# "STUDY AND ANALYSIS OF COLUMNS OF HIGH RISE BUILIDING IN CASE OF SWAY, NON-SWAY AND P-DELTA EFFECT IN SEISMIC ZONE-IV BY USING ETABS SOFTWARE"

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**Abstract:**

Now-a- days the requirement of High rise building with proper design is increasing day by day because of heavy increment in the rate of population in the world. All multi story structure should always be analysed and designed to withstand lateral loads and wind load within the safety limit set by standards. As construction demand is increasing, we cannot ignore to include a very important factor, which is the cost of construction. The cost of construction further depends upon the method and types of analysis adopted. The method and analysis should be such that it provides economical size of members and quantity of steel following all safety requirements of standards. For easy understanding, when a structure is under load, it 'll definitely deform or deflect to relieve the force coming from resultants of various loads i.e. wind loads, earthquake load, gravity load or self-weight. To find out the maximum possible deformation of structure and best quantity of steel in the member of building like column, the proper and most accurate method of analysis is required for a designer.

In this study the high-rise building (13 stories) is to be modelled in ETABS software. The same geometry of building is to be designed by three different methods of analysis, including

1) Design by Sway model

2) Design by Non sway model

3) Design by P-Delta effects

The different design parameters of structure like displacement, bending moment, shear force and in last reinforcement of column will be calculated for each design method of analysis. The corner column of the building is more affected due to earth quake loads, wind load (lateral loaded) as compared with middle or edges column. So, in this research the different data and results of corner column for all three methods of analysis will be evaluated in the form of figure

and graphs. The best and most economical analysis will be found out for the building. The stability in the building comes from vertical and horizontal a member, that's why the extra safety and focuses are required in the design and analysis of corner columns.

The size of building is taken rectangular in plane; the total 4 bays are given in X and Y direction. The geometry of building in X bay is taken as 18 m and 22 m in Y bay. The analysis of frame is done for Sway, Non-sway and P-Delta effects and results of building various parameters are shown in tabular forms along with graphs.

Shear force for corner column of top storey in X direction (major axis) is 151.49 KN in case of P-Delta frame, but its value decreases to 146.92 KN when the building is designed as Non sway and increases to 151.55 KN when the building is designed as sway respectively. The changes in percentage for non-sway is 3.01% and 0.03% for sway frame. The biaxial moment of corner column of top storey in X direction (major axis) for P-Delta frame is obtained as -88.59 KN-m, but these values of biaxial moments for Non-sway and Sway frame are obtained as -37.89KN-m and -88.59 KN-m respectively. Means in case of non-sway frame the moments is developed in the column because of combined effect of load combinations, but it is seen that moments in the column in case of sway frame building is very similar to that of P-Delta due to mixed effect of dead load and dynamic earthquake load in X direction. The minimum moments corresponding to eccentricity of column of top storey in X direction are 0.76 KN-m for P-Delta, 0.77 KN-m for non-sway and 0.77 KN-m for Sway frame building. And these values are direct correlation with axial forces. The value of moment in case of non-sway is 1.01 times more as that of P-Delta condition frame because of gravity loading. And sway frame having similar moment value as compared with P-Delta effect frame building. In case of non-sway frame building the decrement in area of steel is found to be 10.6 % as compared with P-Delta results, and similarly in sway frame it values increases to 0.18 % as compared with P-Delta results. The value of K factor for Sway frame is found between 1.774 and 4.345. And for Non-sway K factor value lies between 0.761 and 0.955. From study it is observed that the P-Delta have the same K factor value for all columns of stories.

Finally, it may be concluded that the results obtained from P-Delta frame analysis are more effective because, P-Delta effect considers both secondary moment due to axial load or gravity load as well as primary moment due to lateral loads. Also, effective length factor or K factor used is one in case of P-Delta ductile analysis which makes it best method as compared with Sway and Non-sway frame analysis because, in case of sway frame the k factor is 4.34 times more as compared with P-Delta factor which means that columns will be designed for 4.34 times extra height which makes the construction costly. Due to more k factor in Sway frame more additional moments are created which makes the design costly. Therefore, from the current study it may be concluded that P-Delta with ductile structure is recommended for the analysis of high-rise structures. And all structure designers should go for P-Delta effect analysis.

**Keywords**: Sway, Non-sway, P-Delta, Biaxial moments, Seismic loading.

## 1. Introduction

The construction of building impacts by many factors including skill labors, type of execution adopted, designing methodology used and so on. The construction is taking by one-by-one step, and each step requires very strict supervision of engineers and workmen force. It was a time when the monuments and similar structures constructed by majority of stones and lime. All members of the structure have been involved either a great hardworking of masons or workers. As the requirement of people, no high-rise structure was constructed because of less knowledge of building technology.

