SEISMIC RESPONSE STUDY OF MULTI-STORIED REINFORCED CONCRETE BUILDING WITH FLUID VISCOUS DAMPERS

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Abstract : Damping Plays vital job in plan of Earthquake Resistant Structures, which lessens the reaction of the structure when they are exposed to horizontal burdens. There are a wide range of sorts of dampers being used. In the present investigation Fluid Viscous dampers (FVD) are utilized to assess the reaction of RC structures.
The principle assignment of a structure is to shoulder the horizontal loads and exchange them to the establishment. Since the sidelong loads forced on a structure are dynamic in nature, they cause vibrations in the structure. So as to have tremor safe structures, Fluid Viscous Dampers have been utilized. Structures having square and rectangular plans, with square and rectangular segment cross-areas are investigated, with and without FVD. In the present examination the product ETABS 2015 have been utilized. Utilizing Push over and Time history investigations the reaction of the RC building considered in the present examination is assessed and contrasted and without FVD.
It has been seen that structures with square sections are performing great as far as reaction of the structure when contrasted with the rectangular segments regardless of the floor plan. In Time History investigation, up to 90% lessening in the timeframe is acquired when FVD are utilized. FVD250 decreased the Base Shear of the structures by 70%. Consequently FVD's can be utilized in RC multi-storey structures to lessen the reaction adequately.

I. INTRODUCTION

1.1 GENERAL

The viscous fluid dampers (VFD) are the more applied tools for controlling responses of the structures. These tools are applied based on different construction technologies in order to decrease the structural responses to the seismic excitation.Though over the recent years heavy costs have been paid for accurate recognition of force of an earthquake in the research institutes of the world with the purpose of decreasing its damage, the increasing need for more research studies on the effects resulted from the earthquake is felt in the theoretical and laboratorial scales [1]. Over the last fifty years, the earthquakes are categorized into two groups of near-field earthquakes and far-field earthquakes based on the distance of the place of recording the earthquake from the fault. Later, this definition was modified and other factors also influenced this categorization. Over the recent years, the research studies concentrated on the study of impacts of ground motion in the near-field earthquake on the structural performance. The devastative effects of the recent earthquakes such as Northridge earthquake (1994), Kobe earthquake (1995), and Taiwan earthquake (1999) on the buildings of the cities adjacent to fault, and with regard to the close location of many of the cities of India to the active faults indicate the significance of the research.

In last few years, many essential developments in seismic codes are turned up. Utmost of the modification in the seismic design area derive from greater awareness of actual poor buildings performances in contemporary earthquakes. Due to the renewed knowledge of the existing buildings behaviour, retrofit of buildings is a paramount task in reducing seismic risk. New techniques for protecting buildings against earthquake have been developed with the aim of improving their capacity. Seismic isolation and energy dissipation are widely recognized as effective protection techniques for reaching the performance objectives of modern codes. However, many codes include design specifications for seismically isolated buildings, while there is still need of improved rules for energy dissipation protective systems.[2]

DAMPING

It is defined as energy loss in the response over the time period. Energy dissipation involves factors such as materials, radiation of soil etc. Clear understanding of damping is required for incorporating its effect to the structure. The shape of response curve doesn't change by damping but the magnitudes are reduced.[3]

IMPORTANCE OF DAMPING

When the structure has much absorbing capacity than the Seismic energy then it can withstand the structural damage. Equivalent viscous damping can be used as a feasible means of decreasing the structural damage.[3]

SOURCES

The 4 different sources are Material Damping, Structural Damping, Radiation Damping and External Damping.

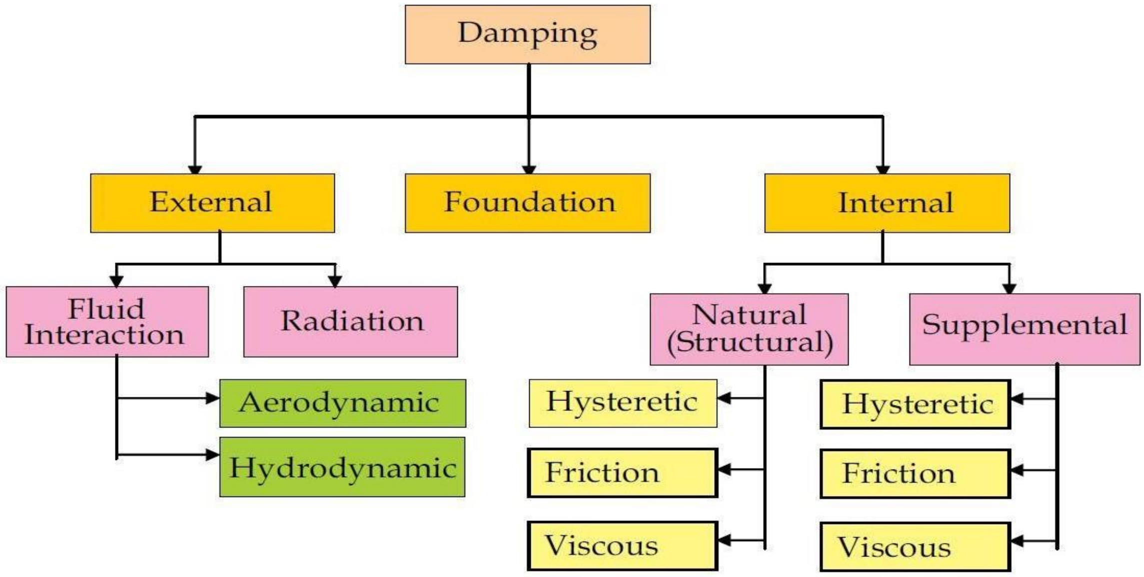


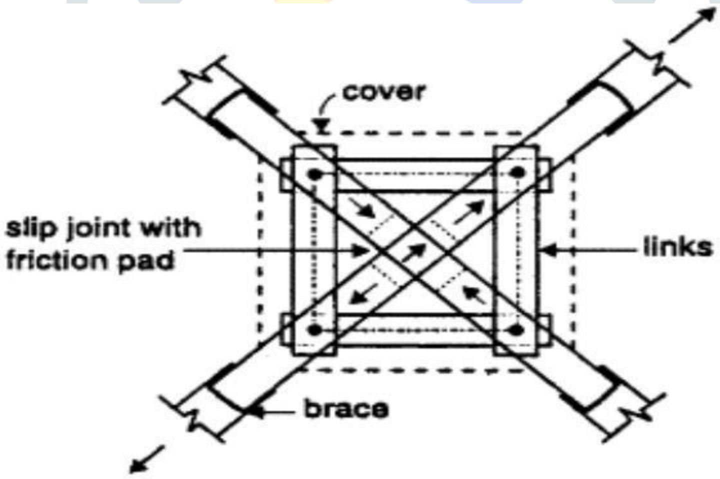
Figure 1: Sources of Damping.

1.2 TYPES OF DAMPERS

Dampers are classified based on their performance of friction, metal (Flowing), Viscous, Viscoelastic, shape memory alloys (SMA) and mass dampers. About the advantages of using dampers we can infer to high energy absorbance, easy to install and replace them as well as coordination to other structure members.

1.2.1 Friction dampers

In this type of damper, seismic energy is spent in overcoming friction in the contact surfaces. Among the others features of these dampers can be classified as avoiding fatigue in served loads (due to the non-active dampers under load) and their performance independent to loading velocity and ambient temperature. These dampers are installed in parallel to bracing.



Because of very simple behaviour and easy to install and make this type of damper is converted to one of the most types of friction dampers.

Figure 2: Friction Damper

1.2.2 PVD Damper

It is another type of friction damper and due to ease to installation, is one of the most widely used damper in structures[4]. PVD damper can be used to create necessary damping for flexible structures, such as bending steel frame or to provide effective damping to relative stiffness of structures[5]. PVD damper is designed to installation where displacement can generate necessary damping such as installation of metal skeleton brace or concrete moment frame. The advantages of PVD damper include:

1. PVD damper acts effectively on low displacements. For example, one 1MN PVD damper can acts effectively for 0.5 mm to 5 mm displacement.
2. PVD damper requires no maintenance and does not have any lubrication or winder components.

3.PVD damper behaviour is like the behaviour of a metal damper.

Figure 3: PVD Damper

Figure 4: PVD Damper Installation

1.2.3 Viscous Dampers

In this damper, by using viscous fluid inside a cylinder, energy is dissipated. Due to ease of installation, adaptability and coordination with other members also diversity in their sizes, viscous dampers have many applications in designing and retrofitting.

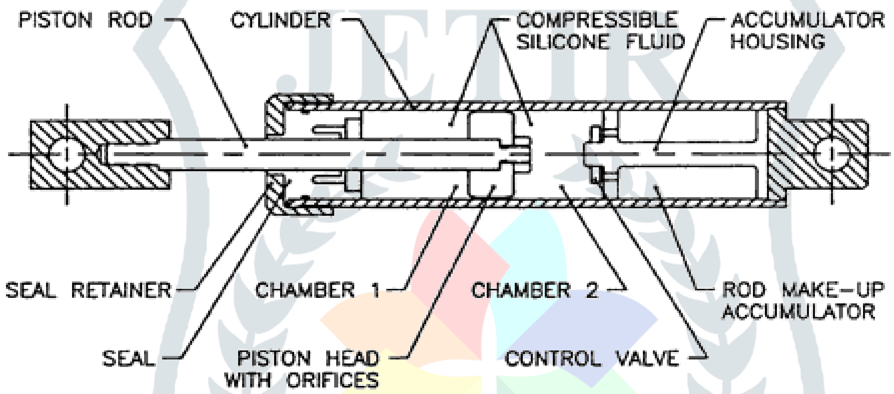


Figure 5: Longitudinal Section of Viscous Damper

These types of dampers are connected to the structure in three ways:

- Damper installation in the floor or foundation (in the method of seismic isolation).
- Connecting dampers in stern pericardial braces.
- Damper installation in diagonal braces.

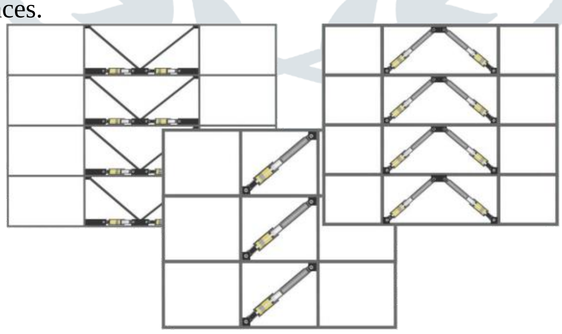


Figure 12: Viscous Damper Installation Methods

1.1.1 *Active Seismic Control Systems (Active)*

Compared with passive control system, active control system structural response is controlled, effectively by 2 factors:

- By a special amount of output power or required energy.
- The process of decision-making based on measured real-time and involved data.

In this respect, active control includes a widespread technology. In terms of engineering control, active control system is composed of 4 connected components, these includes:
Structure, sensor, computer control and controller and actuators, each of them works as lateral system. And they are integrated that an output of a systems is an input of another system is a feedback control system. So, priority of an active systems is in widespread use due forces controlling and they are created by real stimulating and structural behaviour. In active system, when the output excitation is considered as an output. And it is called open- loop system. When the structure response is used as an input, the system us called closed- loop. When both excitation and response are used, system is called open-close control system [13].

1.1.2 Hybrid and Semi-Active System

The term of hybrid control systems is used for a hybrid using of active and passive control systems. Semi-active systems are extracted from active control systems. In this case, the required output energy is lower than active control system. And it is only the producer of electric pulse to provide control system. Semi active control components dose not add mechanical additional energy to structure system (which includes structural and stimulus control), so the stability of input and output connections are guaranteed. Semi-active control components often can be seen as passive control components. Particularly, more resistant or depreciate forces are produced by internal mechanism based on feedback output sensor. So, the combination ability of the best active and passive systems or against less reduction of desired components and due to low power, have high control ability. Semi-active systems are an attractive alternative for active and hybrid systems.[12]

1.2 NEWTON'S SECOND LAW OF MOTION

The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

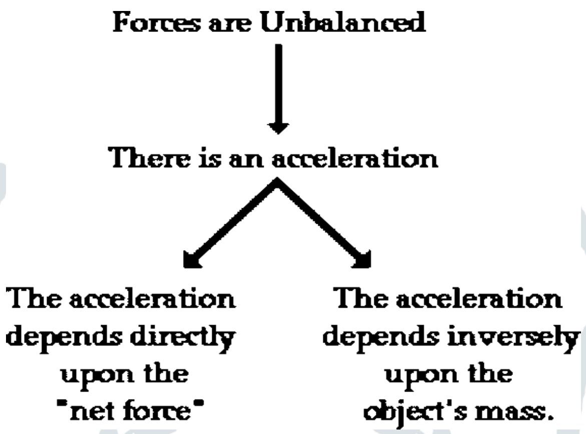


Figure 17: Representation of Newton's second law of motion.

Acceleration is a change in velocity. As long as we know the mass of the object and the net force acting on the object, we can determine acceleration. Let's look at the formula:

$\boldsymbol{a} = \boldsymbol{f}\ (\boldsymbol{net})\ /\ \boldsymbol{m}$, where *a = acceleration, f (net) = the net force acting on the object, m = the mass of the object.*

If we know the mass and acceleration of an object, we can calculate for force. Simply rearrange the equation to solve for force. $\boldsymbol{f}(\boldsymbol{net}) = \boldsymbol{m} * \boldsymbol{a}$

LITERATURE REVIEW

2.1 GENERAL

The literature review of a few powerful basic assets assembled are appeared sensible posting of research. The prerequisite of damping from characterizing it, to its significance in powerful reaction of the structure, likewise extraordinary wellsprings of damping that might be considered as needs be to the circumstance of the structure. Further a few sorts of dampers and base isolators are talked about in the past part, primarily focused on this examination; fluid viscous dampers were profoundly illuminated with its significance, need, places where it tends to be utilized and its determinations. The Codal arrangements required for the examination and the heaps thought surveys are likewise clarified.

