"SEISMIC BEHAVIOUR OF BUILDINGS RESTING ON SLOPING GROUND"

A THESIS

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Under the supervision of

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TO

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CERTIFICATE

This is to certify that the work which is being presented in the project title **"SEISMIC ANALYSIS OF BUILDINGS RESTING ON SLOPING GROUND"** in partial fulfillment of the requirements for the award of the degree of Masters of technology in civil engineering with specialization in "**Structural Engineering**" and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Vikas Rana during a period from July 2015 to June 2016 under the supervision of **Mrs. Poonam Dhiman** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

The work presented here is a study of seismic response of buildings resting on hill slopes. The dynamic response of the structure on hill slope has been discussed. A review of studies on the seismic behavior of buildings resting on sloping ground has been presented. It is observed that the seismic behavior of buildings on sloping ground differ from other buildings. The various floors of such buildings step backs towards hill slope and at the same time buildings may have setbacks also. Most of the studies agree that the buildings resting on sloping ground has higher displacement and base shear compared to buildings resting on plain ground and the shorter column attracts more forces and undergo damage when subjected to earthquake. Step back building could prove more vulnerable to seismic excitation.

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LIST OF ABBREVATIONS AND SYMBOLS

RSA	Response Spectrum Analysis
EQ	Earthquake
Sa/g	Structural Response Factor
T	Natural Period
λ	Base Shear Ratio
DL	Dead Load
LL	Live Load
EL	Earthquake Load
Step	Storey
EQ.	Earthquake
S.F.	Shear Force
B.M.	Bending Moment
Step 4	4 Storey building
Step 5	5 Storey building
Step 6	6 Storey building
Step 7	7 Storey building
Step 10	10 Storey building

CHAPTER 1

INTRODUCTION

1.1 Earthquake

Buildings behaviour in earthquakes depends on various uncertainty factors. These uncertainties originate from different sources, earthquake nature, components behaviour, and the analytical methods. Therefore, the response of the building is dependent on ground motions and an assembly of individual responses of structural and non-structural components in a fully probabilistic framework. Experience in past earthquakes has demonstrated that many common buildings and typical methods of construction lack basic resistance to earthquake forces. In most cases this resistance can be achieved by following simple, inexpensive principles of good building construction practice. Adherence to these simple rules will not prevent all damage in moderate or large earthquakes, but life threatening collapses should be prevented, and damage limited to repairable proportions. These principles fall into several broad categories:

(i) Planning and layout of the building involving consideration of the location of rooms and walls openings such as doors and windows, the number of stories, etc. At this stage, site and foundation aspects should also be considered.

(ii) Lay out and general design of the structural framing system with special attention to furnishing lateral resistance.

(iii) Consideration of highly loaded and critical sections with provision of reinforcement as required.

Studies has provided a good overview of structural action, mechanism of damage and modes of failure of buildings. From these studies, certain general principles have emerged:

(i) Structures should not be brittle or collapse suddenly. Rather, they should be tough, able to deflect or deform a considerable amount.

(ii) Resisting elements, such as bracing or shear walls, must be provided evenly throughout the building, in both directions side-to-side, as well as top to bottom.

(iii) All elements, such as walls and the roof, should be tied together so as to act as an integrated unit during earthquake shaking, transferring forces across connections and preventing separation.

(iv) The building must be well connected to a good foundation and the earth. Wet, soft soils should be avoided, and the foundation must be well tied together, as well as tied to the wall.

(v) Care must be taken that all materials used are of good quality, and are protected from rain, sun, insects and other weakening actions, so that their strength lasts.

(vi) Unreinforced earth and masonry have no reliable strength in tension, and are brittle in compression. Generally, they must be suitably reinforced by steel or wood.

1.2 About construction in hilly areas

In some parts of world, hilly area is more prone to seismic activity; e.g. northeast region of India. In this hilly regions, traditionally material like, the adobe, brunt brick, stone masonry and dressed stone masonry, timber reinforced concrete, bamboo, etc., which is locally available, is used for the construction of houses. A scarcity of plain ground in hilly area compels the construction activity on sloping ground. Hill buildings constructed in masonry with mud mortar/cement mortar without conforming to seismic codal provisions have proved unsafe and, resulted in loss of life and property when subjected to earthquake ground motions .The economic growth and rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has increased enormously. Therefore, there is popular and pressing demand for the construction of multi-storey buildings on hill slope in and around the cities. The total seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. The behaviour of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path, any deviation or discontinuity in this load transfer path results in poor performance of the building.

1.3 What is structural dynamics

Structural analysis is mainly concerned with finding out the behaviour of a structure when subjected to force. This force can be in the form of 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. A static load is one which varies very slowly & dynamic load is one which changes with time fairly quickly in comparison to the structure's natural frequency. If it changes slowly, the structure's response may be determined with static analysis, but if it varies quickly, the response must be determined with a dynamic analysis. Dynamic analysis for simple structures can be carried out manually, but for complex structures finite element analysis can be used to calculate the mode shapes and frequencies.

1.4 Categories of buildings

For categorizing the buildings with the purpose of achieving seismic resistance at economical cost, three parameters turn out to be significant:

(i) Seismic intensity zone where the building is located,
(ii) How important the building is, and
(iii) How stiff is the foundation soil.

A combination of these parameters will determine the extent of appropriate seismic strengthening of the building.

1.5 Seismic zones in India

In most countries, the macro level seismic zones are defined on the basis of Seismic Intensity Scales. In this guide, we shall refer to seismic zones as defined with reference to MSK Intensity Scale as described:

Zone II: Risk of Minor Damage.

Zone III: Risk of Damage.

Zone IV: Risk of Collapse and Heavy Damage.

Zone V: Risk of Widespread Collapse and Destruction.

Table 1.1 seismic zones in India

Seismic zone	II	III	IV	V
Seismic intensity Z	0.10	0.16	0.24	0.36

1.6 Bearing capacity of foundation soil

Three soil types are considered here:

(i) **Type I:** Rocky or hard soil these soils which have an allowable bearing capacity of more than 10 t/m2.

(ii) **Type II:** Medium soil these soils, which have allowable bearing capacity less than or equal to 10 t/m2.

(iii) **Type III:** Soft soil these soils, which are liable to large differential settlement or liquefaction during an earthquake.

Buildings can be constructed on firm and soft soils but it will be dangerous to build them on weak soils. Hence appropriate soil investigations should be carried out to establish the allowable bearing capacity and nature of soil. Weak soils must be avoided or compacted to improve them so as to qualify as firm or soft.

1.7 Significance of this work

Hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes, and torsionally coupled. Hence, they are susceptible to severe damage when affected by earthquake ground motion. Past earthquakes [e.g. Kangra (1905), Bihar-Nepal (1934 & 1980), Assam (1950), Tokachi-Oki-Japan (1968), Uttarkashi-India

(1991), have proved that buildings located near the edge of stretch of hills or sloping ground suffered severe damages. Such buildings have mass and stiffness varying along the vertical and horizontal planes, resulting the center of mass and centre of rigidity do not coincide on various floors. This requires torsional analysis; in addition to lateral forces under the action of earthquakes. Little information is available in the literature about the analysis of buildings on sloping ground. The investigation presented in this paper aimed at predicting the seismic response of RC buildings with different configuration on sloping and plain ground.

1.8 Scope of this work

Three dimensional space frame analysis is carried out for three different configurations of buildings ranging from 4 to 11 storey (15.75 m to 40.25 m height) resting on sloping and plain ground under the action of seismic load. Dynamic response of these buildings, in terms of base shear, fundamental time period and top floor displacement is presented, and compared within the considered configuration as well as with other configurations. At the end, a suitable configuration of building to be used in hilly area is suggested.

1.9 Organization

Presentation of the research effort is organized as follows:

• Chapter 2 presents the literature survey on seismic analysis of buildings resting on sloping ground.

• Chapter 3 presents some theory and formulations used for developing the RSA.

• Chapter 4 presents the validation response of structure under different earthquake response.

• Chapter 5 presents the comparison of results of three different buildings.

• Conclude the result.

• Some important publication and books referred during the present investigation have been listed in the references.

CHAPTER 2

LITERATURE REVIEW

Current literature survey includes earthquake response of multi storey buildings. Some of the literatures emphasized on strengthening of the existing buildings in seismic prone regions.

2.1 *Seismic behaviour of buildings resting on sloping ground*

Authors: *R.B. Khadiranaikar, Arif Masali 2015*

Conclusion drawn: Short columns attracts more forces and are worst affected during seismic excitation. Presence of infill wall and shear wall influences the behaviour of structure by reducing storey displacement and storey drifts considerably. But may increase the base shear.

2.2 *Earthquake behaviour of reinforced concrete framed buildings on hill*

Authors: *Ajay Kumar Sreerama, Pradeep Kumar Ramancharla 2013*

Conclusion drawn: As the slope angle increases, the short column resist almost all the storey shear since other columns are flexible and tend to oscillate. A hinge mechanism is formed near the shorter column zone and is damaged earlier as the slope angle increases. The study clearly helps us to understand the significant difference between the seismic behaviours of building on slopes to building on flat surface. In summary, the natural period of building depends on the distribution of mass and stiffness along the building.

2.3 *Seismic performance of buildings resting on sloping ground−review*

Authors: *Dr. R. B. Khadiranaikar and Arif Masali 2014*

Conclusion drawn: The greater number of bays are found to be better under seismic condition. Number of bays increases time period and top storey displacement decreases.

2.4 *Seismic analysis of buildings*

Authors: *B.G. Birajdar, S.S. Nalawade 2004*

Conclusion drawn: Development of torsional moments in Step back buildings is higher than that in the Step back set back buildings. In Step back buildings and Step back-Set back buildings, it is observed that extreme left column at ground level, which are short, are the worst affected.

2.5 *Seismic behaviour of buildings located on slopes - an analytical study and some observations from Sikkim earthquake of September 18, 2011*

Authors: *Y. Singh, Phani Gade, D.H. Lang & E. Erduran 2012*

Conclusion drawn: The linear and non-linear dynamic analysis shows that the storey at road level, in case of downhill buildings, is most susceptible to damage. The hill buildings are subjected to significant torsional effects under cross-slope excitation.

2.6 *Seismic performance of multi-storeyed building on sloping ground*

Authors: *S.M. Nagargoje and K.S. Sable 2012*

Conclusion drawn: The maximum base shear is induced in Step back Setback building& least in Setback building on levelled ground. Top storey displacement of Step back building is quite high as compared to Step back-Setback building resting on sloping ground. Step back-Set back building may be favoured on sloping ground.

2.7 *Lateral stability of multi-storey building on sloping ground*

Authors: *Nagarjuna, Shiva Kumar B. Patil 2015*

Conclusion drawn: In equivalent static method and response spectrum method, as the slope angle increases the top storey displacement and time period reduces. Base shear is maximum at 20 degree in both step back and step back setback buildings.

2.8 *Seismic analysis of buildings resting on sloping ground with varying number of bays and hill slopes*

Authors: *Dr. S. A. Halkude, Mr M. G Kalyan Shetty, Mr V. D. Ingle 2013*

Conclusion drawn: During seismic performance step back frames could prove more detrimental than other configurations of building frames. As hill slopes increases time period & top storey displacement decreases. As number of bays increases time period & top storey displacement decreases. Therefore, it is concluded that greater number of bays are observed to be better under seismic conditions. Step back & set back frames produces less torsion effects as compared to step back frames.

2.9 *Performance based seismic design of RCC buildings with plan irregularity*

Authors: *Ashish R. Akhare, Abhijeet A. Maske 2015*

Conclusion drawn: Torsion is the most critical factor leading to major damage or complete collapse of buildings. Torsion caused in irregular buildings mostly because of eccentricity between centre of mass and centre of rigidity.

2.10 *Influence of soil-structure interaction in seismic response of step back-set back buildings*

Authors: *Prabhat Kumar, Sharad Sharma and A.D. Pandey 2012*

Conclusion drawn: The dynamic shear ratios in X and Y direction indicate a contradictory trend to the ratios of static analysis. In dynamic analysis the ratio of shear force in columns at ground level shows increasing trend for all type of soils from high point columns to low point columns with increasing height in both the directions (X and Y).

2.11 Objective of this project

The objective of the present work is to study the behavior of multistory buildings with different configurations under earthquake excitations.

- Results from seismic analyses performed on 15 RC buildings with three different configurations like, Step back building, Step back Set back building and Set back building are presented.
- 3 –D analysis including torsional effect has been carried out by using response spectrum method.
- The dynamic response properties *i.e.* fundamental time period, top storey displacement and, the base shear action induced in columns have been studied with reference to the suitability of a building configuration on sloping ground.

CHAPTER 3

RSA OF BUILDINGS RESTING ON SLOPING GROUND

3.1 Response spectrum method

The response spectrum method (RSM) was introduced in 1932 in the doctoral dissertation of Maurice Anthony Biot at Coltech. It is an approach to be found earthquake response structures using waves or vibration mode shapes. The concept of the "Response Spectrum" was applied in design requirements in the mid-20th century. It came into widespread use as the primary theoretical tool in earthquake engineering in the 1970s when strong-motion accelerograph data become widely available. The maximum response of the building is estimated directly from the elastic or inelastic design spectrum characterizing the design earthquake for the site and considering the performance criteria for the building. The response spectrum method plays an important role in practical analysis of multi-storey buildings for earthquake motions. It is also helpful to analyse the performance level of the structure.

3.2 Methodology

Analysis methods are widely characterized as linear and nonlinear static and dynamic. Among them the linear static and dynamic methods are suitable when the structural loads are small. The main difference between the equivalent static procedure and dynamic analysis procedure lies in the magnitude and distribution of lateral forces over the height of the buildings. In the dynamic analysis procedure the lateral forces are based on properties of the natural vibration modes of the building, which are determined by the distribution of mass and stiffness over height. In the equivalent lateral force procedure the magnitude of forces is based on an estimation of the fundamental period and on the distribution of forces as given by a simple formula that is appropriate only for regular buildings.

3.3 Building Data

In the present study, three groups of building *(i.e. configurations*) are considered, out of which two are resting on sloping ground and third one is on plain ground. The first two are step back buildings and step back-setback buildings; and third is the set back building. The slope of ground is 27 degree with horizontal, which is neither too steep or nor too flat. The height and length of building in a particular pattern are in multiple of blocks (in vertical and horizontal direction), the size of block is being maintained at 7 m x 5 m x 3.5 m. The depth of footing below ground level is taken as 1.75 m where, the hard stratum is available.

The buildings shown in figure 3.1, having step back configuration are labelled as STEP 4 to STEP10 for 4 to 10 storey. Step back -Set back configuration of buildings is shown in figure 3.2, are designated as STPSET 4 to STPSET 10, according to height of building. Set back buildings resting on plain ground having 4 to 10 number of bays and labelled as SET 4 to SET 10, as shown in figure 3.3.The building with equal number of storeys/bays have same floor area in all three configurations.

The properties of frame members of buildings that are considered for analysis are given in table 3.3.1.

Table 3.1 Building configurations

Building Configuration	Column Size	Beam Size
Step back building	300x300 mm	300x450 mm
Set back building	300x300 mm	300x450 mm
Step back Set back building	300x300 mm	300x450 mm

Table 3.2 Specification of the building and zone

Seismic zone	IV
Zone factor	0.24
Response reduction factor	5
All general buildings	1
Damping ratio	5%
Structure type	RC frame building
Soil type -medium	2
Concrete grade	M25
Steel grade	Fe415

3.4 Method of analysis

The analysis is based on following assumptions.
(i) Material is homogenous, isotropic and elastic.
(ii) The values of modulus of elasticity and Poisson's ratio are 25000 N/mm2 and 0.20, respectively.
(iii) Secondary effect P-Δ, shrinkage and creep are not considered.
(iv) The floor diaphragms are rigid in their plane.
(v) Axial deformation in column is considered.
(vi) Each nodal point in the frame has six degrees of freedom, three translations and three rotations. vii) Torsional effect is considered as per IS: 1893 (I) –2002.