The only one option is available in front of engineers and planner to overcome the problem of expensive land, which is the concept of high-rise building. In accordance with the National Building Code of India (2016), a high-rise building is defined as the building whose vertical height is equal and greater than 15 m is known as ‘High rise building’. The old structure was mostly built on the concept of load bearing structure i.e. a structure in which load is directly transmitted to ground through bearing walls made up of stones and bricks. But the concept of high-rise building is totally dependent on the columns and beams arrangement. The columns are the vertical elements of building, and beams are inclined or horizontal members of the building. Therefore, the arrangement of horizontal and vertical member creates a frame of monolithically strong structure known as frame structure in which the load of structure is transferred from R.C.C slabs to R.C.C beams, then R.C.C beams to R.C.C columns, and finally R.C.C. columns to foundation then surrounding soil.

**Necessity of R.C.C. columns in building.**

a. It should resist enormous number of compressive forces of building.
b. The column shape and size should be such that it can resist all type of upcoming loading.
c. The reinforcement of columns should be free from corrosion.

d. The most important factors which affects the column is designing, the designing should be such that it cost is economical to give best results of strength.
e. The column is a very important member of building to transfer the heavy intensive loading to surrounding hard strata through footing.
f. To avoid buckling of columns the proper size of columns should be designed

**Materials of a R.C.C. Column**

a. Cement: The cement is a binding material which adheres, binds and hardens to other materials and finally forms a solid R.C.C. structure made up of aggregate, sand, water, cement and some admixture.
b. Water: The water ($H_2O$) is a very useful ingredient of R.C.C. structure
c. Aggregate: The aggregate is an inert material which are used in proper proportion to produce a good quality solid concrete
d. Steel: Steel is a good alloy of carbon and iron. It is highly weldable, malleable, ductile and elastic in nature. The steel can resist wear and tear and apart from this it has very high tensile strength. The steel also has compressive strength. And it is provided in the column in the form of reinforcement. The reinforcement is provided in two forms one is longitudinal and another is helical or ring reinforcement**.**
e. Admixtures: An admixture is a kind of material which is used in the concrete to modify its properties. The admixtures always improve the property of concrete whether it is setting time or strength requirements. Depending on their applications the few examples of admixtures are as follows
    i. Water reducing admixtures
    ii. Bonding admixtures
    iii. Damp proof admixture
    iv. Grouting admixture
    v. Air entraining concrete admixture etc.
    vi. Any lateral or sideward top movement of the column of the building relative to its bottom or base is known as side sway column. The columns in sway state may occur due to different length of columns in the building. Another reason of sway of column may be due to different moment of inertia.
    vii. In sway model of building the columns are allow to give side way and behavior of column at that case is studied by analysis, when it passes all required safety

limit, finally its reinforcement is calculated by the computer-based software (Kumar D. S., 2019).

viii. As per **IS 456:2000**, the permissible lateral sway at the top of a building, under **transient wind loads**, should not exceed **H/500**, where *H* represents the total height of the structure.
In contrast, according to **IS 1893**, under **seismic loading conditions**, the maximum allowable lateral displacement at the top of the structure is limited to **H/250**.

ix. In sway model the relative displacement is calculated in horizontal plane. If the displacement to be more than the limiting value then it would be called as sway structure. The side movement of end columns is the formation of side sway, but the problem of sway may be prevented by providing an unyielding support at level of beam.

**P-Delta effect**

Generally, the structural analyst and designer interested to use first order analysis, which is known as linear static analysis, to calculate moment, displacement and design force which results from upcoming loads of structure. But the main problem in case of first order analysis is created when it does not count the additional effect due to lateral load, first order analysis is made only by imagining small deflection (Kumar R. &., 2021). P-Delta is also known as second order effect or non-linear effect, which is a genuine effect and occurs in every tall structure subjected to axial loading and displacement delta (Kumar R. &., 2021). Suppose during the earthquake the member of the structure which is more affected by seismic force have maximum displacement, then such member in the structure can be easily find out by P-Delta analysis, not by linear static method. Means P-Delta affected member will have more displacement which may be find out by P-Delta analysis easily (Kumar V. P., 2019).

## 2. Methodology

**Seismic analysis method**

This IS code part is designed in system that will focuses on seismic hazard assessment of a building with the clear objectives of earthquake resistant design. And all structure including security cabin, parking structure should be designed for appropriate earthquake loading effect as per this standard. This method is used to analysed the building which prone to a particular seismic zone all over the India, its calculation is simple but consist of few formulas. Since the seismic loads are random. The seismic analysis is conducted in order to obtain several responses of building during the earthquake occurrence. It becomes more important in various area which are suspecting to earthquake action frequently for example Japan, Nepal, Philippines and many more countries. As we know that the seismic action is dynamic in nature, so the dynamic analysis of structure should be carried out for stiffness, mass, ductility as per IS 1893:2002 (Pettinga, 2007).