2.2 STRUCTURAL ANALYSIS

Basic investigation is the judgment of the impacts of burdens on physical structures and their portions. Structures subject to this kind of investigation incorporate all that must withstand loads, for example, structures, spans, vehicles, apparatus, furniture, clothing, soil lamina, prostheses and natural tissue. Auxiliary examination connects with the scope of connected mechanics, materials science and connected arithmetic to figure a structure's disfigurements, interior powers, stresses, bolster responses, increasing speeds, and steadiness. The consequences of the investigation are practiced to check a structure's force for use, regularly anticipating physical tests. Auxiliary investigation is subsequently a key segment of the building plan of structures as portrayed by K. H. Chang in 2009.[15]

Y. G. Zhao and T. Ono in 2001 mentioned about "Moment methods for structural reliability" in which they said, to perform an accurate analysis a structural engineer must determine such information as structural loads, geometry, support conditions, and materials properties. The results of such an analysis typically include support reactions, stresses and displacements. This information is then compared to criteria that indicate the conditions of failure. Advanced structural analysis may examine dynamic response, stability and non-linear behavior.[16]

Mario Paz further discussed about Structural dynamics in 1985 and elaborated as Structural analysis is mainly concerned with finding out the behavior of a physical structure when subjected to force. This action can be in the form of load due to the weight of things such as people, furniture, wind, snow, etc. or some other kind of excitation such as an earthquake, shaking of the ground due to a blast nearby, etc. In essence all these loads are dynamic, including the self-weight of the structure because at some point in time these loads were not there. The distinction is made between the dynamic and the static analysis on the basis of whether the applied action has enough acceleration in comparison to the structure's natural frequency. If a load is applied sufficiently slowly, the inertia forces (Newton's first law of motion) can be ignored and the analysis can be simplified as static analysis. Structural dynamics, therefore, is a type of structural analysis which covers the behavior of structures subjected to dynamic (actions having high acceleration) loading. Dynamic loads include people, wind, waves, traffic, earthquakes, and blasts. Any structure can be subjected to dynamic loading. Dynamic analysis can be used to find dynamic displacements, time history, and modal analysis.[17]

2.3 *FLUID VISCOUS DAMPING APPLICATIONS*

V. Umachagi, K. Venkataramana, G. R. Reddy, and R. Verma in "Applications of Dampers for Vibration Control of Structures: An overview" has briefly explained that Viscous dampers works based on fluid flow through orifices. Viscous damper is as shown in Fig.18 (Feng Qian et al., 2012) consisted viscous wall, piston with a number of small orifices, cover filled with a silicon or some liquid material like oil, through which the fluid pass from one side of the piston to the other. Stefano et al., 2010 have manufactured the viscous damper and it was implemented in 3 storey building structure for seismic control of structure with additional viscous damper. Attar et al., 2007 have proposed optimal viscous damper to reduce the interstory displacement of steel building.[11]

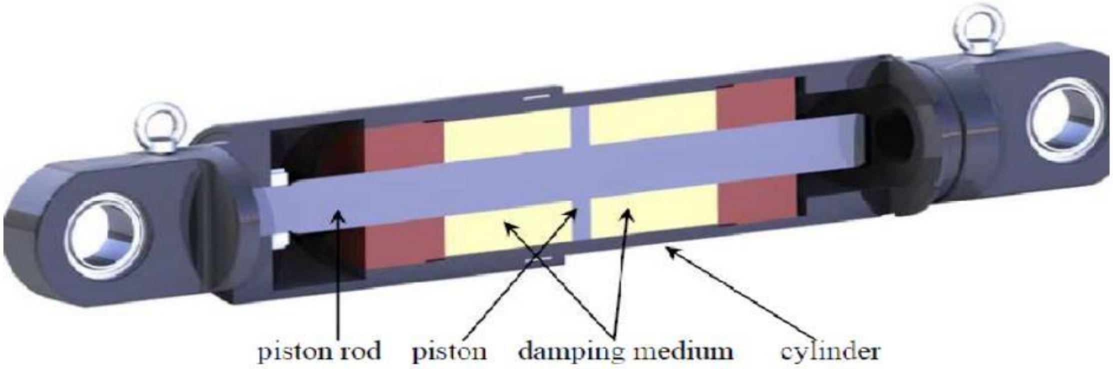


Figure 18: Fluid Viscous Damper Cross-section.

S. Amir and H. Jiaxin in "Optimum Parameter of a Viscous Damper for Seismic and Wind Vibration" found that in most structures, even a relative low damping can also provide a significant energy dissipation which considerably decreases the vibration of a structure. The description in that explains how a nonlinear characteristic is required for a damping system to optimize the vibration of a simple moment frame.[18]

Y. Zhou, X. Lu, D. Weng, and R. Zhang in "A practical design method for reinforced concrete structures with viscous dampers" shown how compared to the retrofitting technology of seismic isolation, the installation of viscous dampers to those existing buildings are more realistic because of easy construction. However, the design of viscous dampers, which provides a high level of damping in a structure, was relatively new application in China for a well-established and proven technology in other seismically active regions in the world.[19]

Özgur Atlayan in 2008 "Effect of Viscous Fluid Dampers on Steel Moment Frame Designed for Strength and Hybrid Steel Moment Frame Design," Said, it was found that as the damping of the structure increases with the help of added dampers, the structural response gets better. Maximum and residual roof displacements, interstory drifts, and IDA (Incremental Dynamic Analysis) dispersion decreases with increasing damping. In addition, by using supplemental damping, most of the collapses that occur for the inherently damped frames are prevented.[20]

2.4 *ANALYSIS USING ETABS 2015 AND CONCLUSIONS*

B. S. Taranath in "Reinforced Concrete Design of Tall Buildings" explains that sophisticated nonlinear time history analysis is required for each of the earthquake ground motions, and the results of the simulations are compared against the performance criteria to ensure the design meets the desired level of safety. The analysis tools used to conduct these simulations have become commercially viable only in the last several years. It is believed that result of this sophisticated and rigorous approach yields a safe and reliable design.[21]

Liya Mathew & C. Prabha in 2014 published "Effect of Fluid Viscous Dampers in Multi-Storeyed Buildings" in which they mentioned that Special protective systems have been developed to enhance safety and reduce damage of structures during earthquakes. Fluid viscous damper (FVD) comes into prominence here. That paper also deals with the study of reinforced concrete buildings with and without fluid viscous dampers. A parametric study for finding optimum damper properties for the reinforced concrete frames was conducted. Nonlinear time history analysis is done on a symmetrical square building. Pushover Analysis has been carried out using software and comparisons are presented in graphical format.[22]

R. Gettu and M. Santhanam, in 2007 "Retrofit of non-engineered buildings," Summarised that the traditional approach to seismic design of a building is a 'force based' analysis and design. The performance based approach is an alternative to that approach, which is based on quantifying the inelastic deformations of the members and the building as a whole, under the seismic loads. The deformations or strains are considered to be better measures than stresses or forces to assess damage. To quantify inelastic deformations, a performance based approach requires a nonlinear lateral load versus deformation analysis. Pushover analysis and nonlinear time history analysis are the static and dynamic methods of nonlinear analysis, respectively. The performance based approach gives the designer more choices of 'performance' of the building, as compared to the demand-to-capacity ratio and drift as mentioned under conventional objectives.[23]

2.5 CODAL PROVISIONS

IS 1893:2002 (Part 1): Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings (Fifth Revision).

IS 875 (Part 1, 2, 3and5): Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures.

- Part 1: Dead Loads--Unit Weights of Building Materials and Stored Materials (Second Revision)
- Part 2: Imposed Loads (Second Revision) by Bureau of Indian Standards (BIS)
- Part 3: Wind Loads (Second Revision)
- Part 5: Special Loads and Load Combinations (Second Revision).

IS 4326: Earthquake Resistant Design and Construction of Buildings--Code of Practice (Second Revision).
IS 456:2000: Plain and Reinforced Concrete - Code of Practice.
SP 16: Design Aids for Reinforced Concrete to IS 456.
IBC-2006: International Building Code, 2006 Edition, Published by the International Code Council, INC.
ACI 318-14: Building Code Requirements for Structural Concrete and Commentary.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 GENERAL

The different procedures of solving the issue are explained from terminology, theory and formulation of the models for getting a rational result at the conclusion.

3.1.1 Single Degree of Freedom System

A simple single degree of freedom system (a mass, M, on a spring of stiffness k, for example) has the following equation of motion:

$$\boldsymbol{M}\ddot{x} + \boldsymbol{Kx} = (\boldsymbol{t})$$

Where**ẍ** is the acceleration (the double derivative of the displacement) and **x** is the displacement.

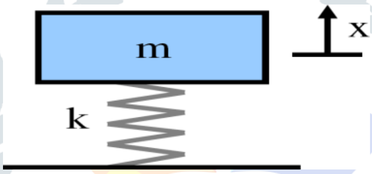


Figure 19: Single degree of freedom system: simple mass spring model

3.2 MODAL ANALYSIS

A modal analysis calculates the frequency modes or natural frequencies of a given system, but not necessarily its full-time history response to a given input. The natural frequency of a system is dependent only on the stiffness of the structure and the mass which participates with the structure (including self-weight). It is not dependent on the load function.

It is useful to know the modal frequencies of a structure as it allows you to ensure that the frequency of any applied periodic loading will not coincide with a modal frequency and hence cause resonance, which leads to large oscillations.

The method is:

1. Find the natural modes (the shape adopted by a structure) and natural frequencies
2. Calculate the response of each mode
3. Optionally superpose the response of each mode to find the full modal response to a given loading

3.3 DETERMINED ANALYSIS ETABS

The analysis and design of the building is carried out using ETABS computer program. The following topics describe some of the important areas in the modelling.

3.3.1 Defining the slab sections

In the present analysis, one-way and two-way slabs are given as membrane type behaviour to provide in plane stiffness / sections are modelled as rigid diaphragms by using the rigid form option in the side menu assignment menu by modelling the slab as rigid diaphragm the masses of the floor are automatically logged lump at their centre of gravity.

3.3.2 Equality static analysis

The natural Period of the building is calculated by the expression t given in IS 1893:2002 where are h is the height and d is the base dimension of the building in the considered direction of vibration. Does the natural periods for all the models in this method is the same as the lateral load calculation and its distribution around the height are done as per IS: 1893- 1984 the seismic weight is calculated using full dead load + 50% of live load.

3.3.3 Response spectrum analysis

Response spectrum analysis of the building models is performed in on ETABS. The lateral load distribution generated by ETABS respond to the seismic zone 4 and the 5% damped response spectrum given in IS: 1893-2002. In Analysis only one invariant lateral load pattern was utilised to represent the likely distribution of inertia forces imposed on the frames during an earthquake and the utilised lateral load pattern is described as follows. Note that the story forces are normalised with the Base shear to have a total Base shear equals to Unity.

3.3.4 Description of case study frames

The effects of lateral load pattern and higher modes on global structural behaviour and on the accuracy of pushover predictions where is studied on reinforced concrete moment resisting frames reinforced concrete frame with tennis stories where utilised to cover a Boat range of fundamental period 3 dimensional models of case study frames where prepared using it apps by considering the necessary geometric and strength characteristics of all members that affect the nonlinear seismic response the configuration member details and shear reinforcement we are not considered since controlling behaviour of frame members was assumed to be pledged both pushover and nonlinear time history analysis where performed using cross section properties and P delta effects were neglected.

CHAPTER 4: MODELLING

4.1 GENERAL

The study in this thesis depends on straight and nonlinear investigation of RC structures with various territories of structure and variable cross area of segment. This section introduces a synopsis of different parameters characterizing the computational models, the fundamental suspicions and the RCC outlines geometry considered for this investigation. Precise demonstrating of the nonlinear properties of different basic components is essential in nonlinear investigation. In the present examination section are displayed with inelastic flexural deformations utilizing nonlinear Hinges or auto Hinges.

4.2 COMPUTATIONAL MODAL

Modelling a building invoice, the demonstrating and collection of its different load conveying components the model must perfect speak to the imprints circulation quality firmness and deformability demonstrating of the material properties and auxiliary components utilized in the present investigation is talked about underneath.

4.3 DESIGN DATA

4.3.1 Material Properties:

M25 grade of concrete and Fe 500 grade of Steel are used for all slabs and beams of the building whereas M30 is used for columns with same grade of Steel. Elastic material properties of these materials are taken as per IS 456-2000. The short-term modulus of elasticity (E_c) of concrete is taken as:

$$= 5000\sqrt{f_{ck}} \text{ Mpa}$$

Where f_{ck} =characteristic compressive strength of concrete cube

For the Steel rebar with stress and modulus of elasticity is taken as per IS 456-2000.

4.4 STRUCTURAL ELEMENTS

The different structural elements considered are columns, beams and slabs with variable sections are mentioned below. Also, the different shapes of building are considered while keeping the total area unchanged.

Description of Members used:-

Column Sizes: 1) Square Columns = 600mm*600mm.

2) Rectangular Columns = 1200mm*300mm.

Beam Sizes: 1) Interior Beams = 230mm*600mm.

2) Exterior Beams = 300mm*650mm.

Slab Sizes: 1) Panel Area = 6m*6m= 36 2) Thickness = 125mm.

Story Data:-

Table 1 : Story Data

Name	Height Mm	Elevation Mm	Master Story	Similar To	Splice Story
Story 10	3000	30000	Yes	None	No
Story 9	3000	27000	No	Story 10	No
Story 8	3000	24000	No	Story 10	No
Story 7	3000	21000	No	Story 10	No
Story 6	3000	18000	No	Story 10	No
Story 5	3000	15000	No	Story 10	No
Story 4	3000	12000	No	Story 10	No
Story 3	3000	9000	No	Story 10	No
Story 2	3000	6000	No	Story 10	No
Story 1	3000	3000	No	Story 10	No
Base	0	0	No	None	No

4.4.1 Loads

While applying the loads to the structure we consider only the external loads which are actually acting on the members neglecting its self-weight because ETABS 2015 automatically takes the members self-weight.

Applied Loads:-

The Shell loads (on Slabs) acting in the Gravity direction are Dead=1.5kN/m^2 and Live=4kN/m^2. The Frame loads applied uniformly on the beams as Dead=5.25kN/m.

The Seismic loads EQ-x and EQ-y are given in Load patterns directly using Code IS1893:2002. Also the Wind loads wind-x and wind-y are given using Code IS875:1987.

