# Seismic Analysis of a Tall Building with and without Open Storeys for Hard Soil Type and Seismic Zone IV

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***Abstract* - A common feature which we see in the modern Tall building constructions in growing urban India is Open storey. Though tall buildings with open storeys are quite vulnerable to collapse due to earthquake but still their construction is largely in use in a developing country like India. Providing openings for car parking space or even for basements at ground level or at a level below and for offices with open storey's at different levels of building are in big demand nowadays and this completely disagree with the warnings which is given against such buildings from engineering sector. Now, with the availability of fast computers and with the easy usage of these computers, the various complexities that arise in the analysis and designing of a project have been highly reduced by the use of different civil engineering software's. The aim of this study is to find out the seismic behavior of a model in four different conditions i.e., a bare frame, an infilled frame, an open ground and first storey frame and an open ground storey frame under Seismic zone IV with hard soil type and then perform the comparative study and give results. ANSYS CivilFEM 12.0 is used for doing the analysis wok. The basic thing we analyze is which structure out of these is the most suitable for construction in seismic zone IV with hard soil and how much impact providing of open storey has in these structures. It is concluded that the maximum force values and maximum moment values (majority of them) are obtained in case of an infilled frame model and an open ground storey frame model. There is same impact acting on infilled model and open ground storey model as the shear force values and the bending moment values are the same in both the cases. Bare frame model gets the minimum bending moments (majority of them except moment in X direction) and the minimum shear forces as compared to other models in our study. The least shear force out of all the models is in case of bare frame model.**

**As bare frame model gets the minimum forces and moments as compared to other models in our study so the chances of failure of the bare frame model is the least so bare frame type of model is the safest among all the models considered in our study for seismic zone IV and hard soil type.**

***Keywords - Open storey, seismic analysis, Tall buildings, bare frame, infilled frame, open ground and first storey frame, open ground storey frame, seismic zone IV, hard soil type, comparative study.***

## I. INTRODUCTION

Tall Buildings throughout the world are becoming more popular day by day with the advancement of modern day construction technology and computers, the basic aim now is the construction of safer buildings keeping in view the complete economics of the project. In some areas tall buildings are called as 'vertical cities' or even 'high rise buildings'. Basically we can define tall building as a structure which has a height of 35 meter or more. Nowadays, the increasing population since past few years have increased the demand of construction of apartments or buildings with more car parking space and more safer designing and aesthetic beauty of the building and this is why construction of multi storey buildings with open storey's has become a common practice especially in basement and first storey. As regarding existing structures, it is important to strengthen and evaluate them based on evaluation criteria before an earthquake. The lateral loads which occur in Tall buildings due to earthquake are a main matter of concern. Steel – concrete composite construction is a faster technology which saves a lot of time in construction which helps the people in the planning field to match the demand with minimum time in real estate market. Composite construction also enhances the life expectancy of the structure. At present people are facing lot of problems of land scarcity, cost of land. The rapid increase in population and the upcoming of industrial revolution led to the exodus of people moving from villages to urban areas i.e. construction of tall buildings has become inevitable both for residential as well as office purposes.

The high raised buildings are not properly designed accordingly for the resistance of lateral forces and this may cause to the complete failure of the buildings. The earthquake resistance structures are designed based on some factors and these factors are natural frequency of the structure, type of foundation, damping factor, importance of the building and ductility of the structure. A high rise building, apartment tower, office tower, apartment block, or block of flats, is a tall building or structure used for a residential purpose or for an office purpose. They have the potential to decongest the continuous network of urban communities on the ground level, and increase the urban density, providing housing to higher number of families in lesser space. The mass of the building is a very important factor that controls the seismic design in addition to the building stiffness when building is designed because earthquake induces inertia forces that are proportional to the building mass. When buildings are designed to behave elastically during earthquakes without causing any damage it may render the project economically unviable. As a consequence, it may be necessary for the structure to undergo damage and thereby dissipate the energy input to it during the earthquake.

An Open Storey building or also known as Soft Storey building is basically a multistory building in which one or more floors have wide windows and doors, large spaces without any obstruction or any other openings in places where normally there is requirement of a shear wall or even a masonry wall for providing stability as a matter of earthquake engineering design. Soft or Open Storey buildings can also be defined as the type of buildings having no infill masonry walls. And when there are no infill masonry walls in ground storey but all upper storey's are infilled with masonry walls, those types of buildings are called as 'Soft first storey or Open ground storey buildings'. As per the Indian Seismic code IS 1893 (Part 1) - 2002, an Open storey is the one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storey's above. Soft or Open Storey buildings are quite vulnerable to collapse in an earthquake situation. The inadequately braced level is less resistant than surrounding floors to lateral earthquake motion, so a disproportionate amount of buildings overall side to side drift is focused on that floor subject to disproportionate lateral stress, and less able to withstand this stress, as a result the floor becomes a weak point that may suffer structural damage or complete failure which in turn finally results in the collapse of the entire building. Soft storey's are under larger lateral loads during an earthquake and this lateral force cannot be distributed properly along the height of the structure, so dynamic analysis is needed for the proper distribution of the earthquake and lateral loads and avoids the collapse of the structure. In this study by doing the comparison and observing the results we are understanding that which structure is the most suitable for construction in zone IV with presence of hard soil.