3.5 Frames of buildings analysed

Three types of buildings are analysed in staad pro v8i, which are as follow:

- Step back building
- Setback building
- Step back set back building

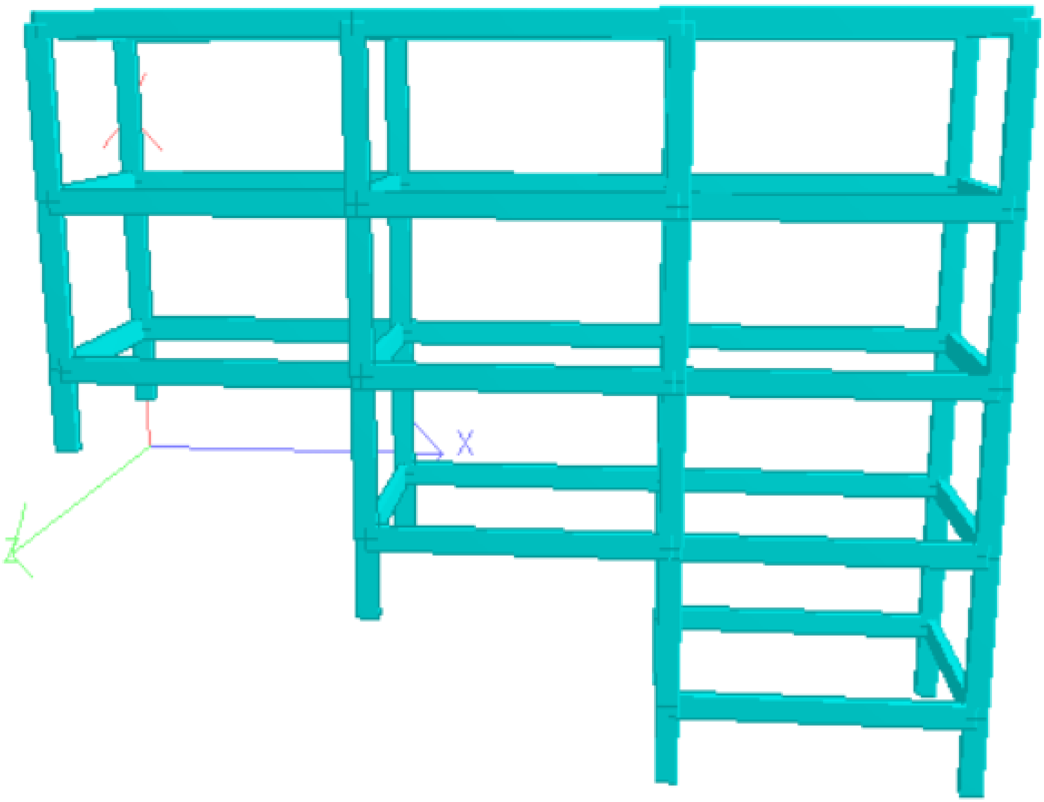

Fig. 3.1 Step back building

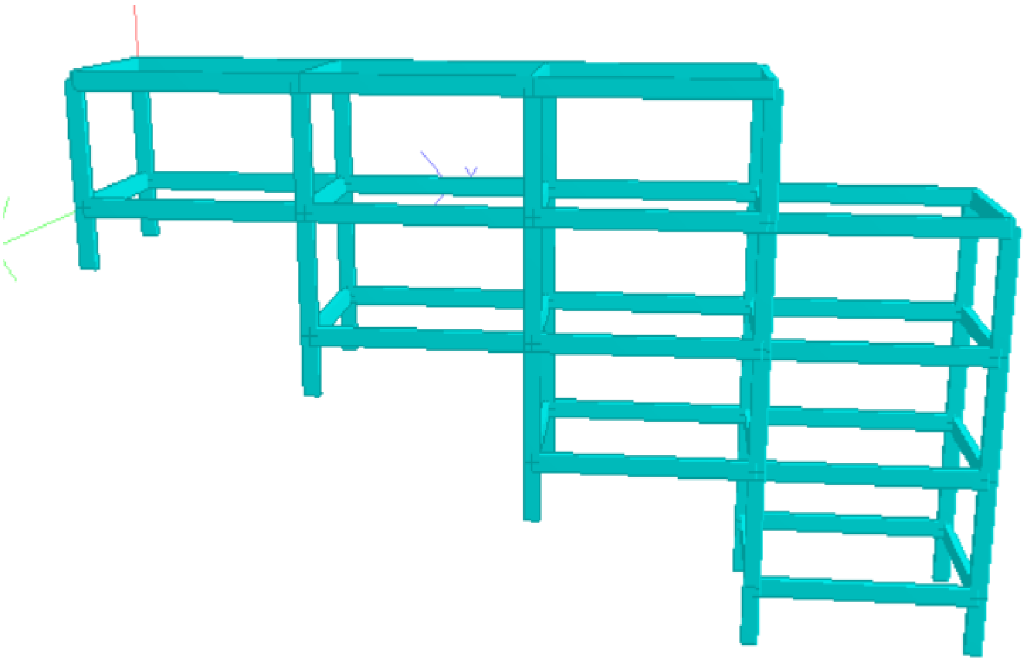

Fig. 3.2 Step back Set back building

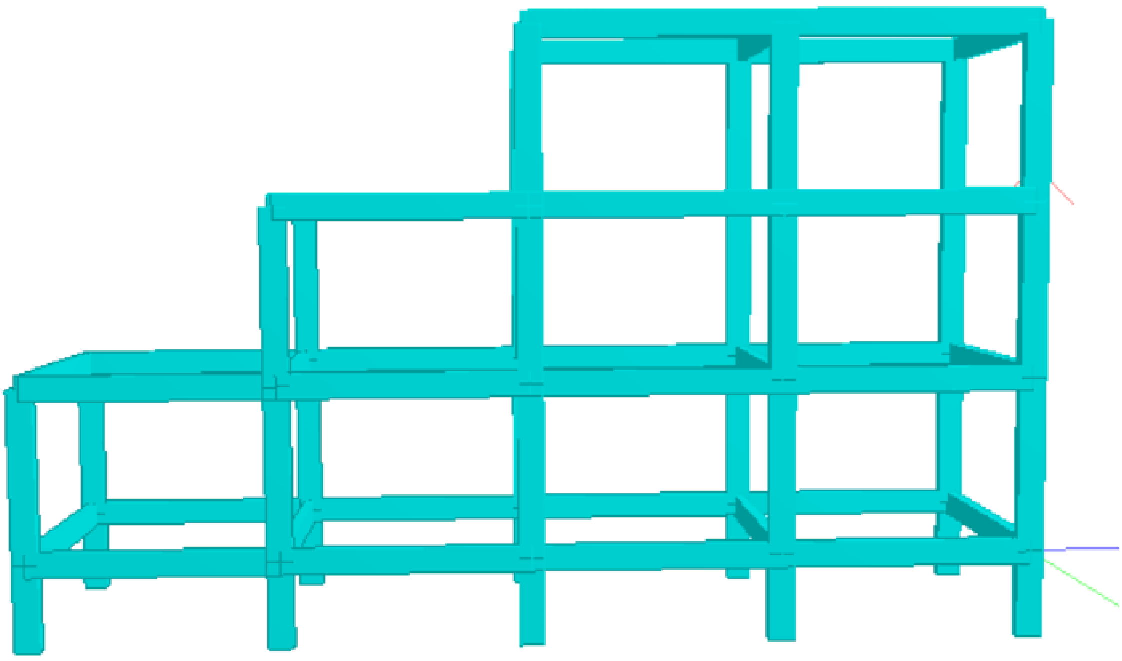

Fig. 3.3 Step back building

3.6 Response Spectrum Analysis (RSA)

The seismic analysis of all buildings are carried out by response spectrum method by using IS: 1893(I) –2002, [2] including the effect of eccentricity (static + accidental). The other parameters used in seismic analysis are, moderate seismic zone (IV), zone factor 0.24, importance factor 1.0, 5 % damping and response reduction factor 3.0, presuming ordinary moment resistant frame for all configurations and height of buildings.

For each building case, adequate modes (minimum six) were considered, in which, the sum of modal masses of all modes was at least 99 % of the total seismic mass. The member forces for each contributing mode due to dynamic loading were computed and the modal responses were combined using CQC method. The following design spectrum was utilized in response spectrum analysis.

$$Sa/g = \left\{ \begin{array}{ll} 1+15\,T & \textit{when } 0.00 \le T \le 0.10 \text{ seconds} \\ 2.50 & 0.10 \le T \le 0.40 \text{ seconds} \\ 1/T & 0.40 \le T \le 4.00 \text{ seconds} \end{array} \right\}$$

3.7 Consideration of Torsional Moment due to Accidental Eccentricity

First, the dynamic analyses of buildings without shifting the center of mass from their locations were carried out. Then the results due to the application of torsional moments at each floor level equal to the lateral force times the accidental eccentricity at that floor were superimposed on the results from dynamic analysis. The accidental eccentricity at each floor level was considered equal to 0.05 times the floor plan dimension perpendicular to the direction of seismic force. Only selected results are presented in this paper due to space restrictions. As per codal provision, dynamic results were normalized by multiplying with a *base shear ratio*, λ =Vb/VB , where Vb is the base shear evaluation based on time period given by empirical equation and, VB is the base shear from dynamic analysis , if Vb/VB ratio is more than one.

3.8 Load combinations

Load Combinations are taken as per **IS 1893** and are as follows:

In the limit state design of reinforced and pre-stressed concrete structures, the following load combinations shall be accounted for:

1. ***1.5(DL+LL)***
2. ***1.2(DL+ZL+EL)***
3. ***1.2(DL+ZL-EL)***
4. ***1.5(DL+EL)***
5. ***1.5(DL-EL)***
6. ***0.9DL+ 1.5EL***
7. ***0.9DL- 1.5EL***

3.9 Combination for two or three component motion

When responses from the three earthquake components are to be considered, the responses due to each component may be combined using the assumption that when the maximum response from one component occurs, the responses from the other two components are 30 percent of their maximum. All possible combinations of the three components (*ELx*, *ELy and ELz*) including variations in sign (plus or minus) shall be considered, Thus, the response due earthquake force (EL) is the maximum of the following three cases:

I. ±ELx±0.3ELy±0.3ELz

II. ±ELy±0.3ELx±0.3ELZ

III. ±ELz±0.3ELx±0.3Ely

Where x and y are two orthogonal directions and z is vertical direction.

CHAPTER 4

ANALYSIS OF RESULTS

All buildings have been analysed for seismic load with an effect of accidental eccentricity. The seismic force was applied in X direction and Z direction independently. Important results are presented in the subsequent sections.

4.1 Step Back Buildings:

In this configuration, building have been analysed, with varying height from 15.75m.

4.1.1 *EQ. force in X direction (along the slope line):*

The dynamic response of step back building in term of fundamental time period, top storey displacement and, base shear in columns at ground level is presented in Table 1. The fundamental time period and base shear ratio (λ) as per IS: 1893 (I)-2002, are evaluated and are presented in the same table. It is observed that there is linear increase in the value of top storey displacement and time period as the height of step back building increases. The value of fundamental time period by dynamic analysis is substantially higher than the values estimated by empirical equation given in IS: 1893 (I) –2002. Hence, the value of shear coefficient by dynamic analysis is less than the static method as per IS: 1893 (I)-2002.
Though the building plan is symmetrical along the sloping line and the torsional effect including accidental eccentricity is insignificant in x direction, it is observed the shear force in the column towards extreme left is *significantly higher* as compared to the rest of the columns at ground level for different heights of buildings. Comparatively, in the extreme right columns and adjacent to them (*frame D & frame C*) at ground level, normalized values of shear force are just 5 to 7 % of that of the extreme left columns.

Table 4.1 Dynamic response properties of STEP BACK building due to earthquake force in X direction

Number of storey (ht. in meters)	Fundamental Time period by RSA, in sec.	Time period by IS: 1893(I)-2002 in sec.	Maxi. Top storey displacement in mm.	Base shear ratio (λ)	Normalized value of shear force in columns at ground level in kN			
					Frame A	Frame B	Frame C	Frame D
4(15.75)	0.678	0.310	9.75	1.695	134.1	45.7	8.6	9.1
5(19.25)	0.9775	0.378	19.86	2.443	178.5	57.1	11.3	10.9
6(22.75)	1.1041	0.446	23.07	2.471	223.2	48.3	9.7	10.1
7(26.25)	1.392	0.515	31.45	2.7	246.9	50.9	10.5	10.7
10(36.75)	2.130	0.721	47.54	2.792	345.2	58.2	17.6	17.7

4.1.2 ***EQ. force in Y direction (across the slope line):***

Table 2, shows the dynamic properties of each of the step back building for excitation in Y direction. The effect of accidental eccentricity is substantial when earthquake force is in Y direction. The torsional moment due to an accidental eccentricity on each floor, which varies from 4 kN-m, were applied at respective floor levels. The value of fundamental time period and the top storey displacement in Y direction are substantially higher than the corresponding values when the earthquake force is in X direction. The evaluation of fundamental time period in Y direction as per IS: 1983 (I)-2002 is remarkably lower than the values obtained by response spectrum analysis in the same direction. Though the effect of torsional moment is dominant in Y direction, the corresponding normalized values of shear force in extreme left columns at ground level are less than the corresponding normalized values obtained for earthquake forces in X direction. From design point of view, it is to be noted that particular attention should be given to the size (strength), orientation (stiffness) and ductility demand of the extreme left column at ground level such that it is safe under worst possible load combinations in X and Y directions.

Table 4.2 Dynamic response properties of STEP BACK building due to earthquake force in Y direction

Number of storey (ht. in meters)	Fundamental Time period by RSA, in sec.	Time period by IS: 1893(I)-2002 in sec.	Maxi. Top storey displacement in mm.	Base shear ratio (λ)	Normalized value of shear force in columns at ground level in kN			
					Frame A	Frame B	Frame C	Frame D
4(15.75)	1.3706	0.633	44.29	2.635	64.75	52.1	21.4	30.6
5(19.25)	1.8168	0.774	49.57	2.344	59.6	44.8	18.8	26.6
6(22.75)	2.0507	0.915	50.87	2.241	71.5	47.3	16.3	22.5
7(26.25)	2.5428	1.056	64.41	2.400	76.6	49.3	17.2	23.7
10(36.75)	2.0130	0.721	47.54	2.792	345.2	58.2	17.6	17.7

4.2 Step Back Set Back Buildings:

4.2.1 ***EQ. force in X direction (along the slope line):***

The results of dynamic analysis of step back set back building is presented in Table 3. It is seen that the evaluation of fundamental time period using dynamic analysis (RSA) for 4 storey height of building in the range of 0.437 sec. Whereas, it has 0.267 sec. evaluation using static method. On the whole it is observed that the value of base shear ratio varies 1.09 to 1.23, indicating that the results obtained from static and dynamic analysis do not differ substantially as the case of step back buildings.

Observations from Table 2 indicates that,
i) The columns at extreme left (frame A) attracts maximum shear varying between 86 to 103 kN.
ii) Adjacent frames (frame B onwards) and but last two frames attract shear force varying between 26 to 97 kN.
iii) The last two frames to the extreme right are subjected to least shear forces.

Table 4.3 Dynamic response properties of STEP BACK –SET BACK Buildings due to earthquake force in X direction

Number of storey (ht. in meters)	Fundamental Time period by RSA, in sec.	Time period by IS: 1893(I)-2002 in sec.	Maxi. Top storey displacement in mm.	Base shear ratio (λ)	Normalized value of shear force in columns at ground level in kN			
					Frame A	Frame B	Frame C	Frame D
4(15.75)	0.437	0.267	3.61	1.092	86.26	50.74	29.06	6.52
5(19.25)	0.458	0.293	3.96	1.144	93.93	63.67	54.61	28.97
6(22.75)	0.475	0.316	4.18	1.188	98.1	67	74.36	57.20
7(26.25)	0.465	0.367	4.10	1.163	96.92	62.97	76.94	77.65
10(36.75)	0.492	0.395	4.35	1.231	102.6	59.93	71.87	86.95

4.2.2 *EQ. force in Y direction (across the slope line):*

When earthquake force is applied in Y direction, it is observed from Table 4 that,

i. Variation of shear force in all frames is found to be less significant.
ii. Unlike the behaviour due to earthquake force in X direction extreme left *frame A* is not severely stressed, indicating the lateral forces in Y direction cause in significant effect due to torsion.
iii. For building having height 8 to 11 storey, the results obtained from dynamic analysis governed the design as against the results obtained from static analysis.
iv. The fundamental time period in Y direction by dynamic analysis is not much affected by the height of step back set back buildings, whereas, IS: 1893(I)-2002 predicts the time period value which varies linearly with the height of building.

It is perceived that in step back set back building configuration, the actions required for design purpose are pre-dominant when earthquake force is in X direction. Moreover, the top storey displacement is comparatively higher (about 3.8 to 4 times) in Y direction than the corresponding values in X direction, under the seismic action.

From design point of view, the uniform section (having constant area of steel and concrete throughout) from bottom to top for extreme left column (*frame A)*, would be sufficient to fulfil the design requirements for different heights of step back set back buildings considered. A similar trend is observed more or less for the rest of the columns.

Table 4.4 Dynamic response properties of STEP BACK –SET BACK Buildings due to earthquake force in Y direction

Number of storey (ht. in meters)	Fundamental Time period by RSA, in sec.	Time period by IS: 1893(I)-2002 in sec.	Maxi. Top storey displacement in mm.	Base shear ratio (λ)	Normalized value of shear force in columns at ground level in kN			
					Frame A	Frame B	Frame C	Frame D
4(15.75)	1.031	0.634	13.41	1.627	42.14	40.85	36.00	14.09
5(19.25)	1.160	0.775	13.52	1.497	35.31	41.15	37.45	32.02
6(22.75)	1.242	0.915	13.62	1.356	30.29	36.85	37.84	33.6
7(26.25)	1.134	1.056	13.61	1.073	22.95	21.8	30.19	29.85
10(36.75)	1.208	1.479	13.45	0.817	19.92	24.31	26.48	27.96

4.3 Set Back Buildings on Plain Ground:

A building on plain ground have been analysed for seismic force in X as well as in Y directions in this configuration of building. The floor area of each set back building on plain ground is same as that of the corresponding type of Step back building and Step Back Set back building resting on sloping ground, *i.e.* floor area of SET 4 = STEP 4 = STPSET 4 and so on. This configuration is intended to create a plain ground in a natural sloping terrain. The cost involved in preparing levelled ground on a sloping terrain would be additional. In the present study, only structural behaviour under the action of seismic load has been carried out without any emphasis on cost construction.

4.3.1 *EQ. force in X direction:*

Table 5 shows the results obtained from dynamic analysis of set back building. It is observed that the time period by RSA for SET 4 to SET 10 buildings has increased from 0.745 sec. to 0.857 seconds, whereas for the same buildings, the value of time period predicted by IS:1893(I) –2002 has decreased from 0.2083 sec. to 0.1256 seconds. The base shear ratio (λ) is found to vary between 1.862 to 2.140 . It is to note that the peripheral frames are found to carry fewer shears as compared to interior frames.

Table 4.5 Dynamic response properties of SET BACK Buildings due to earthquake force in X direction

Number of storey (ht. in meters)	Fundamental Time period by RSA, in sec.	Time period by IS: 1893(I)-2002 in sec.	Maxi. Top storey displacement in mm.	Base shear ratio (λ)	Normalized value of shear force in columns at ground level in kN			
					Frame A	Frame B	Frame C	Frame D
4(15.75)	0.745	0.2083	12.46	1.862	27.02	40.73	40.11	40.58
5(19.25)	0.782	0.186	13.41	1.955	29.44	44.2	43.7	43.6
6(22.75)	0.806	0.1701	13.62	1.955	30.2	45.29	44.8	44.71
7(26.25)	0.822	0.1575	14.47	2.050	34.31	48.34	47.82	47.72
10(36.75)	0.851	0.1317	15.33	2.13	34.35	51.85	51.31	51.31

4.3.2 *EQ. force in Y direction:*

Due to action of earthquake in Y direction, it is noticed that shear force in columns at ground level is more or less same. The fundamental time period as predicted by IS: 1893(I)-2002 is constant for all set back buildings, whereas, prediction using RSA are found to yield higher value of time period. The top storey displacement in Y direction is 3.5 times the higher than the corresponding values in X direction. The base shear ratio has been found to be 2.835 which is significantly high. This indicates that in Setback buildings the design of column will primarily be controlled by actions induced in Y direction.

Table 4.6 Dynamic response properties of SET BACK Buildings due to earthquake force in Y direction

Number of storey (ht. in meters)	Fundamental Time period by RSA, in sec.	Time period by IS: 1893(I)-2002 in sec.	Maxi. Top storey displacement in mm.	Base shear ratio (λ)	Normalized value of shear force in columns at ground level in kN			
					Frame A	Frame B	Frame C	Frame D
4(15.75)	1.398	0.493	41.94	2.835	44.37	42.3	41.6	42.33
5(19.25)	1.288	0.493	39.44	2.613	43.75	41.69	40.8	42.89
6(22.75)	1.357	0.493	45.68	2.754	48.49	46.45	44.83	43.84
7(26.25)	1.384	0.493	47.68	2.8	51.26	49.3	47.48	46.17
10(36.75)	1.491	0.493	53.24	3.025	59.47	57.8	55.9	55.23

CHAPTER 5

COMPARISON OF VARIOUS CONFIGURATIONS

5.1 Step back building v/s Step back Set Back Building

In Step back buildings; frame A has attracted much higher base shear force than the frames B, C, and D. This uneven distribution of shear force in the various frames suggests development of torsional moment due to static and accidental eccentricity, which has caused profound effect in Step back buildings.

