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Effect of Earthquake Resistant System on Vertically Geometric Irregular RC Tall Building

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Abstract
Earthquake is a natural disaster which is experienced throughout the world. The effect of earthquake depends on the magnitude with which the earthquake occurs. There are many lives which are claimed due to earthquake and loss of property. With modernization high rise buildings are seen everywhere due to vertical expansion. The high-rise building possesses more danger to earthquake. Uncertainties involved and behavior studies are vital for all civil engineering structures. The presence of vertical irregular frame subject to devastating earthquake is matter of concern. A high-rise building can have various types of irregularities such as vertical irregularity, mass irregularity, stiffness irregularity, re-entrant corner irregularity and torsional irregularity. Irregular building is more prone to earthquakes and so by providing an earthquake resistant system we can minimize the loss of lives and property. A vertically irregular building can be provided with bracing or base isolation device to reduce the seismic activity and reduce the loss during earthquake.
In this research work, the effect of bracing and base isolation on the seismic analysis of various vertically irregular high-rise buildings will be investigated using nine models. A 20-story high rise vertically irregular building with plan dimension 48 m x 30 m located in zone III with horizontal aspect ratio 1.6 and vertical aspect ratio 2 will be designed as per IS 1893:2002 (part1) and IS 16700:2017 provisions. The seismic analysis of the various vertical irregularities namely setback irregularity, open grounded story irregularity and multiple setback irregularity will be done by CSI ETABS software. A comparison between the seismic analysis of the various vertically irregular building without any earthquake resistant system, with X bracing system and with base isolation will be done. After the analysis of seismic performance, a vertically irregular building with efficient seismic performance amongst the others will be selected based on the results. From present study it is observed that with the provision of base isolation system the seismic performance of building increases. As the vertical irregularity goes on increasing the seismic performance goes on reducing.
Keywords: *Earthquake, Irregularity, ETABS*

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I. INTRODUCTION

A structure cannot be made earthquake proof but with proper design considerations and lateral force resisting system the structure can be made earthquake resistant. Modern tall rise buildings are constructed with irregularities. There are various types of irregularities namely the vertical irregularities and horizontal irregularities. An irregularity is introduced in a building for both aesthetic purpose and utility purpose. Seismic behavior of a building depends on the arrangement of the structural elements of the structure. In an irregular structure the eccentricity is developed because the center of mass does not coincide with the center of stiffness.

Torsion is developed due to eccentricity. As there is occurrence of eccentricity and the irregular placement of structural components a significant impact on torsional coupling is seen which result in damage of the structure. Different structural irregularities show different seismic performance. To make building earthquake resistant the system should be such that it resists the ground motion. There are various methods such as providing bracing, base isolation device, strong column weak beam, outrigger and belt truss system. With the use of any one of the systems the building can be made safe to withstand the ground motions and protect the structure and the occupants inside the structure. Nowadays high-rise buildings with irregular configuration are seen. Irregular configuration either in plan or elevation is the main cause of structural failure.

- **Aim and objective**

The aim of this project is to study the effect of earthquake resistant systems on vertically geometric irregular RC tall building. The objectives to achieve the aim of the project are-
1.) To study the seismic performance of various vertically geometric irregular building with fixed base.

2.) To study the seismic performance of the building when the vertically geometric irregular building is applied by bracing system and lead rubber bearing (LRB) system.
3.) To find out the model with the most effective seismic performance amongst the other models.

- **Vertical geometric irregularity**

In this project vertical geometric irregularity is studied. As per IS 1893:2002 any building in which the horizontal dimension of the lateral force resisting system in any story is more than 150 percent of that in its adjacent story. Vertical setback on one side, vertical set back on both sides and multiple setbacks are the three types of vertical geometric irregularity allowed. Floating column irregularity has now been banned under revised guidelines. Figure1.3 demonstrates the several of types of vertical irregularities which will be considered in the research work. In the Figure shown below three types of irregularities are shown. Multiple steps back irregularity, both sided irregularity and irregularity on one side are the three types of irregularities shown in the Figure.