Load Patterns:-

Table 2 : Load Patterns

Name	Type	Self-Weight Multiplier	Auto Load
Dead	Dead	1	
Live	Live	0	
EQ-x	Seismic	0	IS1893 2002
EQ-y	Seismic	0	IS1893 2002
wind-x	Wind	0	Indian IS875:1987
wind-y	Wind	0	Indian IS875:1987

Functions:-

Response Spectrum Functions:-

Table 3 : Response Spectrum Functions

Name	Period Sec	Accelera tion	Damping	Z	Soil Type
IS RS	0	0.24	5	0.24	II
IS RS	0.1	0.6			
IS RS	0.55	0.6			
IS RS	0.8	0.408			
IS RS	1	0.3264			
IS RS	1.2	0.272			
IS RS	1.4	0.233143			
IS RS	1.6	0.204			
IS RS	1.8	0.181333			
IS RS	2	0.1632			
IS RS	2.5	0.13056			
IS RS	3	0.1088			
IS RS	3.5	0.093257			
IS RS	4	0.0816			
IS RS	4.5	0.0816			
IS RS	5	0.0816			

Name	Period Sec	Accelera tion	Damping	Z	Soil Type
IS RS	5.5	0.0816			
IS RS	6	0.0816			
IS RS	6.5	0.0816			
IS RS	7	0.0816			
IS RS	7.5	0.0816			
IS RS	8	0.0816			
IS RS	8.5	0.0816			
IS RS	9	0.0816			
IS RS	9.5	0.0816			
IS RS	10	0.0816			

4.4.2 Square buildings with square columns (SBSC)

This is square shape building with 6 rows of Slab panels in both X; Y directions and 49 square shaped Columns with 6m spanning connected beams as shown in figure. It is elevated for ten floors with height of 3m between adjacent floors as shown in figure. The 3D view with all connecting structural members is also shown in figure. Gridlines A-G are parallel to Y axis and gridlines 1-7 are parallel to X axis.

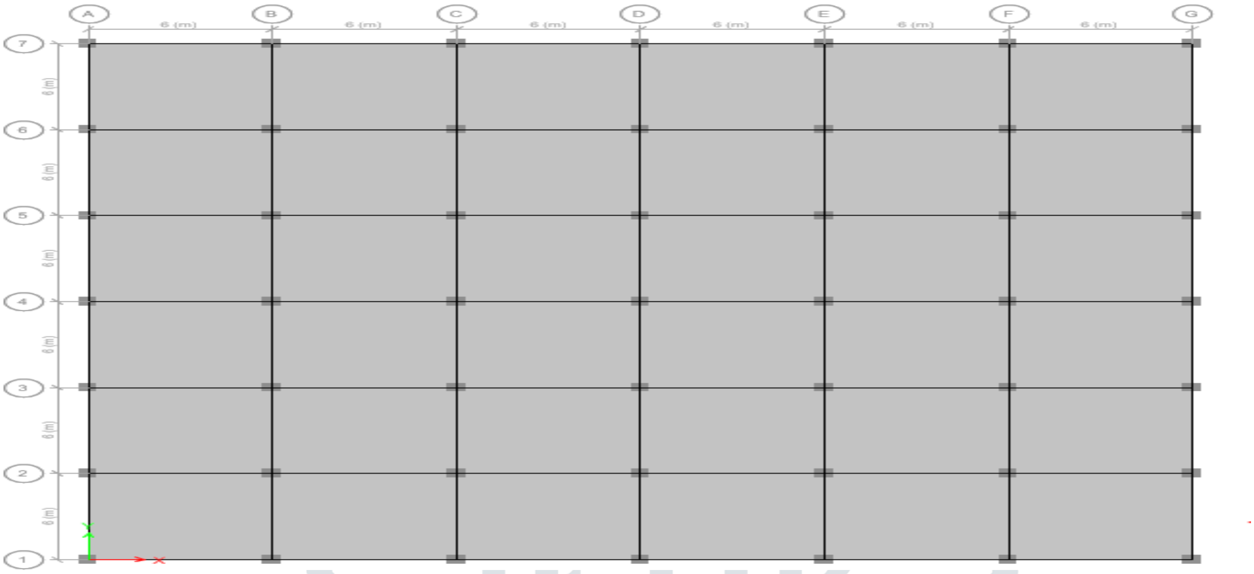


Figure 20 : SBSC Plan.

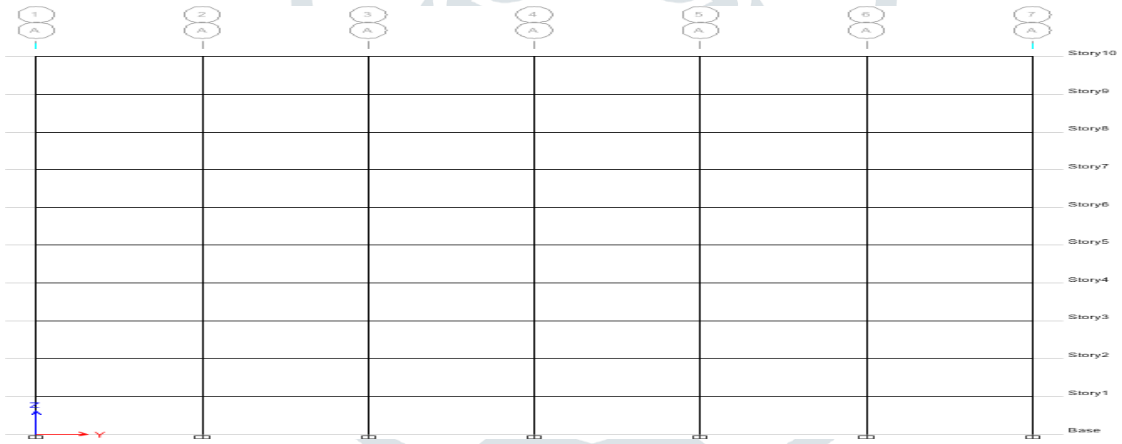


Figure 21 : SBSC Elevation.

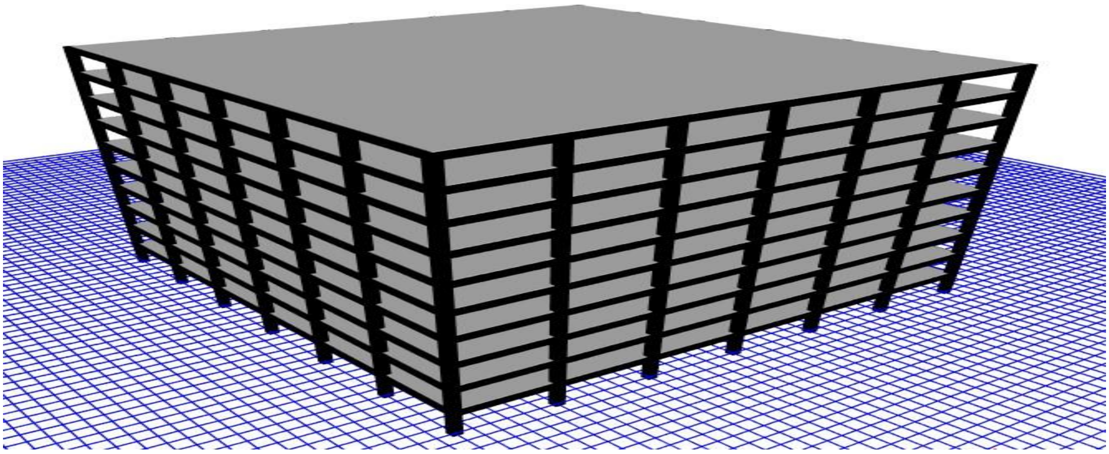


Figure 22 : SBSC 3D view.

4.4.3 Square building with rectangular columns (SBRC)

This is square shape building with 6 rows of Slab panels in both X; Y directions and 49 rectangular shaped Columns with 6m spanning connected beams as shown in figure. Keeping all other things similar to SBSC (no damping); columns are 60% oriented parallel to X-axis and 40% to Y-axis.

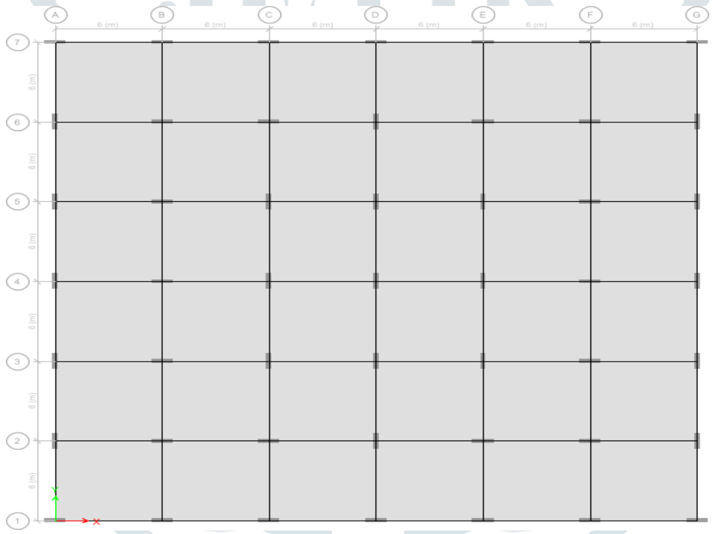


Figure 23 : SBRC Plan.

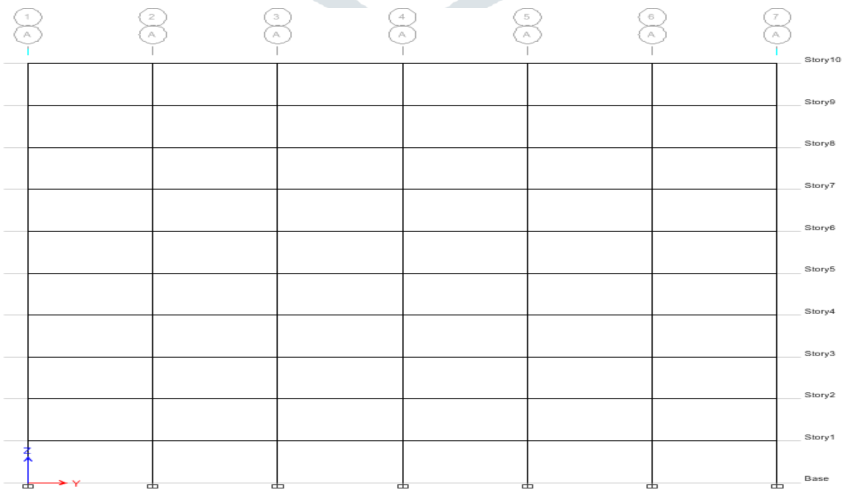


Figure 24 : SBRC elevation.

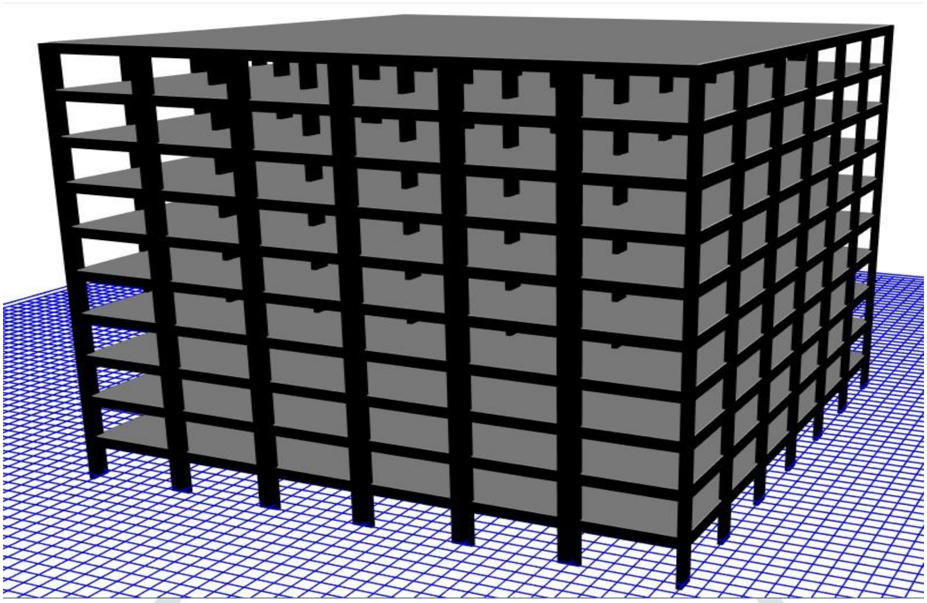


Figure 25 : SBRC 3D-view.

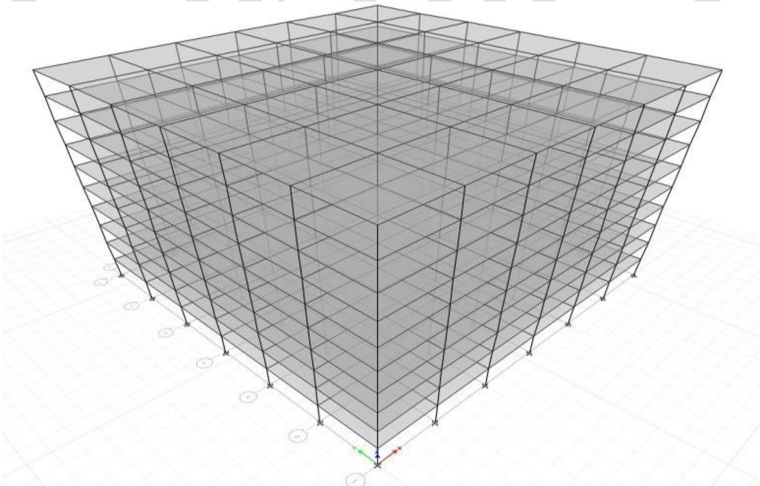


Figure 26 : SBRC Isometric view.

4.4.4 Rectangular building with square columns (RBSC)

This is rectangular shape building with 9 rows of Slab panels in X and 4 in Y directions; and 50 square shaped Columns with 6m spanning connected beams as shown in figure. It is elevated for ten floors with height of 3m between adjacent floors as shown in figure. The Isometric view with all connecting structural members is also shown in figure.