An uneven distribution of base shear in various frames was also observed in Step back –Set back buildings. However, this uneven distribution of shear forces is low to moderate, indicating torsional moments of lesser magnitude under the action of seismic forces.

Based on the above observations, it can be stated that Step back buildings are subjected to higher amount of torsional moments as compared to Step back Set back buildings and may prove more vulnerable during the seismic excitation. The configuration of Step back Set back building has an advantage in neutralizing the torsional effect, resulting into better performance than the Step back building during the earthquake ground motion, provided the short columns are taken care of in design and detailing.

5.2 Step back- set back buildings v/s Set back buildings

Shear action induced in Step back Set back buildings is moderately higher as compared to set back buildings on plain ground. It is to be noted that in Step back set back building, higher stiffness is required in X direction whereas, in Setback buildings more stiffness is required in Z direction.

If, cost component of cutting the sloping ground and other related issues, is within the acceptable limits, set back buildings on plain ground may be preferred than the step back Set back buildings. In addition to this, issues viz. stability of slopes and vulnerability during the earthquake ground motion are less concerned in setback building.

5.3 Base shear, Top storey displacement in X and Y direction for step back, step back-set back and set back building

Table 5.1 Dynamic response properties of Step back building building due to earthquake force in X & Y direction

Table 5.1 shows that base shear for step back building is high along direction x for story level 4, 5 and 6 and along y direction storey level 10 has highest base shear. And storey displacement is high in x direction for storey level 10 and also in y direction the storey displacement is high in storey level 10.

Building configuration	Base shear (kN)		Top storey displacements(mm)	
	EQX	EQY	EQX	EQY
STEP 4	398.43	181.07	7.27	10.21
STEP 5	326.11	173.22	11.78	15.13
STEP 6	343.29	192.79	13.73	18.4
STEP 7	314.43	185.3	18	23.01
STEP 10	320.61	233.66	26.94	28.61

Table 5.2 Dynamic response properties of STEP BACK-SET BACK building due to earthquake force in X & Y direction

Table 5.2 shows that base shear is max in direction x for storey level 5, 6 and 7 and along y direction storey 6 and 7 has highest base shear. Storey displacement along x direction is high at storey level 7 and 10 and in y direction storey 4, 5 and 6 has max base shear

Building configuration	Base shear (kN)		Top storey displacements(mm)	
	EQX	EQY	EQX	EQY
STEP 4	341.32	199.73	9.75	9.91
STEP 5	408.83	219.62	10.6	9.99
STEP 6	473.89	224.29	11.49	9.54
STEP 7	432.79	221.18	10.92	8.81
STEP 10	330.7	202.75	11.18	6.99

Table 5.3 Dynamic response properties of Set BACK building due to earthquake force in X & Y direction

Table 5.3 shows that base shear for set back building is high in direction x for story level 6, 7 and 10 and along y direction storey level 10 has highest base shear. And storey displacement is high in x direction for storey level 10 and also in y direction the storey displacement is high in storey level 10.

Building configuration	Base shear (kN)		Top storey displacements(mm)	
	EQX	EQY	EQX	EQY
STEP 4	188.56	124.25	15.93	22.85
STEP 5	189.93	127.17	19.18	28.04
STEP 6	191.84	128.78	22.43	33.21
STEP 7	191.06	130.25	25.70	38.40
STEP 10	190.03	146.66	35.51	60.46

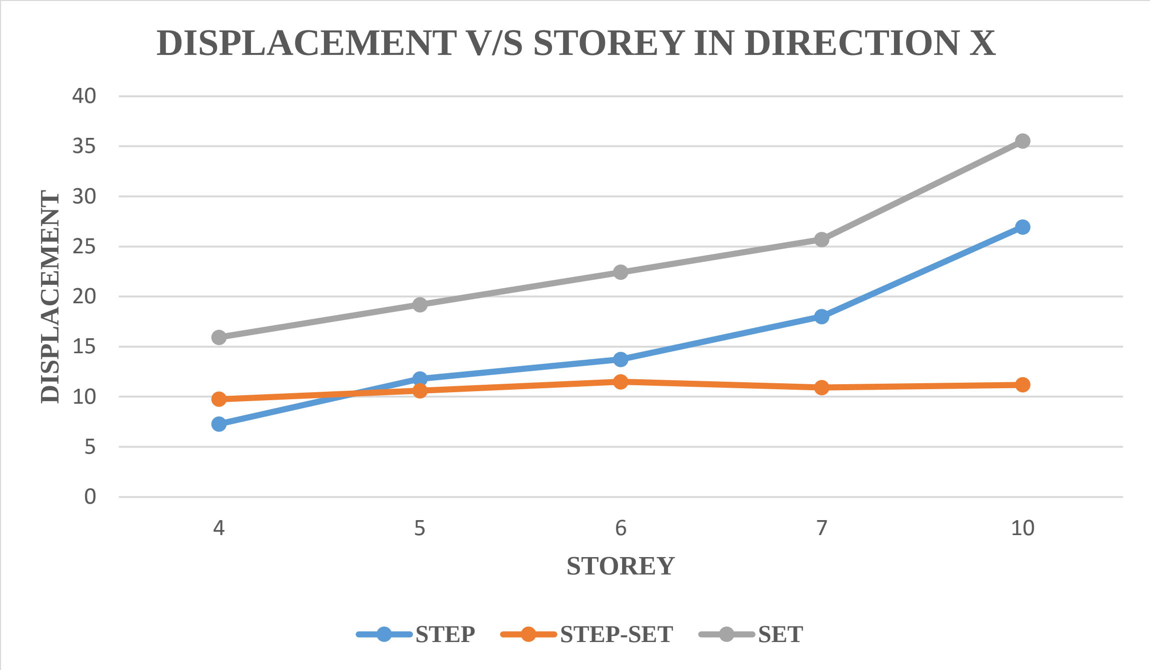

Fig no. 5.1

Fig no. 5.1 shows that set back undergo a huge displacement as increasing the height of the storey.

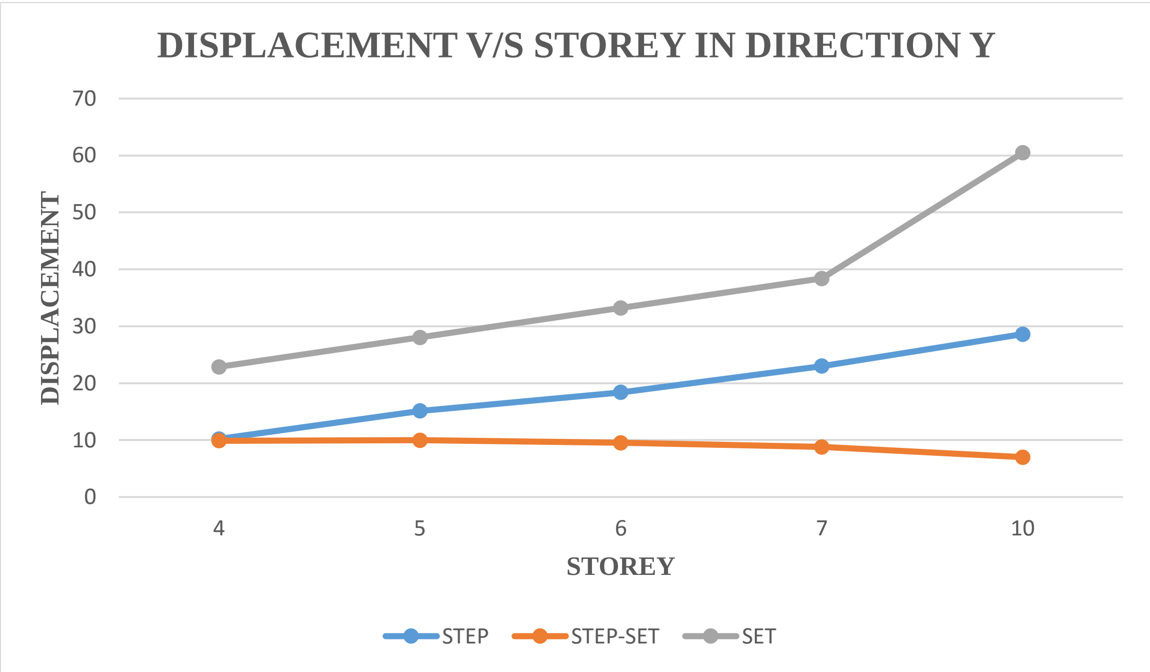

Fig no. 5.2

Fig no. 5.2 shows that set back building produces more displacement as increasing the height of the storey.

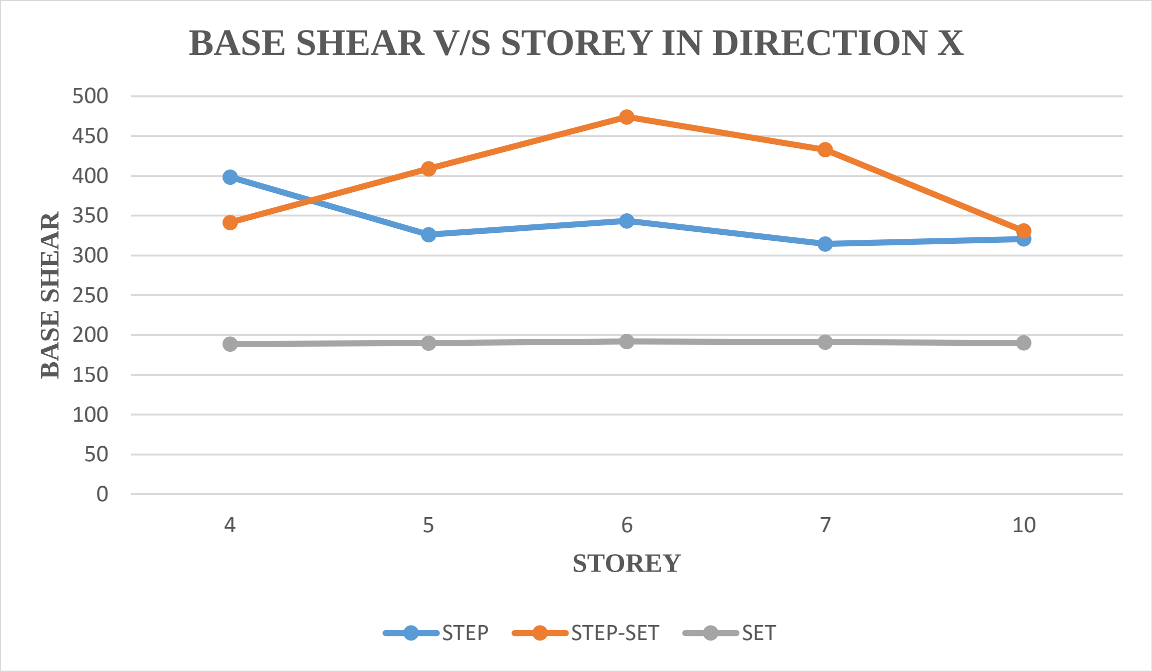

Fig no. 5.3

Fig no. 5.3 shows that step-set back undergo huge base shear but after 6 storey there is a fall in the value of base shear.

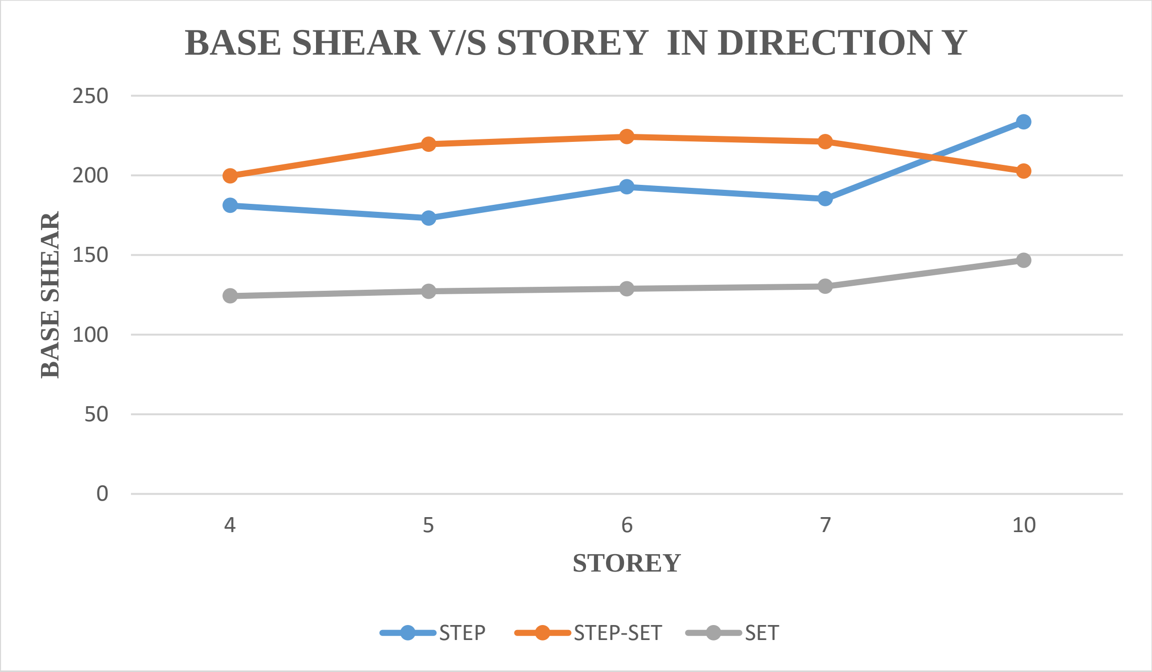

Fig no. 5.4

Fig no. 5.4 shows that step-set back have high base shear but it starts decreasing after 7 storey and inverse in case of step back.

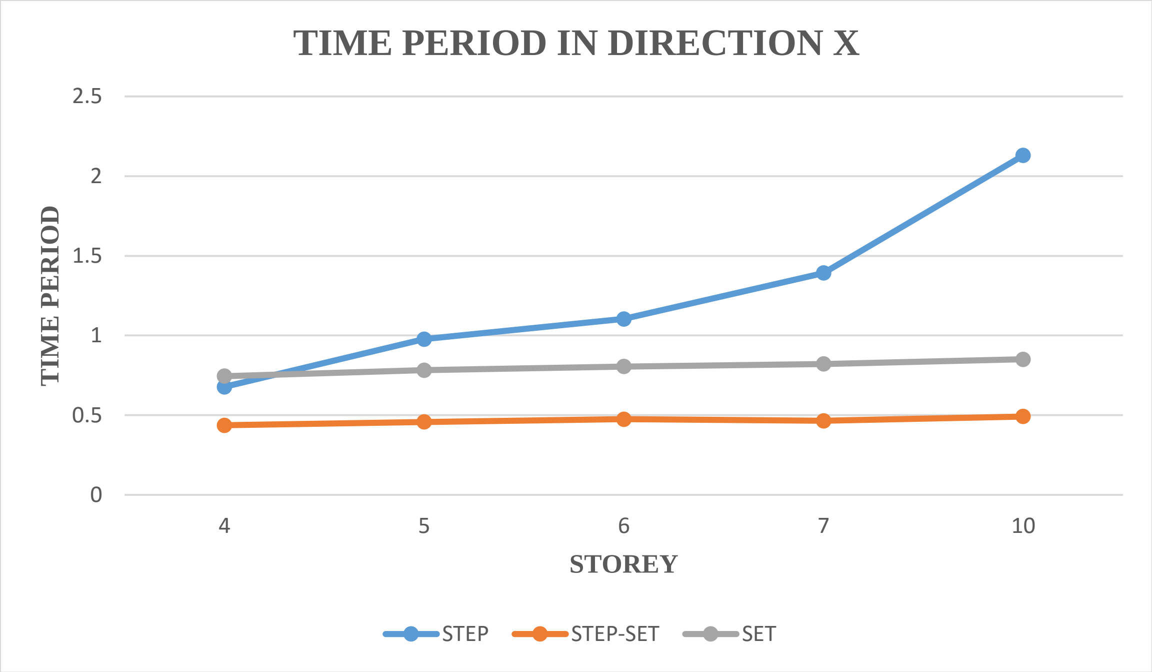

Fig no. 5.5

Fig no. 5.5 shows that time period is increasing in step back as the no of storey and rest of two are linear.

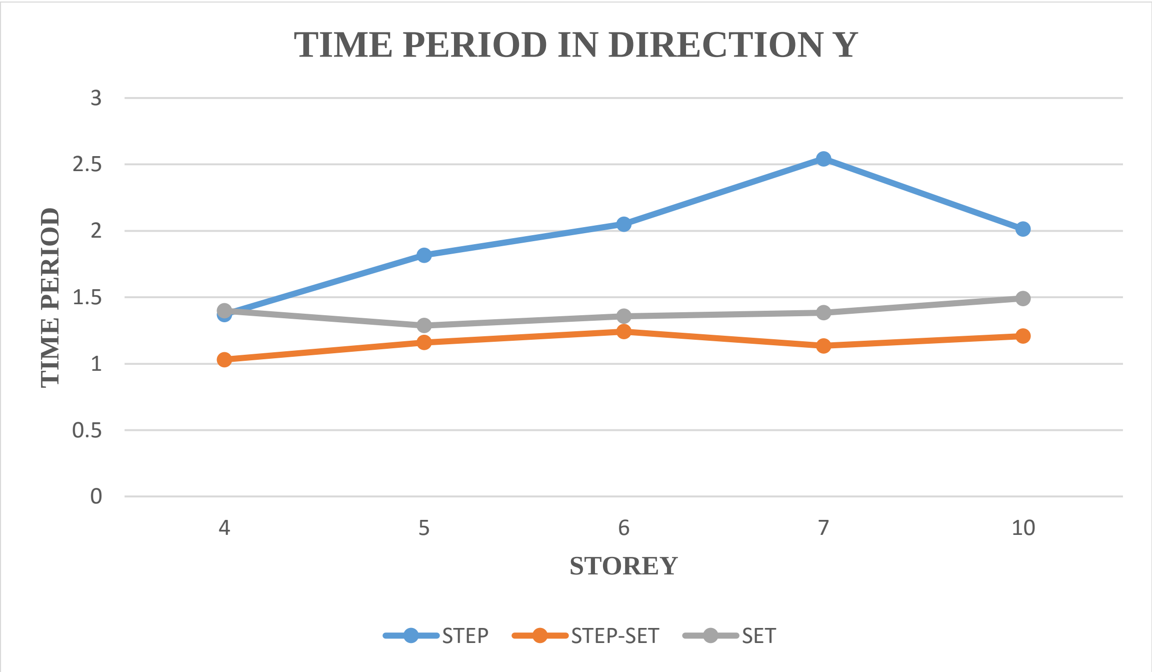

Fig no. 5.6

Fig 5.6 shows that time period is increasing in step back upto 7 storey and decreasing further.