**Equivalent Static method:** The equivalent static method is simple approach in that the dynamic loading of the possible earthquake is distributed by a static lateral force on the building for obtaining design data and results. The total seismic force which applied to the structure is evaluated in two horizontal directions which are same to the building main axis. The entire building is assumed to responds in its fundamental lateral force. But for this analysis the building should be fairly symmetric and have less rising to avoid the effect of torsional movement when the ground motion takes place. Another limitation of equivalent static method is that the building should be strong enough to bear effects of vibrational seismic forces caused in either direction, but building not in both directions together.

**Response Spectrum Analysis:** Normally this analysis is used when the modes of the building other than fundamental affect the structure response. In this method the modal response of structure is determined by performing the spectral analysis of SDOF. The response spectrum analysis is totally based on the type of mode superposition. Using this data the natural frequency and damping of eigen mode amount can be excited efficiently. The simple definition of response spectrum analysis may be as the function of period which helps in showing the peak response of simple harmonic motion or oscillator that is related to transient event.

**Non- Linear dynamic analysis:** The method is based on the Elasto Plastic deformation concept, accordingly direct numerical integration of differential equations of motion is the basis of non-linear dynamic analysis. This method contributes to determination of amplification due to resonance, displacement changes at various storey levels and the increment in the motion. The record of earthquake is used for the analysis which represents design earthquake of structure (Pettinga, 2007). Then with very small interval of time i.e. 1/40 to 1/25, the data are digitalized. Further the lumped mass of building at each storey is used for setting mathematical modeling.

It is imagining that the selected structure is a residential building model of 15 stories with the equal height of 3.5 m of each floor. The earthquake zone-IV is taken for the analysis. The entire analysis and study are taken in ETABS:2018 software. The building model is studied for three different case including sway, non-sway and P-Delta effects case. The simple geometry of the building is taken with 4 bays of 4.5 m each in X direction and 4 bays of 5.5 m each in Y direction (Kumar D. S., 2019). Therefore, the total elevation of geometry taken is 45.5 m. the general information of building is listed below.

| | | |
|---|---|---|
| Slab depth | - | 150 mm thick for entire building structure |
| Modeling software | - | ETABS 2018 |
| Damping ratio | - | 5% |
| Seismic zone- Zone | - | IV |
| Importance factor | - | 1.2 |
| Response reduction factor | - | 5 |
| Location | - | DELHI |
| Type of building | - | Residential building |
| No. of stories | - | 13 (G+12) |
| Live load | - | 3.0 kN/m$^2$ |
| Floor finishing | - | 1.5 kN/m$^2$ |
| Soil type | - | Type-II (medium soil) as per IS 1893 part-1:2016 |
| Seismic loads | - | As per the condition of IS 1893 (part-1):2016 |
| Size of R.C.C. beams | - | 300 mm x 450 mm (12"x18") |
| Size of R.C.C. columns | - | 300 mm x 600 mm (12"x24") |
| Size of building | - | 18 m x 22 m |
| No. bays in X | - | 4 bays of 4.5 m width of each |
| No. bays in Y | - | 4 bays of 5.5 m width of each |

## 3. MODELING & ANALYSIS

**General:**

The modeling of building is taken out in the ETABS software, and dynamic analysis of building is made. The simple geometry of building is taken as given in clause 3.4 of chapter 3. First of all, the layout of building is drawn in software then the data of material to be used, section type with their dimension, type of load are defined in software (Zhang, 2022). The systematic elevation of the building frame is given in figure 4.2. The defining and assigning of loads, sections are given in this chapter. Few modeling interfaces of assigning and defining are shown.

**Modeling of building**

The G+12 residential structure is taken for the study and analysis. The unsymmetrical geometry of building is 18 m x 22 m with 4 bays in each direction. The same model of R.C.C. is used for different cases as follows:

Model-1 for Sway case

Model-1 for non-Sway case

Model-1 for P-Delta case

The location and seismic zone for the building is assumed for Delhi and seismic zone-IV respectively. The all floors of building are modeled for the same floor area (from bottom to top). The size of columns is taken same for entire geometry; size of columns is given in clause 3.4 of previous chapter. Total 13 stories (G+12) of equal floor height are taken and modeled in ETABS 2018 software. Total numbers of bays in X directions are 4, and numbers of bays in Y direction are also 4 i.e. the geometry of building is rectangular in shape. The size of each bay in X (4.5 m) and Y (5.5 m) is as shown in figure 1.1 of this chapter. The ETABS software enables me a lot of facilities while modeling, as no confusing icons and terminology is used. The plan view and elevation view of model is given in the figure 1.1

