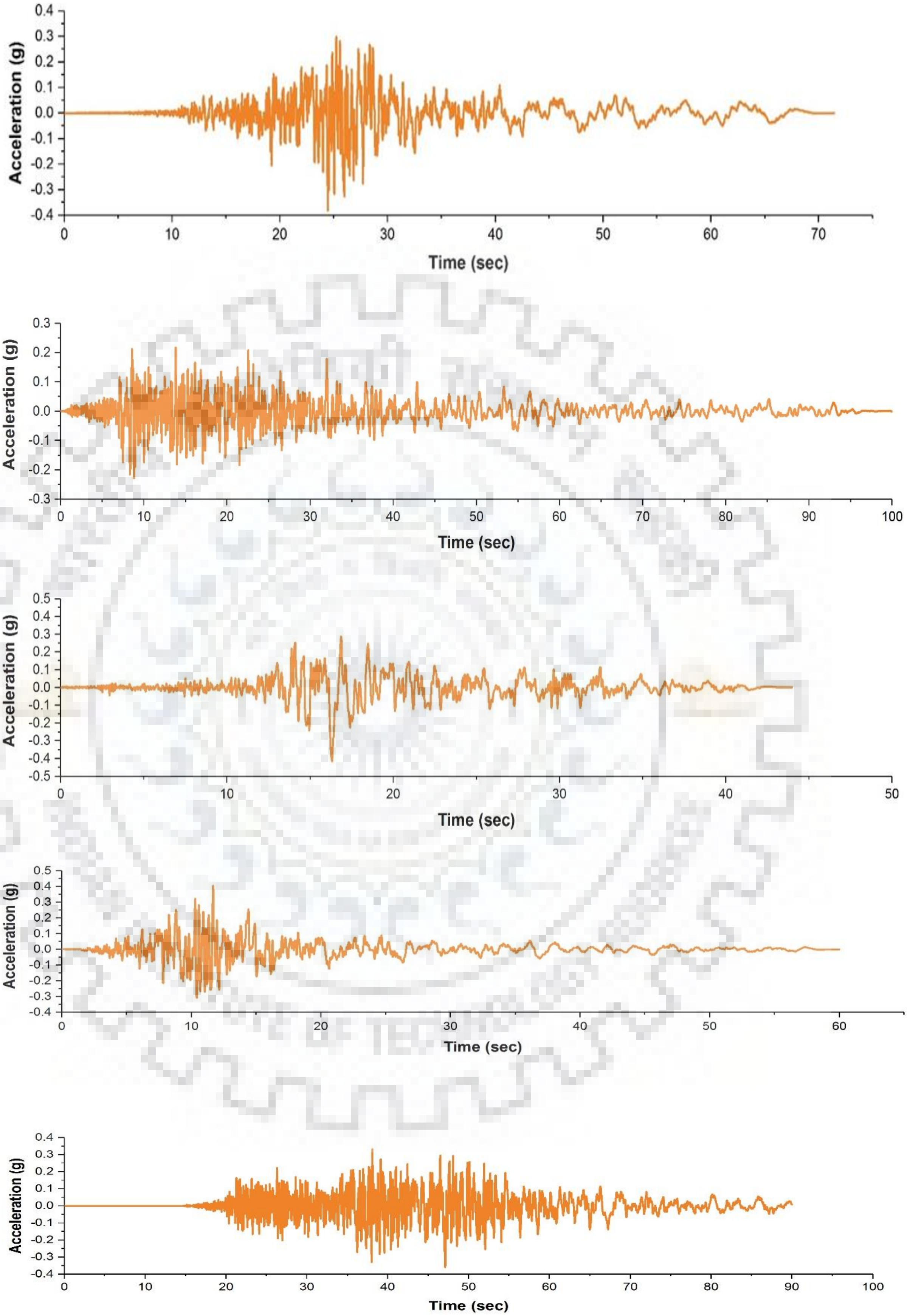


Figure 3.5 *Compatible Scaled Earthquake Ground Motion with Target Spectrum*

The nonlinear time history has taken into account Rayleigh damping. The coefficient are calculated using SAP2000 auto tool. Figure shown below represents the combination of both types of damping. It shall take care of combination of both as stiffness varies with time.

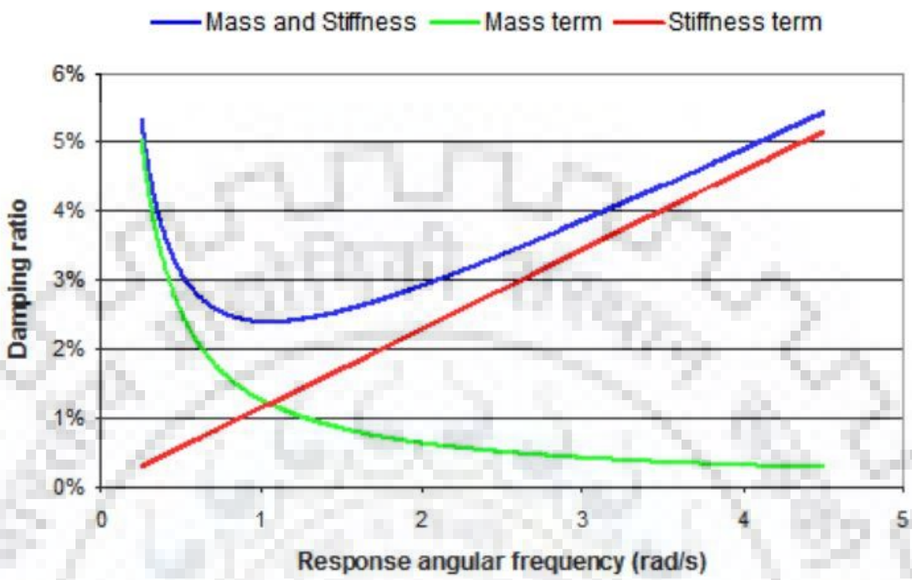


Figure 3.6 *Rayleigh Damping Combination of Mass and Stiffness term*

3.4 Response of Existing RC Frame

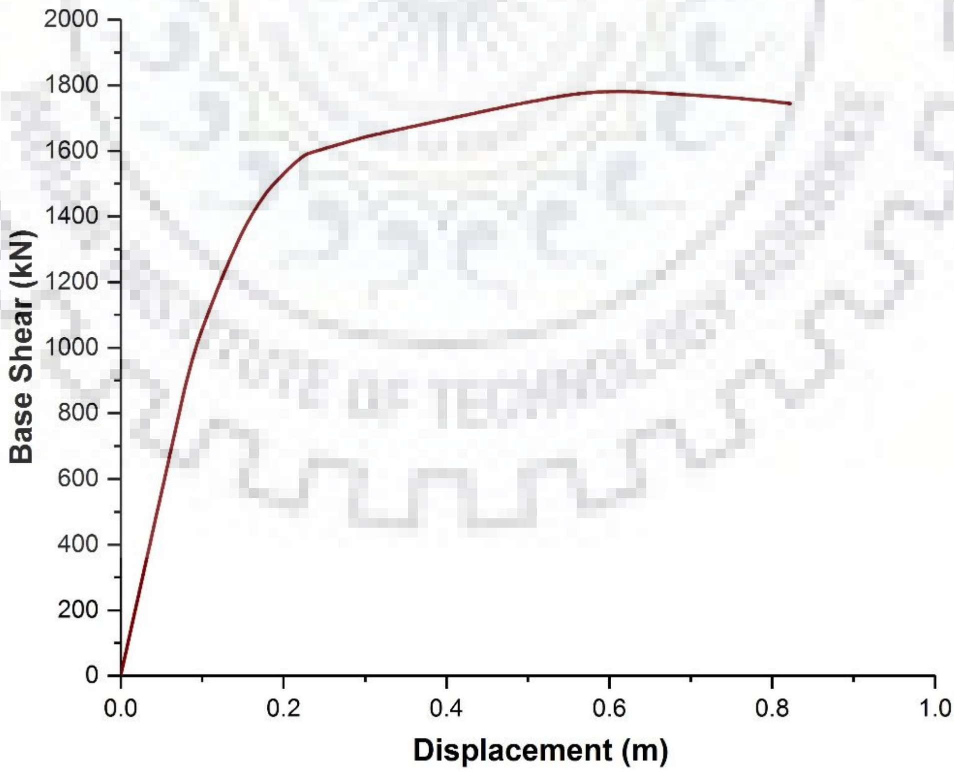


Figure 3.7 *Pushover Curve in X-Direction for Building Designed for Gravity Loading*