## II.SEISMIC ANALYSIS AND METHOD USED

Earthquakes are the hazards which occur naturally under which disasters are mainly caused by the damage or collapsing of buildings and other man - made structures. Past experiences have shown that for newer constructions, creating and establishing earthquake resistant regulations and their implementation is a highly important safeguard against earthquake induced damage. Earthquake damage depends on many parameters, including intensity, duration and frequency, geologic and soil condition, content of ground motion, quality of construction. A large portion of India is prone to high level of damage of seismic hazards. Hence, it is necessary to take in to account the seismic load for the design of high rise structure.

During major earthquakes the seismic analysis and structural design of buildings for seismic loading is primarily concerned with structural safety. In Tall Buildings, it is very important to ensure adequate lateral stiffness to resist lateral load. When buildings are tall, beam and column sizes are quite heavy and requirement of steel is very large so there are number of problems at joints and concrete is difficult to place properly at these places and displacement is quite heavy. Then arises the question of providing walls or not i.e., providing open storey's or not. The Response spectrum analysis mainly gives us many modes of response of a building which can be then taken into account. The response of a structure is a combination of many special modes that in a vibrating string corresponds to harmonics. But in cases where structures are very irregular or too tall or have a big significance to a community in disaster response, we don't use response spectrum approach then, and then in that case more complex analysis is used such as non linear dynamic analysis. Non Linear dynamic analysis mainly uses the combination of records of ground motion with a detailed structural model and so gives us the results with low uncertainty. Here in our study analysis is done by using response spectrum approach and modes in seismic design are combined using square root of sum of squares method.

## III. MODELLING AND ANALYSIS WORK

In this study a G + 11 storey tall building having the same plan but under different conditions of with open storey and without open storey for hard soil type and seismic zone IV as per IS 1893 (Part 1) : 2002 is considered. The same structure here is modeled for four different cases as loading is different for these cases. Here 4 models are created i.e., a bare frame, an infilled frame, an open ground and first storey frame and an open ground storey frame and then a comparative study is done on the basis of maximum values of moments and forces generated in these models and then finally results are presented.

### A. *General details of frame :-*

- Building plan = 30m x 20m
- Columns spacing = 5m from each other at center to center.
- Number of bays in X direction = 6
- Number of bays in Z direction = 4
- Floor to floor height = 3m
- Number of storey's = G + 11 (total 12)
- Seismic zone = Zone IV
- Soil type = Hard or rocky soil

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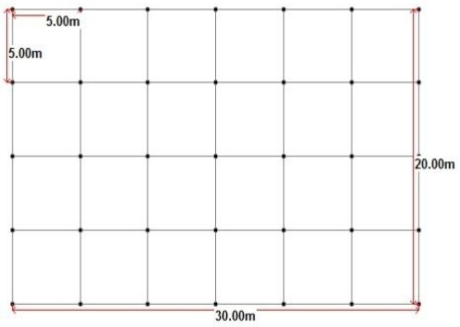


Figure 3.1 :- Plan considered

B. *Materials and Geometrical Properties :-*

Following properties are considered for the modeling of the frame :-

Table 3.1 : Details of material and geometrical properties

| S.No | Parameter | Value taken |
|---|---|---|
| 1 | Floor to floor height | 3.0 m |
| 2 | Grade of Concrete | M 30 |
| 3 | Type of Steel | Fe 415 |
| 4 | Column size (Bottom 4 storey's) | 0.8m x 0.8 m |
| 5 | Column size (From 5 to 8 storey's) | 0.6m x 0.6 m |
| 6 | Column size (From 9 to topmost storey's) | 0.4m x 0.4 m |
| 7 | Beam size (Bottom 4 storey's) | 0.6m x 0.4 m |
| 8 | Beam size (From 5 to 8 storey's) | 0.5m x 0.3 m |
| 9 | Beam size (From 9 to topmost storey's) | 0.4m x 0.25 m |
| 10 | Unit weight of masonry wall | 20 KN/m$^3$ |
| 11 | Unit weight of concrete | 25 KN/m$^3$ |
| 12 | Slab thickness | 150 mm |
| 13 | Wall thickness | 230 mm |