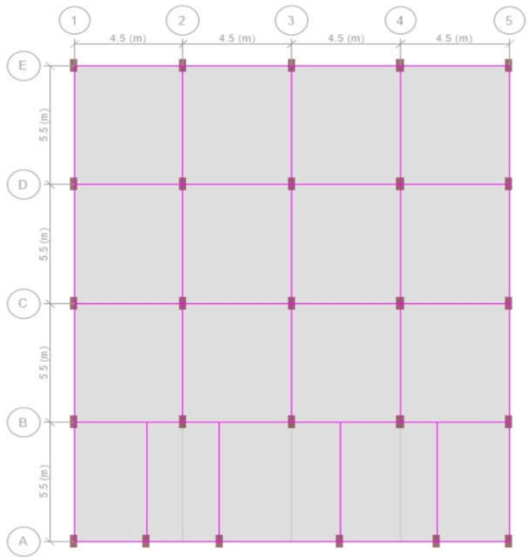


**Figure 1.1-Plan of building**

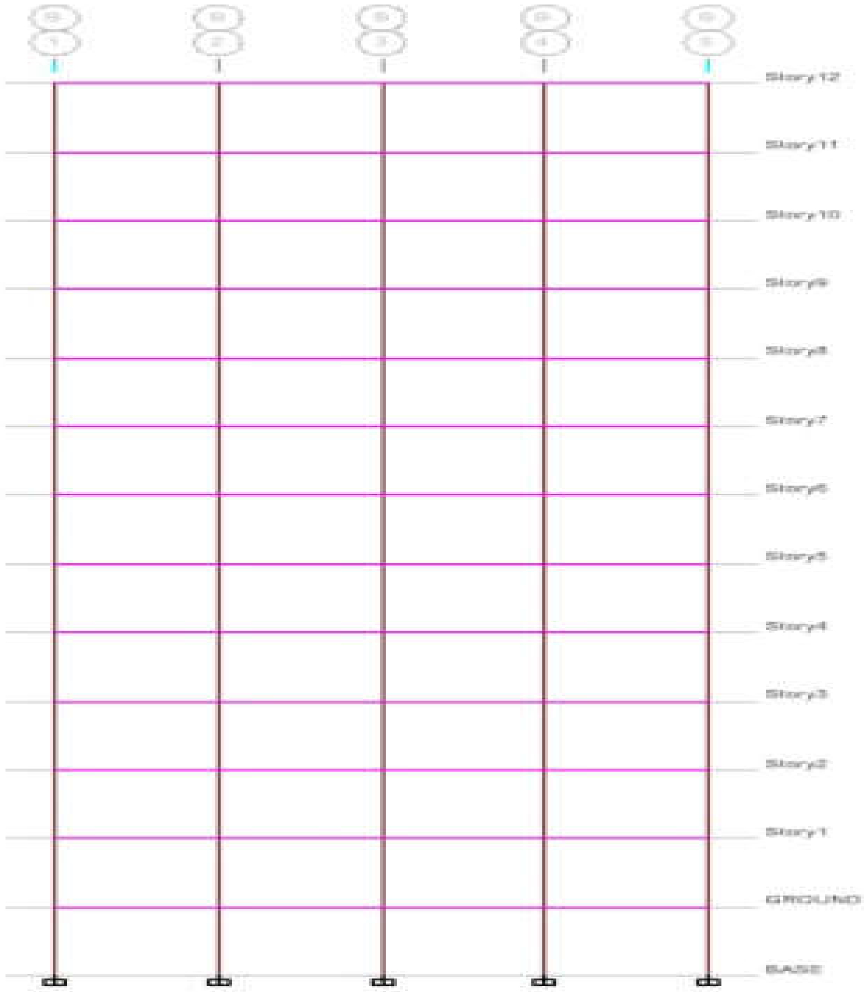


**Figure 1.2-Elevation plan of building**

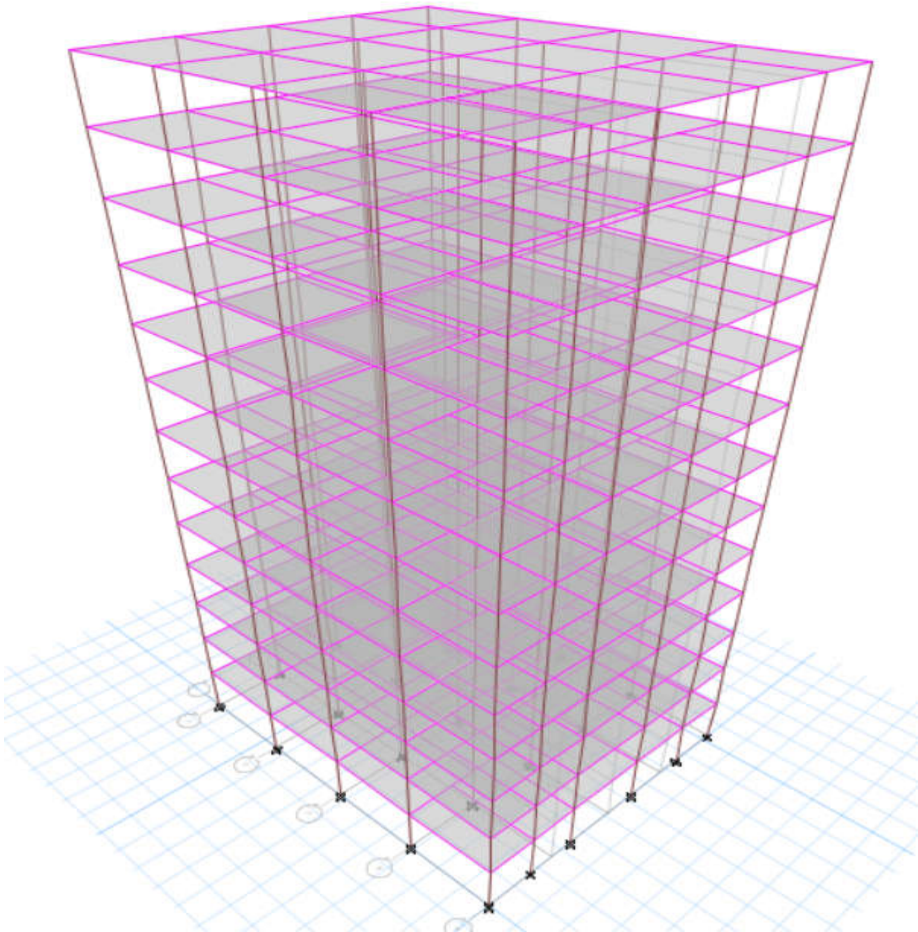

**Figure 1.3- 3D view of building**

**Member and Material properties**

ETABS software require various various values for the anaysis, that values are decided by the designer which are shown in the table below:

**Table 1.1- Properties of member and materials**

| Members | Grade | Material | Unit Weight ($kN/m^3$) | Young's Modulus (Mpa) | Strength ($N/mm^2$) |
|---|---|---|---|---|---|
| Column (300mmx600mm) | M 40 | Concrete | 25 | 31622.78 | 40 |
| Beam (300mmx450mm) | M 40 | Concrete | 25 | 31622.78 | 40 |
| Rebar | HYSD 550 | Steeel Bars | 76.97 | 200000 | 550 |

**Steps for analysis of structure**

First of all, a fast analyzing and designing software is required for the outcomes. Here the ETABS software is being used for modeling (Mahmoud, 2016). The required procedure from modeling to analysis is given below:

- Prepare the geometry of building structure
- Second step is defining of material properties

- Then define section properties i.e. shape, size etc.
- Define the loads pattern
- Assigning loads to structure
- Run the file and check no error and warning
- Set diaphragm of the whole building
- Then defining dynamic function of building
- At last made post analysis modifications

**Geometry of building**

Before starting the modeling of building the unit of the software is set to SI metrics, then set IS code 456:2000 for R.C.C design of building. Then set the X and Y values in grid interface. Modify the grid system as per geometry of building as shown in figure below (Kumar R. &., 2021).