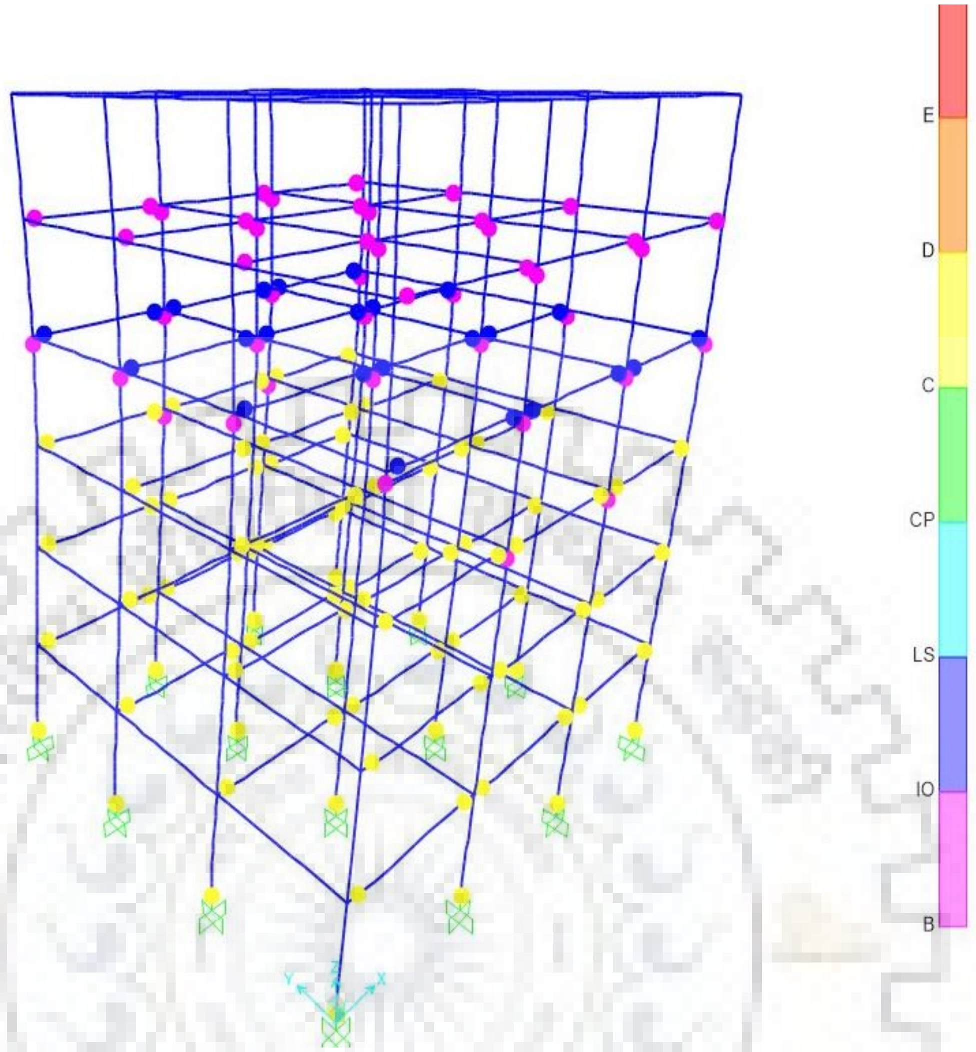


Figure 3.8 *Hinge Pattern Formation in Gravity Designed Building*

3.5 Methodology to Retrofit Building

Four middle bottom column of core side of building was failing under seismic loading. The demand coming on the demand is lying outside the P-M interaction curve, which clearly shows the deficiency. The reinforcement requirement exceeds the upper permissible limit of column as per IS-456.There has to be a proper methodology to retrofit the structure presented below

1. **Calculation of forces on each storey.** Determine the demand shear force at each of the storey of the building using response spectrum analysis. Section cut tool of SAP2000 is used in order to obtain the values. It is assumed that all dampers installed in particular storey shares equal forces.

Table 3.6 *Design Forces for Dampers on each Storey*

Storey	Storey Shear (kN)	Number of Dampers	Design Damper Force (kN)
1	442.42	**4**	110.60
2	405.13	**4**	101.28
3	353.37	**4**	88.34
4	308.16	**4**	77.04
5	258.31	**4**	64.59
6	172.05	**4**	43.01

2. **Design of link.** Design forces on shear link and shear stress considered and shear strain consideration. TABLE

The shear force coming on each of the storey is used to get the value of shear area of damper. (Rai and Wallace 1998) suggested allowable shear stress value through experimental validation.

$$\tau_{avg} = 2.6\sigma_{0.2}\phi^{0.2} \tag{3}$$

Allowable inter-storey drift of 0.5% is opted for design shear strain of damper.

$$(\Delta_{roof})_i = 0.005H \tag{4}$$

$$(\phi_{link})_i = \frac{\Delta}{D} \tag{5}$$

Shear yield deformation in damper should be less maximum allowable drift of storey.

Table 3.7 *Design Details for Shear Link*

Storey	Damper Design force (kN)	Design shear Strain (φ)	Design Shear Stress (τ_{avg}) (MPa)	Dimensions of Link	
				Depth (mm)	Area (mm^2)
1	110.60	0.0568	51.57	440	2144.7
2	101.28	0.0568	51.57	440	1963.91
3	88.34	0.0568	51.57	440	1713.01
4	77.04	0.0568	51.57	440	1493.84
5	64.59	0.0568	51.57	440	1252.58
6	43.01	0.0568	51.57	440	834.05

3. **Design Data for Brace and Assumption**

The design forces for damper are taken in such a manner that damper yields before the buckling of compression brace in order to prevent sudden loss of stiffness. Over strength factor is observed to be in between one and three.

$$P_{cr} = 1.7 f_a A_b \tag{6}$$

$$V_{cr} = (2P_{cr})\mathrm{Cos}\,\alpha, \tag{7}$$

$$R_{Max} = (1.88\sigma_{0.2})Lt_w \tag{8}$$

Table 3.8 *Brace Design and Over Strength Factor Provided*

Storey	Brace Pipe Section Diameter (mm)		Buckling Force P_{cr} (kN))	Buckling Shear V_{cr} (kN)	Link Strength R_y (kN)	Over strength Factor
	Outer	Inner				
1	80	70	47.05	72.69	54.50	1.33
2	80	70	47.04	72.69	49.91	1.45
3	70	60	30.67	47.39	43.53	1.09
4	70	60	30.67	47.39	37.96	1.25
5	60	48	21.23	32.81	31.83	1.03
6	50	30	15.09	23.33	21.19	1.10

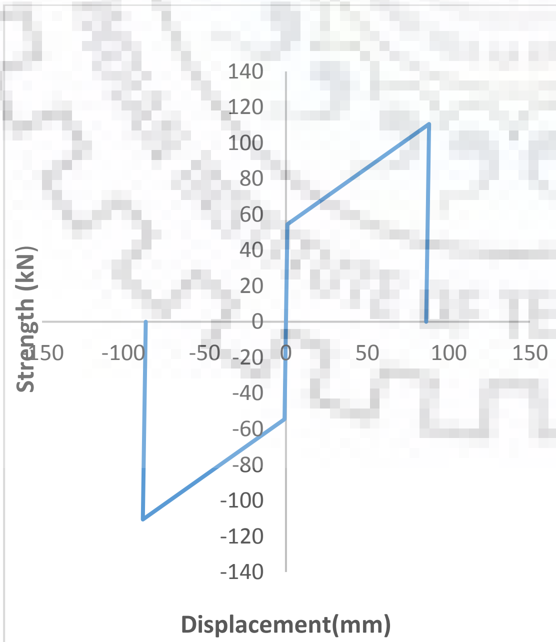
4. Each storey has damper that has unique hysteretic properties. The yield force of damper that is shear link element is given by equation. Yield shear plays an important role as it is signifies the transition of behaviour of stiffness. Wen plastic link element requires the properties mentioned below.

$$R_y = (0.722\sigma_{0.2})A_{web} \tag{9}$$

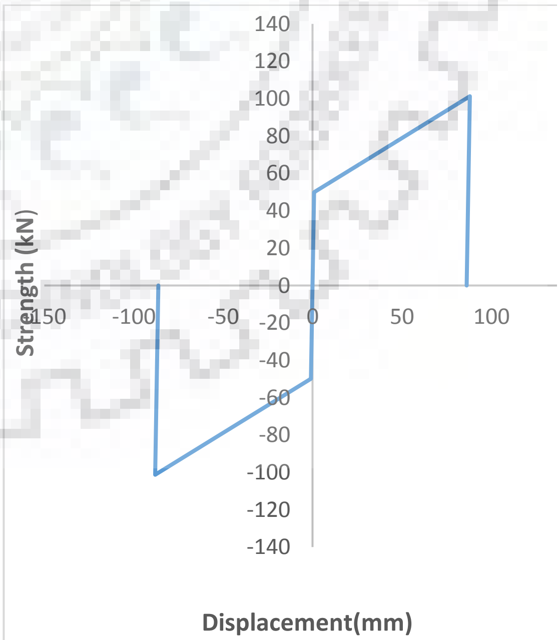
Table 3.9 *Properties of Idealized Link Element*

Storeys	Yield Shear R_y (kN)	Maximum Strength R_{Max} (kN)	Pre Yield stiffness k_1 (kN/mm)	Post Yield stiffness K_2 (kN/mm)	K_2/K_1
1	54.5	110.65	61.9	0.643	0.01039
2	49.9	101.28	56.7	0.589	0.01039
3	43.5	88.34	49.5	0.514	0.01039
4	37.9	77.04	43.1	0.448	0.01039
5	31.8	64.59	36.1	0.376	0.01039
6	21.1	43.00	24.0	0.250	0.01039

The link element properties assigned to element of every storey is unique as it depends on the design storey loads. Backbone curve is representative form of load vs deformation curve shown below