C. *Loads Considered :-*

The loads that are considered are :-

1. Dead Load (DL)
- Gravity load (selfweight) = -9.81 KN/m$^2$
- Wall Load = 13.8 KN/m
- Slab Load = 93.75 KN

2. Live Load (LL)
Live Load on all beams = 5 KN/m

3. Earthquake Load (EL)
Earthquake loads are obtained and applied as per the seismic parameters given in seismic design as per IS 1893 (Part 1) : 2002.
- Seismic zone = IV
- Importance factor (I) = 1
- Response reduction factor (R) = 5
- Damping factor = 5
- Soil type = Hard or rock soil
- Spectrum type = Maximum considered earthquake

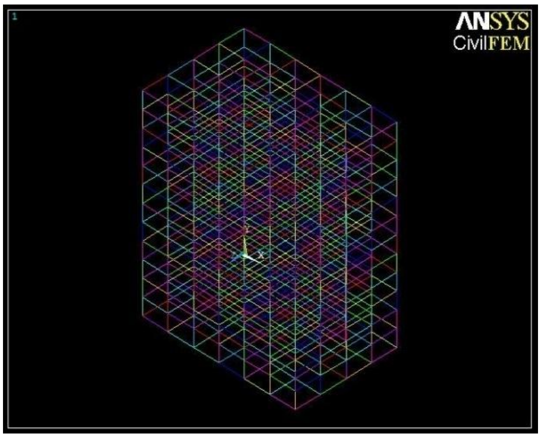


Figure 3.2 :- Created model (Isometric view)

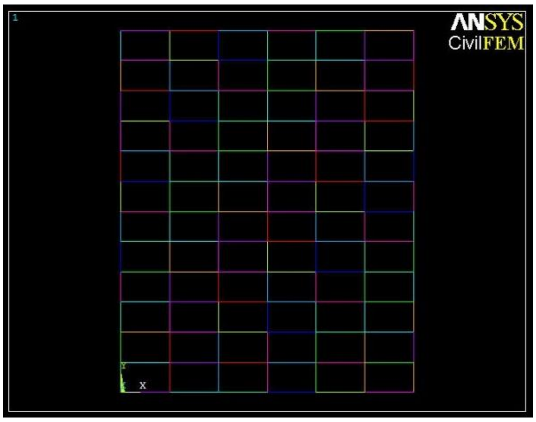


Figure 3.3 :- Created model (Front view)

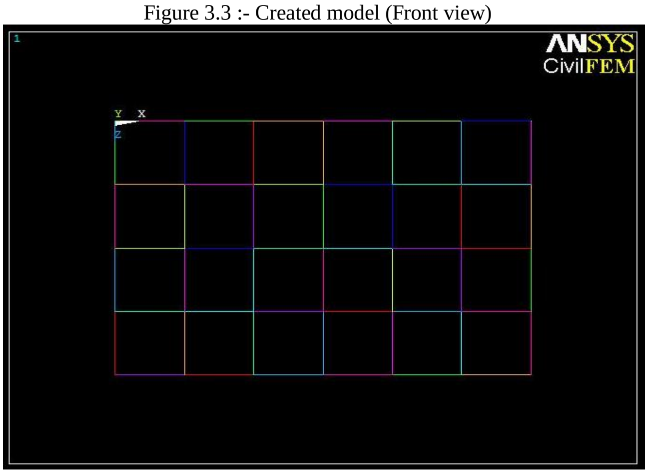


Figure 3.4 :- Created model (Top view)

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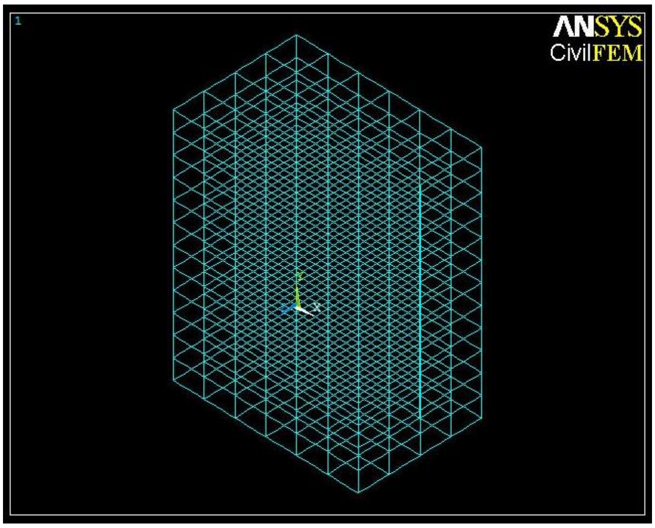


