

Structural Analysis and Design of Commercial Building for Earthquake Resistance by Using SAP2000

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ABSTRACT: Earthquake is a natural disaster which can generate the most destructive forces on the structure. Buildings should be made safe by proper structural analysis and design. The concept of earthquake resistant design is that the building should be designed to resist the earthquake forces. This project report of structural analysis and design of a nine-storied earthquake resistant building. Construction of the frame structured commercial building with dome roof, escalator, lift, shear walls, basement. Building framed has a 3-D structure as space which consists of rigidly interconnected columns, beams and slabs. It produces greater no of the redundancy thus reduces the moments to facilitates even load distribution to the structure. Analysis and design calculations are done using software "SAP2000 V14". Report is focused on the design of foundation (raft foundation and isolated footing), column (square and circular), beam (primary and secondary), slab, staircase (open newel and spiral), and (concrete dome roof).

KEYWORDS: Earth Quake Resistant, Structural Analysis Building, Seismic Design, SAP2000 V-14, 3D structure, Dome roof.

I. INTRODUCTION

At present world, there is a rapid emersion of latest technologies related to economical, safe, stable construction. In these conditions, earthquake had become one of major and natural challenging factor for the efficient construction works. It is one of the dominant constraints while designing the frame building in the earthquake prone zones like china Nepal etc. Earthquake is a natural disaster as old as the history of the earth itself and is considered to be most unpredictable one among all other natural disasters. At present, engineers and designers are giving more effort towards the earthquake resistance structures while analysing and designing any structure to minimize the seismic impact. Being a good analyst and designer we have to deal with simple ones structures like the precast poles, electric poles ,and curtailment rods and more complex ones like bridges, multi-storied frames ,shell roofs, buildings etc. Structural design deals with the designing (reinforcement details and sizing member sizes, grading of materials) Structural Analysis deals with the prediction of a structure under stipulated loads and other external effects. The structures are subjected to various loads like uniformly distributed loads, concentrated loads uniformly varying loads, earthquake load and dynamic forces which are considered during the design phase. The structure transfers its load ultimately to the ground through supports and. While transferring the loads, the members of the structure are subjected to internal forces like shearing forces, axial forces, bending and torsional moments which are discussed while analysing the structures. The project report possess modelling output (SAP 2000), analysis results, load calculations, architectural drawings, structural drawings and sample calculations of various structural elements and their detailing as well.

II. LITERATURE REVIEW

Before the start of the project, the various related literatures should be properly reviewed to develop the concept about the project. It is very helpful for providing the correct path for the smooth functioning of any project work.

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V.Varalaxmi: The design & analysis of multistorey G+4 building at Kukatpally, Hyderabad, India. The study includes design & analysis of columns, beams, footings & slabs by using well known civil engineering software named as SAP2000

P.Jayachandran: The design & analysis of multistorey G+4 building at Salem, Tamilnadu, India. The study includes design & analysis of footings, columns, beams, and slabs by using two software's named as SAP2000 & AUTOCAD.

L.G.Kalurkar: The design & analysis of multistorey G+4 building using composite structure at earthquake zone 3. A 3D modelling & analysis of the structure are carried out with the help of SAP 2000 software. Equivalent static method of analysis & response spectrum analysis method are used for analysis of both composite & RCC structures.

III. METHODOLOGY AND EARTHQUAKE RESISTANT DESIGN PHILOSOPHY

Preliminary Design

Estimation of various structural elements such as beam and slab were designed and checks were done with the help of deflection criteria and moment criteria. For the column, vertical axial capacity was taken for the design and percentage of steel was checked.

Load Calculations

After the study of architectural drawing and preliminary design, load calculations were done using the IS 875:1987 as reference. The exact value of unit weights of the materials from the code was used in the calculation. The thickness of materials was taken as per design requirement.

Gravity load calculation

There are three types of loads for which are considered in this analysis.

1. Deadload
2. Liveload
3. Lateralload

Lateral load

Lateral load acting in the building is earthquake/seismic load and wind load. Earthquake load is determined by calculating lumped mass at floor level and horizontal base shear (IS 1893). It was done by Seismic Coefficient Method. Wind load (IS 875 Part 3) is obtained by design wind speed and design wind pressure. Earthquake load being the predominant one between the two lateral loads, hence its effect was only considered. For the analysis of earthquake load, following methods is generally carried out:

1. Seismic Coefficient method(Static)
2. Response Spectrum method(Dynamic)

In this project we used **seismic coefficient method** (linear static method).