(1)



(2)

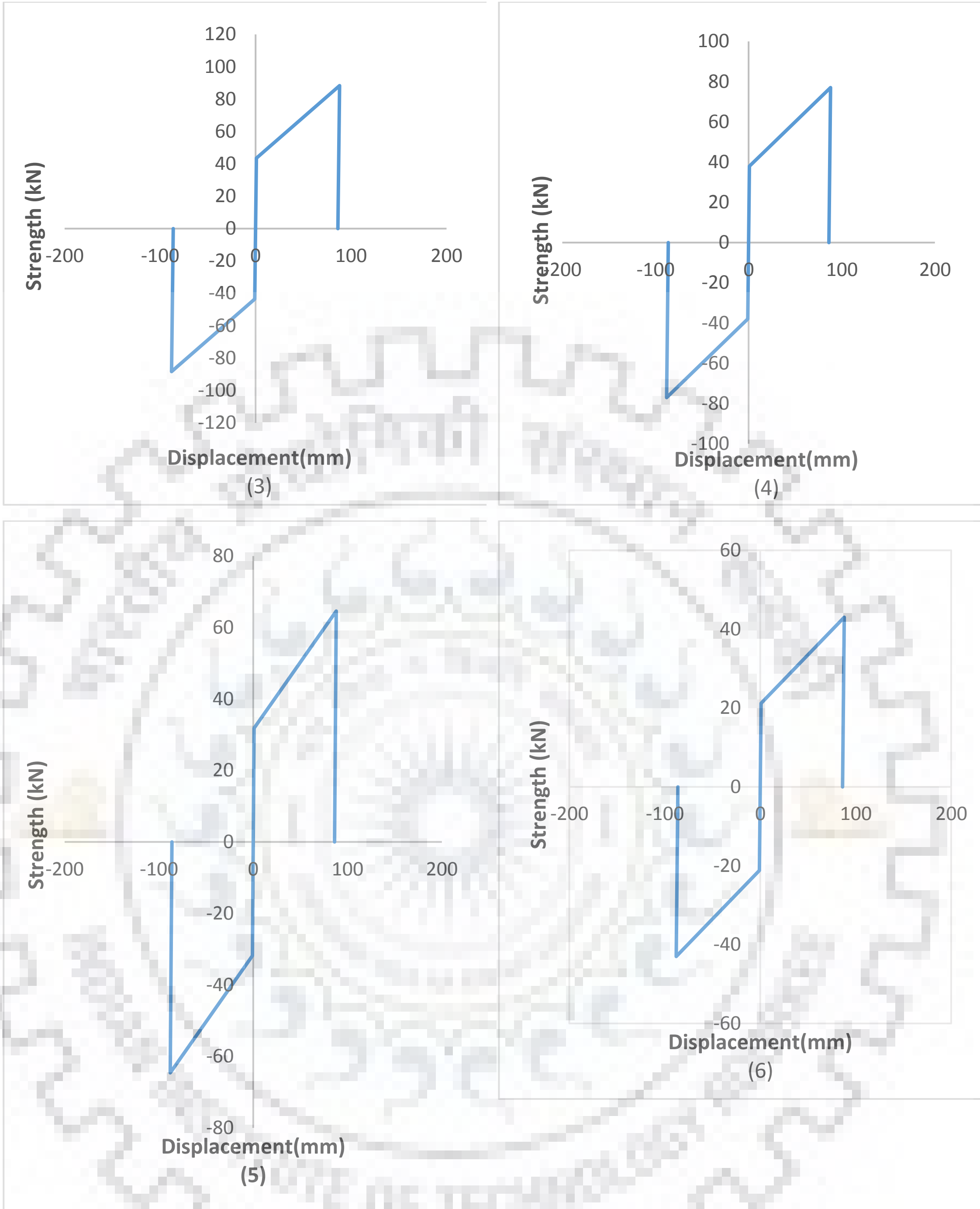


Figure 3.9 *Backbone Curve for Damper Each Storey Respectively*

3.6 Response of Link Braced Frame

Using shear link also increases forces on column so it must also be ascertained that hinges forming in primary member are after the yielding of dampers. The brace and column are assumed to be in linear range before the implementation of damper. The buckling of brace should not be before the damper yielding.

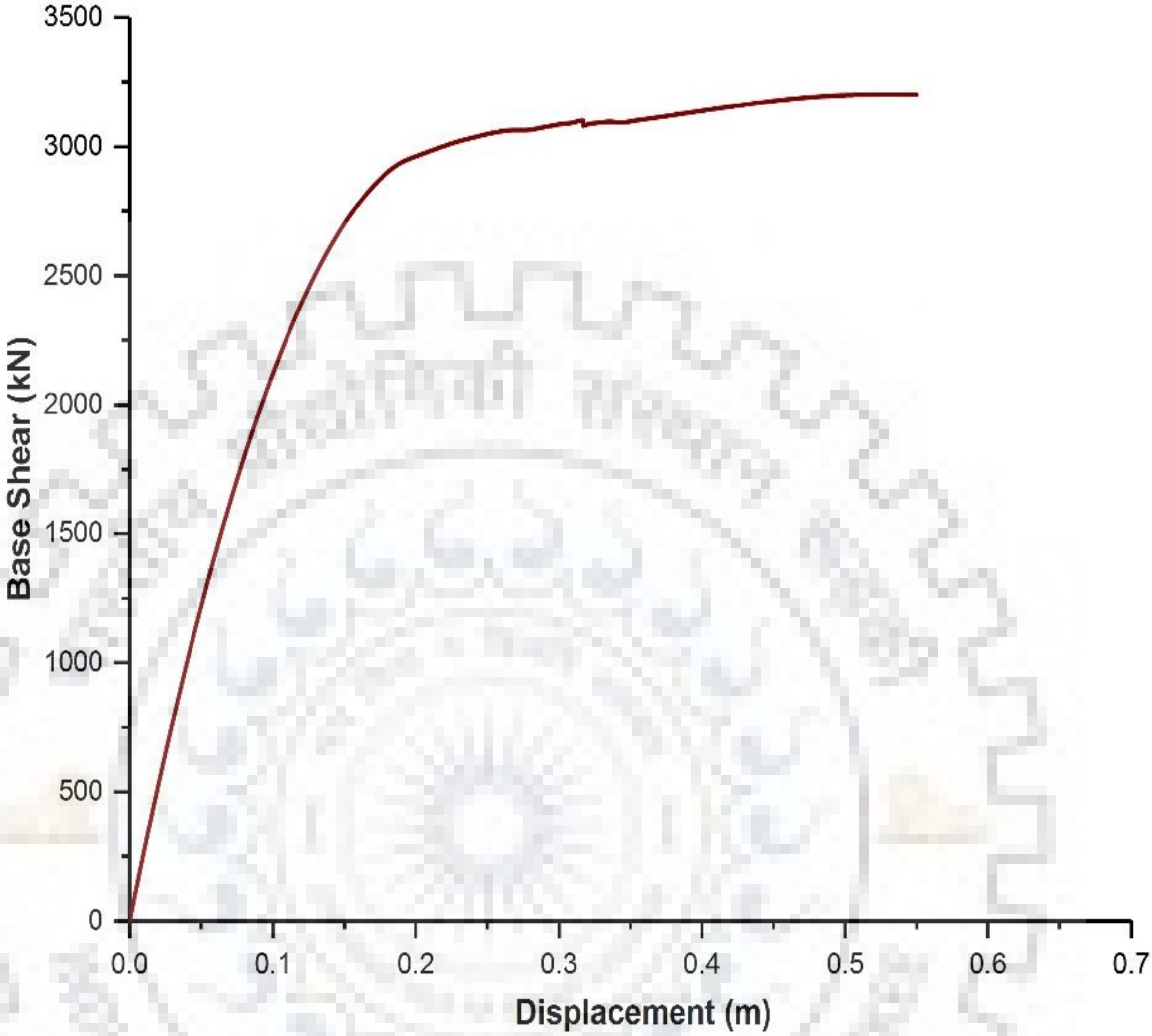


Figure 3.10 *Pushover Curve in X-Direction for Linked Braced Frame*

Sequence of Hinge formation clearly shows that the hinge are formed in beams first followed by column. The sequence of hinge formation claims that the inherent behavior of original frame is having weak beam strong column type configuration. Change in demand due to damper and brace installation did not affect the basic hinge formation mechanism. Bracing are not allowed to buckle before yielding of damper that is shear link.