Figure 3.5 :- Meshed Model (Isometric view)

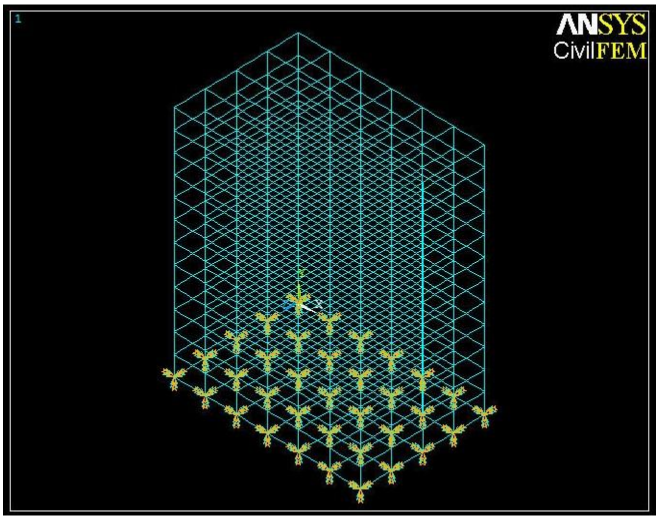


Figure 3.6 :- Fixed Supports assigned (Isometric view)

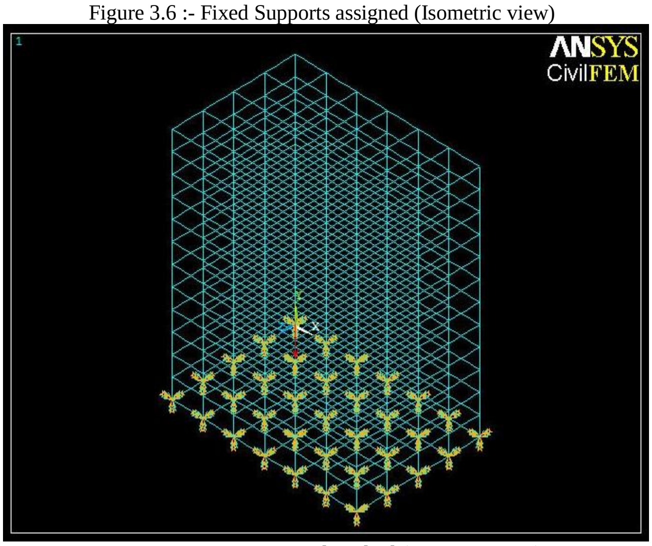


Figure 3.7 :- Gravity Load applied (Isometric view)

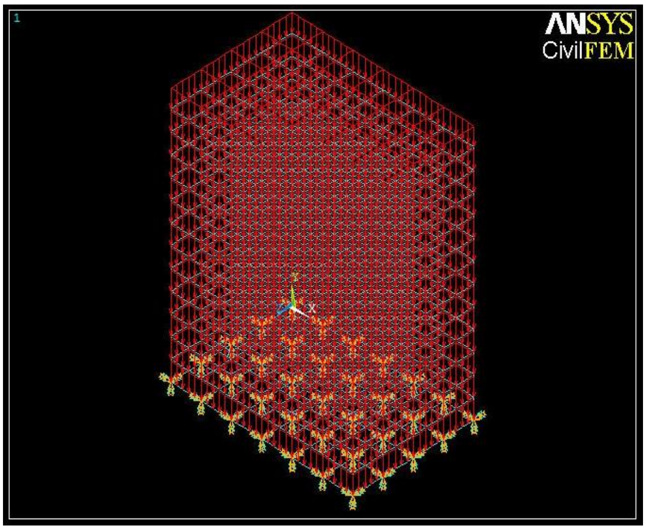


Figure 3.8 :- Live Load applied (Isometric view)

Now we give the seismic parameters and define the spectrum and then we do the solution and then we create the load combination and apply it and then we check whether all elements of the structure are ok or not and then if all are ok then we see our final results.