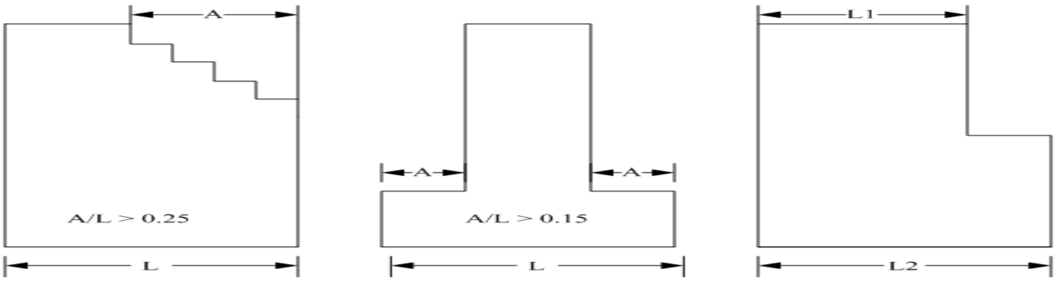

Figure 1: Vertical geometric irregularity as per IS code

II. METHODOLOGY

The dissertation is to investigate the effect of different earthquake resistant systems on reinforced concrete vertically irregular building. Three buildings having vertical geometric irregularity are considered. The vertical geometric irregularities considered are step back irregularity, one sided irregularity and both sided irregularities. Bracing and base isolation are the earthquake resistant system applied. The seismic response of each irregularity is analyzed on ETABS with fixed base, bracing and base isolation.

Dynamic linear analysis is carried on structures to study the seismic response of each structure. Dynamic linear analysis is carried on with the help of response spectrum method. For reaching to a conclusion various parameter such as base shear, story drift, story displacement and time period will be compared.

III. MODELING AND ANALYSIS

Table 1. Specification of structure

Sr. No.	Parameter	Value
1	Height of building	59 m
2	Type of structure	Multi story RC frame
3	Soil type	Type-I
4	Number of stories	G+18
5	Plan dimension	48 m x 30 m
6	Size of column	600 mm x 600 mm
7	Size of beam	350 mm x 450 mm
8	Thickness of slab	125 mm
9	Location	Pune
10	Seismic Zone	III

Table 2. Various models considered in the project

Sr. No.	Model Number	Type of Irregularity
1	Model 1	Irregularity on both sides
2	Model 2	Multiple setback irregularity
3	Model 3	Irregularity on one side

Table 3. Table showing loading details

Sr. No.	Type of Load	Intensity of Load
1	Dead Load	1 kN/m^2
2	Live Load	3 kN/m^2
3	Wall Load	14.28 kN/m^2
4	Waterproofing Load	3 kN/m^2