Sequence and final mechanism in braced frame clearly shows that compression brace are prone to fail early. This phenomenon may be attributed to the buckling of compression brace

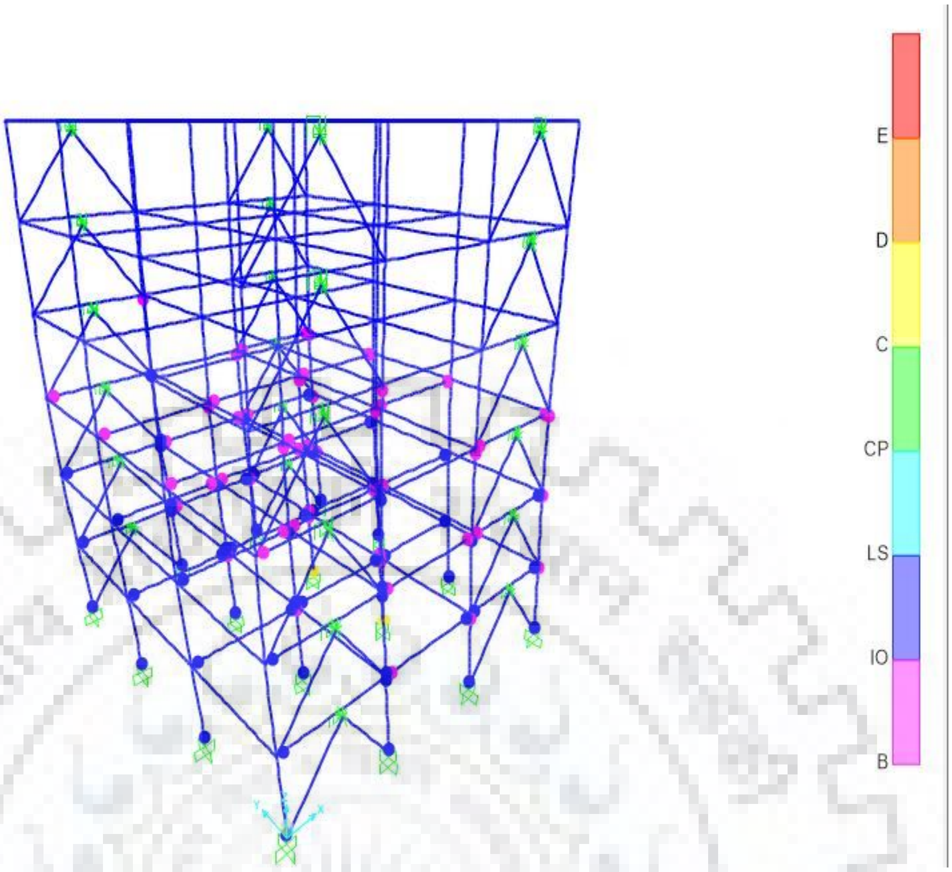


Figure 3.11 *Hinge Pattern Formation in Link Braced Frame*

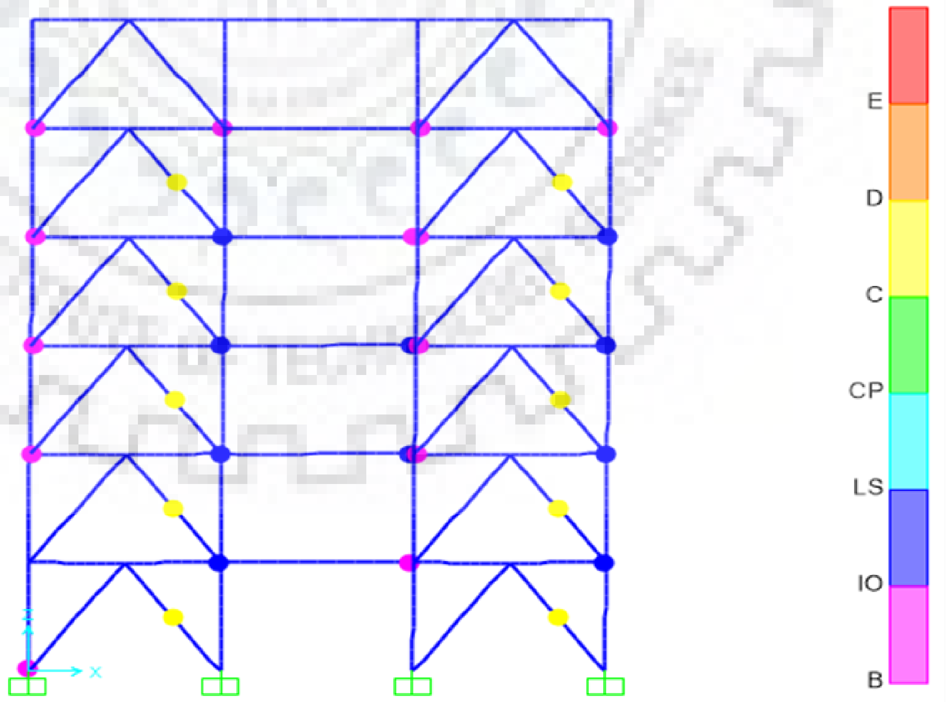


Figure 3.12 *Hinge Pattern Formation in Braced Frame*

3.7 Comparative Results

The retrofitted structure has enhanced stiffness that leads to reduction in roof displacement. The comparative graphs shown below clearly suggest if only roof displacement is concerned parameter. Braced frame is preferable option. Although there are other governing phenomenon that needs attention which enquires about the response and failure mechanism of structure. The other parameter and justification is discussion in further topics.

Compatible ground motion are imposed to building with and without dampers, braced frame is the intermediate choice to compare the transition in behavior. The peak roof displacement of link-braced frame is considered and compared with deficient frame to show the improved behavior.

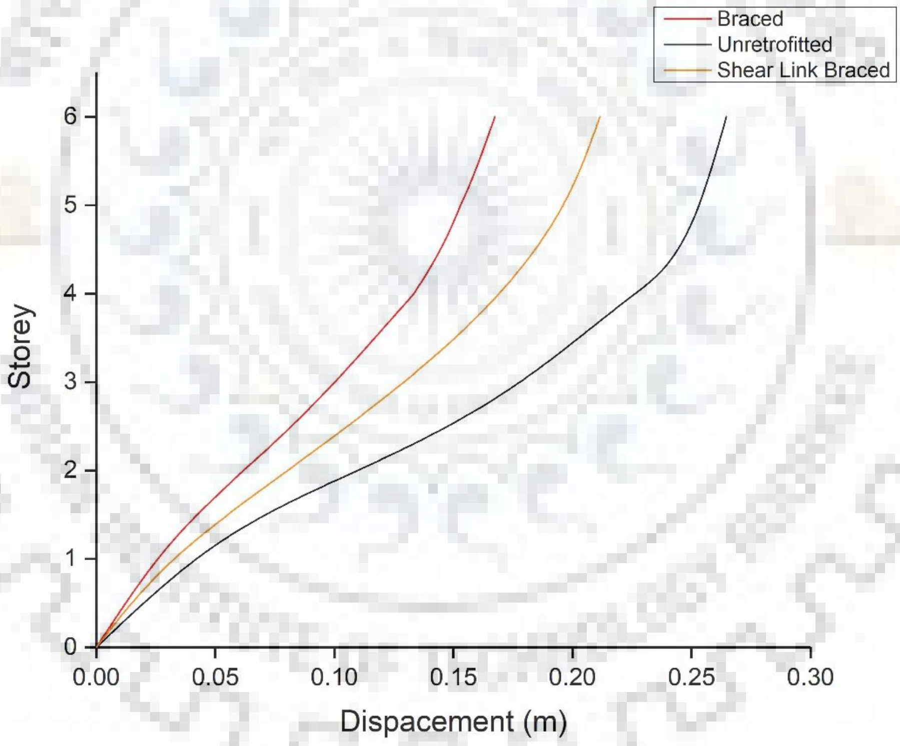


Figure 3.13 *Comparison of Average Displacement Response of Time Histories*

Inter-storey drift plays a significant parameter in evaluation of structural response and its global behavior. It has vital role is controlling the non-structural and structural damages in the structure. The relative value of inter-storey drift also signifies the relative stiffness of the storey under comparison. The reduction expected after retrofitting of structure can be easily interpreted from the Figure 3.11.

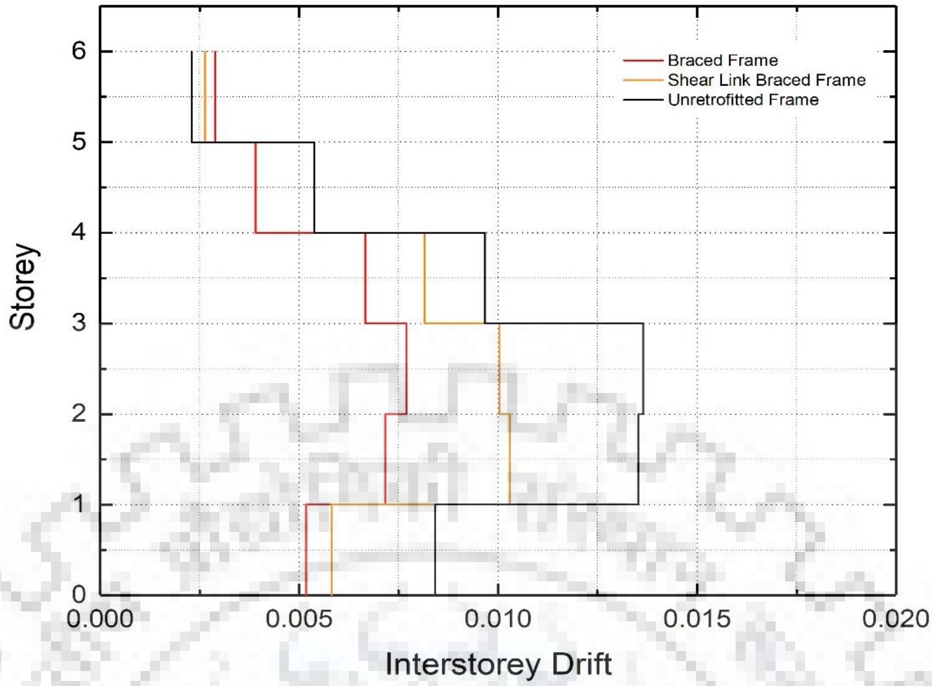


Figure 3.14 *Comparison of Inter-Storey Drifts*

After Implementation and proportioning of dampers and braces it is to be assured that there is no storey that causes soft storey phenomenon. The provision recommended by Indian code is followed. The proposed methodology and redistribution may cause increase and decrease in retrofitted storey stiffness. This critical check greatly hampers the demand on the structure. Soft storey may initiates the global failure of the building. Figure 3.12 presents that the storey are sufficiently rigid relative to each other.