Load combination used in our study is as per our Indian seismic code and the combination used here is,
= 1.2 (DL + LL + EL)

where,

DL = Dead Load,
LL = Live Load,
EL = Earthquake Load

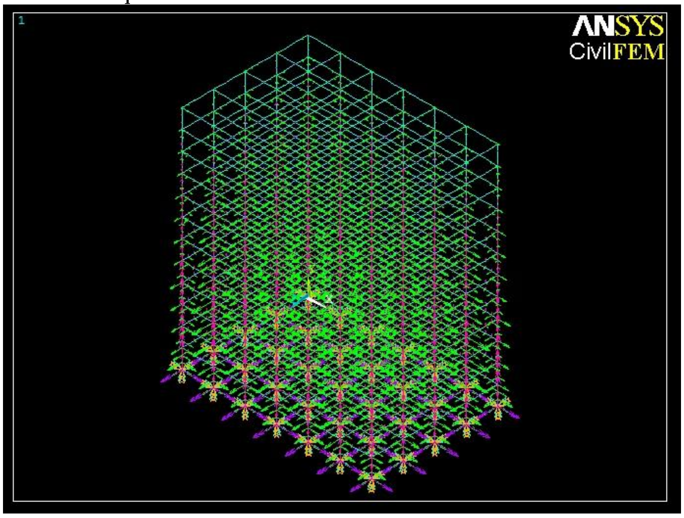


Figure 3.9 :- Model after the solution done (Isometric view)

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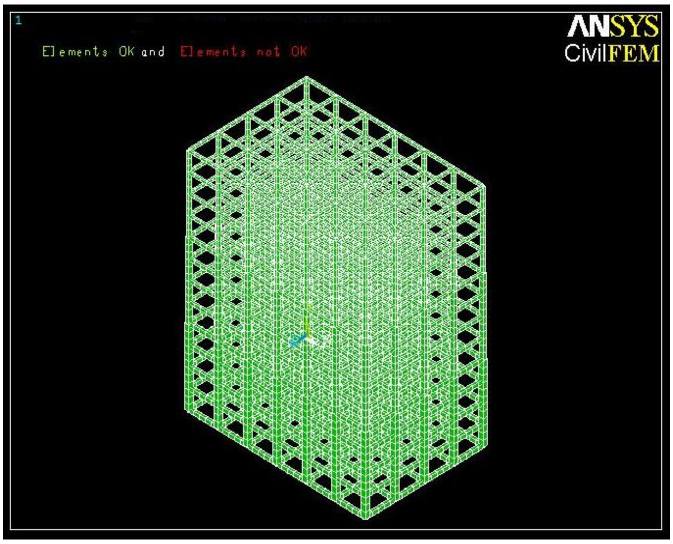



Figure 3.10 :- Final element checked model (Isometric view)

## IV. RESULTS AND DISCUSSIONS

The parameters or the items which we obtained after analysis for our study are Moment in Z direction (Mz), Moment in Y direction (My), Moment in X direction (Mx), Force in Z direction (Fz), Force in Y direction (Fy) and Force in X direction (Fx). **Here, we got both a minimum value and a maximum value of each item but for our comparative study we are only considering maximum values of each item**. For our better understanding in graphs some colour identifications are made as (Mz) is denoted with RED colour, (My) is denoted with GREEN colour, (Mx) is denoted with BLUE colour, (Fz) is denoted with YELLOW colour, (Fy) is denoted with ORANGE colour and (Fx) is denoted with PURPLE colour.

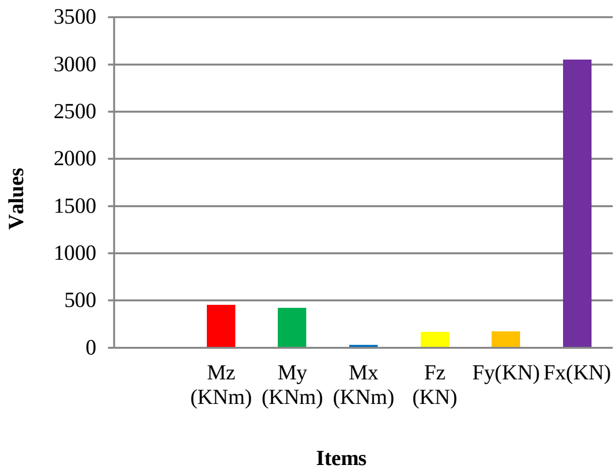
### *A. Frames result table and graphs*

- FOR BARE FRAME

Table 4.1 :- Results for Bare frame model

| S.No | Item | Maximum value |
|---|---|---|
| 1 | Mz (KNm) | 450.400 |
| 2 | My (KNm) | 418.318 |
| 3 | Mx (KNm) | 12.324 |
| 4 | Fz (KN) | 165.966 |
| 5 | Fy (KN) | 169.788 |
| 6 | Fx (KN) | 3050.288 |