Loading pattern

The loading is applied to the slab elements directly. The load on slab is taken as per the requirement stated in IS875:1987(Part I & II).

$$L_{Xqt} = W * L_x / 2$$

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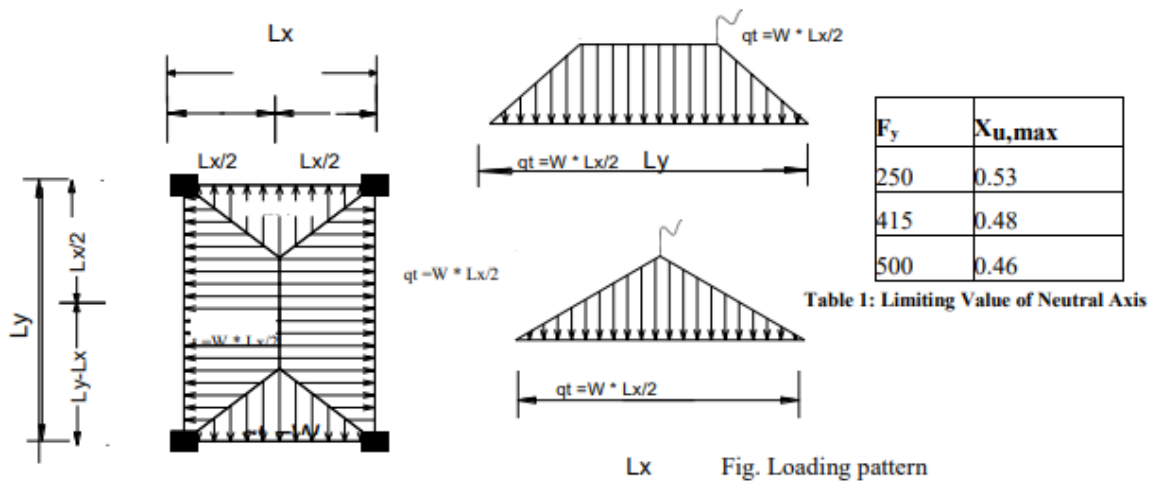


Fig. Loading pattern

Load cases

Load cases are independent loading for which the structure is explicitly analyzed. Earthquake forces occur in random fashion in all directions. For building whose lateral load resisting elements are oriented in two principal directions. It is usually sufficient to analyze in these two principal directions (X and Y direction) separately one at a time. Thus the load cases adopted are as follows.

- Deadload(DL)
- Liveload(LL)
- Earthquake load in X direction(EQX)
- Earthquake load in Y direction(EQY)

Following load combination are adopted for design

1. $1.5(DL \pm LL)$
2. $1.5(DL + LL \pm EQX)$
3. $1.5(DL + LL \pm EQY)$
4. $1.2(DL + LL \pm EQX)$
5. $1.2(DL + LL \pm EQY)$
6. $0.9(DL \pm EQX)$

IV. MODELING AND ANALYSIS OF BUILDING

For the purpose of Seismic analysis of our building we have used the structural analysis program SAP 2000. It has a special option for modeling horizontal rigid floor diaphragm system.

A floor diaphragm is modeled as a rigid horizontal plane parallel to global X-Y plane, so that all points on any floor diaphragm cannot displace relative to each other in X-Y plane.

Initially, the characteristics of the materials used were defined such as concrete – M25 and reinforcement – Fe415. Then, the load cases as well as their combinations with load factors were introduced. Next, structures were analyzed for different load combinations and the final output was determined in the form of SF, BM and AFetc.

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V. METHODS AND TOOLS FOR ANALYSIS

1. Creating grid/model
2. Defining
 - a) Material
 - b) Section (beam, column, slab)
 - c) Loadcases
 - d) Loadpattern
 - e) Loadcombination
3. Assigning
 - f) Section
 - g) Load
4. Analyse the structure.
5. Design of structural elements
6. Limit state design using above mentioned codes.

VI. PRELIMINARY DESIGN

Preliminary design is carried out to estimate approximate size of the structural members. Grid diagram is taken as basic guideline for analysis. Preliminary design of flexural members of the structural system i.e. for beam and slab are done as per the limit state of serviceability. Work out is done from deflection criteria and moment criteria. And for column, it was done from net vertical axial load capacity assuming suitable percentage of steel.