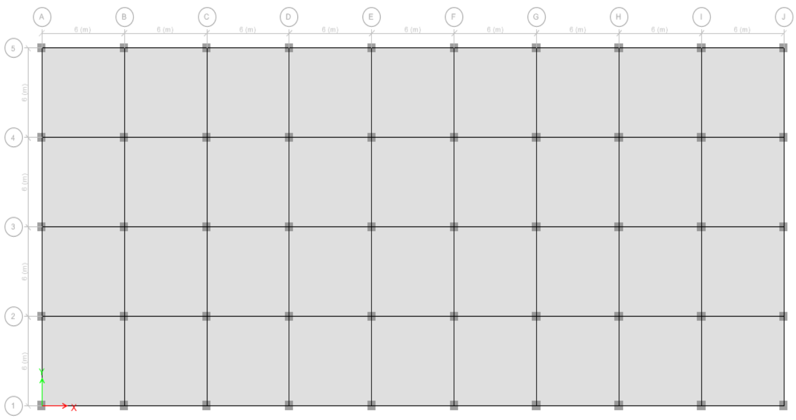


Figure 27 : RBSC Plan.

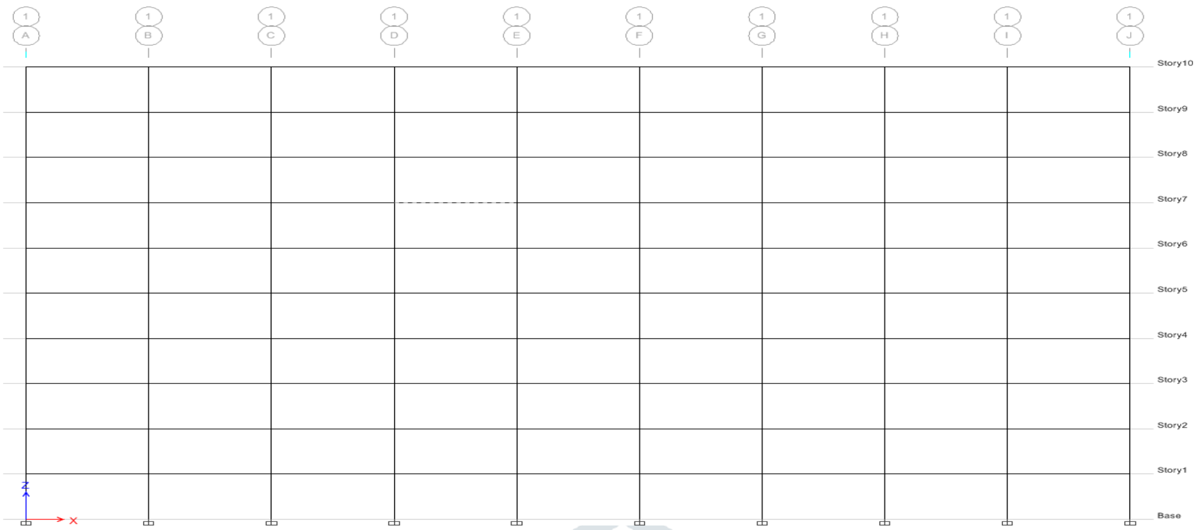


Figure 28 : RBSC Elevation.

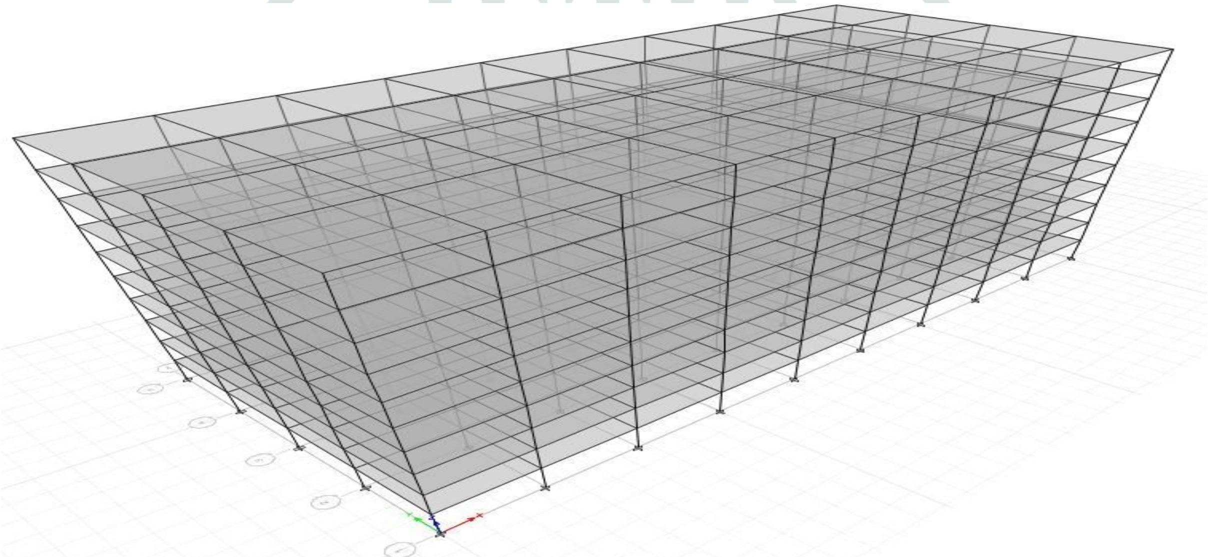


Figure 29 : RBSC Isometric view.

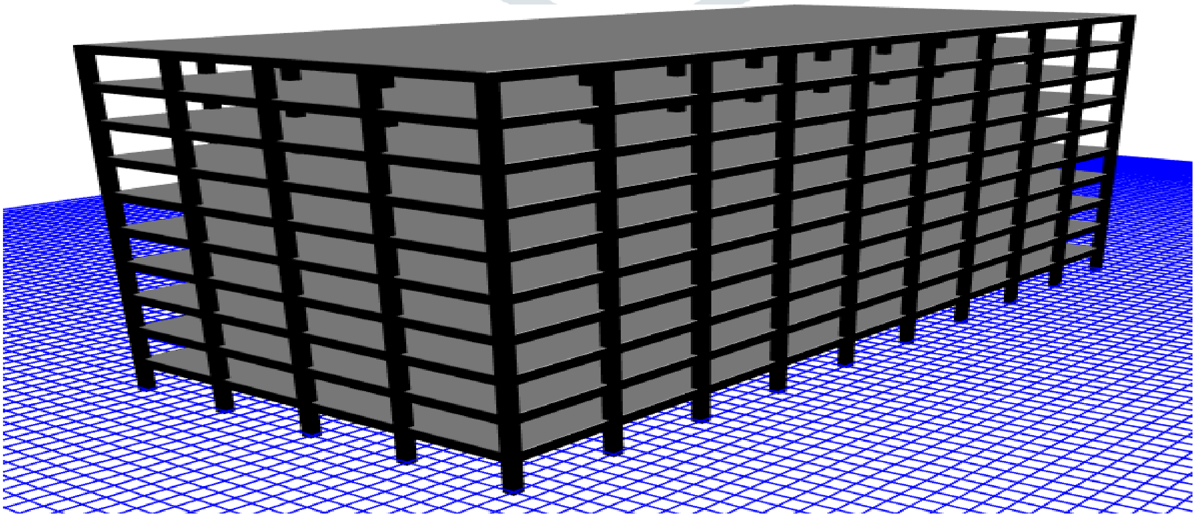


Figure 30 : RBSC 3D-view.

4.4.5 *Rectangular building with rectangular column (RBRC)*

This is rectangular shape building with 9 rows of Slab panels in X and 4 in Y directions; and 50 rectangular shaped Columns with 6m spanning connected beams as shown in figure. It is elevated for ten floors with height of 3m between adjacent floors as shown in figure. The 3D- view with all connecting structural members is also shown in figure.

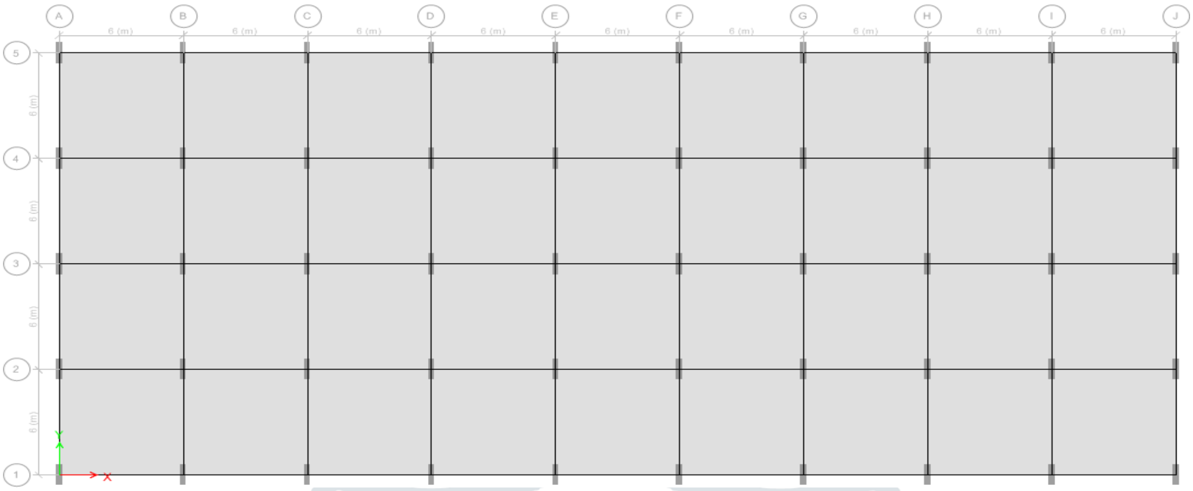


Figure 31 : RBRC Plan.

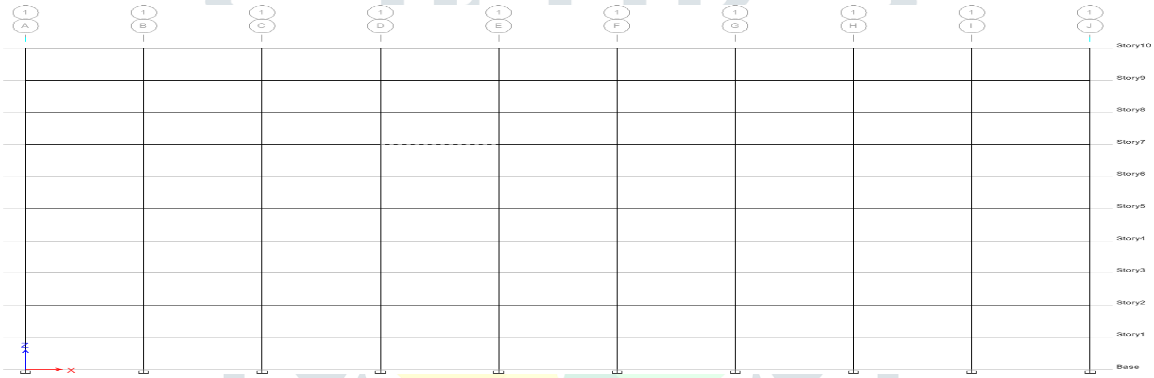


Figure 32 : RBRC Elevation XZ-plane.

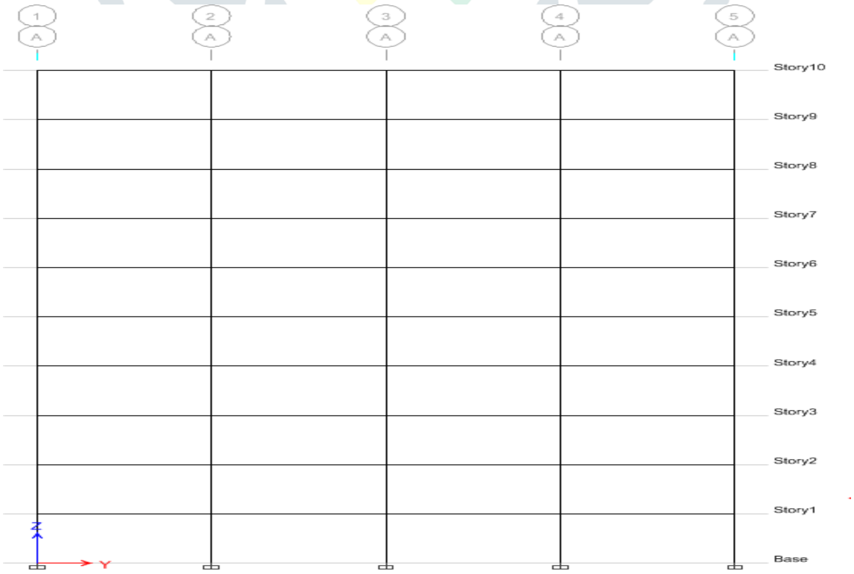


Figure 33 : RBRC Elevation YZ-plane.

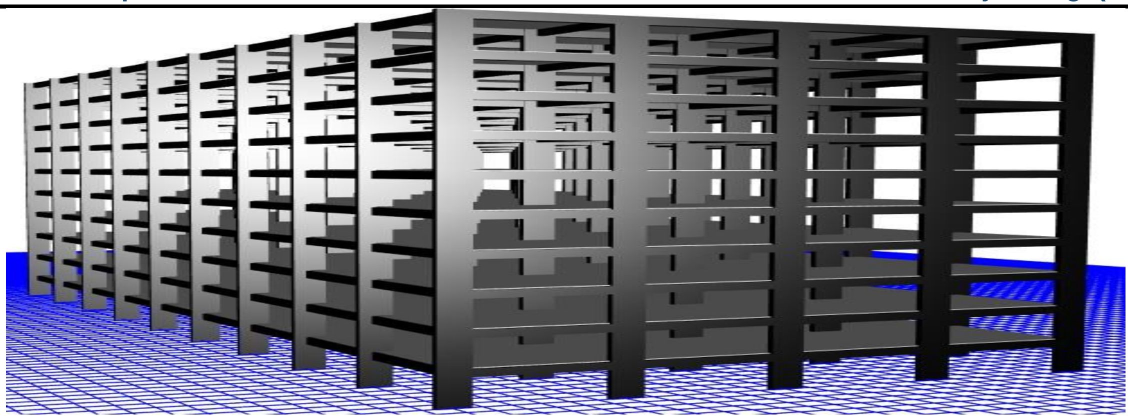


Figure 34 : RBRC 3D-view.