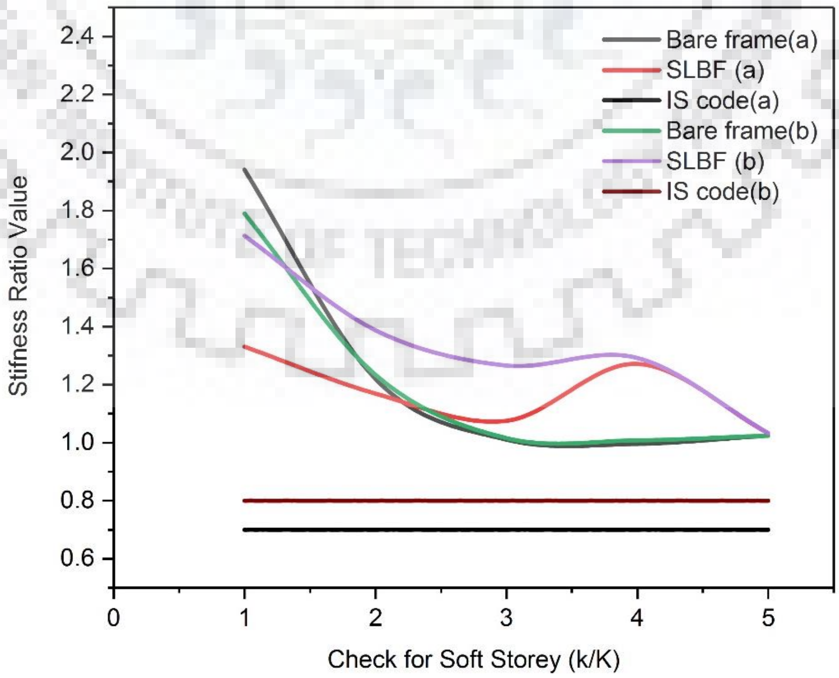
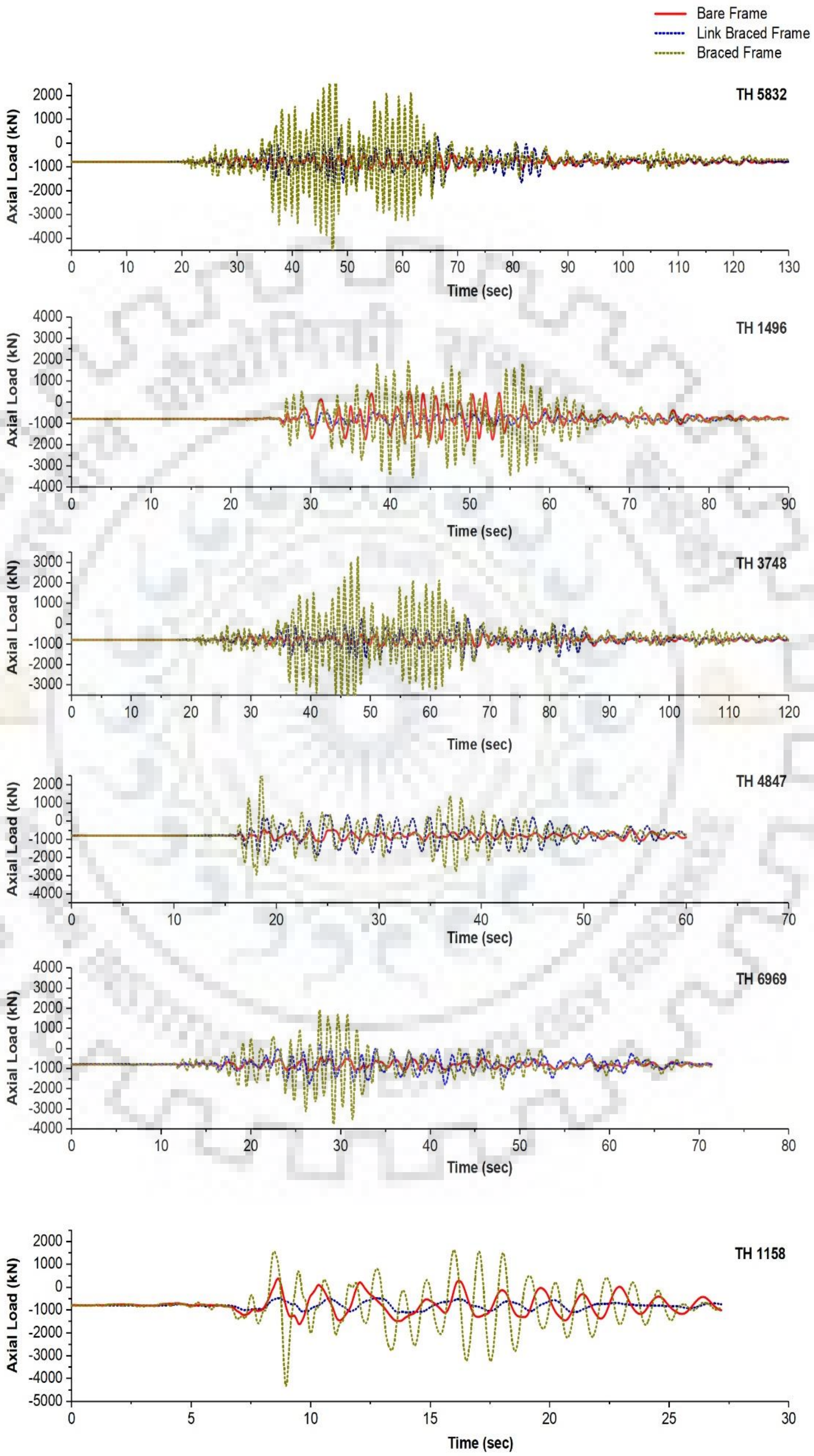