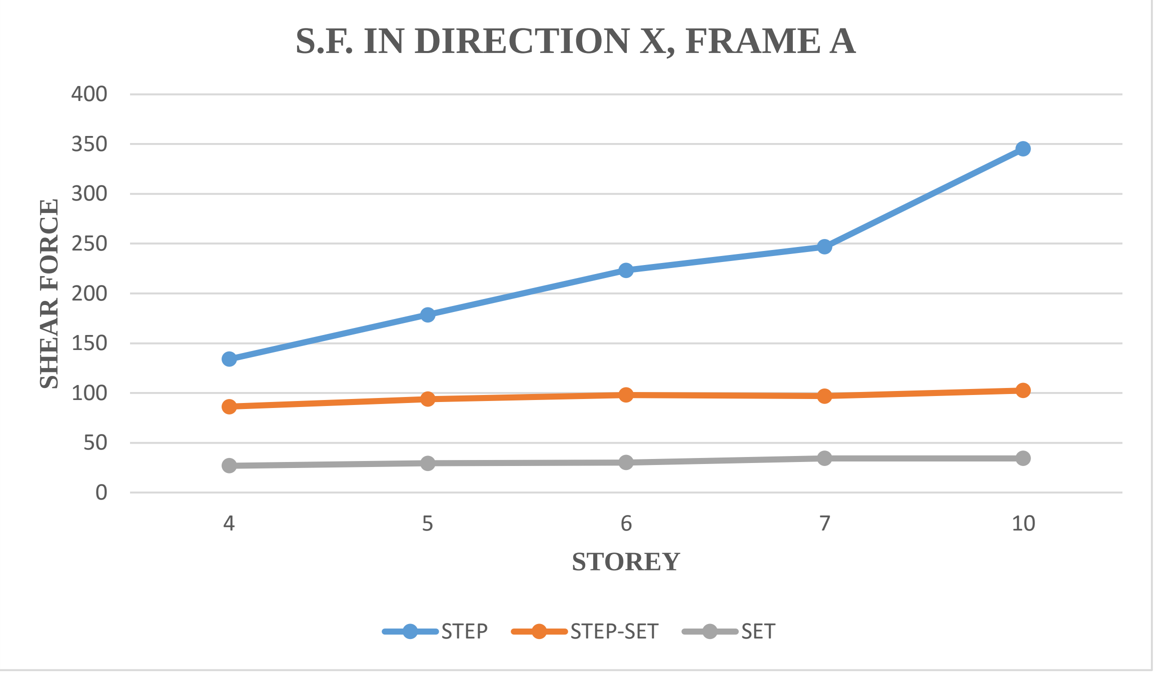

Fig no. 5.7

Fig no. 5.7 shows that shear force increasing in step back and rest of two are linear.

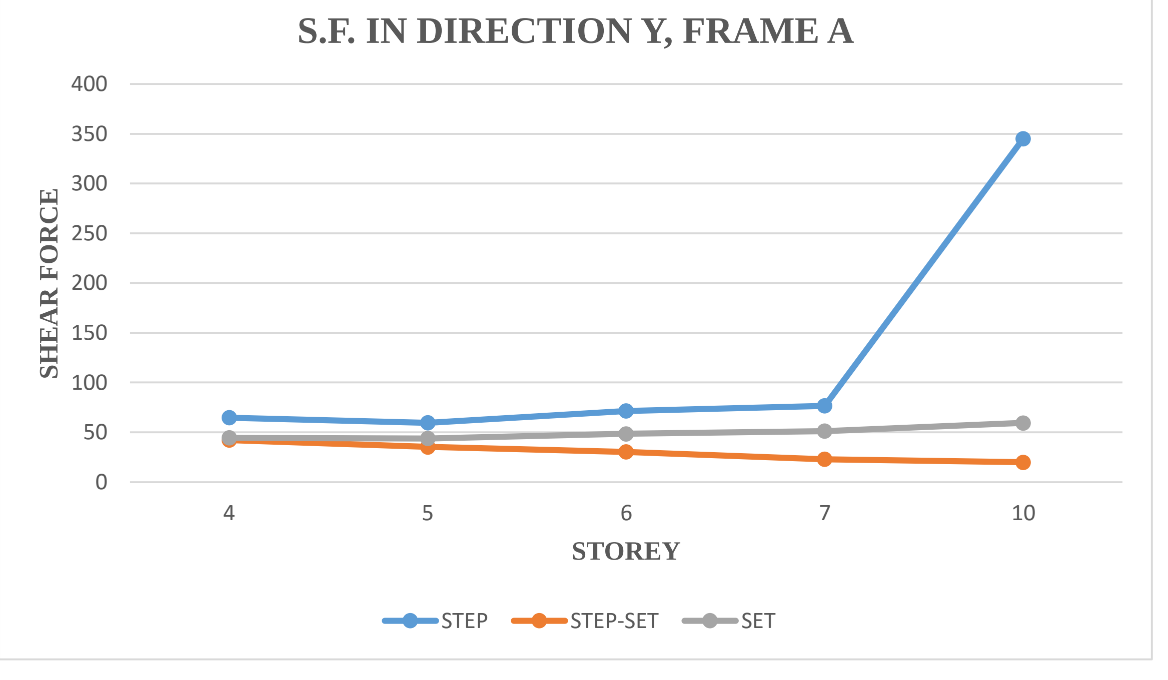

Fig no. 5.8

Fig no. 5.8 shows that shear force is increasing and there is huge increment after 7 storey and rest of the two are linear.

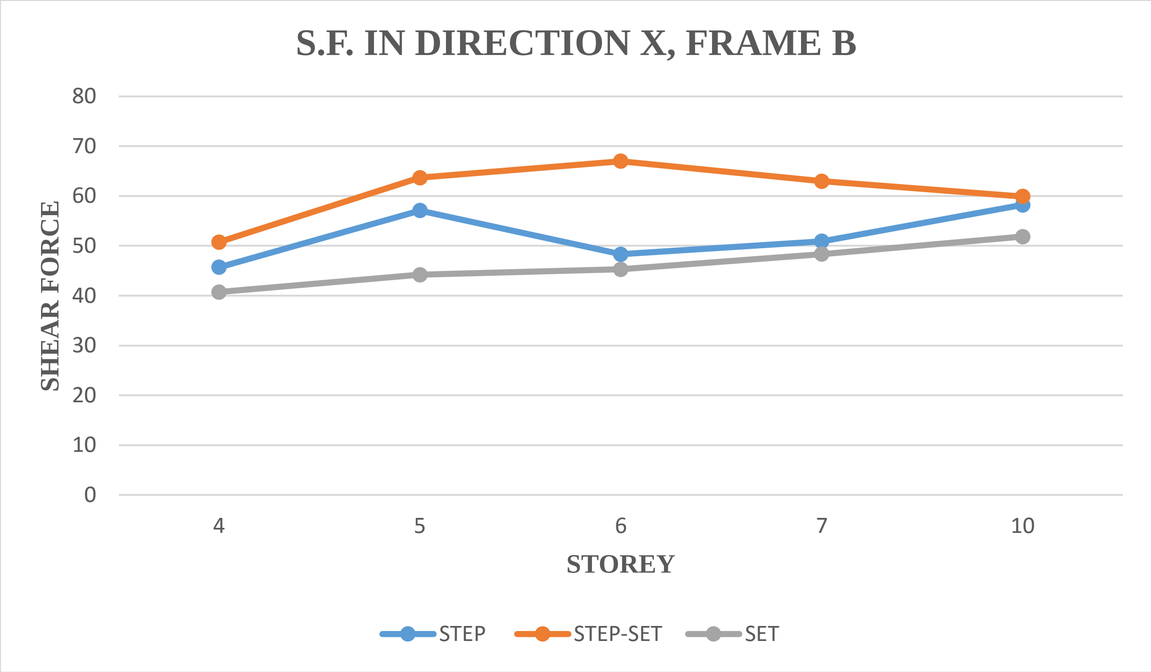

Fig no. 5.9

Fig no. 5.9 shows that step-set back have high shear force as compared to others after 6 storey it starts decreasing.

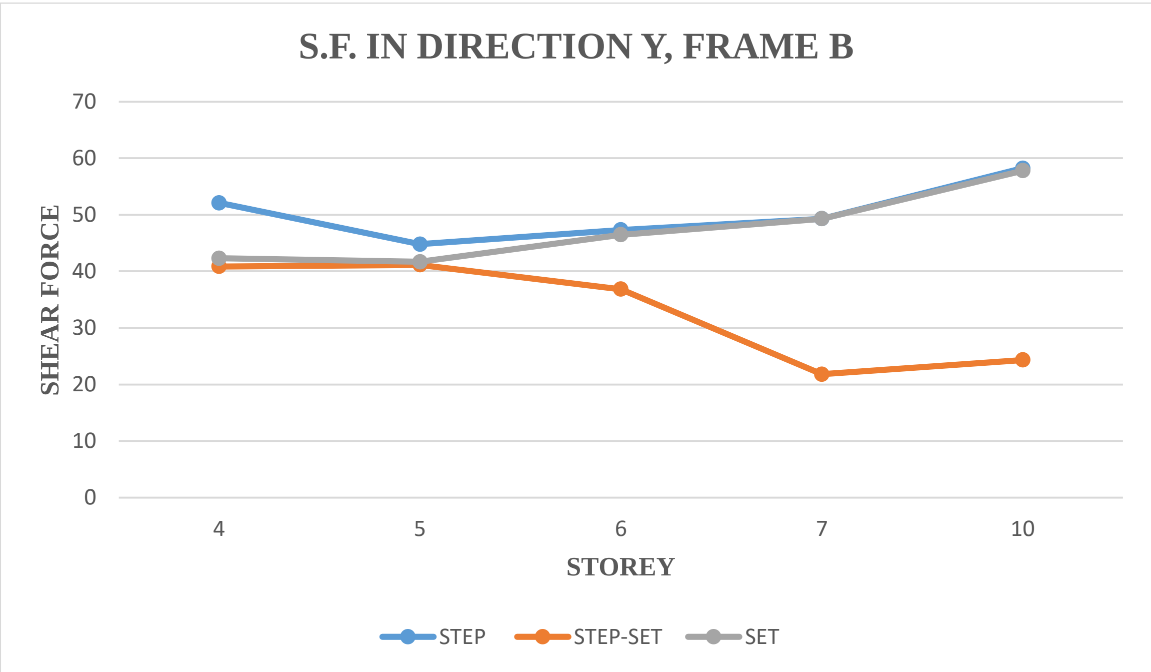

Fig no. 5.10

Fig no. 5.10 shows that step back have high shear force but after 5 storey shear force in set back increasing.

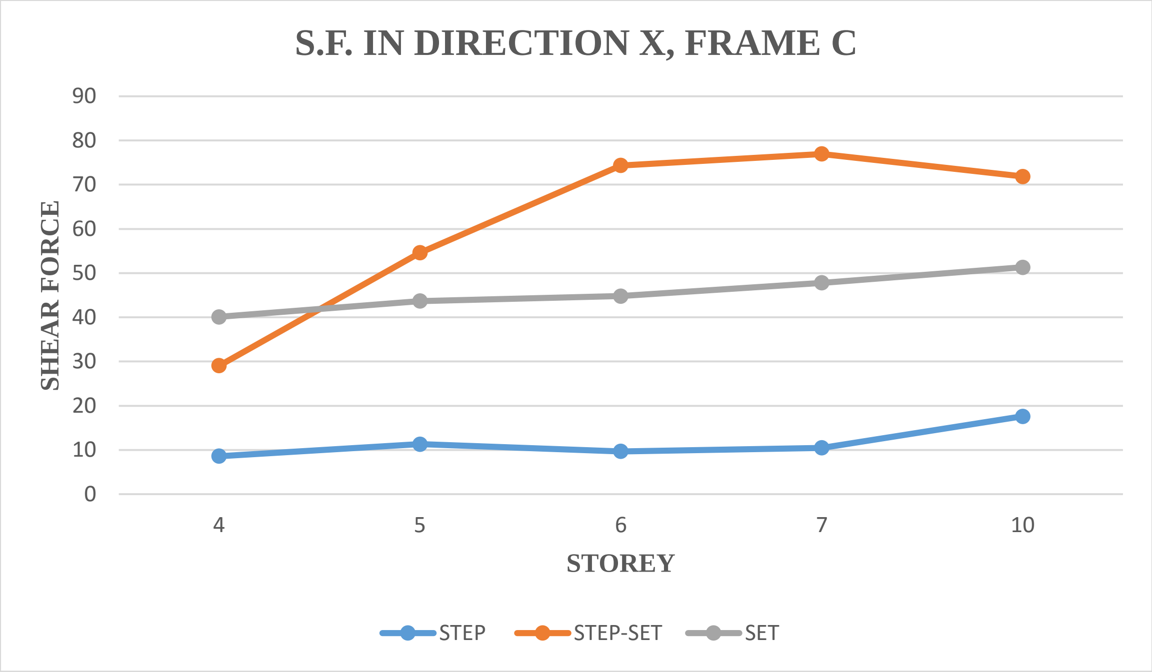

Fig no. 5.11

Fig no. 5.11 shows that step-set back have high value of shear force as compared to others.

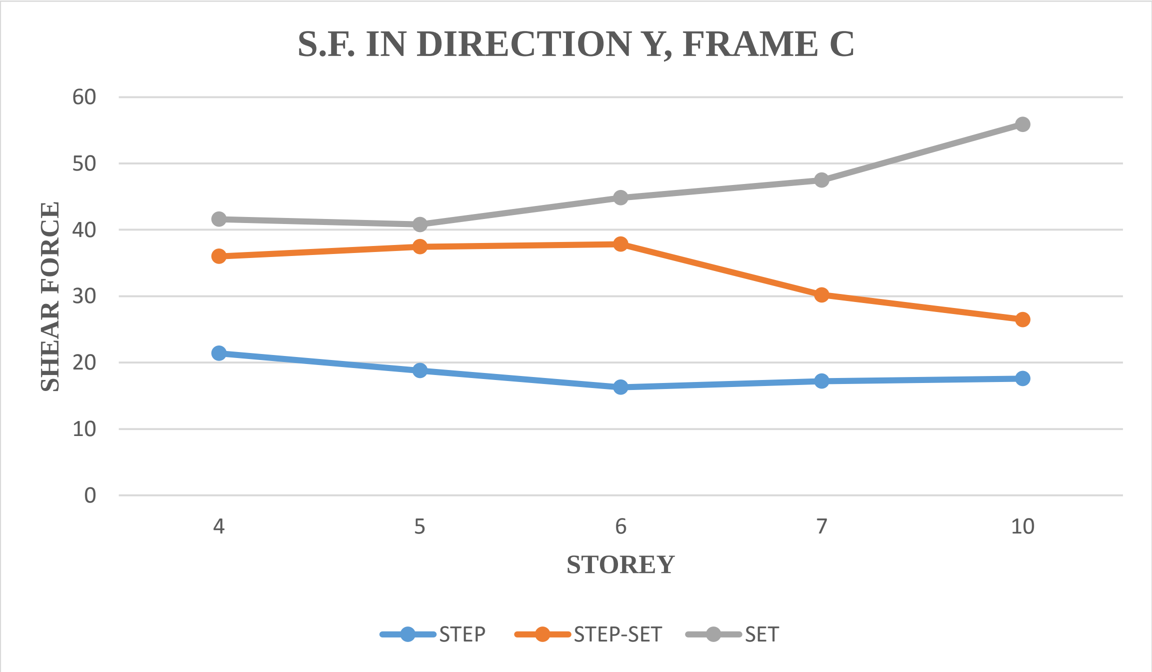

Fig no. 5.12

Fig no. 5.12 shows that set back have high value of shear force and step-set back is decreasing after 6 storey.

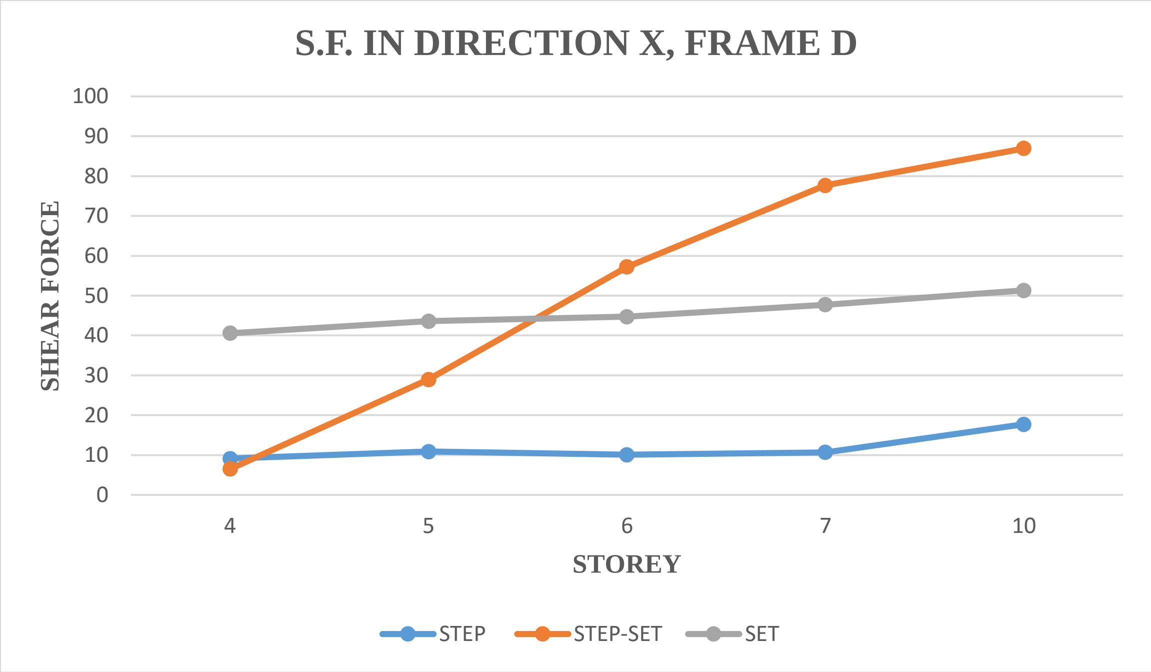

Fig no. 5.13

Fig no. 5.13 shows that shear force is increasing more in step-set back and rest of the two are increasing linearly.