4.5 MODELLING OF DAMPERS

The dampers used in modelling these buildings are from Taylor Devices Inc. made in USA. They provide two types of FVD with data that can be used in ETABS 2015 for modelling of structure. They are: -

1. Fluid viscous dampers & lock-up devices clevis – clevis configuration.
2. Fluid viscous dampers & lock-up devices clevis – base plate configuration.

Any one of these can be used in the structure, since it is easy to fit FVD with base plate is selected here for modelling of structure here. The details of fluid viscous dampers & lock-up devices clevis – base plate configuration are as shown below.

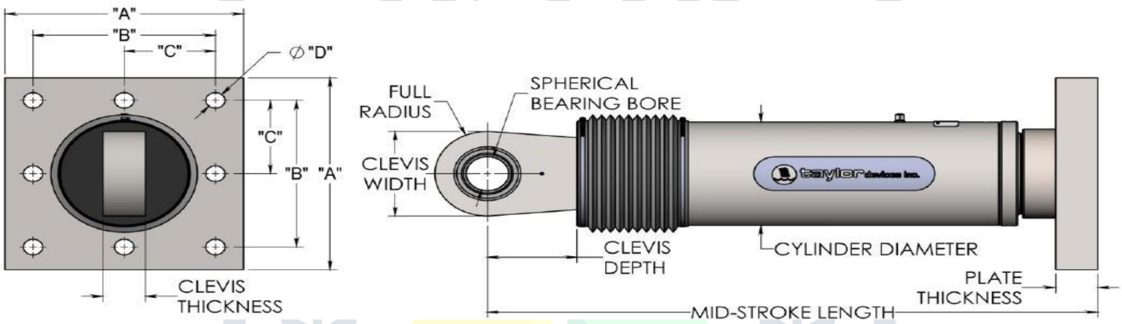


Figure 35 : Fluid viscous dampers & lock-up devices clevis – base plate configuration.
Courtesy: Taylor Devices.

NOTE:

Various strokes are available, from ±50 to ±900 mm. Force capacity may be reduced for stroke longer than stroke listed in the table. Any stroke change from the standard stroke version depicted changes the midstroke length by 5 mm per ±1 mm of stroke.

Example: 1000kN±100mm stroke, mid-stroke LG is 1048mm 1000kN ± 150 mm stroke, 150-100= 50, 50*5=250
1048+250 = 1298 mm mid-stroke length

Bellows may be replaced with a steel sleeve as desired stroke lengths increase. Consult Taylor devices for stroke over ±300 mm and/or for force capacities for stroke longer than listed in table.

Table 5 : FVD with Different Capacities Force(kN).

FORCE (kN)	TAYLOR DEVICES MODEL NUMBER	SPHERICAL BEARING BORE DIAMETER (mm)	MID-STROKE LENGTH (mm)	STROKE (mm)	CLEVIS THICKNESS (mm)	MAXIMUM CLEVIS WIDTH (mm)	CLEVIS DEPTH (mm)	BEARING THICKNESS (mm)	MAXIMUM CYLINDER DIAMETER (mm)	WEIGHT (kg)
250	17120	38.10	787	±75	43	100	83	33	114	44
500	17130	50.80	997	±100	55	127	102	44	150	98
750	17140	57.15	1016	±100	59	155	129	50	184	168
1000	17150	69.85	1048	±100	71	185	150	61	210	254
1500	17160	76.20	1105	±100	77	205	162	67	241	306
2000	17170	88.90	1346	±125	91	230	191	78	286	500
3000	17180	101.60	1441	±125	117	290	203	89	350	800
4000	17190	127.00	1645	±125	142	325	273	111	425	1088
6500	17200	152.40	1752	±125	154	350	305	121	515	1930
8000	17210	177.80	1867	±125	178	415	317	135	565	2625

Fluid viscous dampers with different forces can be used for different types of buildings, since structure modelled is of low height; smaller devices were used to start analysis. This tabular data can be fed in program as shown below.

FVD is added to structure after defining in Link properties by adding a new Damper- Exponential in Link Property Data.

ETABS MENU=> Define=> Link Properties=> Add new Link=> Link Property Data.

Since FVD 250 is linear it is used for direction U1 with fixed end properties. The Mass is 44kg and Weight is 250kN from the above table; to be mentioned in Total Mass and Weight.

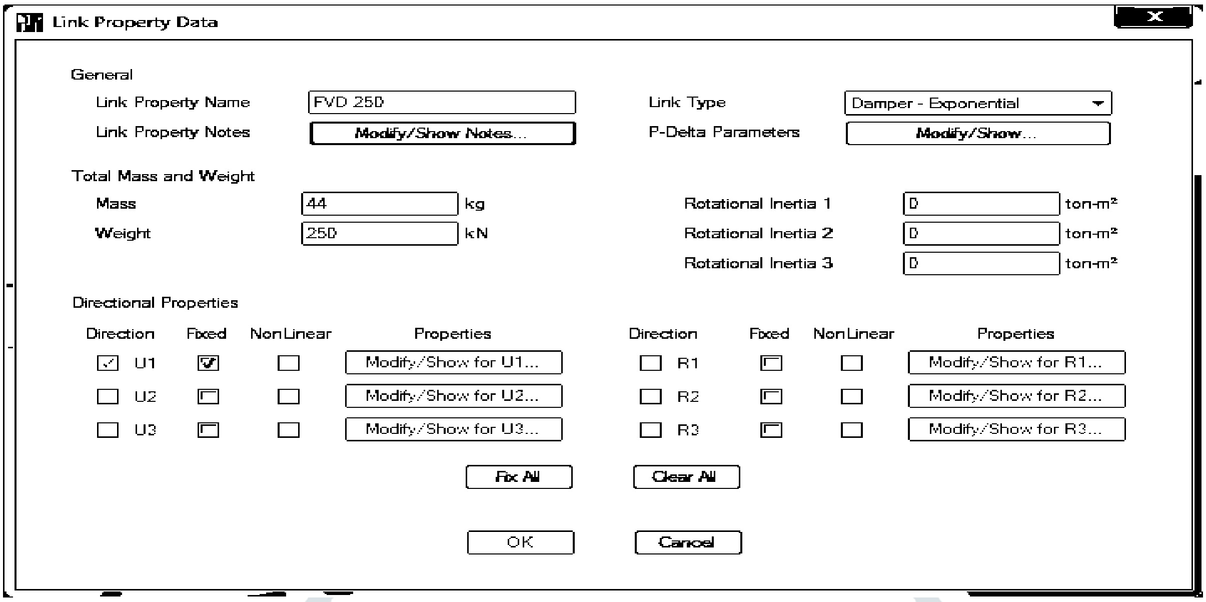


Figure 36 : Adding a new damper property.

Then press OK to add and OK once more to close the tab. Now this damper can be added by draw link option and selecting the FVD 250 damper property across the floor beams ends diagonally; starting from top end to bottom end; Keeping the structure in elevation view for more accuracy. This can be done in two ways 1) Adding dampers to the structure at Its Middle of Exterior Frame(DEM), 2) Adding dampers at Exterior Corners(DEC). Based on previous studies adding dampers to the exterior corner DEC gives much more effective results, hence using DEC method of adding dampers.

4.5.1 *SBSC with dampers*

This is square shape building with 6 rows of Slab panels in both X; Y directions and 49 square shaped Columns with 6m spanning connected beams as shown in figure. It is elevated for ten floors with height of 3m between adjacent floors as shown in figure. The Isometric view with all connecting structural members is also shown in figure.

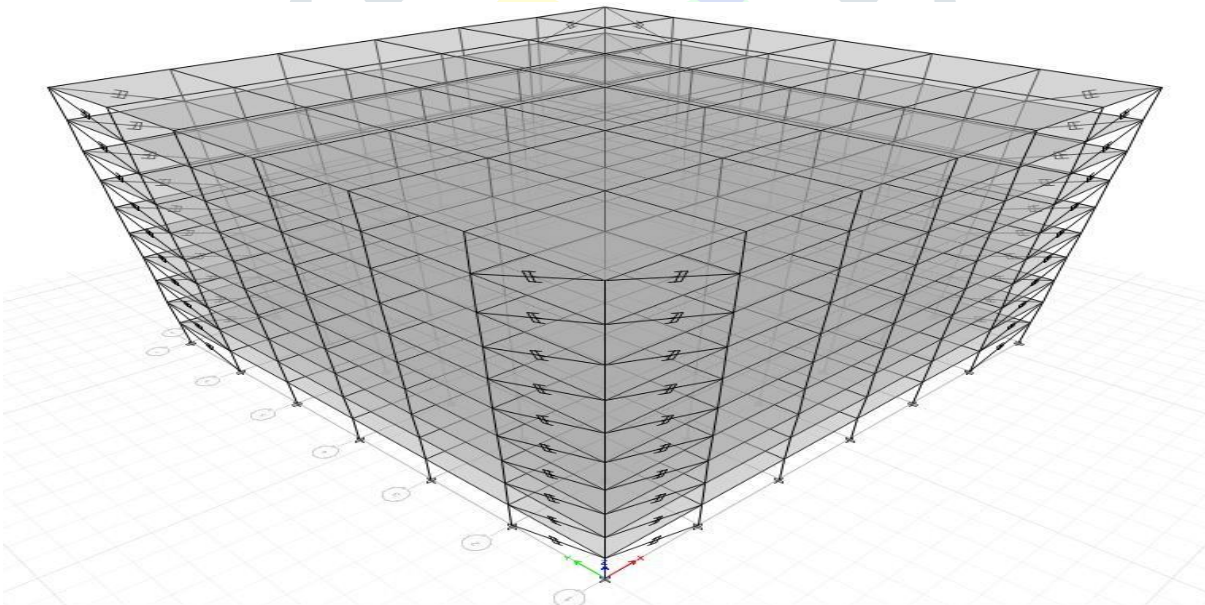


Figure 37 : SBSC with FVD at Exterior Corners Isometric View.

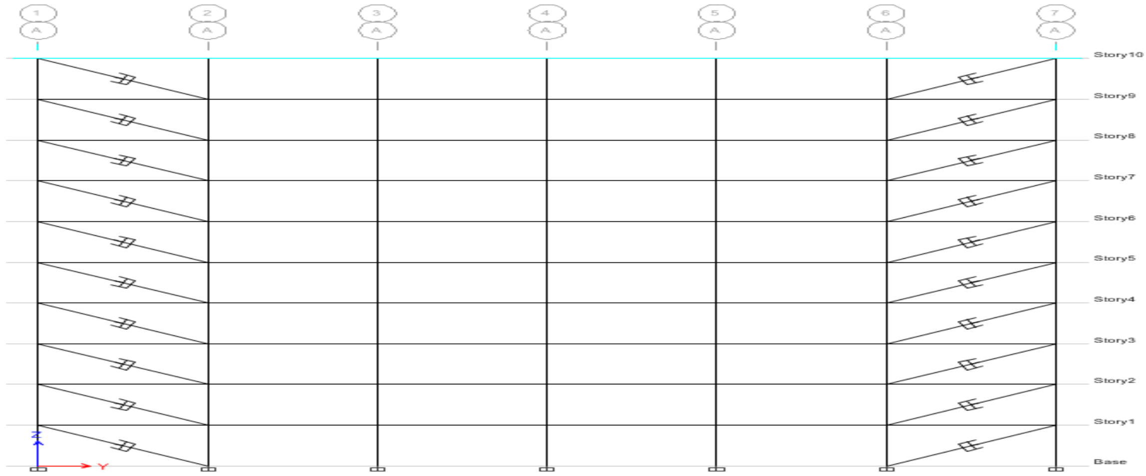


Figure 38 : SBSC with FVD at Exterior Corners Elevation.

4.5.2 SBRC with dampers

This is square shape building with 6 rows of Slab panels in both X; Y directions and 49 rectangular shaped Columns with 6m spanning connected beams as shown in figure. Keeping all other things similar to SBSC (no damping); columns are 60% oriented parallel to X-axis and 40% to Y-axis.

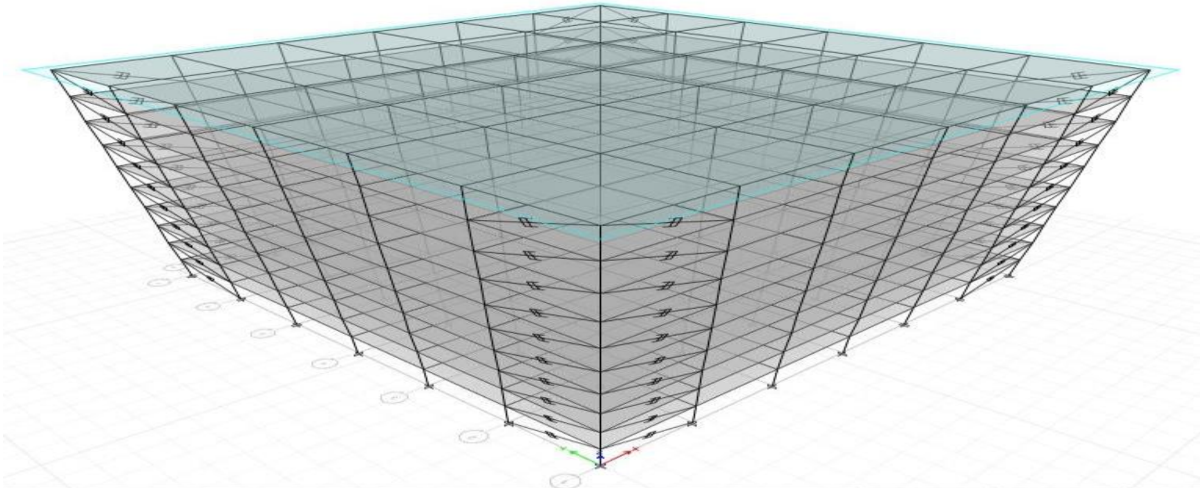


Figure 39 : SBRC with FVD at Exterior Corners Isometric View.

4.5.3 RBSC with dampers

This is rectangular shape building with 9 rows of Slab panels in X and 4 in Y directions; and 50 square shaped Columns with 6m spanning connected beams as shown in figure. It is elevated for ten floors with height of 3m between adjacent floors as shown in figure. The Isometric view with all connecting structural members is also shown in figure.