5	Parapet Load	6.72 kN/m^2

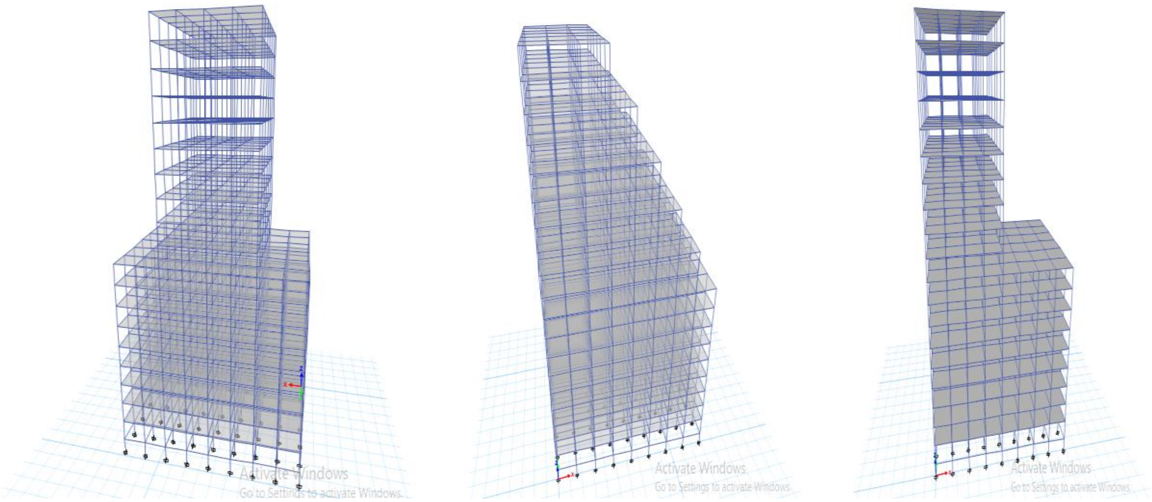

Figure 2: Representation of model 1, 2, 3

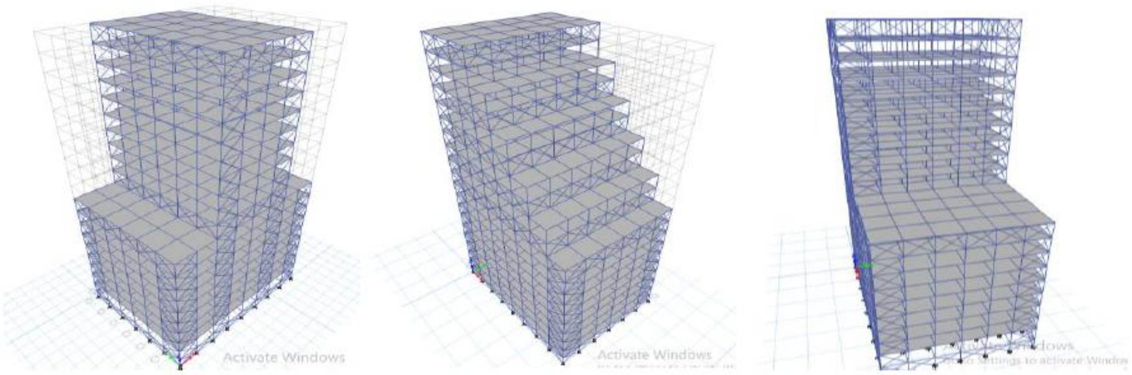

Figure 3: Representation of model 1, 2, 3 with bracing

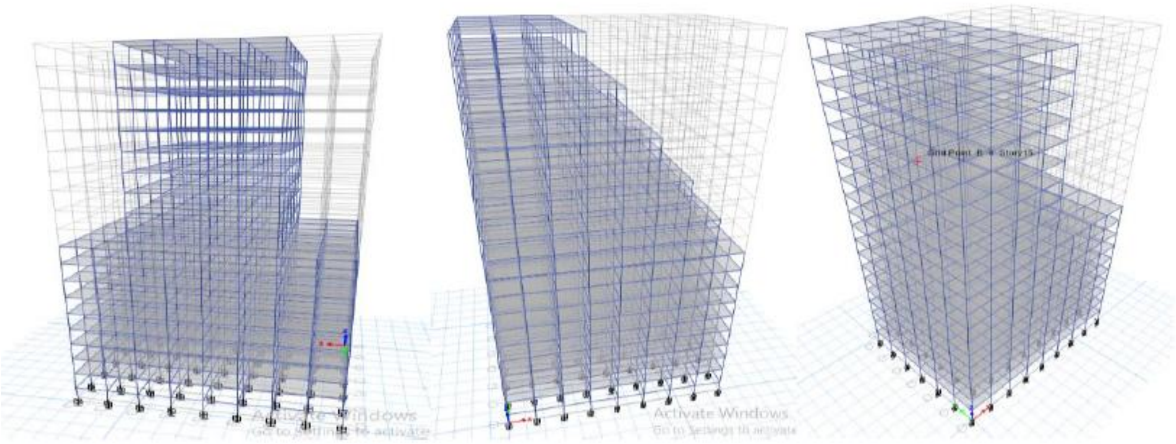

Figure 4: Representation of model 1, 2, 3 with LRB

Table 4. LRB properties for model 1, 2, 3

Sr. No.	Property	Value Model 1	Value Model 2	Value Model 3
1	Rotational Inertia	0.00231 kN/m	0.004233 kN/m	0.00582 kN/m
2	For U1 effective stiffness	389220 kN/m	524840 kN/m	567840 kN/m
3	For U2 and U3 effective stiffness	389.20 kN/m	524.84 kN/m	567.84 kN/m
4	For U2 and U3 effective damping	0.05	0.05	0.05
5	For U2 and U3 distance from end J	0.00316 m	0.00318 m	0.00316 m
6	For U2 and U3 stiffness	3586.8 kN/m	4816.7 kN/m	5233 kN/m
7	For U2 and U3 yield strength	11.36 kN	15.32 kN	➤ N

IV. RESULTS AND DISCUSSION

The result of each model with vertical irregularity is obtained for fixed base, bracing system and base isolation system. While doing the analysis certain parameters are considered. The parameters which will be considered during this research will be base shear, story displacement, story drift and modal time period. A brief introduction of the various parameters is mentioned below.

1.) Base Shear: It is the estimate of the maximum expected lateral force on the base of the structure due to seismic activity. Whenever a structure experiences seismic activity the base of the structure will experience a maximum force, this maximum force is called as base shear. The criteria on which base shear depends are soil condition and the seismic zone present in that area. The unit of calculation of base shear is kN.

2.) Story Displacement: Story displacement is the lateral displacement of a story relative to its base. When conducting seismic analysis story displacement plays a very important role in detecting the stability of a building under horizontal seismic forces. Lateral force resisting system help in reducing the story displacement of a structure. Story displacement is measured in mm.