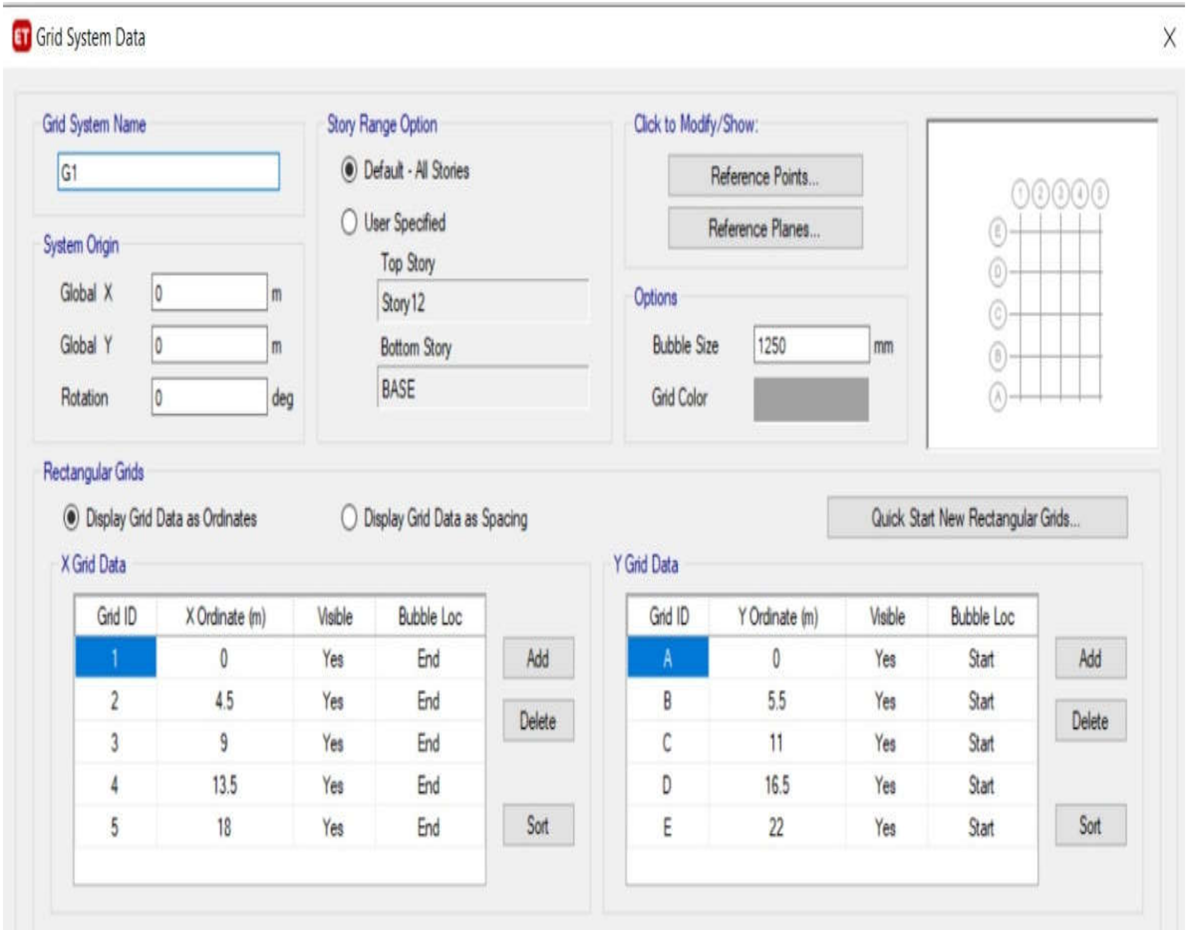


**Figure 1.4 Grid system of geometry**

**Material property defining**

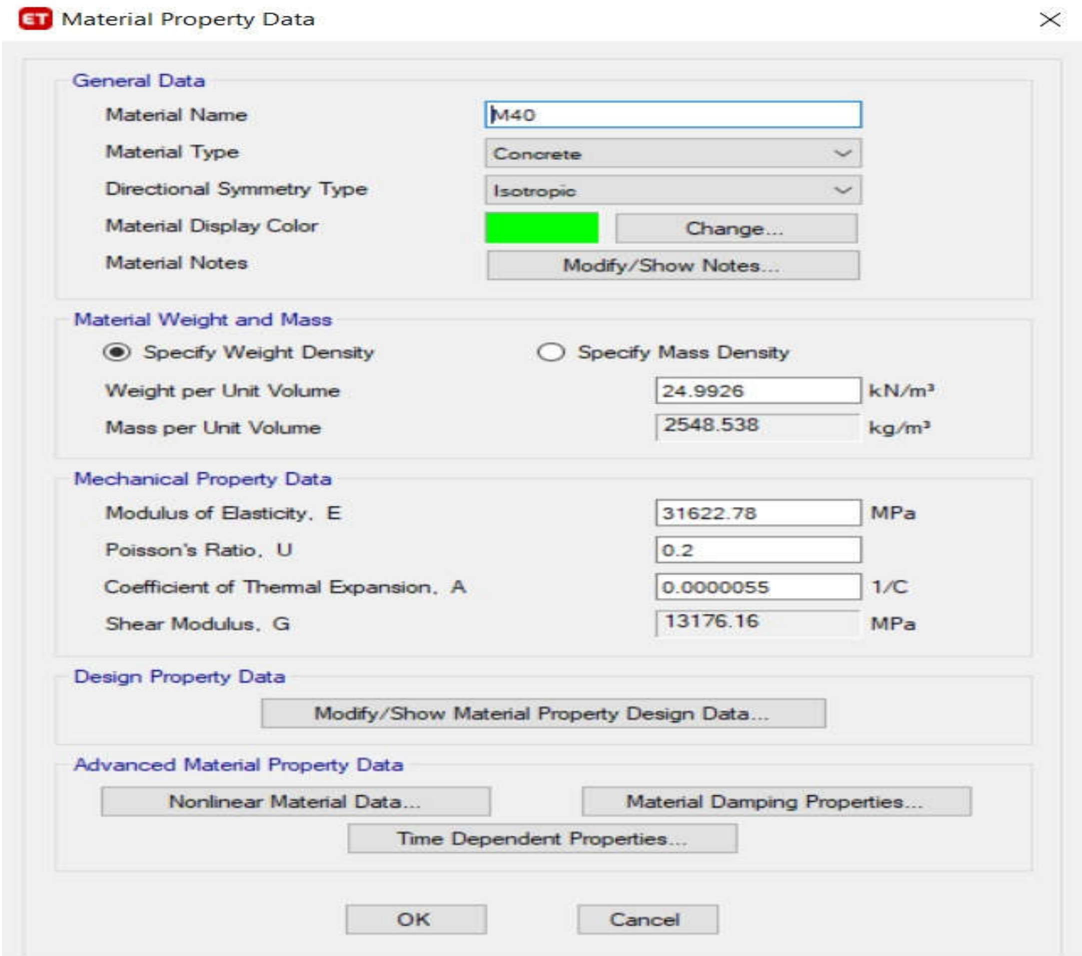


**Figure 1.5 Defining material property**

By clicking on define, then click on 'section property'. Enter on frame section option**.** At last, click on 'add new property' and enter its values as shown in figures 1.5.