Figure 3.15 *Check for Soft Storey Phenomenon as per IS1893(Part-1)-2016*

3.7.1 Axial load variation of column



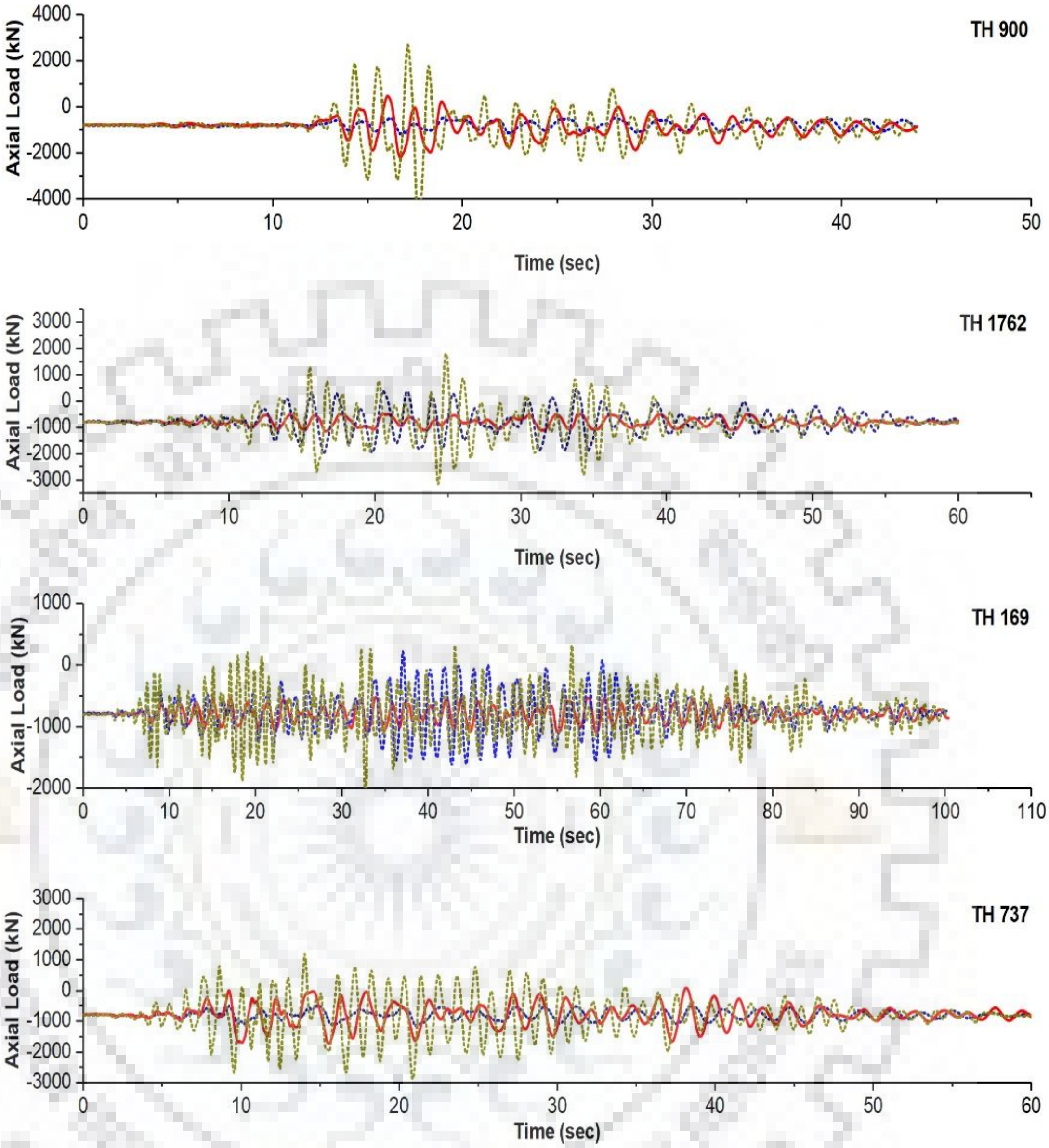
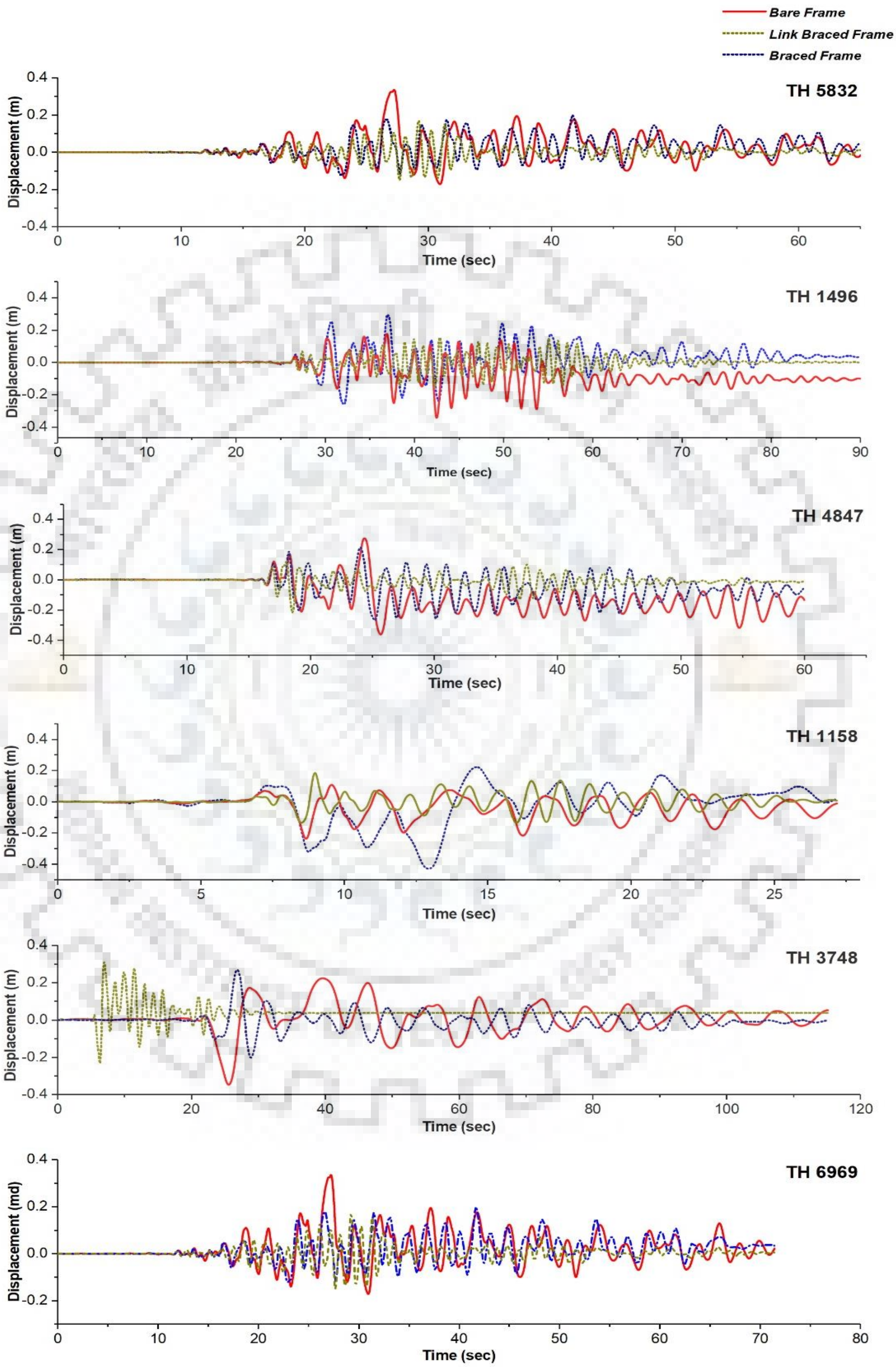


Figure 3.16 *Response of Column Axial Force (element 92) of 6-storey Building for Spectrum Compatible Time Histories*

Time history response of axial forces generated in the column 92 has been studied. It is the outer most column in ground storey.

The response is relatable for the shear link braced frame, deficient building and braced frame. Installation of brace and dampers has individually changed the response of structure. The distribution of seismic forces varies with the lateral load resisting systems. As the rigidity of infill system increases, the building behavior will be more likely as that of cantilever.

3.7.2 Roof displacement variation



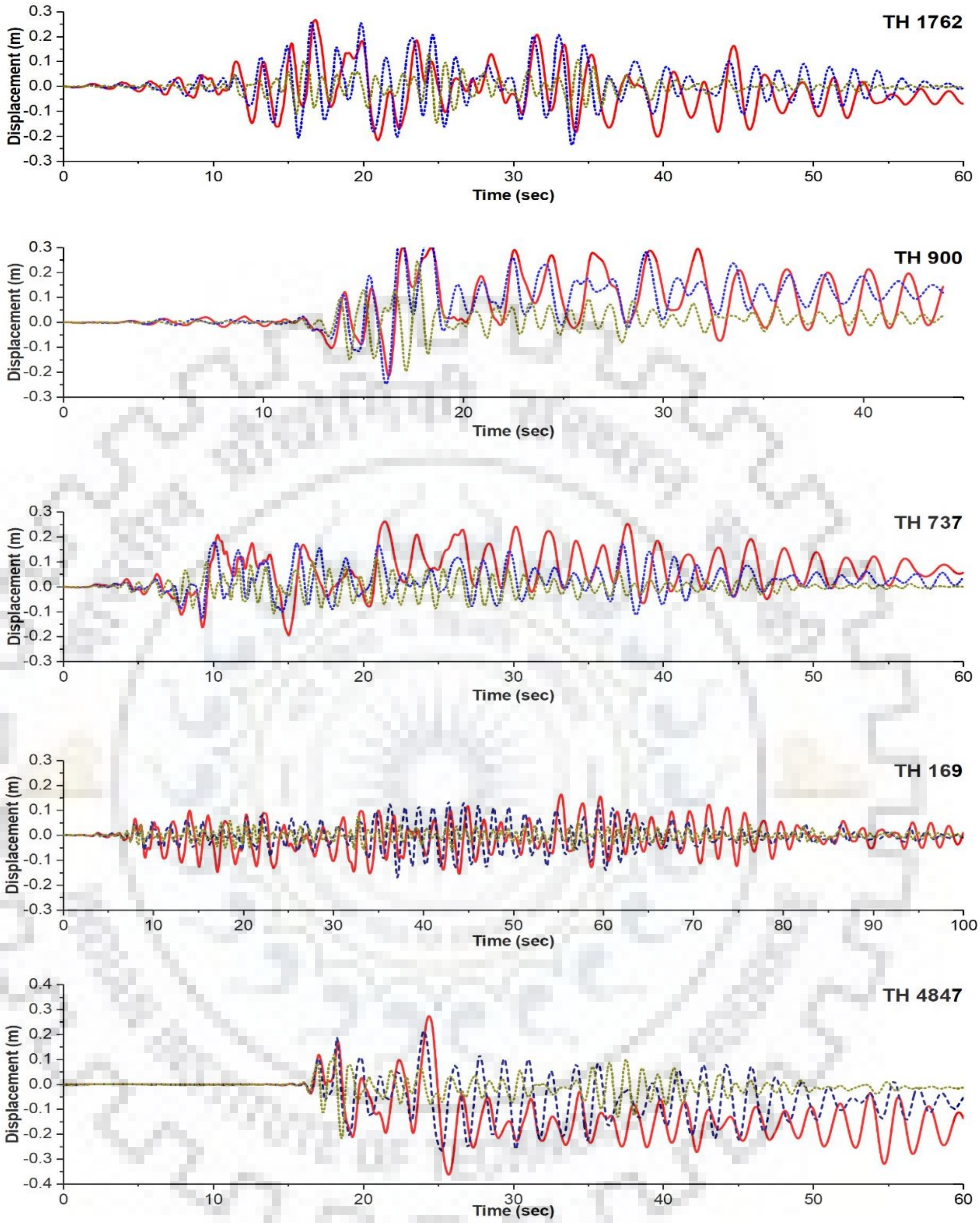


Figure 3.17 *Roof Displacement Response of 6-Storey Building for Spectrum Compatible Time Histories*

Roof Displacement are reduced considerably in case of braced frame but the system has some drawback. If any of the brace fails due to buckling, the sudden drop in stiffness of that storey may cause undesirable phenomenon. On other side, link braced frame has advantage of metallic yield phenomenon. The post yielding characteristics and hysteresis behavior of damper enhances the endurance of structure to tackle earthquake.