3.) Story Drift: Story drift is the relative displacement of one story relative to the other. Story drift ratio is the story drift divided by height of the structure. Story drift ratio is unit less quantity while story drift is measured in mm.

4.) Modal time period: When modal analysis is performed on a structure it will use to the overall mass and stiffness of a structure to find the various periods at which the structure will resonate naturally. When performing seismic analysis this plays a very important role because it denotes whether the natural frequency of building matches with the frequency of expected earthquake in the region. Modal time period is usually analyzed for 12 modes but the initial three modes give a brief characteristic of the structure. Modal time period is calculated in the S.I. unit of time that is sounds.

Table 5. Base Shear for irregularity 1, 2, 3

Sr. No.	Model	Load Case	Base Shear (KN) 1	Base Shear (KN) 2	Base Shear (KN) 3
1	Fixed	SPX	1019.217	1109.5064	1217.639
		SPY	1014.901	887.3162	991.6942
2	Bracing	SPX	1603.469	1622.38	2080.863
		SPY	1383.602	1523.1363	1799.177
3	Base Isolation	SPX	798.7344	866.7901	1056.768
		SPY	798.1505	727.5498	833.3542

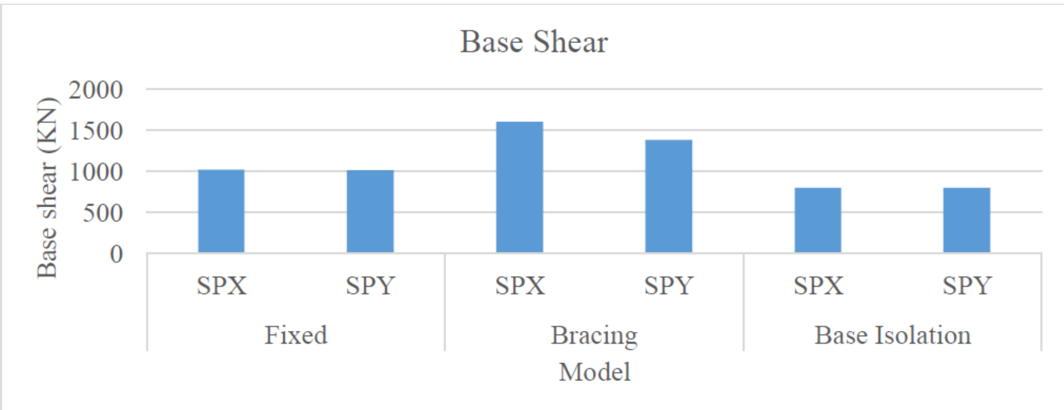

Figure 5: Base Shear for irregularity 1

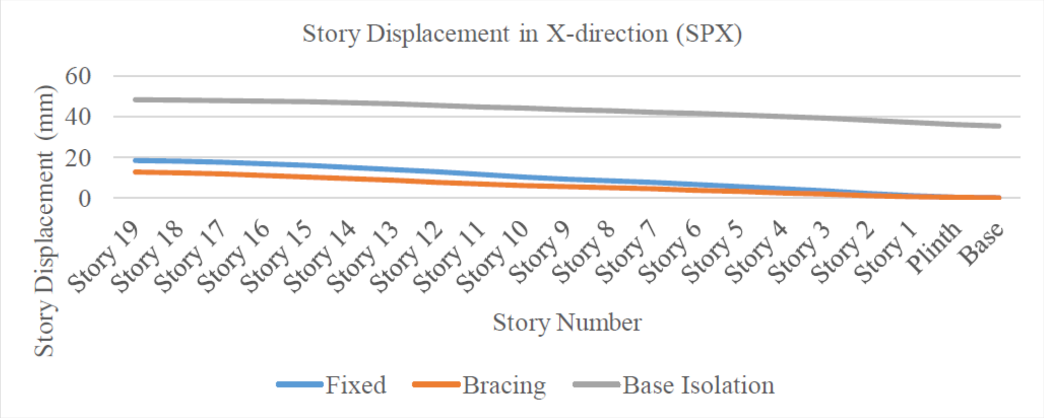

Figure 6: Story displacement due to SPX in x-direction

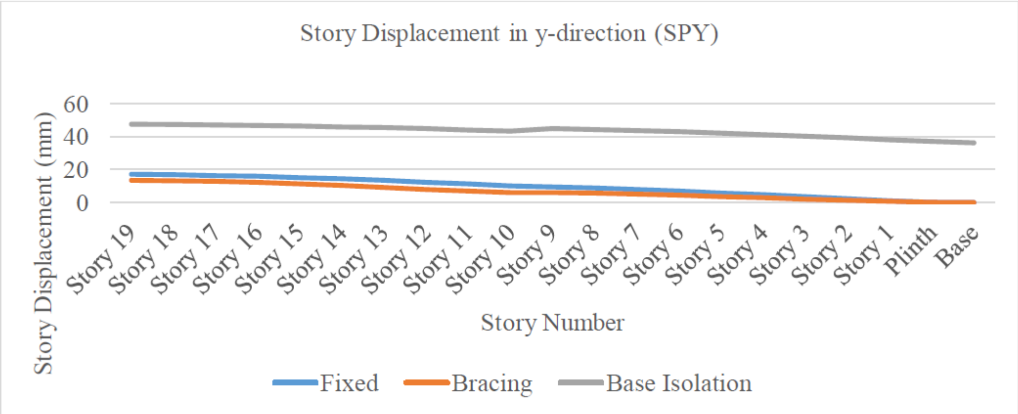

Figure 7: Story displacement due to SPY in y-direction

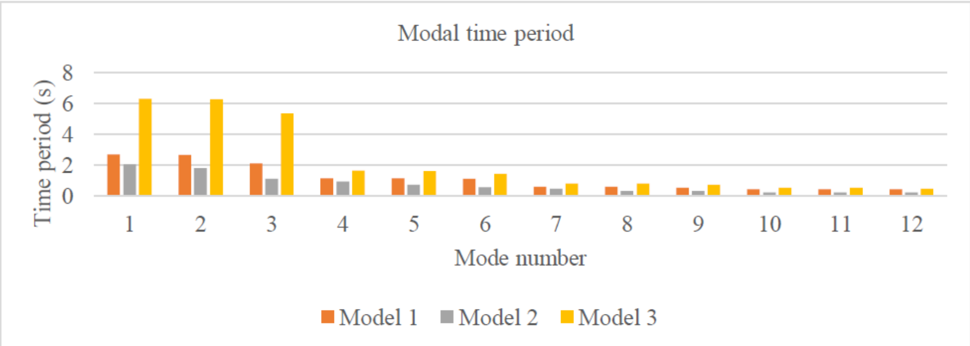

Figure 8: Modal time period for irregularity 1

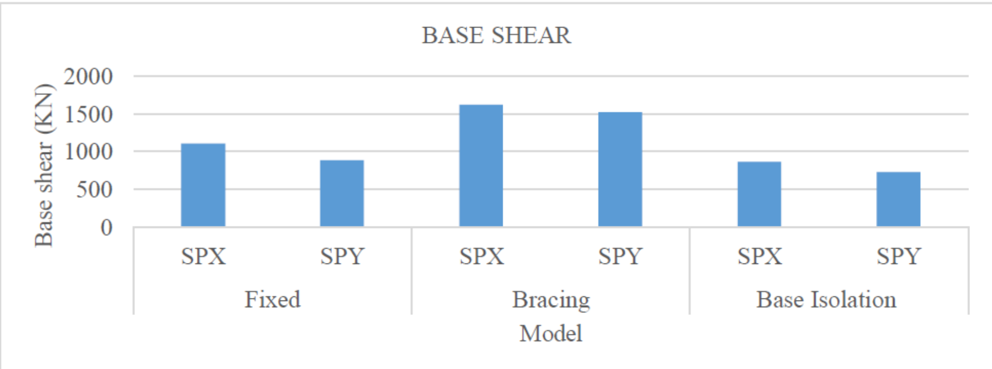

Figure: Base shear for irregularity 2

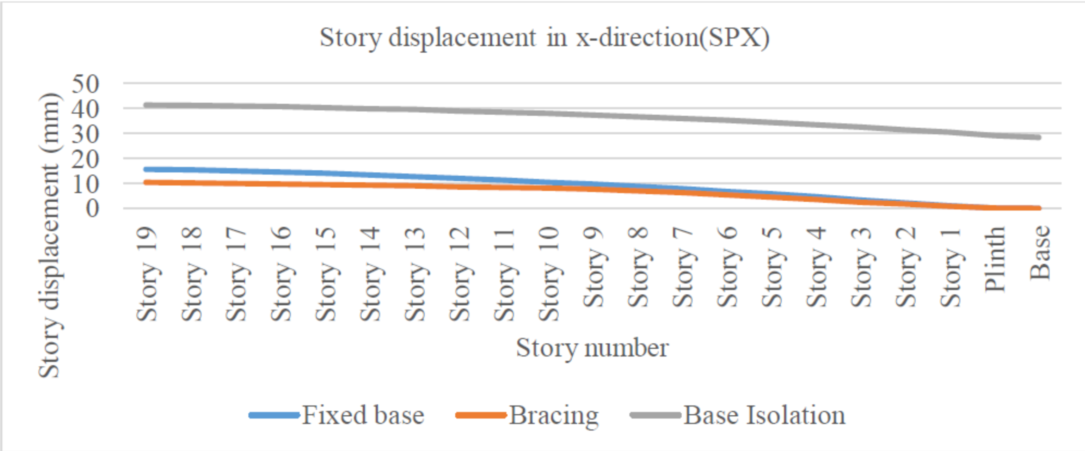

Figure 9: Story displacement due to SPX in x-direction

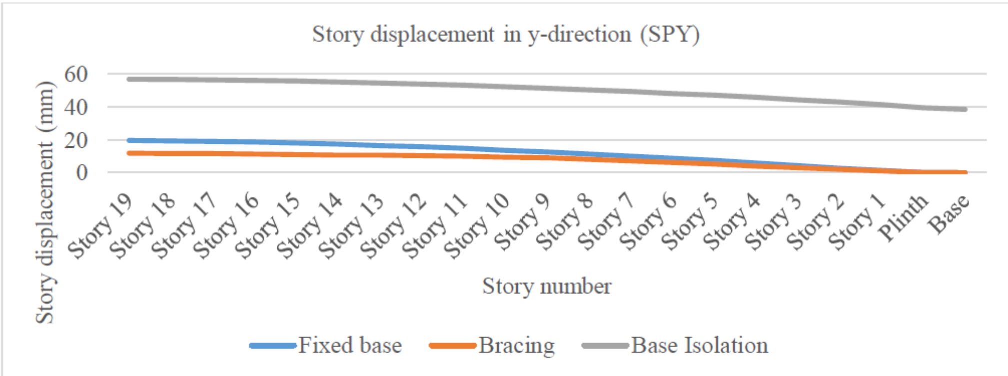

Figure 10: Story displacement due to SPY in y-direction