**Graph No. 4.1 :-** Showing results for Bare Frame model

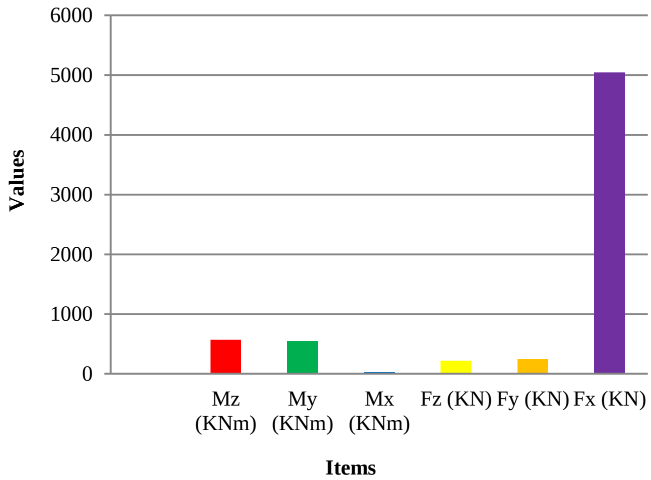



- FOR INFILLED FRAME

Table 4.2 :- Results for Infilled frame model

| S.No | Item | Maximum value |
|---|---|---|
| 1 | Mz (KNm) | 568.616 |
| 2 | My (KNm) | 542.297 |
| 3 | Mx (KNm) | 10.774 |
| 4 | Fz (KN) | 216.473 |
| 5 | Fy (KN) | 244.275 |
| 6 | Fx (KN) | 5039.092 |

**Graph No. 4.2 :-** Showing results for Infilled Frame model



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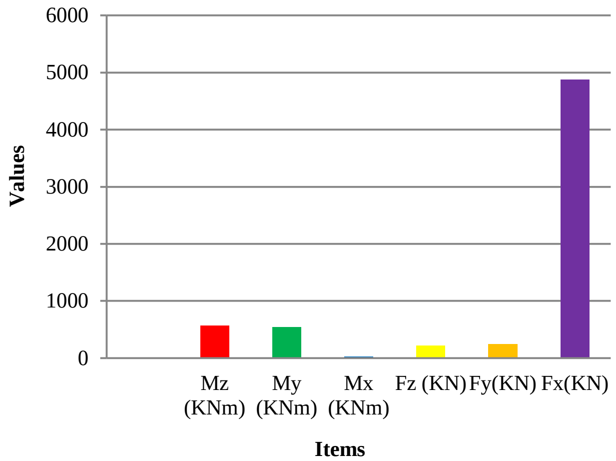
- FOR OPEN GROUND AND FIRST STOREY FRAME

Table 4.3 :- Results for Open ground and first storey frame model

| S.No | Item | Maximum value |
|---|---|---|
| 1 | Mz (KNm) | 567.720 |
| 2 | My (KNm) | 541.558 |
| 3 | Mx (KNm) | 10.698 |
| 4 | Fz (KN) | 216.127 |
| 5 | Fy (KN) | 243.925 |
| 6 | Fx (KN) | 4873.481 |

**Graph No. 4.3 :-** Showing results for Open Ground and First Storey Frame model

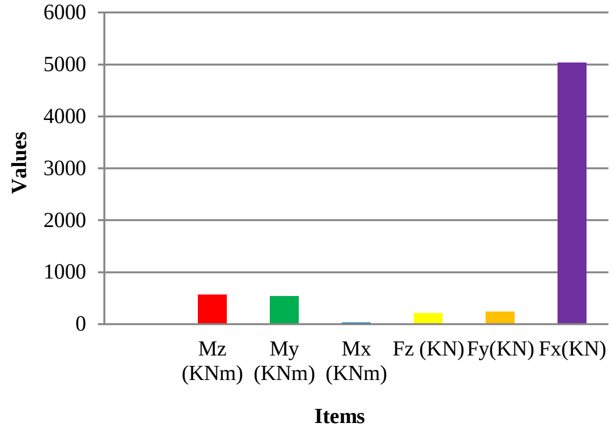



- FOR OPEN GROUND STOREY FRAME

Table 4.4 :- Results for Open ground storey frame model

| S.No | Item | Maximum value |
|---|---|---|
| 1 | Mz (KNm) | 568.616 |
| 2 | My (KNm) | 542.297 |
| 3 | Mx (KNm) | 10.774 |
| 4 | Fz (KN) | 216.473 |
| 5 | Fy (KN) | 244.275 |
| 6 | Fx (KN) | 5039.092 |