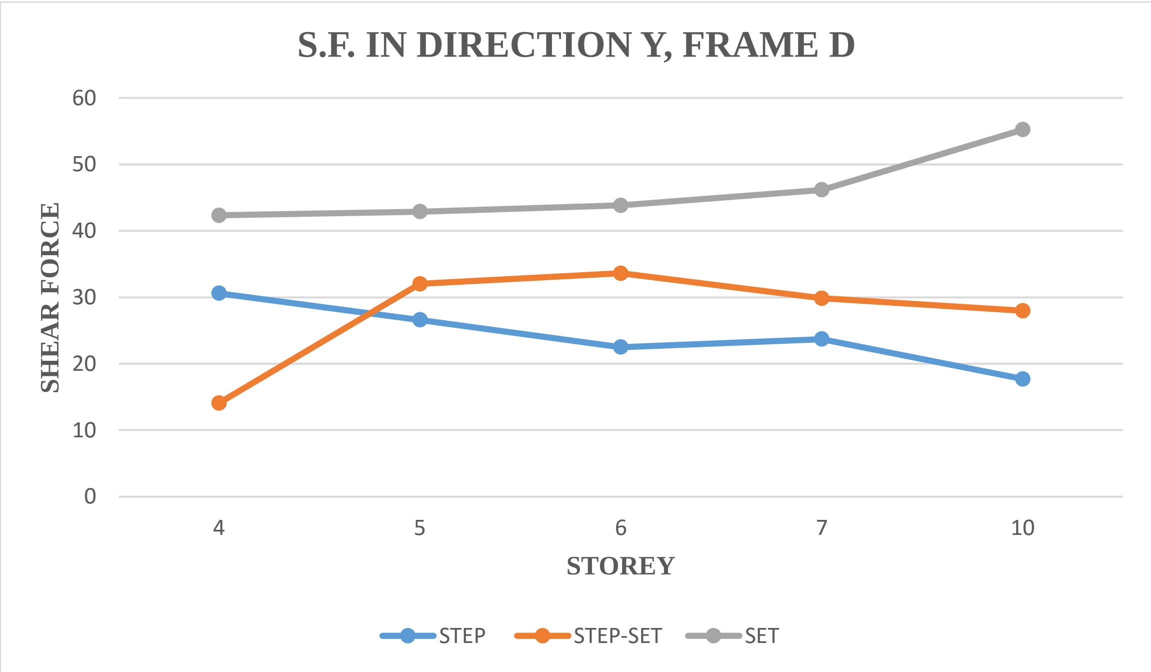

Fig no. 5.14

Fig no. 5.14 shows that set back have high value of shear force and rest of the two have decreasing values.

OBSERVATIONS AND CONCLUSIONS

Several observations are made after analyzing the results from staad files:

- As it is clear from the graphs plotted for shear force for various configuration of buildings, that shear force is maximum for the STEP back buildings when analysed for different frames.

- It is observed that shear force is very high for the frame A in case of step back and step back set back.

- Also it is observed that their is less damage on set back building which are resting on plain ground.

- It is observed that value of base shear is higher for step back –set back building and step back building.

Based on dynamic analysis of three different configurations of buildings, the following conclusions can be drawn:

- The performance of STEP back building during seismic excitation could prove more vulnerable than other configurations of buildings.

- Extreme left short column at ground level are damaged most during earthquake in case of Step back and Step back-Set back buildings.

- Less damage occurs in case of Set back building on flat soil. Detailed study of economic cost for levelling sloping soil and other issues need to be studied.

- Base shear is higher for Step back-Setback building and lower for Set back building.

- Lateral displacement of top storey is maximum for Step back building.

- On sloping soil Setback- Stepback building is favoured.

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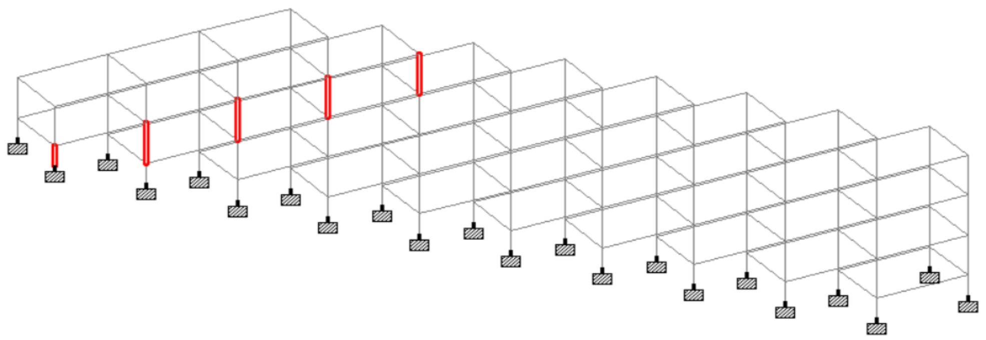
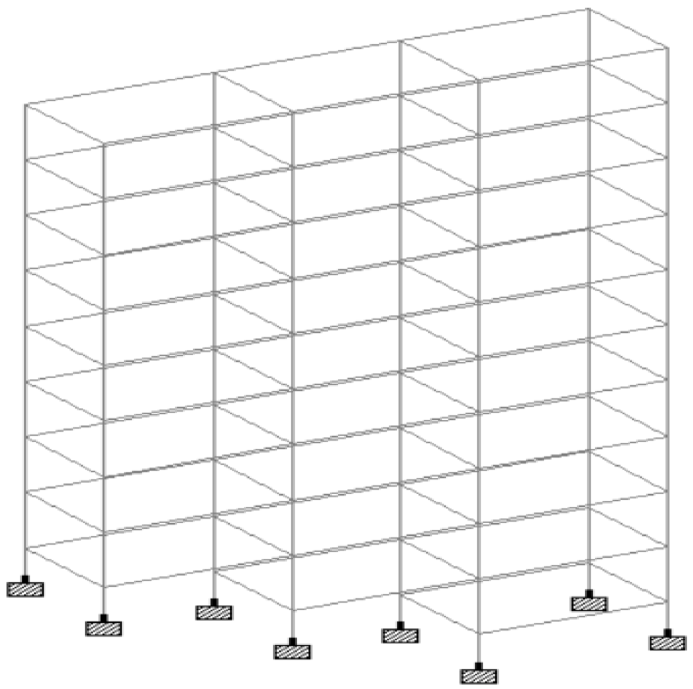
ANNEXURE A

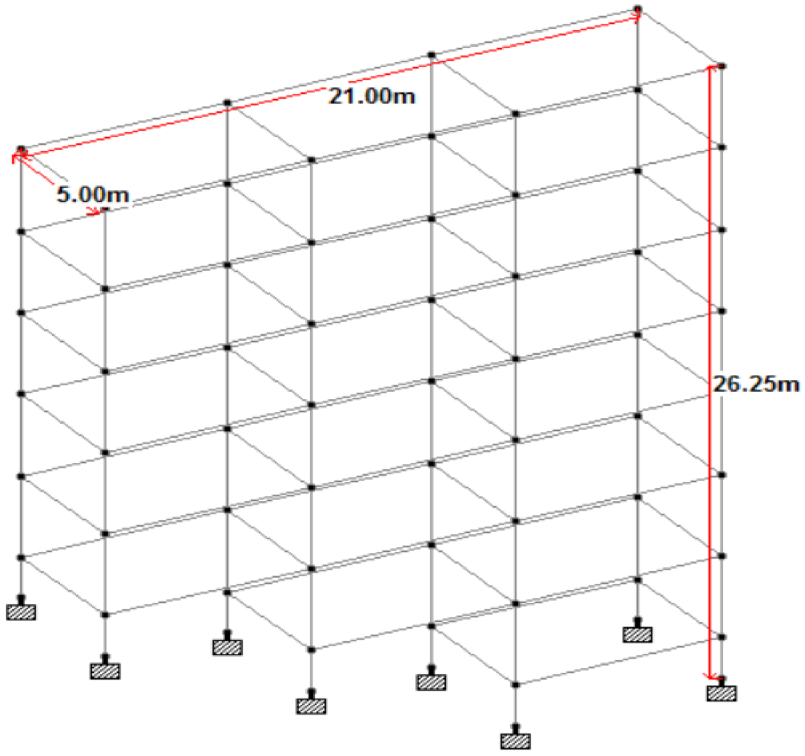
Frames of various configurations



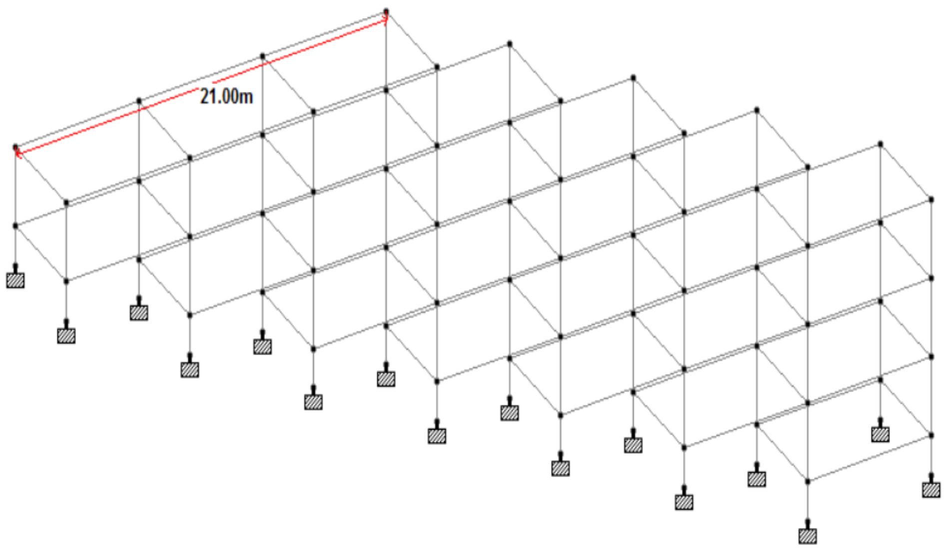
3D FRAME OF 10 STOREY SET BACK-SET BACK BUILDING



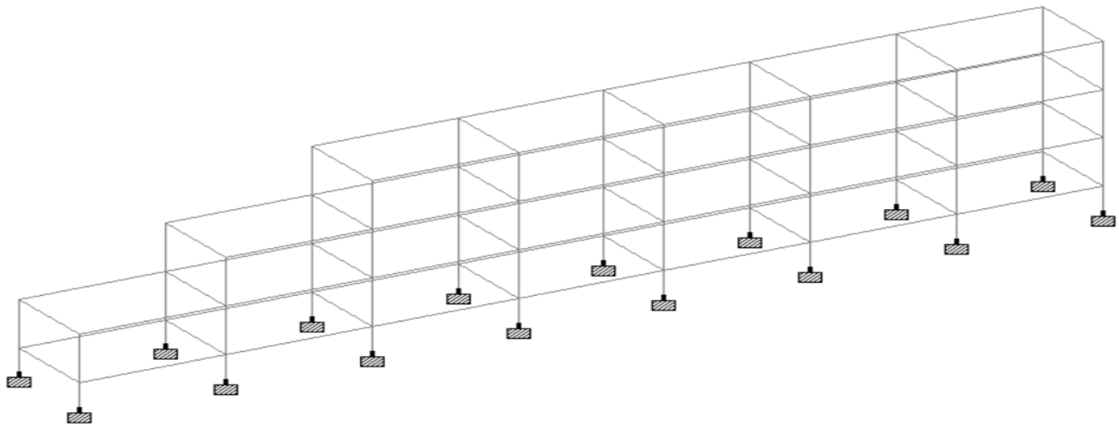
3D FRAME OF STEP BACK BUILDING



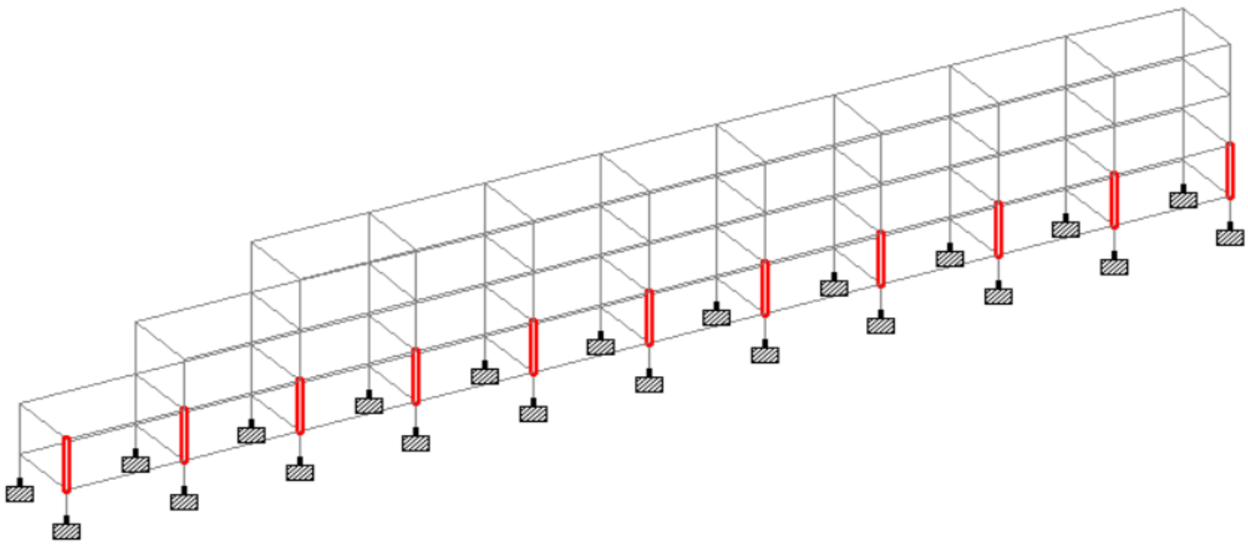
3D FRAME OF 7 STOREY STEP BACK BUILDING



3D FRAME OF 7 STOREY STEP BACK SET BACK BUILDING



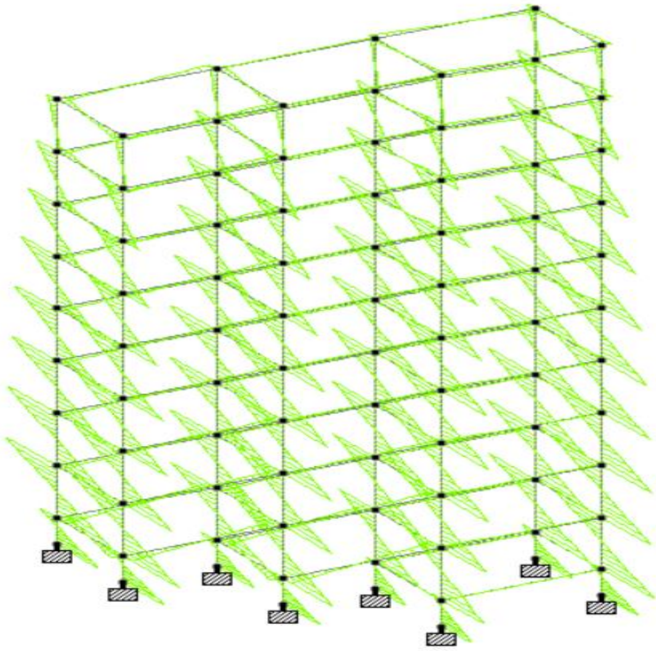
3D FRAME OF SET BACK BUILDING



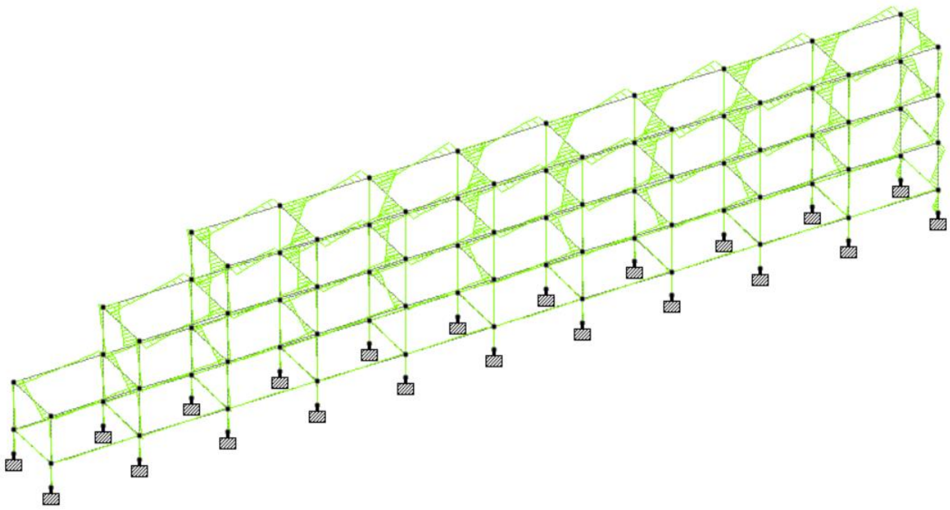
3D FRAME OF SET BACK BUILDING

ANNEXURE B

Bending moment diagrams for various configurations



B.M. DIAGRAM OF STEP BACK BUILDING



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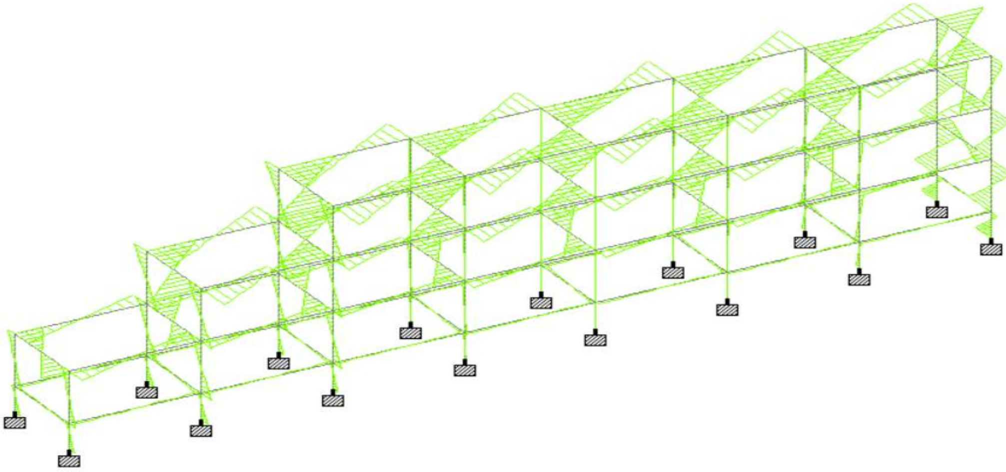