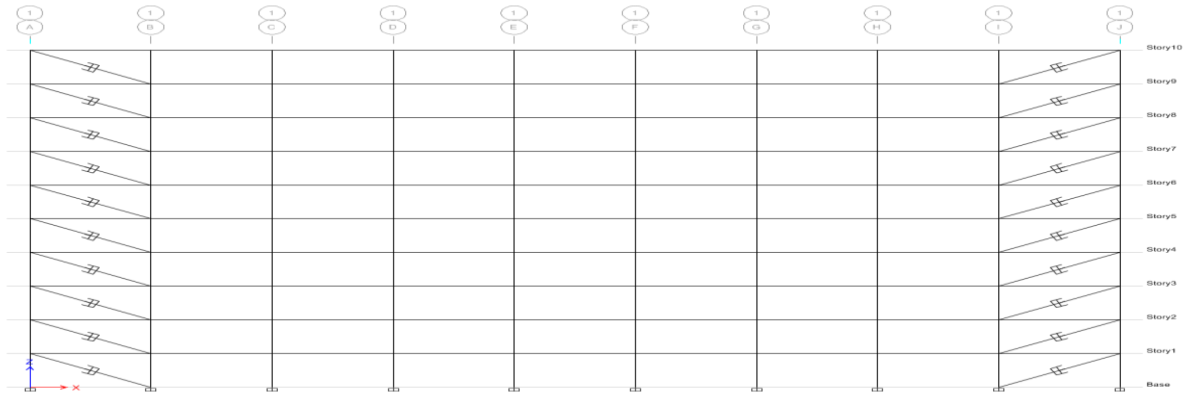


Figure 40 : RBSC with FVD at Exterior Corners Elevation XZ-plane.

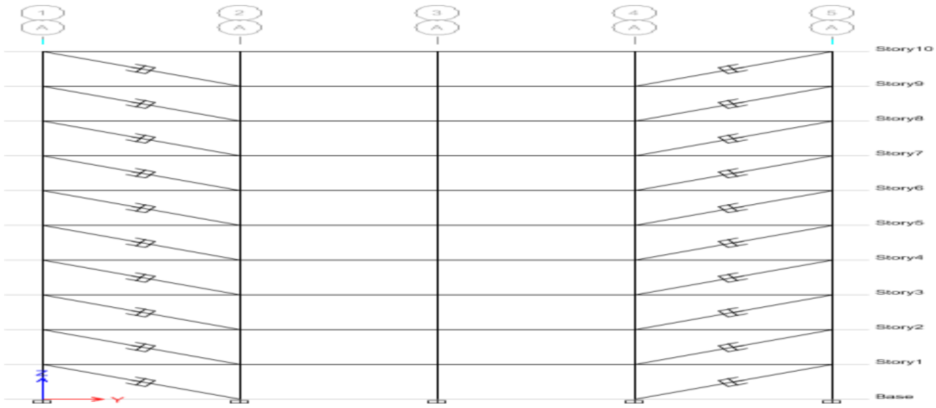


Figure 41 : RBSC with FVD at Exterior Corners Elevation YZ-plane.

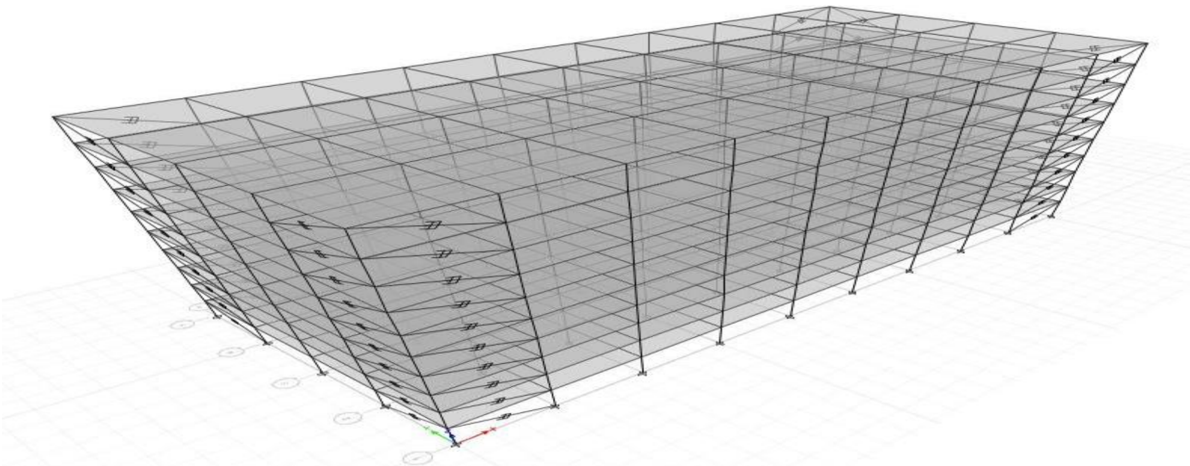


Figure 42 : RBSC with FVD at Exterior Corners Isometric View.

4.5.4 RBRC with dampers

This is rectangular shape building with 9 rows of Slab panels in X and 4 in Y directions; and 50 rectangular shaped Columns with 6m spanning connected beams as shown in figure. It is elevated for ten floors with height of 3m between adjacent floors as shown in figure. The 3D- view with all connecting structural members is also shown in figure.

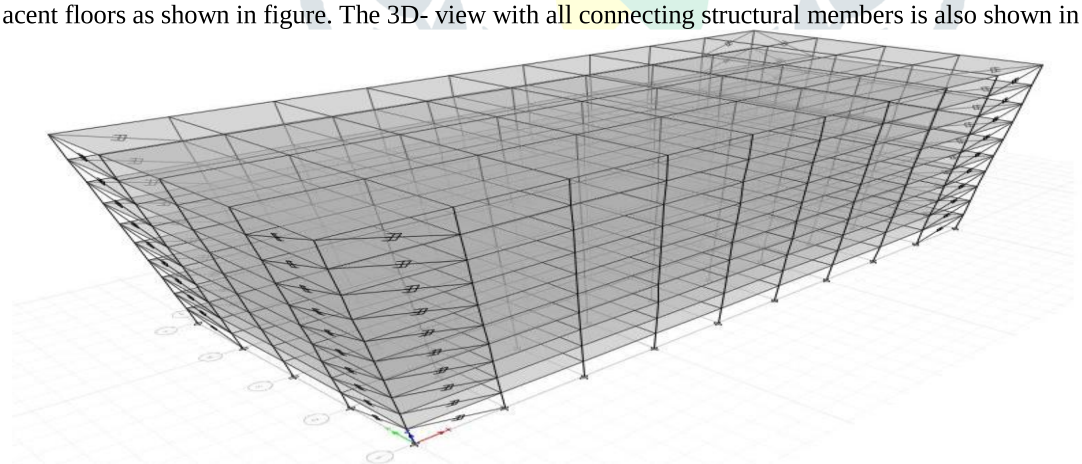


Figure 43 : RBRC with FVD at Exterior Corners Isometric View.

5.1 RESULTS

5.1.1 *Response Spectrum Curves from Time History*

This shows response spectrum plots obtained from time history results at a specified point for a specified time history load case.

Table 6 : Input Data

Name	RSFromTH1		
Load Case	THX	Coordinate System	Modal
Story	Story10	Response Direction	X
Point	1	Spectrum Widening	0 %

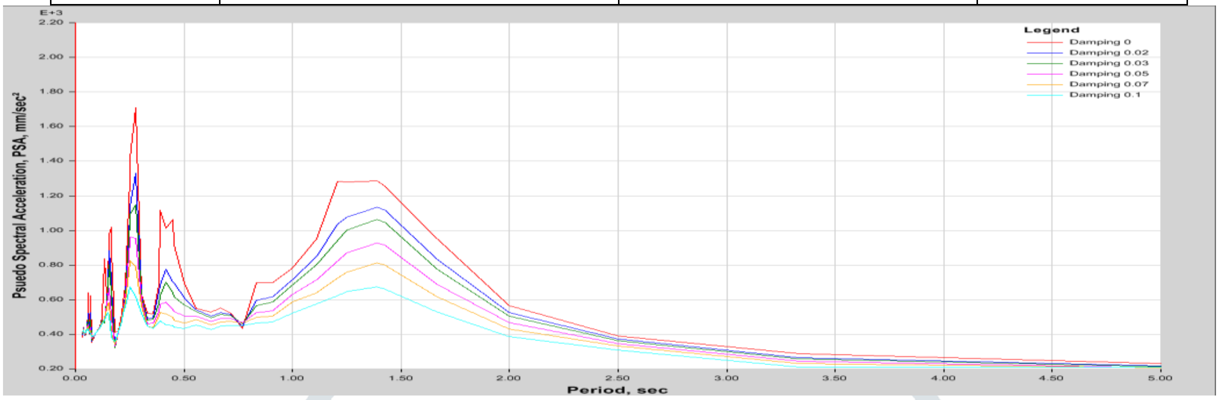


Figure 47 : SBSC RS curves.

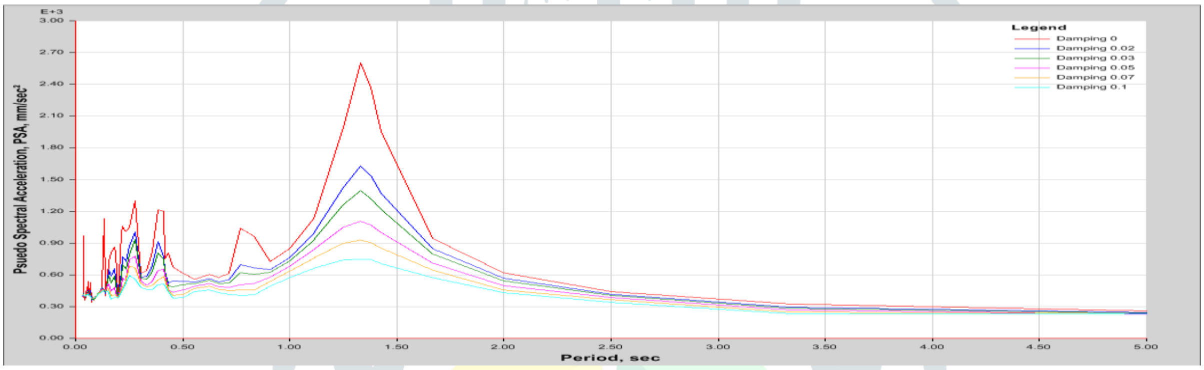


Figure 48 : SBRC RS curves.

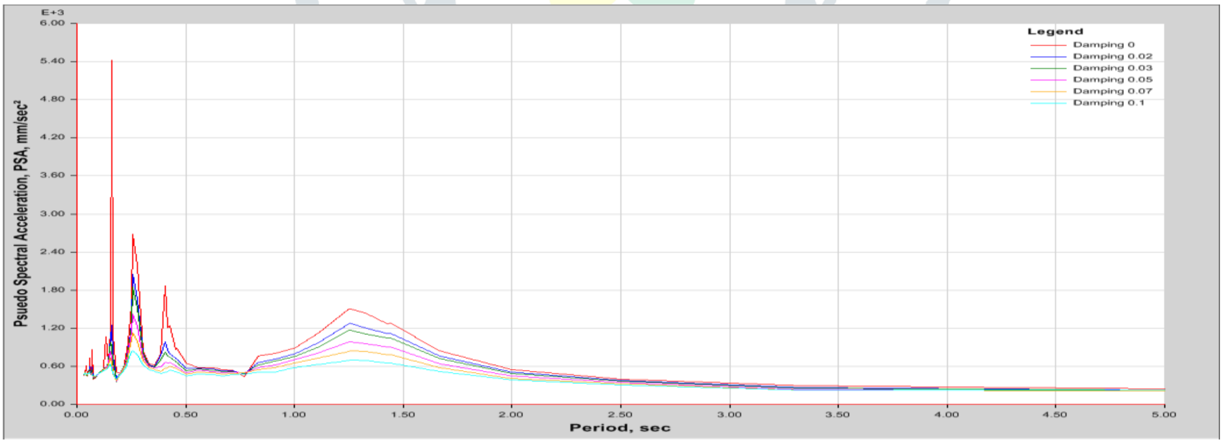


Figure 49 : RBSC RS curves.

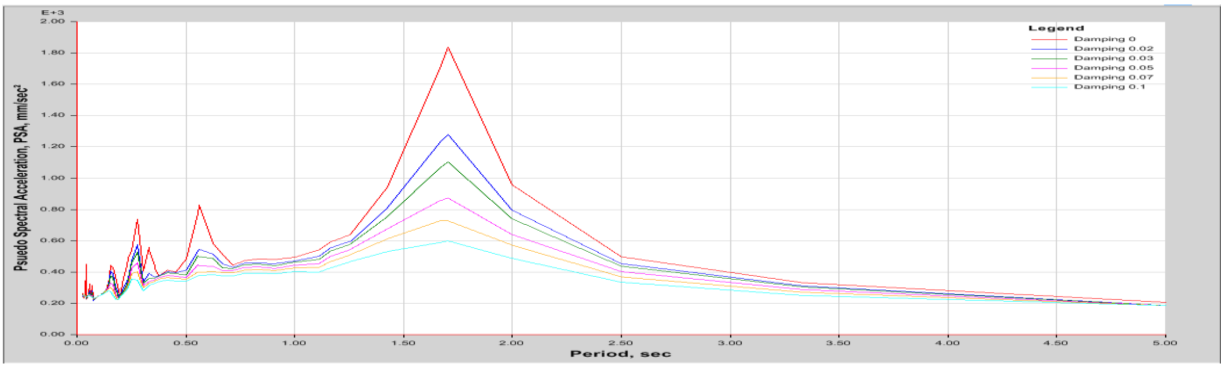


Figure 50 : RBRC RS curves.