**Defining section property**

The various property of member-like shape, size are defined as per the requirement. Here the size of beam is taken as 300 mm x 500 mm, and size of column is taken as 300 mm x 600 mm. The 150 mm thick of slab is taken for all the stories of building. First of all, click on define, then click on section property, open frame section and enter the require value as shown in figure below.

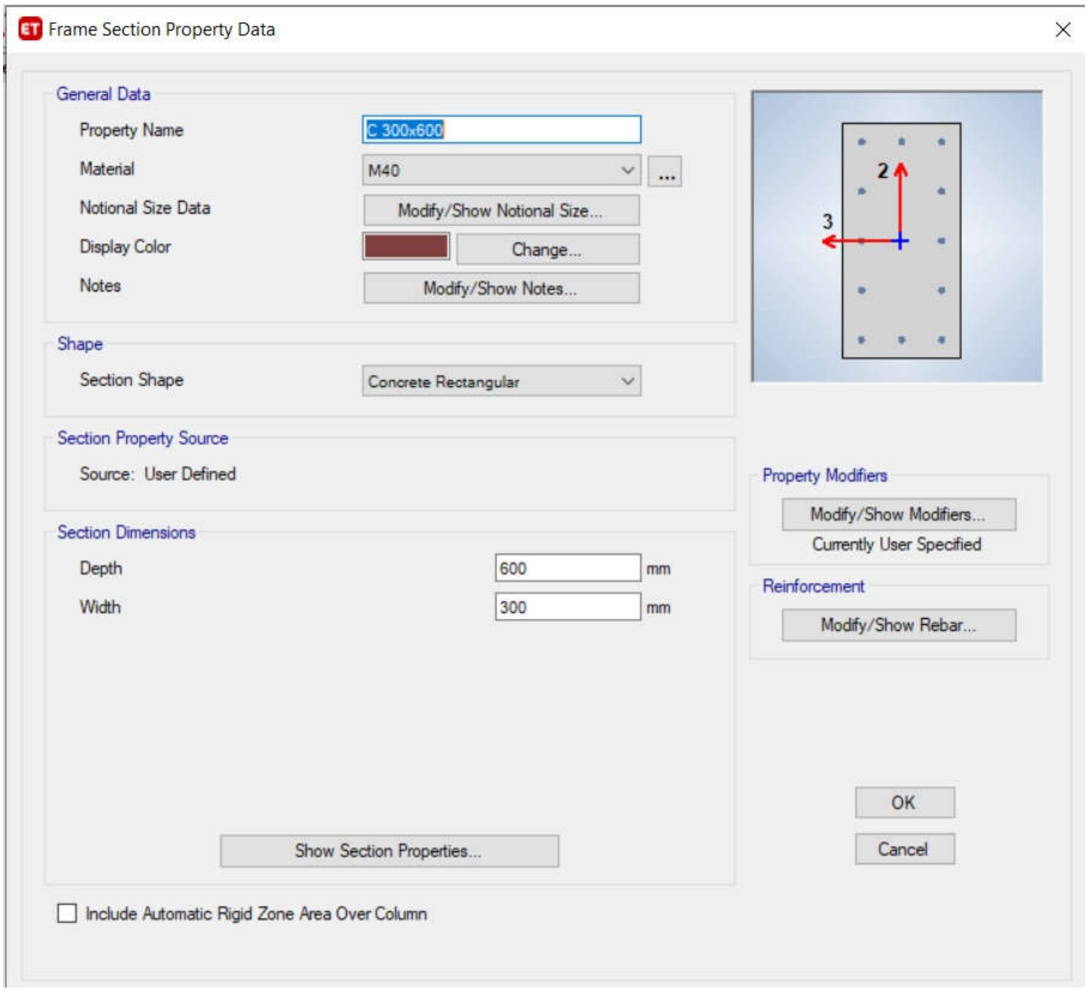


**Figure 1.6- Defining section property**

## 4. Conclusion

i. The G+12 building is selected for the study with seismic zone IV and after analysis of building it is found that building is having top storey displacement as 243.159 mm in normal case in X Direction, when second order effect is considered, it values increases to 285.413 mm, which is a vast change in the percentage of displacement. The change in percentage of displacement in X direction is 17.37 % as compared with normal condition frame.

ii. The top storey displacement in Y direction is found to be 55.056 mm and when second order effect is considered it is increased to 63.032 mm, which is 14.48 % increments in its value from normal condition frame.