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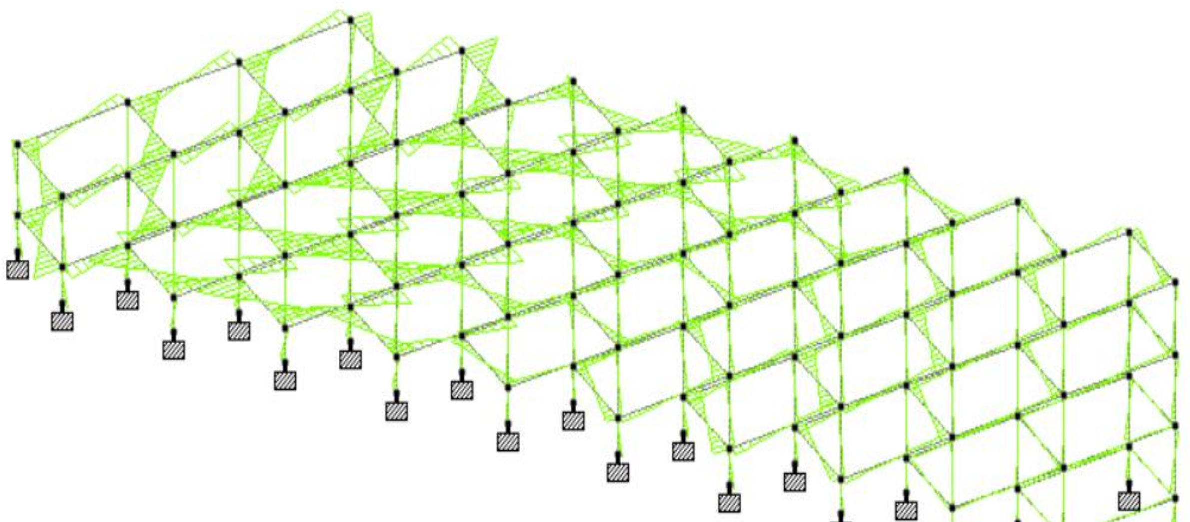

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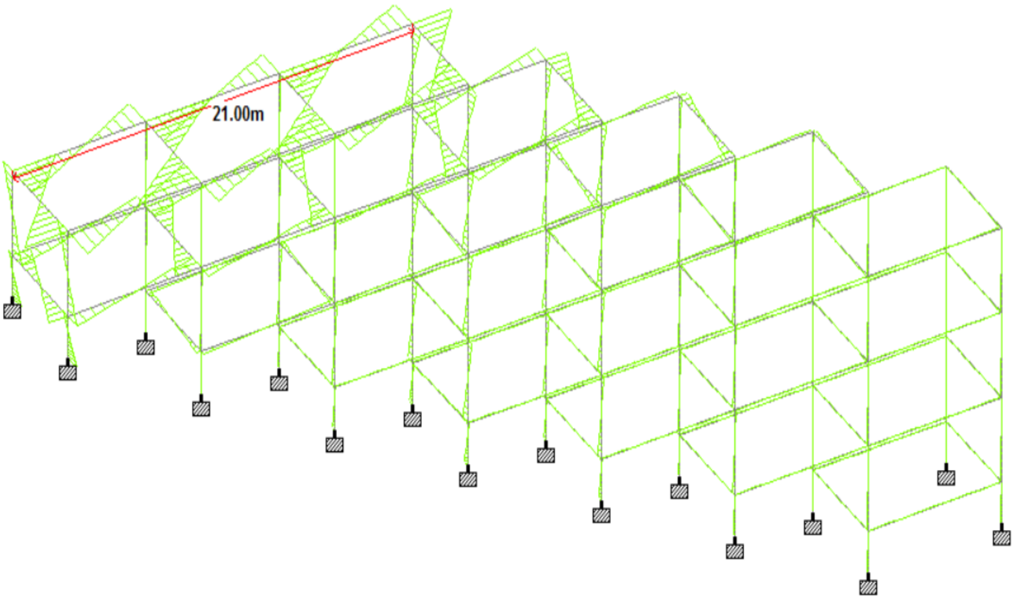

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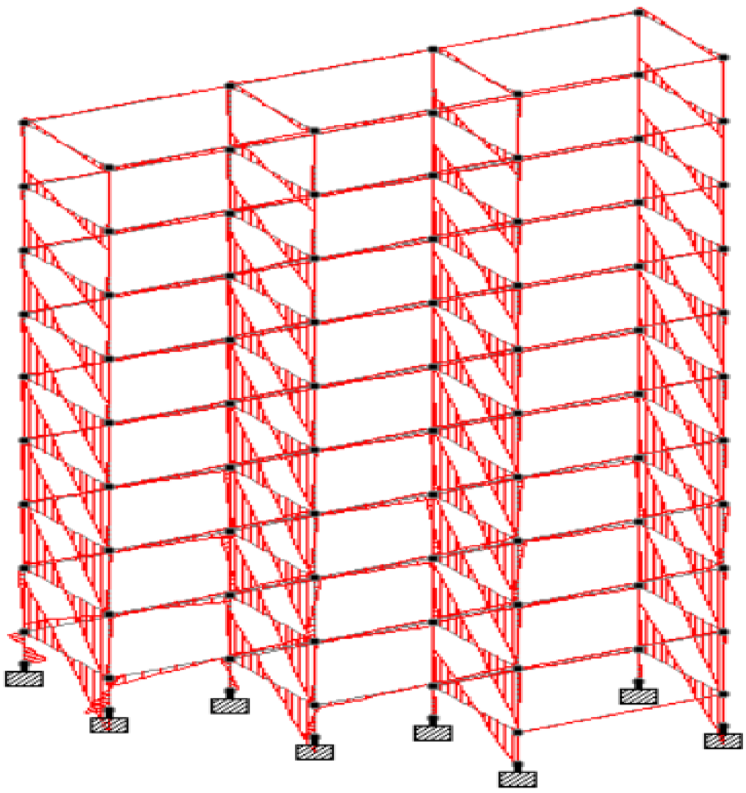
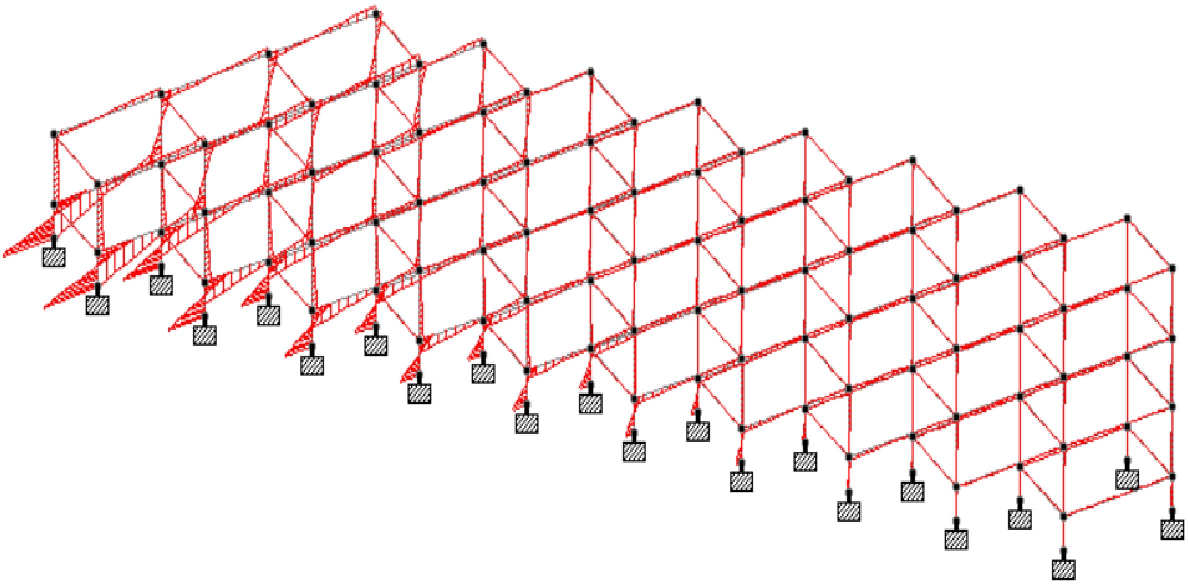


B.M. DIAGRAM OF STEP BACK BUILDING ALONG Y PLANE



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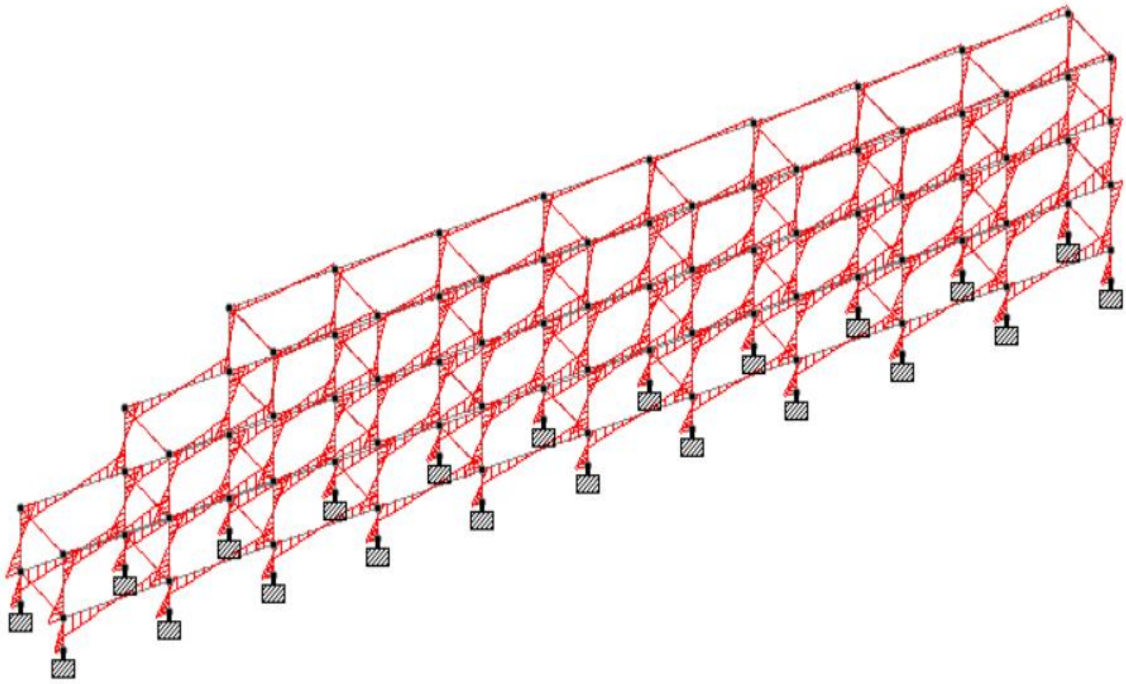

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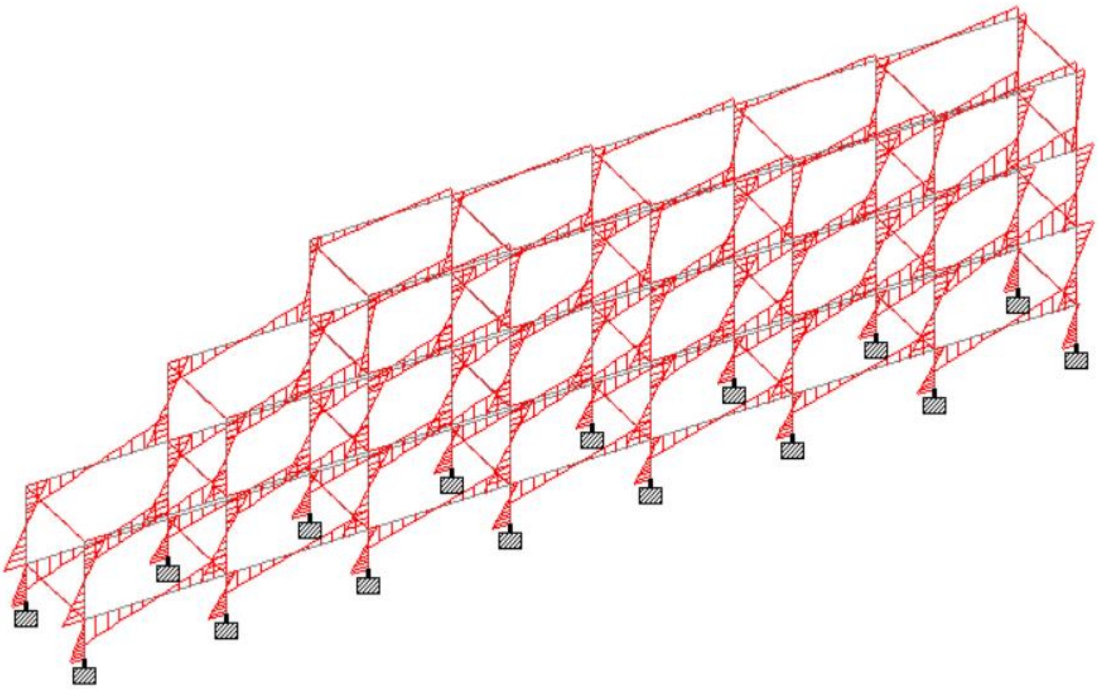
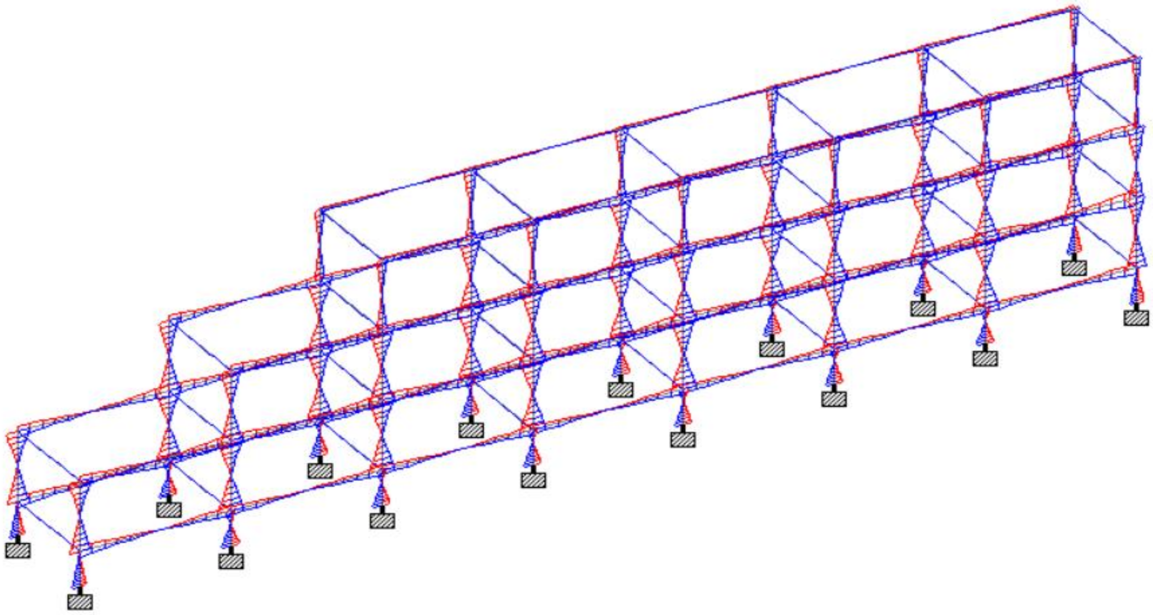