The principal purpose for preliminary design of any structure is:

- a. Obtained a clear picture of structural action
- b. Established the dimensions of structure
- c. Use the preliminary design as a check on the final design

The preliminary bridges the gap between the design concept and the detail phase.

Design data

Construction Material

| | | |
|--------------------------|-------------------------|------------------------|
| Concrete Grade | : M25 | |
| Steel Grade | : Fe415 | |
| Live load on slab | : 4 KN/m ² | (IS 875-1964 Table I) |
| Live load on staircase | : 3 KN/m ² | (IS 875-1964 Table I) |
| Live load on roof | : 1.5 KN/m ² | (IS 875-1964 Table II) |
| Marble stressed | : 26.5KN/m ² | (IS 875-1964 Table I) |
| Brick masonry | : 20.4KN/m ³ | (IS 875-1964 Table I) |
| RCC Specific Weight | : 25KN/m ³ | |
| Bearing Capacity of Soil | : 100KN/m ³ | |

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Design of column

Columns are vertical structural element subjected to axial loads, whose length is more than twice the least lateral dimension. It is reinforced with longitudinal and transverse steel. Reinforced concrete column are used to transfer the load of the structure to its main longitudinal bars to resist compression or bending; and transverse steel to resist bursting force. The shape of a column may be square, rectangular, hexagonal, octagonal or circular. The strength of columns depends on the strength of materials, shape and size of the cross-section, length and the degree of positional and directional restraint at its ends.

For Column C (E, 2)

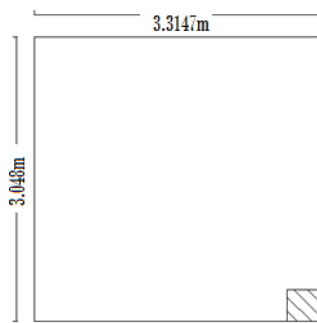


fig. column (E,2)

For Column C (B, 4)

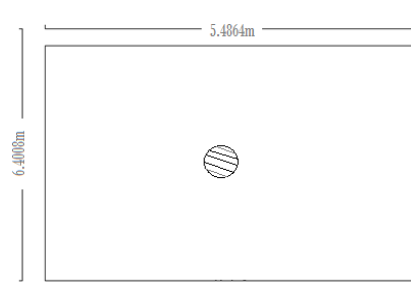


fig. column (B,3)

For Column C(C, 3)

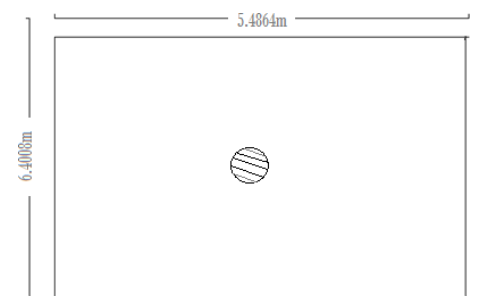


fig. column (C,3)

Design of beam

Beam is a flexural member and supports the imposed load. It carry load by bending action. The beam may be rectangle, L and T section consisting of singly and doubly reinforcement

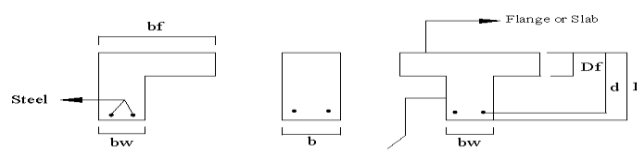


Fig. L-beam, rectangular beam and T- beam

Design of Slab

Slabs are designed by using the same theories of bending and shear as are used for beams.

Important information regarding the design of slab according to Effective length $l_x = 3.3147 \text{ m} = 3314.7 \text{ mm}$, $l_y = 3.3528 \text{ m} = 3352.8 \text{ mm}$ Provide $d = 100 \text{ mm}$

Assuming clear span cover = 20 mm Providing 10 mm ϕ bar

Total depth of slab, $= 100 + 20 + 10/2 = 125 \text{ mm}$ Assuming total depth, $D = 125 \text{ mm}$

Since $\frac{l_y}{d} = \frac{3352.8}{100} = 33.528 < 2$ Hence design Two way slab