**Graph No. 4.4 :-** Showing results for Open Ground Storey Frame



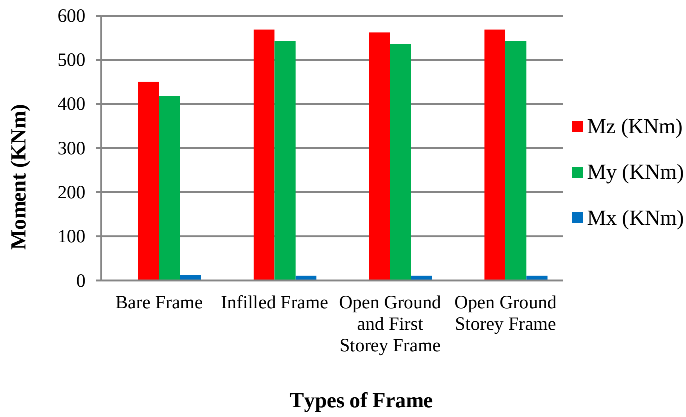

*B. Comparative Study*

- Based on the results of Moment in all directions

**Table 4.5** :- Comparison of results of all Moments

| Item (KNm) | Bare Frame | Infilled Frame | Open Ground and First Storey Frame | Open Ground Storey Frame |
|---|---|---|---|---|
| Mz | 450.400 | 568.616 | 567.720 | 568.616 |
| My | 418.318 | 542.297 | 541.558 | 542.297 |
| Mx | 12.324 | 10.774 | 10.698 | 10.774 |

**Graph No. 4.5 :-** Comparison of results of Moment in all directions (Mz, My, Mx)



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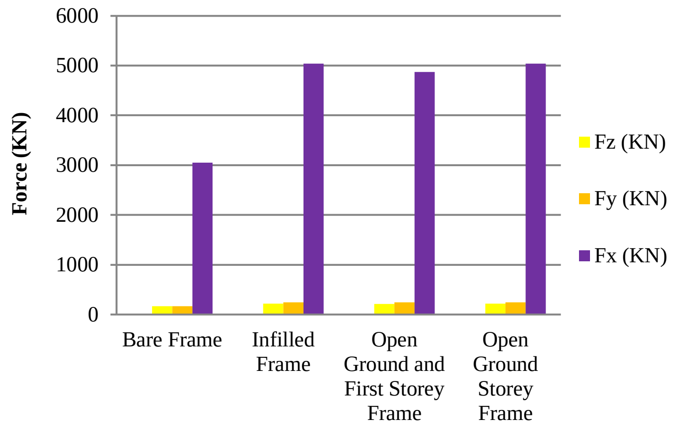
- Based on the results of Force in all directions

Table 4.6 :- Comparison of results of all Forces

| Item (KN) | Bare Frame | Infilled Frame | Open Ground and First Storey Frame | Open Ground Storey Frame |
|---|---|---|---|---|
| Fz | 165.966 | 216.473 | 216.127 | 216.473 |
| Fy | 169.788 | 244.275 | 243.925 | 244.275 |
| Fx | 3050.288 | 5039.092 | 4873.481 | 5039.092 |

**Graph No. 4.6 :-** Comparison of results of Force in all directions (Fz, Fy, Fx)

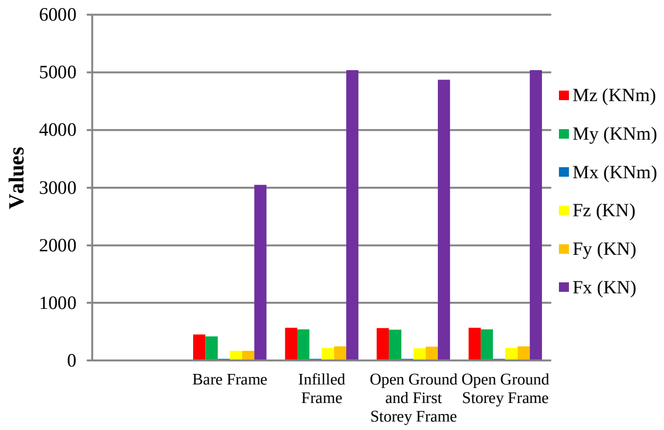



- Final comparison based on all Moments and Forces

Table 4.7 :- Comparison of results of all Forces

| Item | Bare Frame | Infilled Frame | Open Ground and First Storey Frame | Open Ground Storey Frame |
|---|---|---|---|---|
| Mz (KNm) | 450.400 | 568.616 | 567.720 | 568.616 |
| My (KNm) | 418.318 | 542.297 | 541.558 | 542.297 |
| Mx (KNm) | 12.324 | 10.774 | 10.698 | 10.774 |
| Fz (KN) | 165.966 | 216.473 | 216.127 | 216.473 |
| Fy (KN) | 169.788 | 244.275 | 243.925 | 244.275 |
| Fx (KN) | 3050.288 | 5039.092 | 4873.481 | 5039.092 |