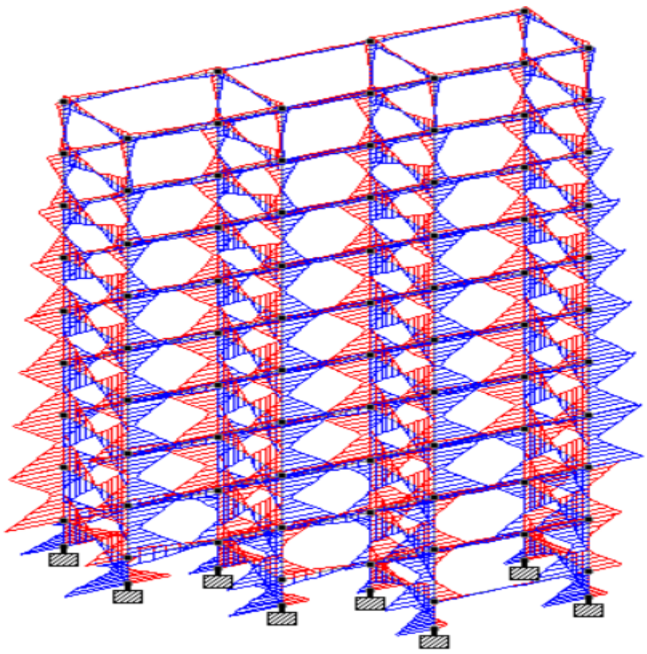
B.M. DIAGRAM OF SET BACK BUILDING

ANNEXURE C

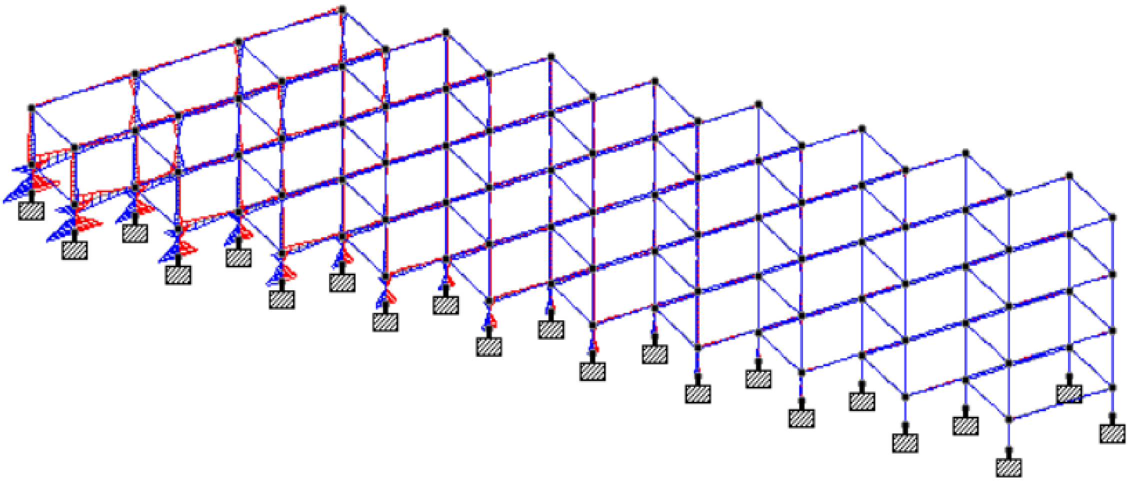
BEAM STRESS DIAGRAMS OF VARIOUS CONFIGURATIONS



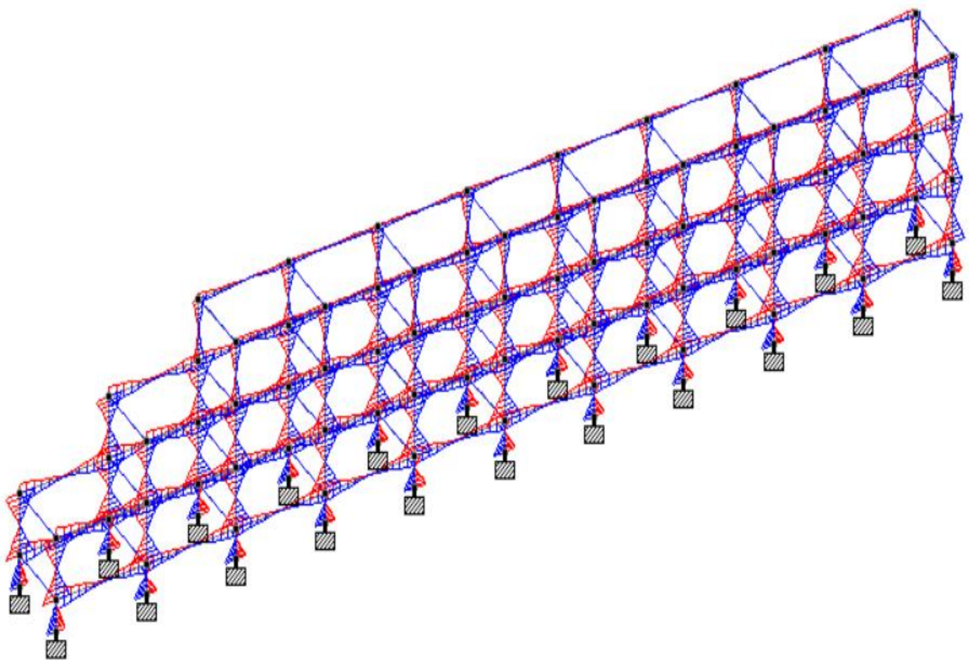
SET BACK BUILDING



STEP BACK BUILDING



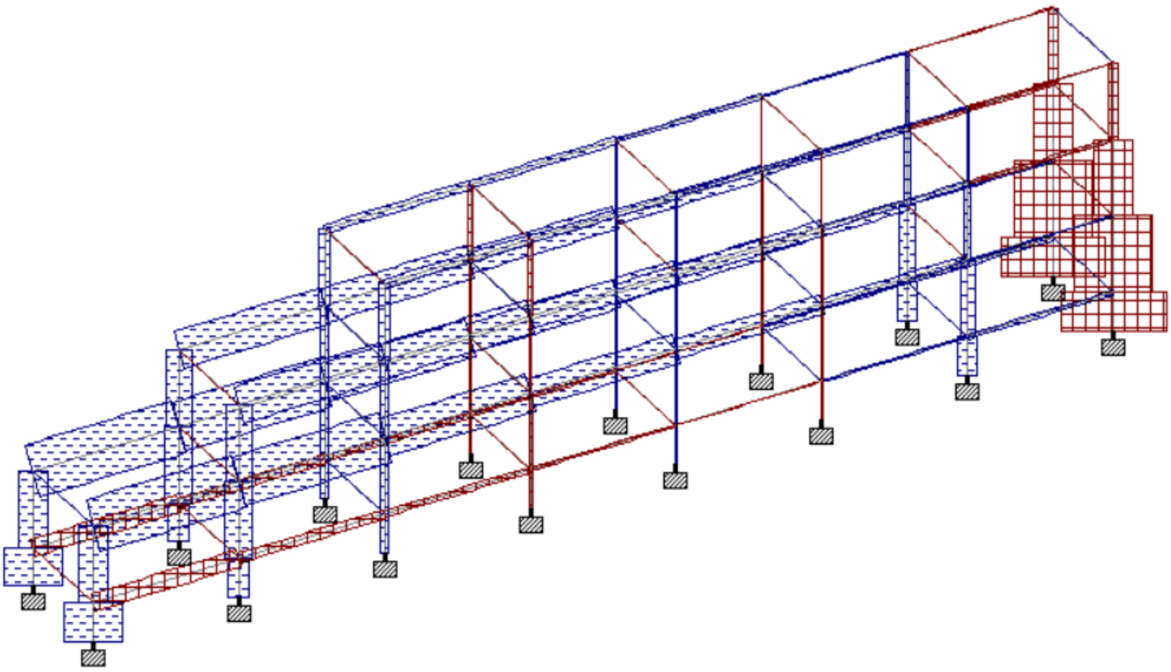
STEP BACK SET BACK BUILDING



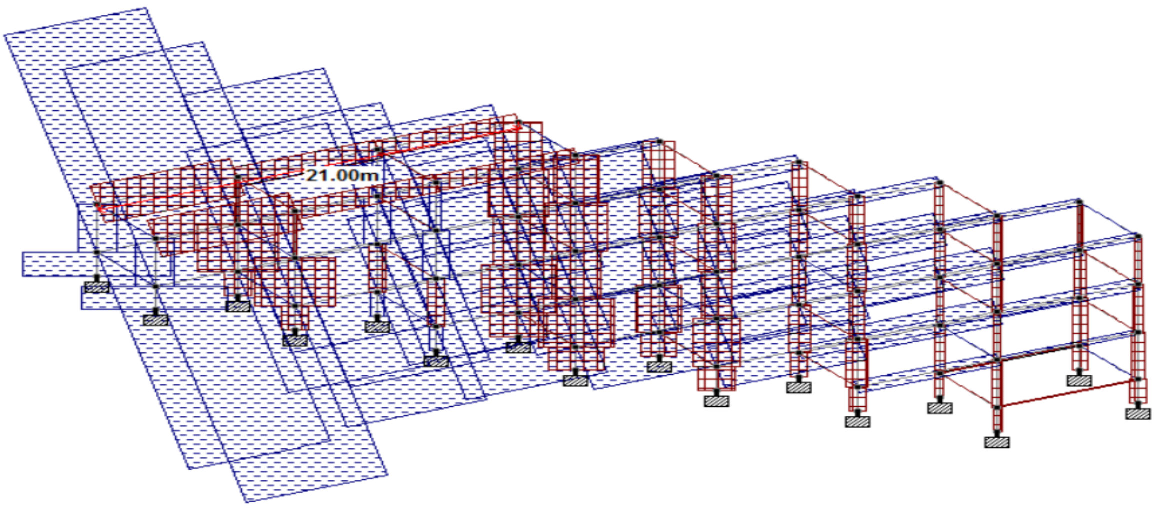
10 BAY SET BACK BUILDING

ANNEXURE D

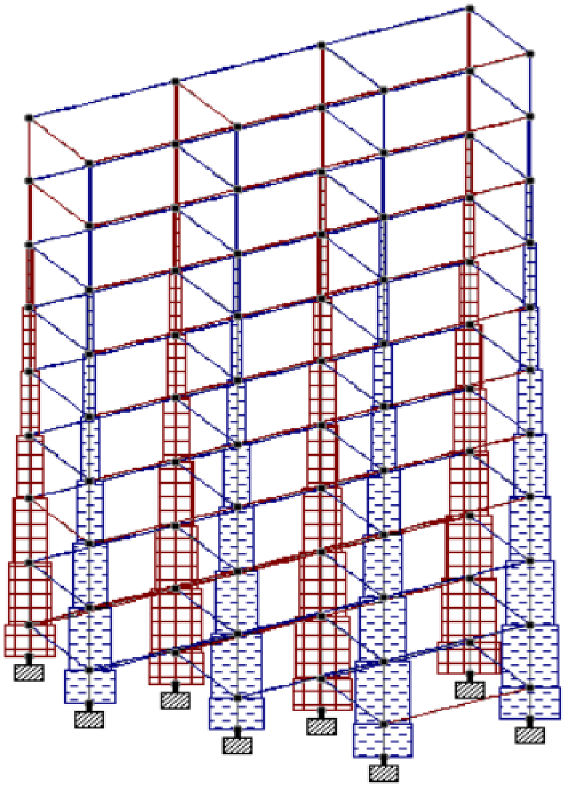
AXIAL FORCE DIAGRAMS OF VARIOUS CONFIGURATIONS



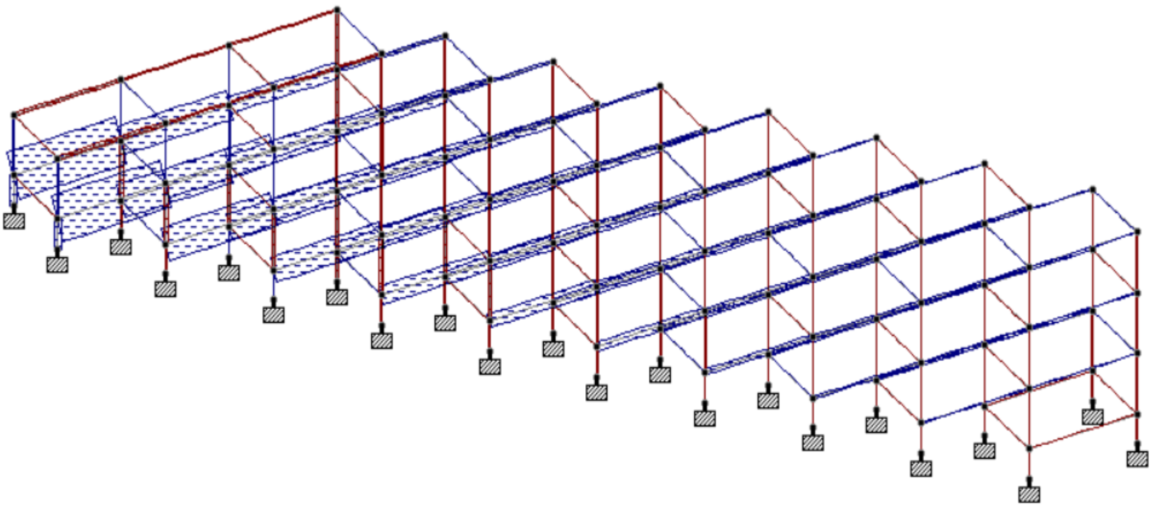
7 BAY SET BACK BUILDING



5 STOREY STEP BACK SET BACK BUILDING



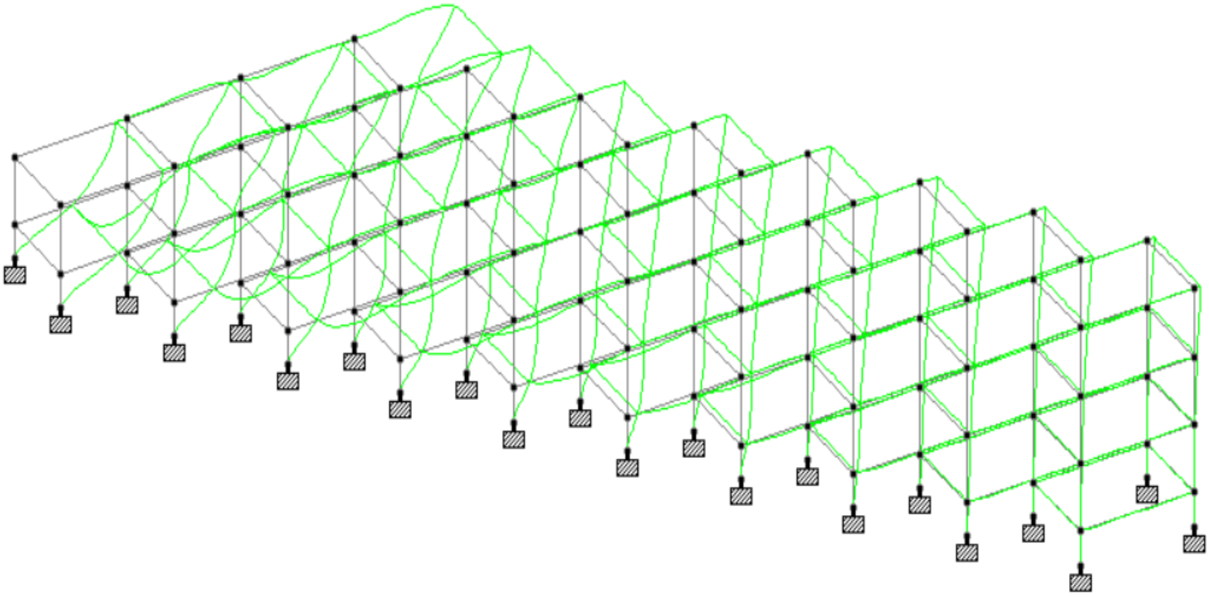
10 STOREY STEP BACK BUILDING



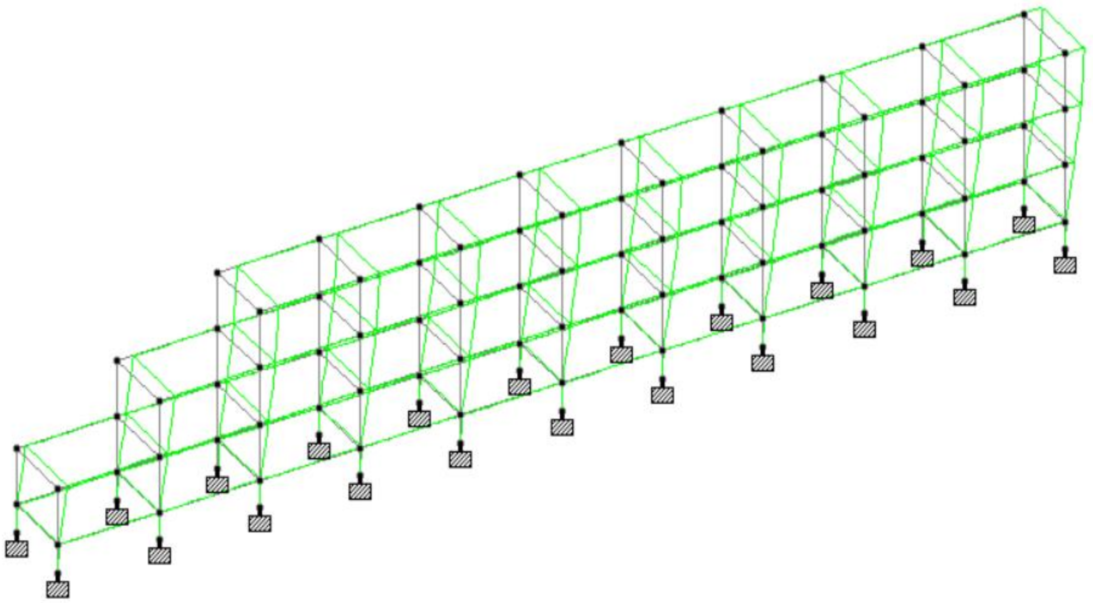
10 STOREY STEP BACK SET BACK BUILDING

ANNEXURE E

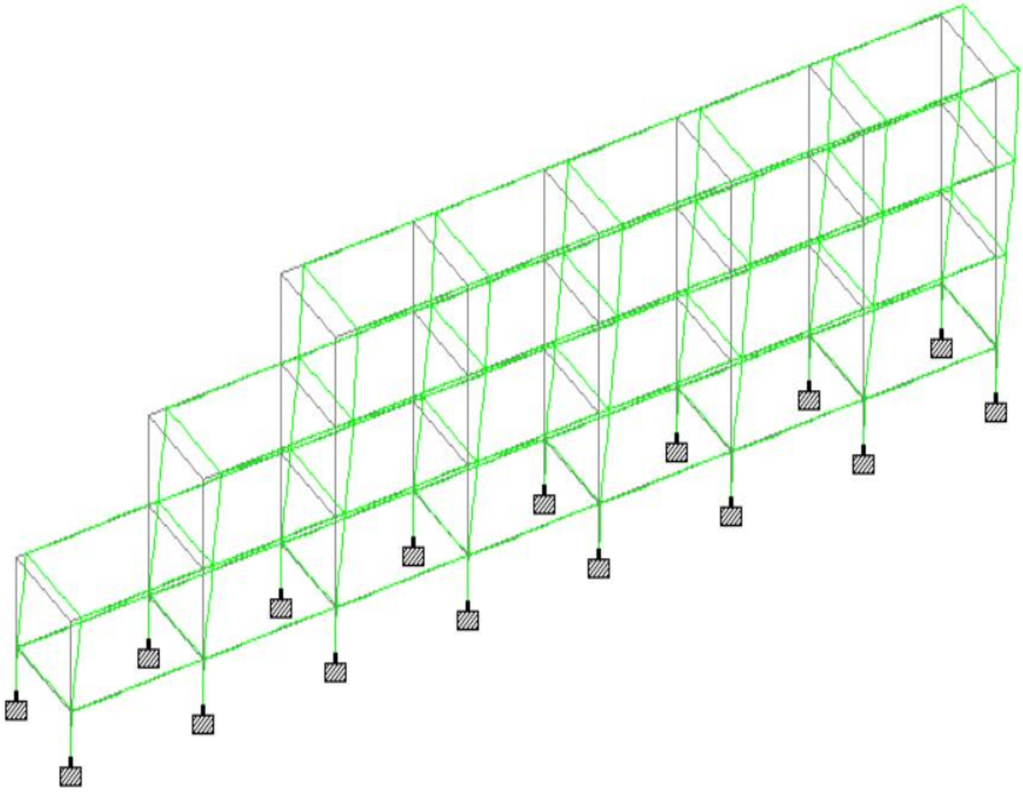
DEFLECTION DIAGRAMS OF VARIOUS CONFIGURATIONS



10 STOREY STEP BACK SET BACK BUILDING



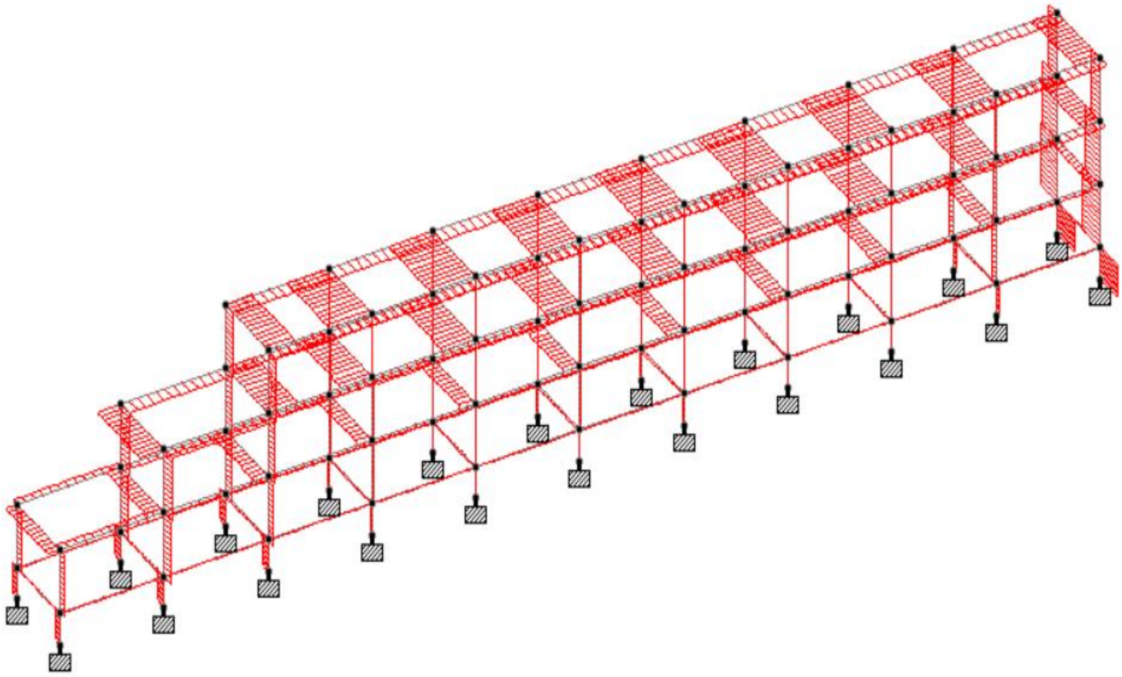