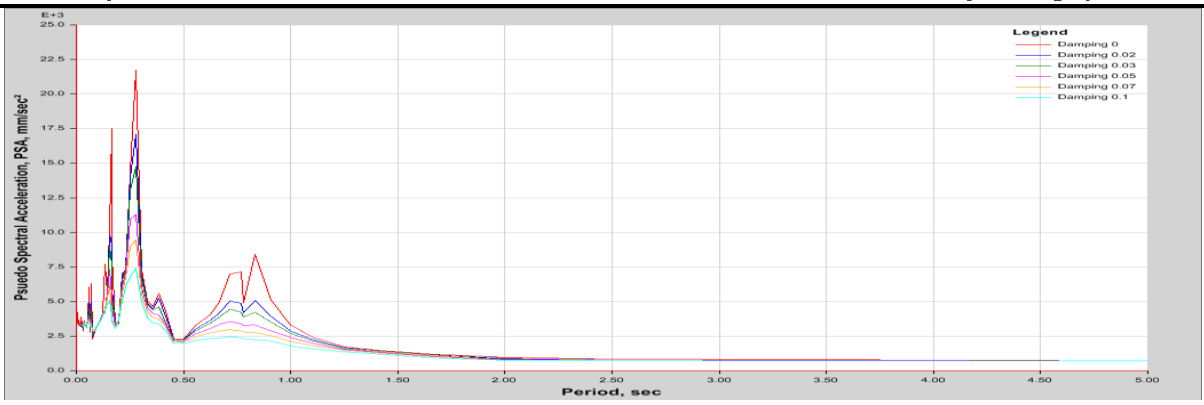


Figure 51 : SBSC with FVD RS curves.

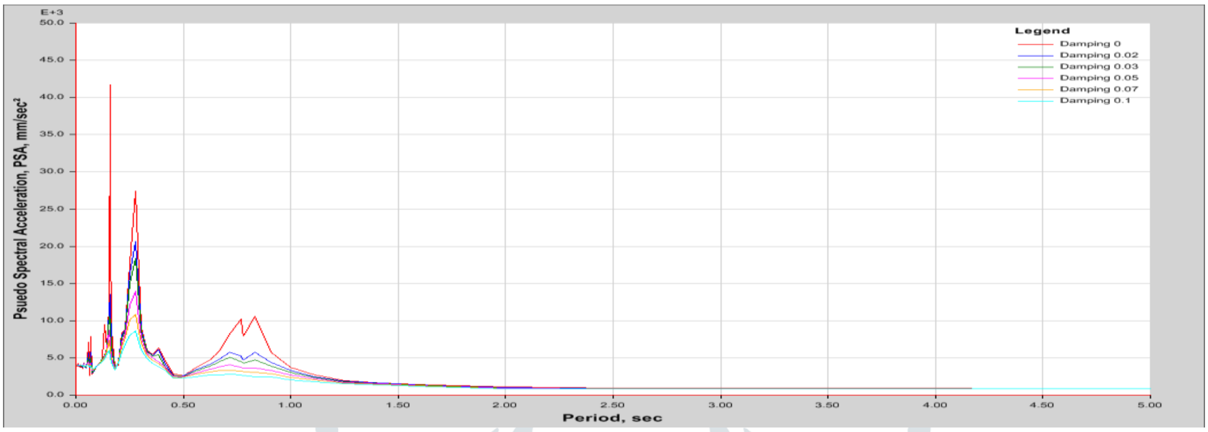


Figure 52 : SBRC with FVD RS curves.

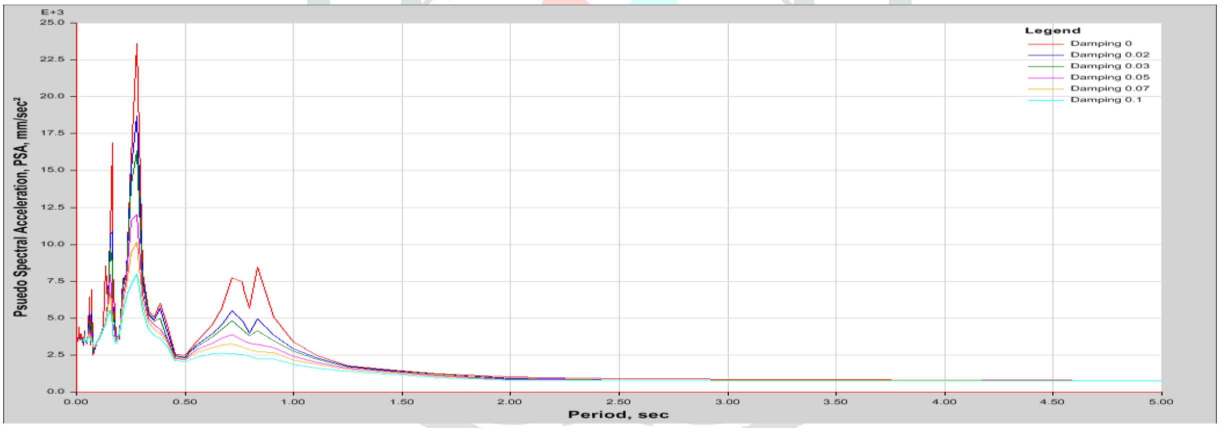


Figure 53 : RBSC with FVD RS curves.

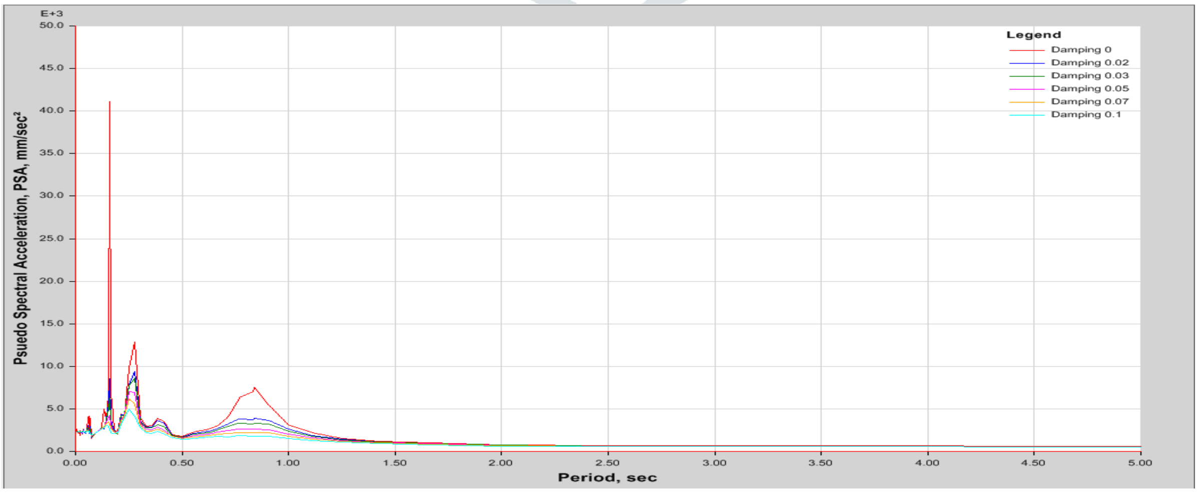


Figure 54 : RBRC with FVD RS curves.

5.1.2 Responses when loaded in different directions

Table 7 : Maximum PSA at Zero Damping

Max. Values	Load Case/Direction							
Building Modal	THX/X		THX/Y		THY/X		THY/Y	
	Period (sec)	**PSA (mm/sec^2)**	**Period (sec)**	**PSA (mm/sec^2)**	**Period (sec)**	**PSA (mm/sec^2)**	**Period (sec)**	**PSA (mm/sec^2)**
SBSC no Damp	0.278	1710	0.389	0.000066	0.389	0.000066	0.278	1710
SBRC no Damp	1.329	2605	0.777	0	0.412	0.000004	1.38	2276
RBSC no Damp	0.161	5417	0.769	0.000018	0.833	0.000012	0.161	3520
RBRC no Damp	1.703	1838	0.769	0.000006	0.769	0.000004	1.25	2563
SBSC With FVD	0.278	21759	0.769	0	0.714	0	0.278	21759
SBRC With FVD	0.161	41674	0.777	0	0.777	0	0.161	39347
RBSC With FVD	0.278	23603	0.714	0	0.769	0	0.278	18861
RBRC With FVD	0.16	41081	0.764	0	0.769	0	0.16	105797

5.1.3 Base Reactions

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Calculations of base shear (**V**) depend on:

- Soil conditions at the site
- Proximity to potential sources of seismic activity (such as geological faults)
- Probability of significant seismic ground motion
- The level of ductility and over-strength associated with various structural configurations and the total weight of the structure
- The fundamental (natural) period of vibration of the structure when subjected to dynamic loading.

Table 8 : Base Reactions of SBSC

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	0	0	98204.96	1767689	-1767689	0
Live	0	0	51840	933120	-933120	0
EQ-x	-2898.82	0	0	0	-68067.88	52178.79
EQ-y	0	-2898.82	0	68067.880	0	-52178.79
Wind-x 1	-8446.15	0	0	-6.359E-07	-138832	152030.69
Wind-x 2	8446.15	0	0	6.359E-07	138832.19	-152031
Wind-y 1	0	-8446.15	0	138832.19	6.356E-07	-152031
Wind-y 2	0	8446.15	0	-138832	-6.356E-07	152030.69
TH-x Max	2898.84	0.0000355	0	0.0000203	42700.4629	35328.21
TH-x Min	-1962.67	-0.0000332	0	-0.0000186	-36063.48	-52179.18
TH-y Max	0.0002	2898.84	0	36063.48	0.0003	52179.18
TH-y Min	-0.0001	-1962.67	0	-42700.46	-0.0003	-35328.21
PushX Max	18376.71	0	0	0.00000166	300254.17	0
PushX Min	0	0	0	0	0	-330781
PushY Max	0	13151.21	0	0	0	236721.91
PushY Min	0	0	0	-214876	-0.0000033	0

Table 9 : Base Reactions of SBRC

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	0	0	97795.69	1760323	-1760323	0
Live	0	0	51840	933120	-933120	0
EQ-X	-3021.45	0	0	0	-70946.56	54386.21
EQ-y	0	-2909.22	0	68311.30	0	-52366.07
Wind-x 1	-8446.15	0	0	-5.238E-07	-138832	152030.69
Wind-x 2	8446.15	0	0	5.238E-07	138832.19	-152031
Wind-y 1	0	-8446.15	0	138832.19	5.66E-07	-152031
Wind-y 2	0	8446.15	0	-138832	-5.66E-07	152030.69
THX Max	3021.45	0.0002	0	0.0002	47392.42	36747.05
THX Min	-2041.50	-0.0002	0	-0.0002	-39579.62	-54386.12
THY Max	0.0001	2909.22	0	37622.19	0.0001	52365.98
THY Min	-0.0001	-2022.13	0	-44754.26	-0.0001	-36398.38
PushX Max	17321.50	0	0	0.0000012	282984.01	0
PushX Min	0	0	0	0	0	-311787
PushY Max	0.0000054	20720.76	0	642233.09	0.0002	372973.81
PushY Min	0	-39311.20	-2E-06	-338518	0	-707602

Table 10 : Base Reactions of RBSC

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	0	0	99444.98	1193340	-2685015	0
Live	0	0	51840	622080	-1399680	0
EQ-X	-3057.82	0	0	0	-71798.47	36693.84
EQ-y	0	-2819.35	0	66199.29	0	-76122.65
Wind-x 1	-5630.76	0	0	0	-92554.79	67569.19
Wind-x 2	5630.76	0	0	0	92554.79	-67569.19
Wind-y 1	0	-12669.22	0	208248.29	9.451E-07	-342069
Wind-y 2	0	12669.22	0	-208248	-9.451E-07	342069.07
THX Max	3057.81	0.0002	0	0.0002	45191.78	23772.17
THX Min	-1981.01	-0.0001	0	-0.0002	-37544.81	-36693.79
THY Max	0.0001	2819.31	0	35849.14	0.0001	76121.61
THY Min	-0.0001	-1958.42	0	-42274.75	-0.0001	-52877.38
PushX Max	21446.56	0	0	0.00000223	350376.40	0
PushX Min	0	0	0	0	0	-257359
PushY Max	0	17885.86	0	0	0	482918.40
PushY Min	0	0	0	-292205	-0.0000014	0

Table 11 : Base Reactions of RBRC

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	0	0	99091.39	1189097	-2675468	0
Live	0	0	51840	622080	-1399680	0
EQ-X	-2382.50	0	0	0	-55941.33	28590.10
EQ-y	0	-3239.11	0	76054.27	0	-87455.88
Wind-x 1	-5630.76	0	0	-5.914E-07	-92554.79	67569.19
Wind-x 2	5630.76	0	0	5.914E-07	92554.79	-67569.19
Wind-y 1	0	-12669.22	0	208248.29	7.006E-07	-342069
Wind-y 2	0	12669.22	0	-208248	-7.006E-07	342069.07
THX Max	2382.5	0.0001	0	0.0001	38588.45	22361.63
THX Min	-1863.46	-0.000045	0	-0.0001	-32775.10	-28590.04
THY Max	0	3239.1	0	40700.93	0.0000014	87455.82
THY Min	0	-2106.22	0	-48178.89	-0.0000013	-56868.10
PushX Max	10356.642	0	0	0.0000017	169181.47	0

PushX Min	0	0	0	0	0	-124280
PushY Max	0	22085.12	0	0	0	596298.42
PushY Min	0	0	0	-360773	-0.000017	0

Table 12 : Base Reactions of SBSC with FVD

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	-0.0000036	-0.0000036	104889.63	1888013	-1888013	0
Live	-0.00000314	-0.0000031	49227.86	886101.5	-886102	0
EQ-X	666.51	0	0	0	-4415.29	-11997.27
EQ-y	0	666.51	0	4415.29	0	11997.27
Wind-x 1	675.03	0	0	0	1716.6	-12150.667
Wind-x 2	-675.03	0	0	0	-1716.6	12150.67
Wind-y 1	0	675.03	0	-1716.6	0	12150.67
Wind-y 2	0	-675.03	0	1716.6	0	-12150.67
THX Max	666.50	0	0	0.0000029	20451.47	20953.95
THX Min	-1164.10	0	0	-0.0000035	-24122.75	-11997.14
THY Max	0	666.5076	0	24122.75	0.0000014	11997.14
THY Min	0	-1164.11	0	-20451.47	-0.0000016	-20953.95
PushX Max	0	0	0.1	2.86	0	6892.41
PushX Min	-382.93	-0.0103	-0.09	-0.76	-1483.52	0
PushY Max	3.11	0	2765.73	26578.63	1.53	0
PushY Min	-0.25	-3099.58	-0.15	0	-49822.47	-55914.16