**Graph No. 4.7 :-** Final Comparative Graph




As observed by the present results, their comparative study and their respective graphs we see that

1. There is a same impact acting on an Infilled frame model and an Open ground storey frame model under an earthquake for zone IV with hard soil present. The values of moments and forces generated are the same in both these models. Also, the maximum moments (majority of them) and maximum forces are obtained here in case of an infilled frame model and an open ground storey frame model. This shows that these two types of frame will need more reinforcement for much safer design which will eventually increase the cost of the structure. The maximum moment obtained out of all the models is 568.616 KNm and the maximum force obtained out of all the models is 5039.092 KN and these both are in case of infilled and open ground storey model. This shows that we have to provide extra reinforcement in these directions for these two types of models for further proper design as they are getting the maximum moments and forces acting on them as compared to other models.
2. Open ground and first storey frame model does not undergo a huge difference in terms of impact as it is seen that the moment and force values obtained in it are almost near to the values that of an infilled and an open ground storey models except that of the bare frame model. The least bending moment obtained out of all the models is 10.698 KNm and it is in case of open ground and first storey model.
3. Bare frame model gets the least bending moments (majority of them except moment in X direction) and least shear forces as compared to all other models. The maximum moment generated in X direction is 12.324 KNm and it is in bare frame model as compared to all other models but for bare frame model when it comes to moment in all directions, the least bending moment is 12.324 KNm and it is in X direction of bare frame model. And the least shear force value out of all the models is 165.966 KN and it is in Z direction of bare frame model. Here, as per our results we observe that

bare frame gets the minimum bending moments (majority of them) and the minimum shear forces in respective directions when compared to other models so the chances of failure of bare frame model is the least compared to other models so, bare frame model is the safest as compared to other models that are considered in our study for seismic zone IV and hard soil type.

4. Generally, we can say that the buildings where glazing work of aluminium and steel,etc are done in majority or the buildings where walls are not completely made till the top and are kept upto a particular height of the storey (on every storey), all buildings of these types come under the category of bare frame model. The dead load of these glazing is almost negligible when it comes to the total weight of the structure.
5. Although our results show that an infilled frame and an open ground storey frame model gets the same impact and have the same results for hard soil under seismic zone IV but as seen by the past earthquakes throughout the world, open ground storey buildings have performed very poorly. Even in the 2001 Bhuj earthquake in India, it was seen that over a hundred RC Frame buildings with open ground storeys got the maximum damage and it showed that these open ground storey buildings are highly vulnerable to strong earthquakes. We should avoid construction of open ground storey buildings because as when there are walls present in upper storeys and no walls in ground storey, the upper storeys become much more stiffer than the open ground storey. And the upper storeys here together act as a single block and large horizontal displacement occurs in the open ground storey. In simple terms we can say that it is like the building is standing on some sort of sticks. And in this case buildings swing backward and forward during earthquake and so columns gets large stresses and it is not able to bear it and column fails which eventually leads to collapse of building.

## V. CONCLUSIONS

Generally the RC Frame Tall buildings with open storey's are known to perform poorly under strong earthquake shaking. For a building where there is no lateral load resistance component provided such as shear wall or bracing i.e., with open storey's, the strength is considered very weak and it can fail very easily during an earthquake as when compared to a building with some lateral resistance provided, these buildings without open storey's are more stronger. And here in our work, seismic behavior of a tall building with and without open storey's is analyzed under four different cases for seismic zone IV with hard soil present and then a comparative study is done on the results obtained. Basically in simple terms we can say that buildings having brick masonry infill on majority of floors especially bottom floors are more resistant, safe, strong and dependable as compared to buildings which don't have brick masonry infill when undergone seismic analysis. It is concluded that,

1. The maximum force values and maximum moment values (majority of them) are obtained in case of an infilled frame model and an open ground storey frame model. The maximum bending moment obtained out of all the models is 568.616 KN and the maximum shear force obtained out of all the models is 5039.092 KN and these both are in case of infilled model and open ground storey model.
2. There is same impact acting on infilled model and open ground storey model as the shear force values and the bending moment values are the same in both the cases.
3. Open ground and first storey frame model gets the least bending moment in X direction and it is 10.698 KNm.
4. Bare frame model gets the minimum bending moments (majority of them except moment in X direction) and the minimum shear forces as compared to other models in our study. The least shear force out of all the models is 165.966 KN and it is in case of bare frame model.
5. As bare frame model gets the minimum forces and moments as compared to other models in our study so the chances of failure of the bare frame model is the least so bare frame type of model is the safest among all the models considered in our study for seismic zone IV and hard soil type.

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