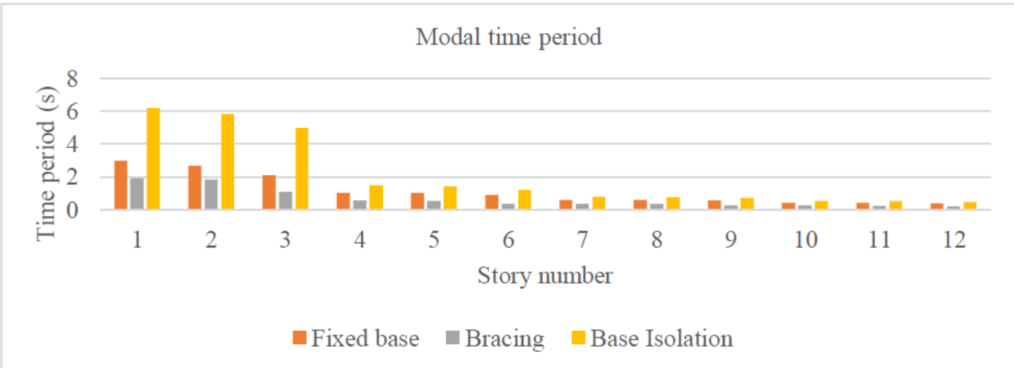

Table 11: Modal time period

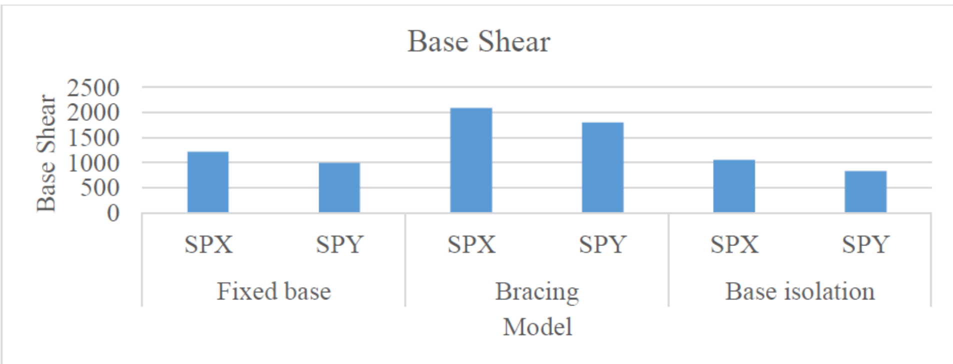

Figure 12: Base shear for irregularity 3

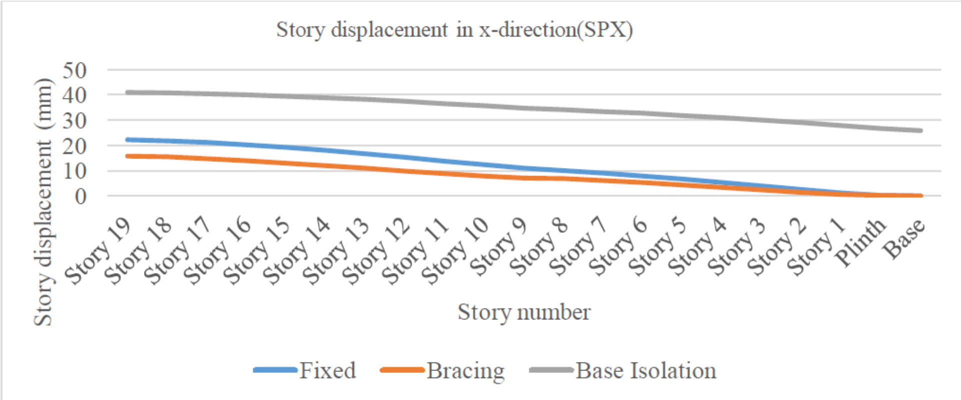

Figure 13: Story displacement due to SPX in x-direction

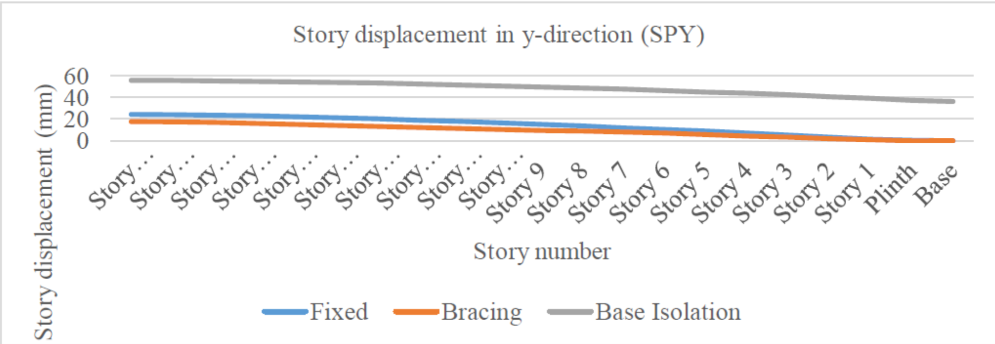

Figure 14: Story displacement due to SPY in y-direction

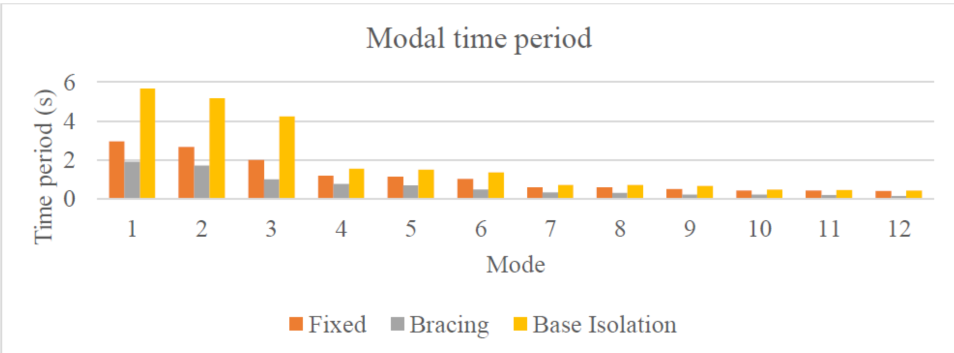

Figure 15: Model time period for irregularity 3

Discussion is that results obtained from the analysis performed on CSI ETABS are discussed below. Base shear, story displacement, story drift and model time is studied.

➢ **Base Shear**

a.) For model 1 from Table 5.1 it is evident that the base shear for base isolation system is the least amongst the other two i.e., fixed base and bracing. For base isolation in x-direction it is 798.73 kN, for bracing it is 1603.469 kN and for fixed base it is 1019.21 kN. The base shear for bracing is highest for model 1. The same behavior is observed for y-direction.

b.) For model 2 the base shear in the direction of x-axis from Table 5.7 for fixed base is 11095 kN, for bracing it I 1622.38 kN and for base isolation it is 866.79 kN. It is seen from the result Table that base shear is least for base isolation. The same behavior is followed for y-direction.

c.) For model 3 after reviewing Table 5.13 it is seen that for response spectrum in x- direction the base shear is 1217.639 kN, for bracing it is 2080.863 kN and for base isolation it is 1056.768 kN. The same type of behavior is observed for y-direction.

d.) From the results of base shear, it is visible that the base shear for bracing is the most in all the irregularities while the base shear for base isolation is least.

e.) The increase in the base shear due to base isolation is due to the distribution of mass and stiffness which further gives more fundamental time period.