Table 3.10 *Peak Value of Response of Different Frames*

	Roof Displacement of Frame(m)			Axial force -column92 (kN)		
Ground Motion	**Deficient**	**Link Braced**	**Braced only**	**Deficient**	**Link Braced**	**Braced only**
TH 1158	0.222	0.108	0.101	1103.14	1626.69	4321.71
TH 1115	0.276	0.183	0.121	1116.13	1781.62	2295.83
TH 1496	0.295	0.177	0.153	908.22	1027.78	2046.54
TH 1762	0.267	0.258	0.131	1150.38	1998.07	3162.03
TH 3748	0.224	0.309	0.269	1150.78	2202.99	5312.90
TH 4847	0.274	0.213	0.121	1117.17	1877.56	2965.86
TH 5832	0.349	0.207	0.262	931.13	953.73	1374.01
TH 6969	0.335	0.197	0.169	1141.40	1778.09	2374.83
TH 737	0.262	0.180	0.116	1136.33	1729.35	2889.04
TH 900	0.299	0.358	0.246	1180.08	2210.19	5075.04

Table 3.11 *Inter Storey Drift Comparison*

Storey	**Average Displacement(m)**	**Inter storey Drift**	**Average Displacement(m)**	**Inter storey Drift**
	Deficient Frame		**Link Braced Frame**	
1	0.042	0.042	0.029	0.029
2	0.110	0.068	0.081	0.052
3	0.178	0.068	0.131	0.050
4	0.226	0.048	0.171	0.040
5	0.253	0.027	0.198	0.027
6	0.265	0.012	0.212	0.013

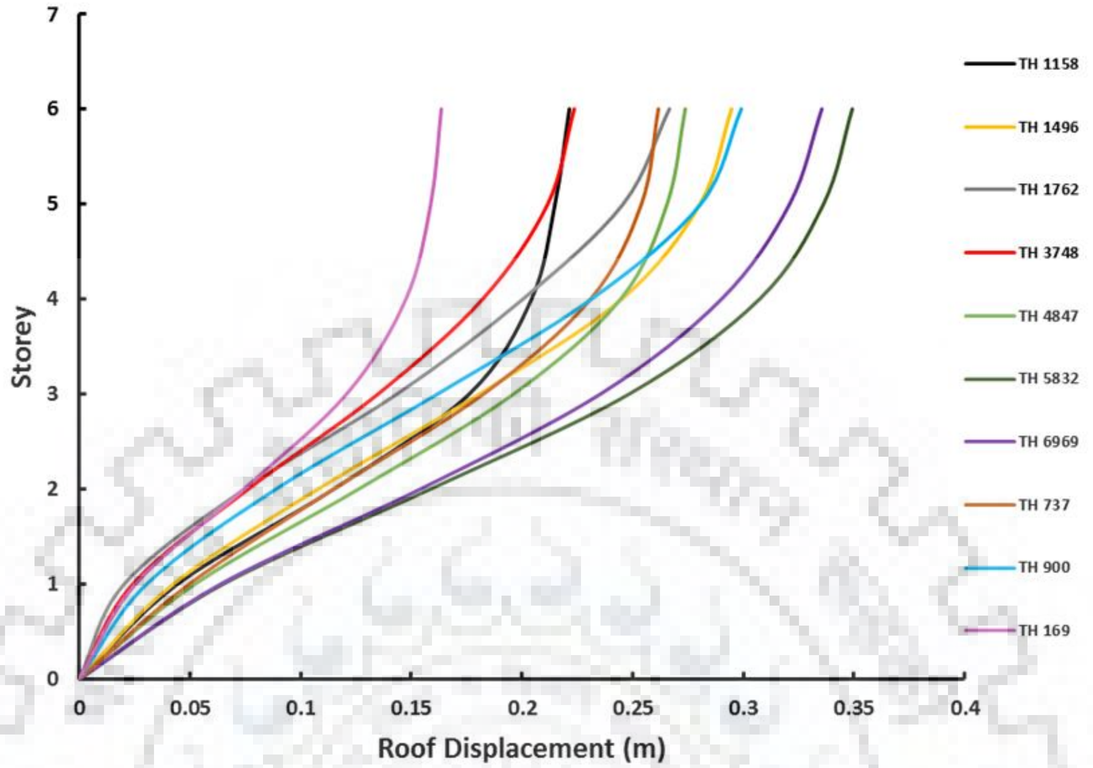


Figure 3.18 *Roof Displacement Response of Deficient Frame*

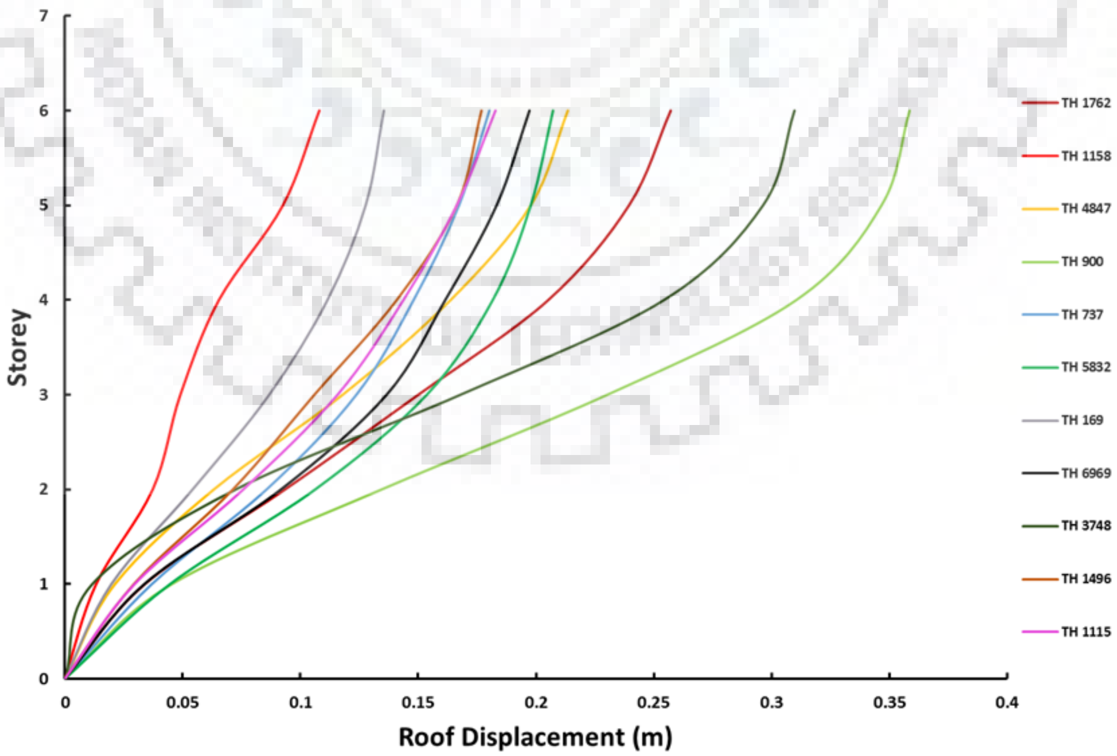


Figure 3.19 *Roof Displacement Response of Shear Link Braced Frame*

CHAPTER 4 : EFFECT OF STIFFNESS RATIO

4.1 General

Stiffness of damper brace and storey is important because the resultant of all three causes response of structure. Higher stiffness of assembly provides more rigidity to the structure, which leads to increase in axial compressive forces on primary member. On other side, lower stiffness of damper and brace will not serve the intended purpose. It is important to choose the design stiffness of damper and brace to get the reasonably good response of structure.

Stiffness ratio of damper to chevron brace (B/D) plays an important role in the design of building. It acts as important design parameter for the improved performance of building. Past studies suggested to adopt single value of B/D=2 that may not result in best performance of structure as the distribution of loads are different. The b/d distribution clearly suggests that the lower storey has lower value than 2 and higher storey has value more than 2. Therefore, it is easily interpretable that each storey has its own B/D ratio.