Table 13 : Base Reactions of SBRC with FVD

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	-0.00000399	-0.00000354	104587.5405	1882576	-1882576	0.000008243
Live	-0.0000034	-0.00000302	49301.4821	887426.67	-887427	0.00000699
EQ-X	1362.2058	0	0	0	-3687.9383	-24519.7041
EQ-y	0	1051.658	0	4147.54	0	18929.8446
Wind-x 1	1370.4584	0	0	0	2305.7045	-24668.252

Wind-x 2	-1370.4584	0	0	0	-2305.7045	24668.252
Wind-y 1	0	1061.6648	0	-1939.22	0	19109.9659
Wind-y 2	0	-1061.6648	0	1939.22	0	-19109.9659
THX Max	1362.214	0	0	0.000006546	25868.8893	47756.1861
THX Min	-2653.1214	0	0	-0.0000078	-31225.2386	-24519.8518
THY Max	0	1051.6547	0	28329.68	0	18929.7851
THY Min	0	-1963.356	0	-24058.05	0	-35340.4081
PushX Max	0	0.000002126	0.0112	0.201	0	12128.8277
PushX Min	-673.8265	-0.0035	-0.5922	-10.66	-1116.759	0
PushY Max	0.0247	0	44.0179	25424.26	5869.6678	0
PushY Min	-0.4107	-6525.4811	-326.5882	0	-792.3258	-117458

Table 14 : Base Reactions of RBSC with FVD

Load Case/Combo	**FX kN**	**FY kN**	**FZ kN**	**MX kN-m**	**MY kN-m**	**MZ kN-m**
Dead	-0.000003555	-0.000003852	106127.1985	1273526	-2865434	-0.0001
Live	-0.000003031	-0.000003288	49228.1629	590737.9545	-1329160	-0.0001
EQ-X	666.1333	0	0	0	48165.4507	-7993.6002
EQ-y	0	697.757	0	40160.2319	0	18839.439
Wind-x 1	439.6246	0	0	0	35310.0811	-5275.4952
Wind-x 2	-439.6246	0	0	0	-35310.0811	5275.4952
Wind-y 1	0	1068.6387	0	51324.7701	-5.614E-07	28853.2461
Wind-y 2	0	-1068.6387	0	-51324.7701	5.613E-07	-28853.2461
THX Max	666.13	0	0	0	50149.0651	14736.9854
THX Min	-1228.0821	0	0	0	-119383	-7993.5605
THY Max	0	697.7616	0	33579.4853	0.00001181	18839.5619
THY Min	0	-1109.8058	0	-41096.1076	-0.00001009	-29964.7556
PushX Max	0	0	13.9102	195.272	0	4646.2934

PushX Min	-387.3156	-0.1136	-0.0959	-0.3686	-37235.437	0
PushY Max	54.3913	0	543.587	0	10.0461	0
PushY Min	-0.0158	-1798.692	-0.4508	-107080	-14680.8833	-48221.0492

Table 15 : Base Reactions of RBRC with FVD

Load Case/Combo	**FX kN**	**FY kN**	**FZ kN**	**MX kN-m**	**MY kN-m**	**MZ kN-m**
Dead	-0.000001966	-0.000006048	105816.9816	1269804	-2857059	-0.0001
Live	-0.000001677	-0.00000516	49256.1582	591073.899	-1329916	-0.0001
EQ-X	144.71	0	0	0	62391.7217	-1736.5203
EQ-y	0	2316.4475	0	41878.4126	0	62544.0815
Wind-x 1	102.5717	0	0	0	46710.5913	-1230.8607
Wind-x 2	-102.5717	0	0	0	-46710.5913	1230.8607
Wind-y 1	0	3422.6708	0	51244.8298	0	92412.1128
Wind-y 2	0	-3422.6708	0	-51244.8298	0	-92412.1128
THX Max	144.7098	0	0	0	63676.8678	2235.0746
THX Min	-186.2562	0	0	0	-93667.4215	-1736.5176
THY Max	0	2316.4456	0	52095.2401	0.00001925	62544.0314
THY Min	0	-5069.3032	0	-65367.4274	-0.00001599	-136871
PushX Max	0	0	1080.5888	12967.0651	0	719.9016
PushX Min	-59.9918	-0.00003417	0	0	-75380.096	0
PushY Max	0	0	254.7276	0	0.000002347	0
PushY Min	-0.2232	-34879.5399	0	-542238	-6875.885	-941749

5.1.4 Modal Periods and Frequencies

One analysis technique for calculating the linear response of structures to dynamic loading is a modal analysis. In modal analysis, we decompose the response of the structure into several vibration modes. A mode is defined by its frequency and shape. Structural engineers call the mode with the shortest frequency (the longest period) the fundamental mode.

During dynamic loading, i.e. earthquake, wind or blast loading, not all modes are excited in the same manner. The extent to which dynamic loading excites a specific vibration modes depends on the spatial distribution and the frequency content of the load.

Hence the Eigen values, frequencies and periods for 10 modes of each Modal are shown below.

Table 16: SBSC modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	Sec	cyc/sec	rad/sec	rad²/sec²
1	1.39	0.719	4.5197	20.4279
2	1.39	0.719	4.5197	20.4279
3	1.206	0.829	5.2108	27.1526
4	0.447	2.239	14.0654	197.836
5	0.447	2.239	14.0654	197.836
6	0.39	2.566	16.124	259.9828
7	0.251	3.986	25.0419	627.0972
8	0.251	3.986	25.0419	627.0972
9	0.221	4.521	28.4092	807.0804
10	0.166	6.031	37.8947	1436.0068

Table 17 : SBRC modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	Sec	cyc/sec	rad/sec	rad²/sec²
1	1.381	0.724	4.551	20.7119
2	1.329	0.752	4.7266	22.3408
3	1.117	0.895	5.6251	31.642
4	0.433	2.31	14.5137	210.6471
5	0.412	2.427	15.2474	232.4843
6	0.348	2.874	18.0574	326.0696
7	0.234	4.27	26.8284	719.764
8	0.219	4.565	28.6848	822.8161
9	0.187	5.361	33.6817	1134.4579
10	0.149	6.725	42.2561	1785.5761

Table 18 : RBSC modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	Sec	cyc/sec	rad/sec	rad²/sec²
1	1.444	0.693	4.3526	18.945
2	1.331	0.751	4.7207	22.2853
3	1.256	0.796	5.0029	25.0293
4	0.462	2.165	13.6004	184.9703
5	0.429	2.33	14.6424	214.3991
6	0.405	2.471	15.5261	241.0592
7	0.258	3.881	24.3858	594.6671
8	0.242	4.125	25.9171	671.6972
9	0.228	4.378	27.507	756.6329
10	0.169	5.91	37.1316	1378.7585

Table 19 : RBRC modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	sec	cyc/sec	rad/sec	rad²/sec²
1	1.703	0.587	3.6886	13.606
2	1.253	0.798	5.0148	25.1485
3	1.163	0.86	5.4043	29.2062
4	0.563	1.776	11.1603	124.5525
5	0.376	2.66	16.7152	279.3988
6	0.356	2.812	17.6685	312.1755
7	0.332	3.01	18.9134	357.7185
8	0.233	4.292	26.9674	727.2424
9	0.191	5.243	32.9415	1085.1412
10	0.185	5.395	33.8965	1148.9753

Table 20 : SBSC FVD modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	sec	cyc/sec	rad/sec	rad²/sec²
1	0.781	1.281	8.0482	64.7733
2	0.781	1.281	8.0482	64.7733
3	0.496	2.016	12.6668	160.4481
4	0.164	6.112	38.4046	1474.9162
5	0.164	6.112	38.4046	1474.9162
6	0.094	10.687	67.1469	4508.7014
7	0.064	15.721	98.781	9757.6926
8	0.064	15.721	98.781	9757.6926
9	0.035	28.279	177.6842	31571.6726
10	0.034	29.065	182.6188	33349.622

Table 21 : SBRC FVD modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	sec	cyc/sec	rad/sec	rad²/sec²
1	0.777	1.286	8.0824	65.3246
2	0.775	1.291	8.1092	65.7597
3	0.486	2.058	12.9318	167.2302
4	0.162	6.154	38.6675	1495.1749
5	0.162	6.18	38.8274	1507.5659
6	0.093	10.793	67.8114	4598.3909
7	0.063	15.841	99.5326	9906.7451
8	0.063	15.912	99.9759	9995.1851
9	0.035	28.478	178.9336	32017.2211
10	0.034	29.299	184.0923	33889.9633

Table 22 : RBSC FVD modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	sec	cyc/sec	rad/sec	rad²/sec²
1	0.797	1.255	7.8869	62.2029
2	0.766	1.306	8.2045	67.314
3	0.519	1.926	12.1044	146.5162
4	0.165	6.056	38.0489	1447.7186
5	0.163	6.135	38.5453	1485.7402
6	0.098	10.235	64.3111	4135.9229
7	0.064	15.628	98.1962	9642.4975
8	0.064	15.7	98.6461	9731.0602
9	0.037	27.094	170.2383	28981.0622
10	0.035	28.919	181.7038	33016.275

Table 23 : RBRC FVD modal periods and frequencies

Mode	Period	Frequency	Circular Frequency	Eigenvalue
	sec	cyc/sec	rad/sec	rad²/sec²
1	0.839	1.192	7.4922	56.1329
2	0.765	1.307	8.2151	67.4876
3	0.516	1.937	12.1726	148.171
4	0.169	5.923	37.2169	1385.0944
5	0.16	6.25	39.2675	1541.9355
6	0.097	10.309	64.775	4195.8008
7	0.065	15.441	97.0174	9412.3806
8	0.062	16.077	101.0176	10204.5568
9	0.037	27.297	171.5105	29415.844
10	0.035	28.638	179.9377	32377.5884

5.1.5 Story Maximum and Average Lateral Displacements

ETABS provides a simple table in the summary output with "Story Maximum and Average Lateral Displacements". This provides indication of maximum to average ratio to check torsional irregularity. The Maximum Displacements due to Push-X in X-direction are:

Table 24 : Max. Disp. of Modals at different stories due to PushX

Story	SBSC		SBRC		RBSC		RBRC	
	no damp	FVD	no damp	FVD	no damp	FVD	no damp	FVD
Story10	111.2	8.7	85	6.9	149.6	8.6	94.6	11.1
Story9	108.8	7.6	82.2	6.1	147	7.5	93.1	9.7
Story8	104.6	6.5	78.1	5.2	142.2	6.5	90.2	8.4
Story7	98.3	5.4	72.3	4.3	134.2	5.4	85.9	6.9
Story6	89.9	4.3	64.7	3.4	122.3	4.3	80.1	5.5
Story5	79.4	3.2	55.4	2.5	106.3	3.2	72.9	4.1
Story4	66.7	2.1	44.4	1.7	86.3	2.1	63.6	2.8
Story3	51.4	1.2	32	0.9	62.6	1.2	51.2	1.6
Story2	33.2	0.4	18.7	0.3	35.8	0.4	28.1	0.6
Story1	12.5	0	6.2	0	11.6	0	9.9	0
Base	0	0	0	0	0	0	0	0

The Maximum Displacements due to Push-Y in Y-direction are:

Table 25 : Max. Disp. of Modals at different stories due to PushY

Story	SBSC		SBRC		RBSC		RBRC	
	no damp	FVD	no damp	FVD	no damp	FVD	no damp	FVD
Story10	65.5	53.4	99.9	147.1	95.2	46.3	88.9	192.8
Story9	63.8	47.1	96.8	129.3	92.6	40.7	85.1	169.7
Story8	61	40.7	92	111	88.3	35	80	145.7
Story7	56.8	34.1	85.3	92.1	82.2	29.1	73.2	121
Story6	51.4	27.4	76.4	72.9	74.1	23.1	64.6	95.9
Story5	44.5	20.8	65.5	54	64.1	17.2	54.4	71
Story4	36.4	14.3	52.6	35.9	52.2	11.5	42.6	47.3
Story3	27	8.4	37.9	19.9	38.5	6.3	29.7	26.3
Story2	16.6	3.5	22.4	7.4	23.3	2.1	16.6	9.7
Story1	6.1	0	7.9	0	8.5	0	5.4	0
Base	0	0	0	0	0	0	0	0

CHAPTER 6: CONCLUSION & RECOMMENDATION

6.1 *CONCLUSIONS*

Based on the results and discussion given in chapter 5 the following conclusions are drawn.

- Up to 90% decrease in Time period of maximum PSA in *Response spectrum* curves when FVD is used. FVD250 reducing the *Base Shear* of the structures by 70% in Time history analysis. The top story *Displacements* are minimized by 90% with use of FVD. The increase of 60% to 70% are observed in *Eigen Values* shows the effective increment in the stiffness of the structure when FVD250 used for exterior corners.
- It is observed that buildings with square columns are performing well in terms of response of the structure when compared to the rectangular columns irrespective of the floor plan.
- In evaluating the seismic performance of structures the prediction of damage in structures is difficult to estimate by using the push-over analysis when compared with the Time history analysis.

6.2 *LIMITATIONS TO CONCLUSIONS*

The following are the limitations have been considered while arriving to the conclusions.

- The following conclusions are limited to the context and comparative characteristics of FVD.
- Applied to other situations, these conclusions may yield incorrect solutions.
- These conclusions are relevant to the process of dwelling evolution in progressive development projects.
- Increasing the story levels or made any changes to properties may fetch different conclusions.
- Position of FVD also matters a lot when arriving at a particular solution.
- Using different cross section of members will change the results obtained from this study.

6.3 *RECOMMENDATIONS FOR FURTHER RESEARCH*

This thesis is limited to use of FVD250 to the structures in exterior corners. The following are few recommendations for further study:

- Same structures can be modified with FVD500 and can be used in exterior middle position.
- Irregular buildings, unsymmetrical buildings and Tall structures can be an extension to this work.
- Its use in Steel structures can bring much effective solutions.
- The structural systems like K-shape and M-shape can be used along with FVD.

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