- **Story Displacement**

a.) For model 1 from Table 5.2 it is observed that the relative displacement is the least for model with base isolation. But at the bottom higher displacement is found for base isolation it is 35.249 mm.
b.) For model 2 from Table 5.8 it is evident that the relative displacement is least for model with base isolation in both the x as well as y direction. But at the bottom again higher displacement is found for model with base isolation. A displacement of 28.395 mm is seen in x- direction.
c.) For model 3 from Table 5.14 at the base a displacement of 25.889 mm is seen in model with base isolation in x direction. But on the whole the relative displacement is lesser of base isolation model as compared to the other two models.
d.) Story displacement is maximum for base isolation in both the directions. While due to provision of bracing the story, displacement reduces drastically in both the directions. The relative displacement in model 1, model 2 and model 3 for fixed base is more as compared to that of bracing and base isolation. In all the three irregularities the same pattern of greater displacement at base and later lesser relative story displacement is observed.
e.) Due to base isolation the top storey displacement reduces and the displacement at the base increases which shows that the structure is flexible when modified with base isolation technique as compared to that of bracing and fixed base.

- **Story Drift**

a.) For model 1 from Table 5.4 if considered about base isolation model than the story drift is initially larger at the bottom but the relative story drift is the least for base isolation ass compared to that of fixed base and bracing the top story drift is also less in case of base isolation.
b.) For model 2 from Table 5.10 it is seen that the bottom story drift is higher for base isolation but the relative story drift and the top story drift is lower for base isolation.
c.) For model 3 from Table 5.16 in both the x as well as y direction it is seen that story drift is higher for base isolation in at the base but the relative story drift and top story drift is less.
d.) Story drift for the base is more in case of base isolation as compared to fixed base and bracing in both the directions. However, after base the relative story drift is less for base isolation. The story drift of the top floor that is story 19 is less as compared to that of fixed base in model 1, model 2 and model 3.
e.) From the Figures it is visible that the story where irregularity is present that is story 10 deformation is seen in the story drift in irregularity 1. In irregularity 2 deformations is seen as story 10, 12, 14 and 16 because the irregularity is multiple steps back irregularity and at the above-mentioned floors irregularity is present. In case of irregularity 3 only 1 irregularity is present at the story 10 so its behavior deforms only once.

- **Modal time period-**

a.) For model 1 from Table 5.6 it is observed that the model time period for fixed base is 2.674 s, for bracing it is 2.035 s and for base isolation it is 6.329 s an increase of almost 3 s is seen.
b.) For model 2 from Table 5.12 it is observed that the model time period for fixed base is 2.976 s for bracing it is 1.904 s and for base isolation it is 6.203 s.
c.) For model 3 from Table 5.18 it is observed that the model time period for fixed base is 2.968 s, for bracing it is 1.914 s and for base isolation it is 5.661 s.
d.) Modal time period is one of the most important factors when seismic analysis is to be done. It is observed that in case of base isolation the time period is increased in each irregularity. The increase in time period due to base isolation makes the structure more stable during an earthquake activity. When the time period increases the structure will experience less seismic forces. Base isolation shifts the fundamental period of the building from the dominant period of earthquake.
e.) The modal time period of the structure increase when applied with base isolation and it is beneficial because it shifts the fundamental period of a building from a more force shorter periods to a less force longer period which makes the system susceptible to less damage during a seismic activity.

V. CONCLUSION

From the present study following conclusions were drawn-
1.) When all the models are applied with a fixed base it is seen that they were more prone to seismic activity.
2.) By application of bracing and base isolation by lead rubber isolator technique it was seen that the base isolation proves to be better in controlling the seismic activity of the building by making the building flexible and by shifting the natural frequency of the structure to longer period less force period.

3.) Out of all the irregularities, model 1 i.e., irregularity on each side performs seismically better as compared to the other two irregularities. As the irregularity increases the seismic performance of the building reduces but it can be increased with the addition of base isolation by lead rubber bearing technique.

7.3 Future Scope

In this research topic seismic analysis of three different types of irregularities is carried on with fixed base, bracing and base isolation.

1.) The further structural designing of all the nine models.

2.) Checking applicability of other techniques such as strong column- weak beam, shear wall and outrigger system.

3.) Considering other types of vertical and geometric irregularities.

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