iii. The storey drift of ground floor in X direction is found to be 0.002108 in normal frame condition (Without P-Delta) and after P-Delta effect is considered with response spectrum analysis it is changed to 0.002182. The change in percentage is 3.51 %.

iv. The changes of percentage of storey drift in Y direction at ground floor are 3.06 %. Its values in case of P-Delta effect were 0.000572 and 0.000555 in case of frame without P-Delta effect.

v. The maximum value of storey drift in X direction at first floor is found 0.00805 and 0.01006 without P-Delta and with P-Delta effect respectively, change in percentage is 24.96 %. And Maximum storey drift value in Y direction is found at First floor having 40.62 % changes as compared with sway and non-sway condition frame.

vi. Shear force for corner column of top storey in X direction (major axis) is 151.49 KN in case of P-Delta frame, but its value decreases to 146.92 KN when the building is designed as Non sway and increases to 151.55 KN when the building is designed as sway respectively. The changes in percentage for non-sway is 3.01% and 0.03% for sway frame.

vii. Shear force for corner column of top storey in Y direction (minor axis) is 141.23 KN in case of P-Delta frame, But for Non-sway and sway frame the shear force values obtained are 137.48 KN and 141.27 KN respectively.

viii. The biaxial moment of corner column of top storey in X direction (major axis) for P-Delta frame is obtained as -88.59KN-m, but these values of biaxial moments for Non-sway and Sway frame are obtained as -37.89KN-m and -88.59KN-m respectively. Means in case of non-sway frame the moments is developed in the column due to combined effect of load combinations, but it is seen that moments in the column in case of sway frame building is very similar to that of P-Delta due to combined effect of dead load and dynamic earthquake load in X direction.

ix. Similarly, In P-Delta frame the biaxial moment of corner column of top storey in Y direction (minor axis) is -35.41KN-m, and its values for Non-sway and Sway frame are -34.89 KN-m and -39.07 KN-m.

x. The minimum moments corresponding to eccentricity of column of top storey in X direction are 0.76 KN-m for P-Delta, 0.77 KN-m for non-sway and 0.77 KN-m for Sway frame building. And these values are directly proportional to axial forces. The value of moment in case of non-sway is 1.01 times more as that of P-Delta condition frame because of gravity loading. And sway frame having similar moment value as compared with P-Delta effect frame building.

xi. The minimum moments corresponding to eccentricity of column of top storey in X direction are 1 KN-m for P-Delta, 1 KN-m for non-sway and 1 KN-m for Sway frame building.

xii. After the analysis of G+12 building frame, it is seen that the building with sway frame consideration leads column to be slender which further increases the lots of additional moments in the columns of building.

xiii. The reinforcement for corner column of top storey is 1611 $mm^2$ for P-Delta frame, but in case of Non-sway and Sway frame these values are observed to be 1440 $mm^2$ and 1614 $mm^2$. In case of non-sway frame building the decrement in area of steel is found to be 10.6 % as compared with P-Delta results, and similarly in sway frame it values increases to 0.18 % as compared with P-Delta results. The sway frame has more K factor value due to which the effective length of column is increased which further more area of steel is required to compensate the buckling. The value of K factor may vary from 0 to infinity but in current study it varies from 0 to 4.345.

xiv. But in non-sway frame condition the area of steel is found to be 1440 $mm^2$ because of restricted value of K. In case of non-sway building the value of K factor is observed in between 0 to 0.955 for all columns of building.

xv. The secondary effect considered building frame is showing satisfactory results because of K factor values considered in the all columns are similar. From the current study it is observed that, in case of P-Delta frame, the K factor considered is 1.

xvi. From the current study it is observed that the values of K factor for Sway and Non-sway are different for top and bottom storey columns in X and Y direction as shown in table 5.8 of chapter 5. For Sway frame the K factor value for top corner column in X direction is 3.632, but further it is increased 19.63 % and becomes 4.345 from 11$^{th}$ to 1$^{st}$ floor.

xvii. Similarly, in case of non-sway frame building the K factor for top storey is 0.936, 13$^{th}$ storey to 1$^{st}$ storey is 0.955 and ground floor is 0.814 in X direction.

## 5. Future recommendations

i. The future scope of current study is for wind analysis of high rise building for Sway, Non-sway and P-Delta type frame.

ii. In this current study the seismic analysis is carried out for two directions (X and Y direction), further research work on three elements of seismic analysis including X, Y and Z can be carried out.

iii. The column height is kept constant for all stories in this study; the same research work can be done on different storey height and comparisons of results can be made with constant height of storey of frame.

iv. The current study is analysed in seismic zone-IV, and further study for seismic zone-II, zone-III, and zone V can be taken. And comparisons of data of three cases (Sway, Non-sway and P-Delta) can be made for all seismic zones.

v. Seismic analysis of steel frame can be carried out for design parameter Sway, Non-sway and P-Delta effect and same work for composite type frame can be done.

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