10 BAY SET BACK BUILDING



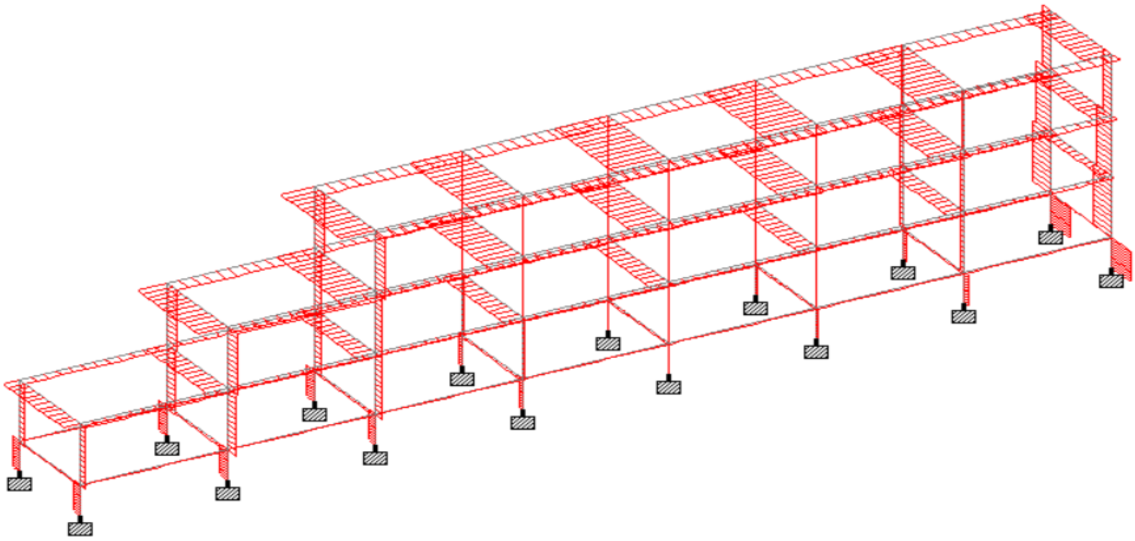
7 STOREY SET BACK BUILDING

ANNEXURE F

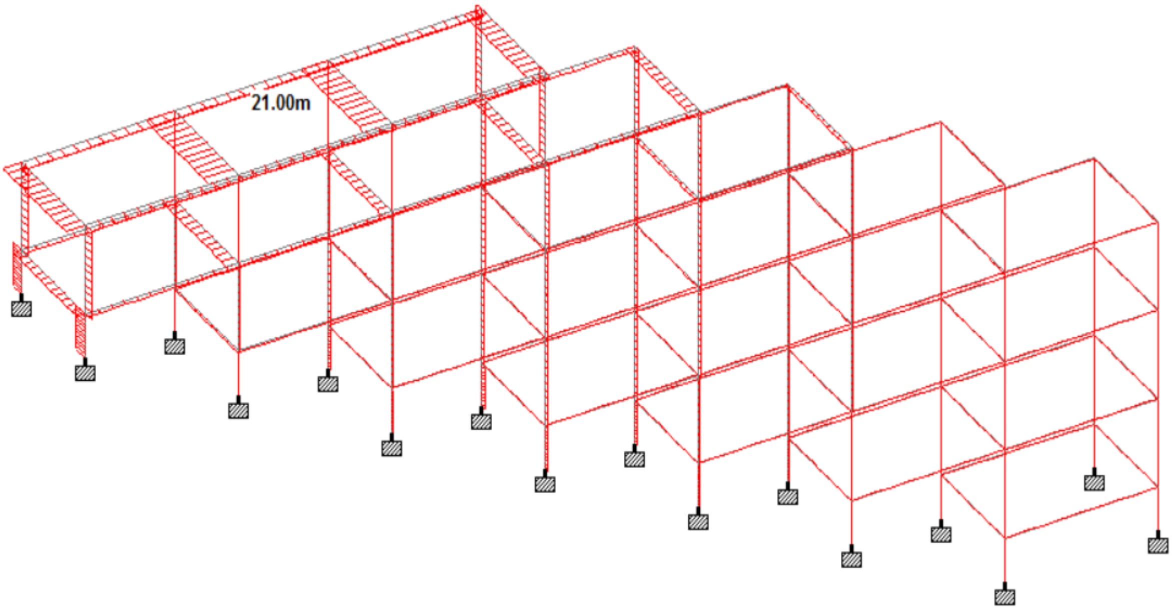
SHEAR FORCE DIAGRAMS OF VARIOUS CONFIGURATIONS



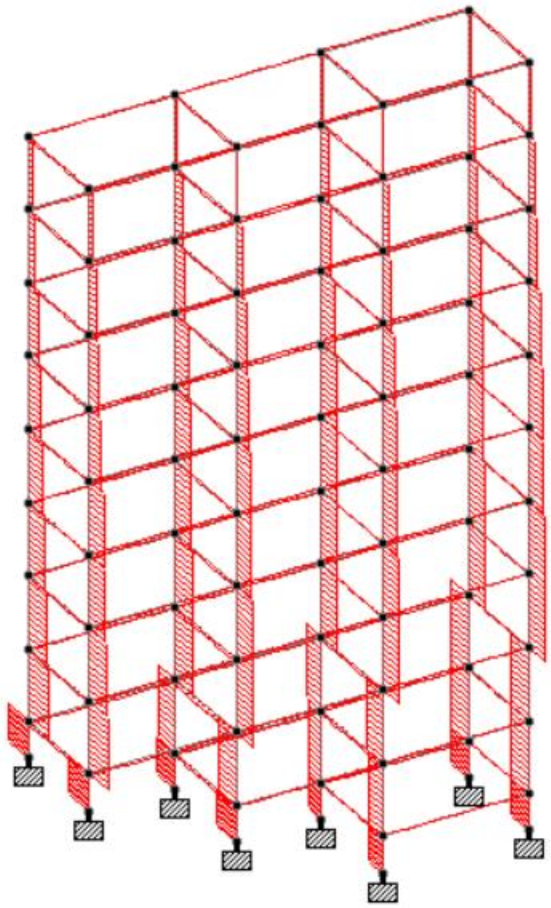
S.F. DIAGRAM OF 10 BAY SET BACK BUILDING



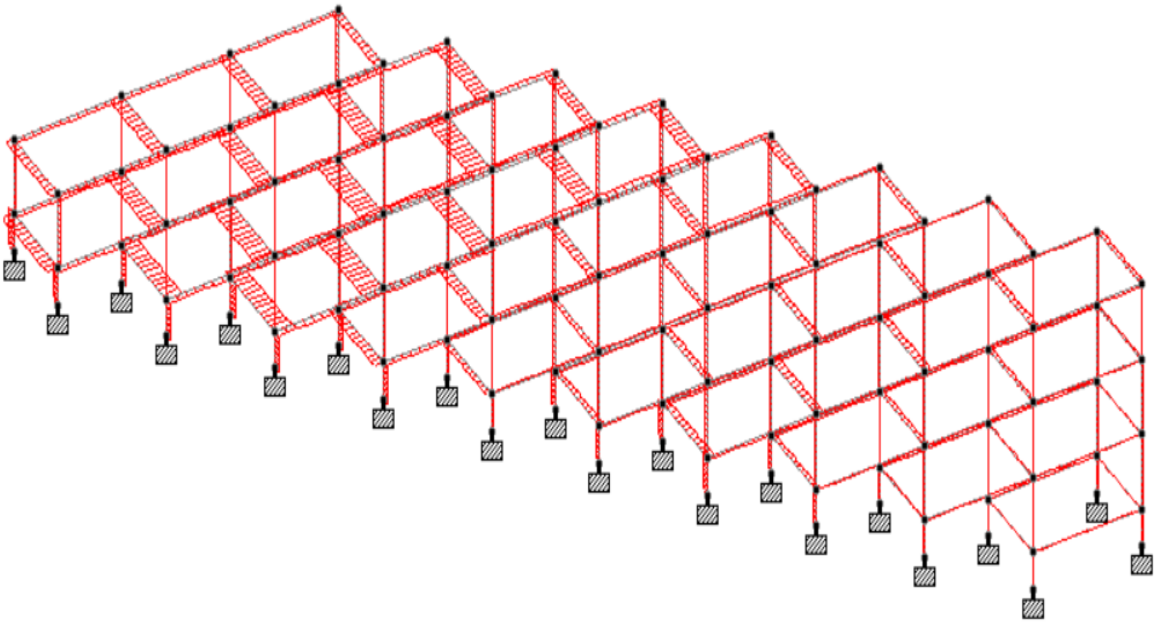
S.F. DIAGRAM OF 7 BAY SET BACK BUILDING



S.F. DIAGRAM OF 7 STOREY STEP BACK BUILDING



S.F. DIAGRAM OF 10 STOREY STEP BACK BUILDING



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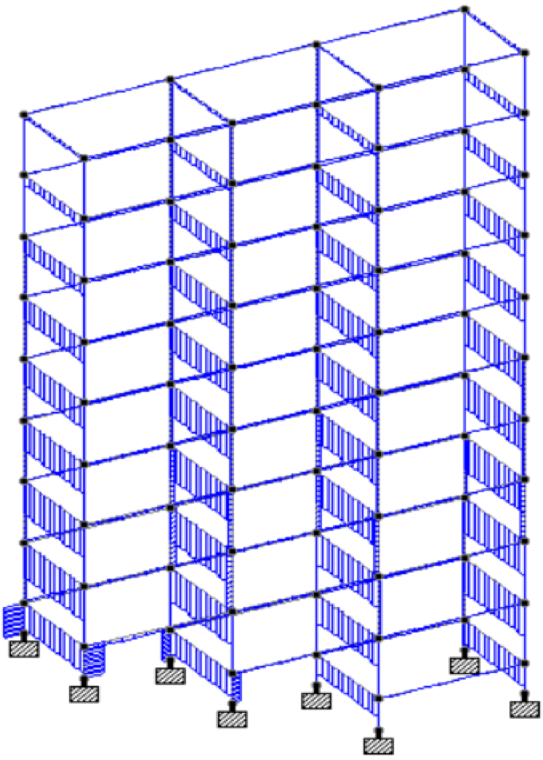
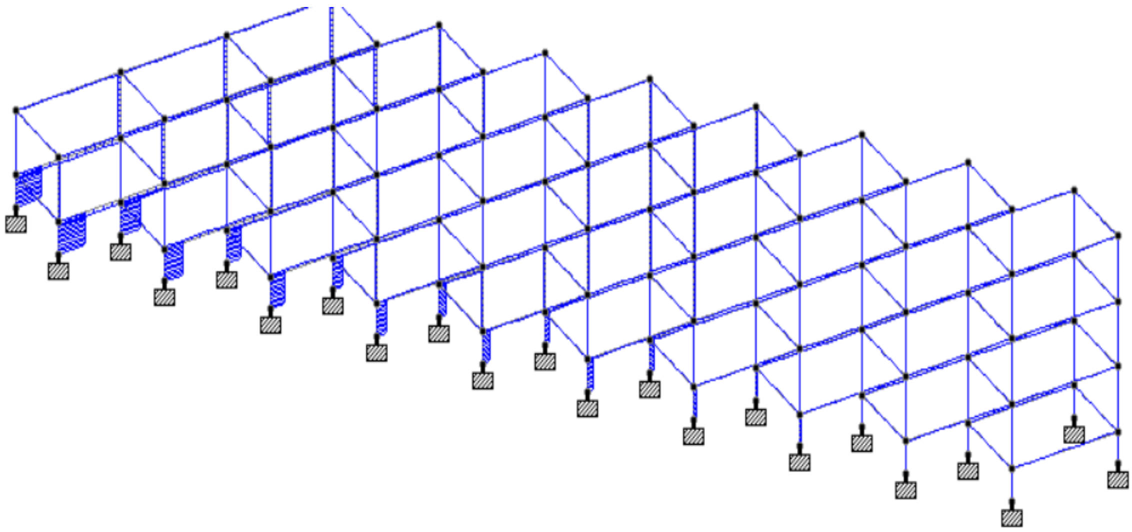


S.F. DIAGRAM IN Y DIRECTION OF 10 STOREY SET BACK BUILDING



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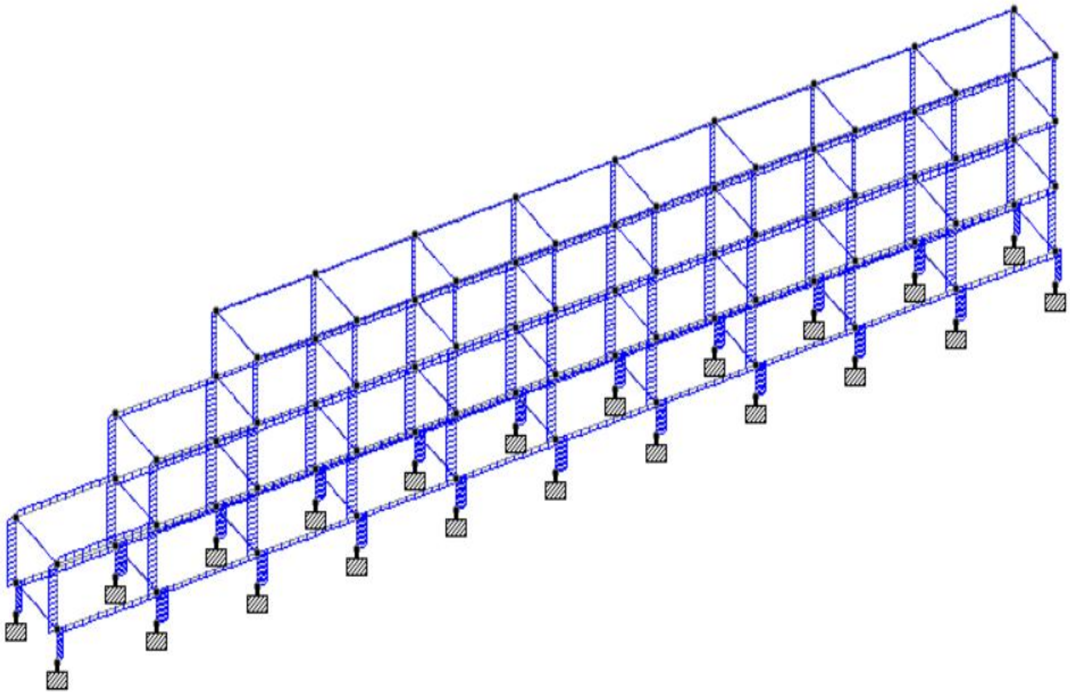
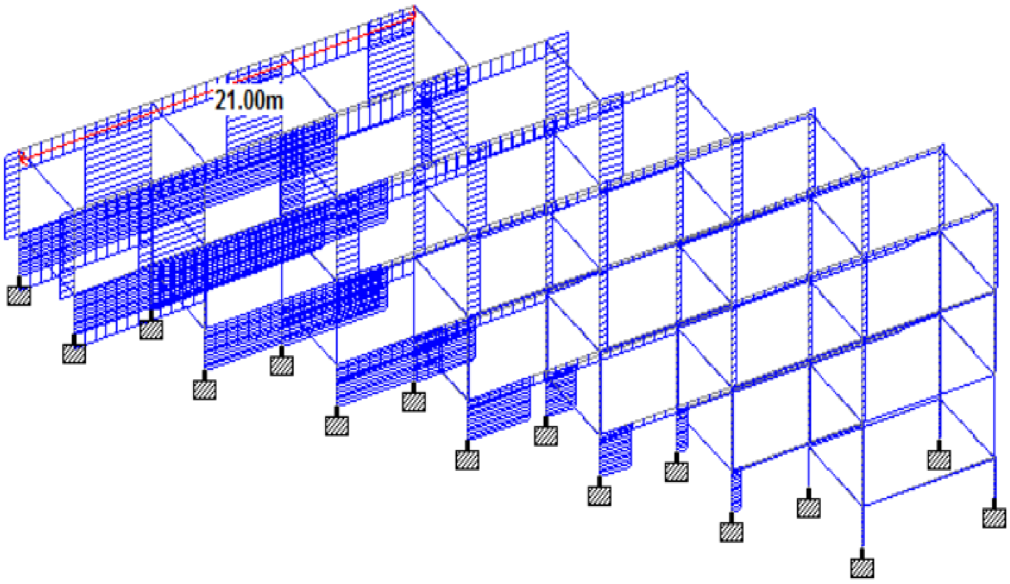


S.F. DIAGRAM IN Y DIRECTION OF 10 BAY SET BACK BUILDING



S.F. DIAGRAM IN Y DIRECTION OF 7 STOREY SET BACK STEP BACK BUILDING