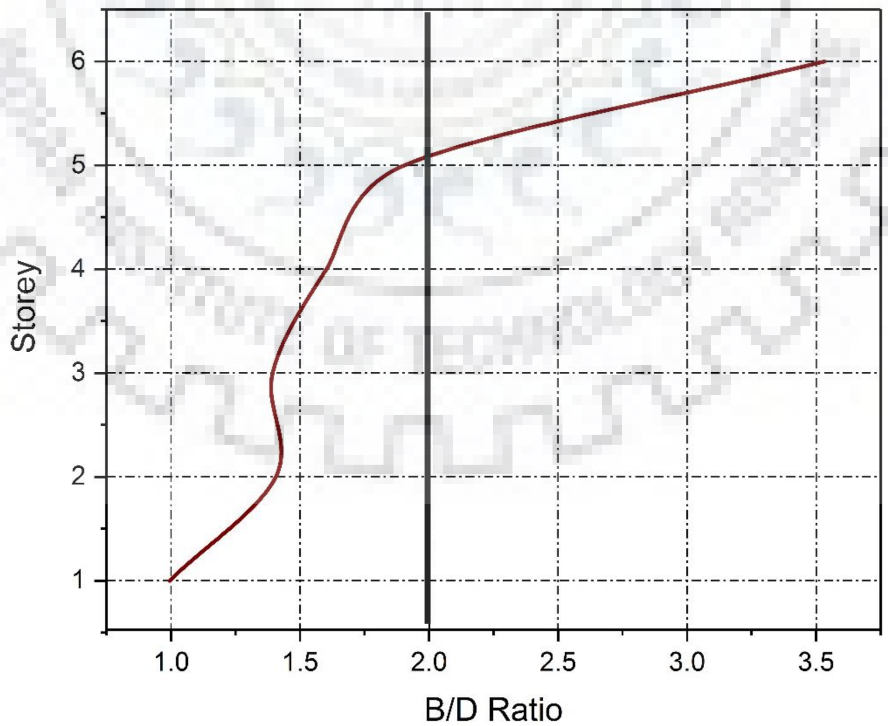


Figure 4.1 *Distribution of B/D Ratio as per Design Methodology*

4.2 Uniform Distribution of Deformation

Based on the concept of uniform deformation the redistribution of stifness is done inorder to bring uniformity in storey drift. The storey which has higher drift ,its stifness is enhanced and storey which has lower drift, its stifness has been lowered.The proportioning is done in such a manner that variation along the height is minimal. Non linear dynamic analysis is performed multiple times inorder to arrive at the response of optimised building having minimum coefficient of variance.

1. The Nonlinear Time history analysis is initially carried out using design parameter obtained by the methodology presented in chapter 3.Peak value(Δ_i) and average value of storey drift(Δ_{Avg}) are obtained.

$$COV = \frac{1}{\Delta_{Avg}} \sqrt{\frac{1}{N-1} \sum_{I=1}^{N} (\Delta_i - \Delta_{Avg})^2} \quad (10)$$

2. Stiffness of damper brace assembly is modified using equation (1). The modification accounts the readjustment of the expected response of building. Again COV is calculated using equation (1.10). α is 0.2 obtained from past literature.
3. Weight of modified assembly is scaled to make the global weight constant.
4. Iteration is stopped if hinge formation is early in case of column and brace buckles before the damper activation.
5. The steps are repeated until the COV is minimised to certain acceptable level. The reduced value of COV signifies that variation among different storey drift is reduced considerably
6. Representative curves are drawn for ($\Delta_{i+1}-\Delta_i$) vs Storey.
7. There is unique optimum distribution of stiffness property in the structure that is not dependent on the initial seismic forces pattern taken for analysis.

The above procedure allows the structure to yield uniformly as the variation is reduced. The maximum inter-storey drift is reduced to minimum that brought the modal response of structure more close to first mode. To improve the seismic performance of the structure the distribution of material is done from weaker part to the stronger part. This results in optimum distribution of stiffness and strength which is related with the optimum performance of the structure under earthquake ground motion.

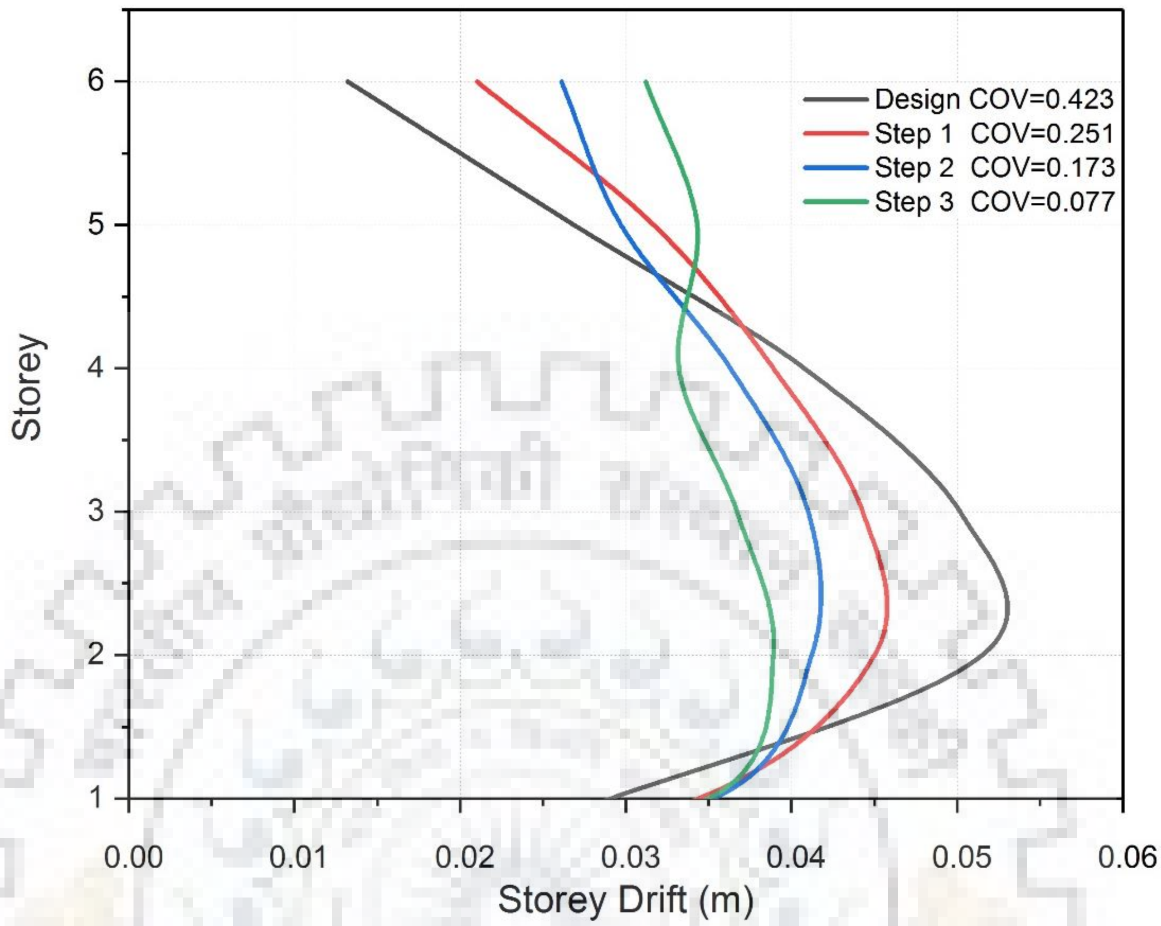


Figure 4.2 *Storey Drift Distribution for Design Methodology and Following steps*

CHAPTER 5 : CONCLUSIONS AND FUTURE SCOPE

5.1 Conclusions

From the study undertaken in this thesis, it is clear those buildings that do not follow the seismic provisions needs consider for analysis. To avoid major disaster in future it is recommended to upgrade the seismic capacity of structure. A proper review of past studies regarding passive energy dissipating device and strengthening of RC building has been undertaken. The state of art allowed us to explore more about lateral load resisting systems and their role in catering earthquake loads.

Based on literature a design method has been suggested to improve seismic performance of building. Design of link element and chevron brace has been presented. It helped in improving the stiffness and strength of building.

1. Comparison between bare frame, braced frame and link-braced frame clearly shows that the average reduction in roof displacement response by average factor of 1.42 for link braced frame. Although reduction is high in Braced frame but it is liable to cause sudden drop in strength and loss of storey stiffness so Link braced frame is first choice.
2. Axial loads on the column 92 is comparatively high in case of braced frame unlike link-braced frame that indicates that the former structure is offering more rigid structure behavior. The average increment in axial force is in the range of 50%. On other hand, link-braced frame offers enhancement of deficient building with minimal increase in axial loads in column.
3. Inter-storey drift has considerably reduced by 20-30% when link braced frame is used for the improvement of deficient building.
4. Link braced frame has improved the strength and stiffness of deficient building although it has reduced the ductility of building which is because the increase in primary member forces due to brace.
5. The design parameter B/D ratio shows its importance as it brings change in response of structure when its value varies along the storey of building. The iteration performed brings down the storey drift to reasonably uniform. The variation in storey drift is bought

down from 0.42 to 0.07 that indicates proper selection of stiffness factor improves performance,

5.2 Future Scope

In the present study, the work is mostly revolves around symmetric midrise RC structure.

- The study can be further extended to unsymmetrical structure.
- Different energy dissipating material and their hysteresis behavior can be studied experimentally.
- Effect of stiffness ratio is the area that needs to work out for other type of building and configuration.
- The location of dampers must be optimized, as it could be another scope.

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