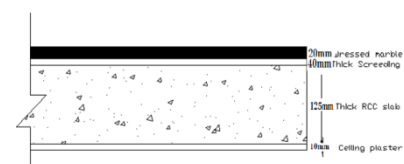


Fig - Cross section of slab with floor finish

$l_x = 3314.7$

Design of Staircase

Staircase is an inclined structural system for the movement from one level to another. Since it is stepped, it is called

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staircase. The geometrical forms of staircase may be quite different depending on the individual circumstances involved. The stairs and landing slab can angle in different form to get different types of staircase. A staircase behaves like an ordinary slab. It may span either in the direction of the steps or in the direction of going. Structurally, staircase may be classified largely into two categories, depending on the predominant direction in which the slab component of the stair undergoes flexure – stair slab spanning transversely and stair slab spanning longitudinally.

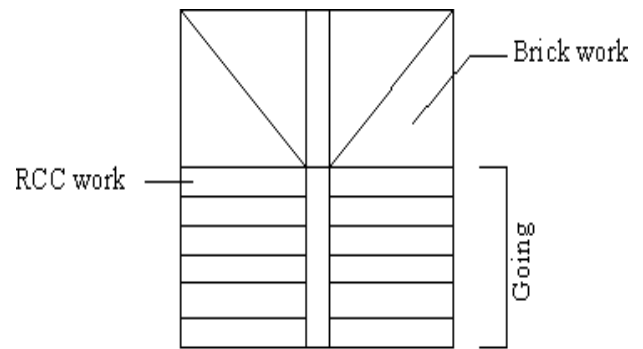
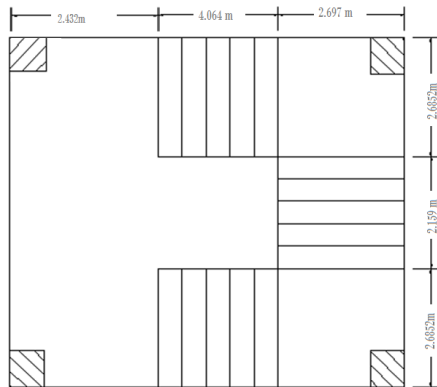


Fig. Open well staircase

Design of Lift wall

Lifts are structural system composed of braced panels (also known as shear panels) to counter the effects of lateral load acting on a structure. Wind and seismic loads are the most common loads that shear walls are designed to carry. Wall thickness varies from 140 mm to 500 mm, depending on the number of stories, building age, and thermal insulation requirements. In general, these walls are continuous throughout the building height; however, some walls are discontinued at the street front or basement level to allow for commercial or parking spaces.

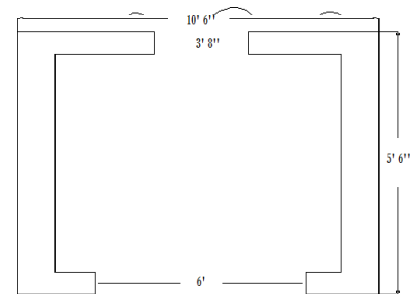


Fig:- Plan of lift

Design of Foundation

Raft or mat foundation

If the loads transmitted by the columns in the structure are so heavy or the allowable soil pressure so small that individual footings would cover more than 50% of the whole area it may be better to provide continuous footing under all columns and walls. Such a footing is called a raft or mat foundation. The raft is designed by analyzing it as a series of continuous strips centered on the appropriate column rows in both directions. The shear and bending moment diagrams may be drawn using continuous beam analysis or coefficients for each strip. The depth is selected to satisfy shear requirements and steel requirement.

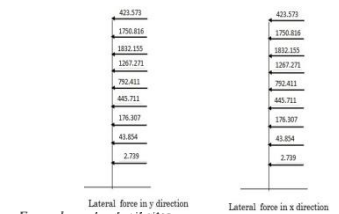
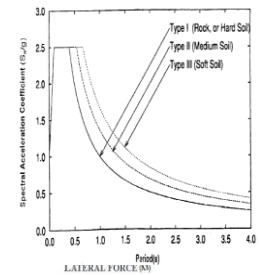
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| Point | P/A (KN/m ²) | ±Mx/Ix (KN/m ³) | ±My/Iy (KN/m ³) | X (m) | Y (m) | σ (KN/m ²) |
|-------|-----------------------------|--------------------------------|--------------------------------|----------|----------|------------------------|
| A2 | 142.022 | 0.966 | -1.899 | -13.566 | -10.417 | 157.721 |
| A3 | 142.022 | 0.966 | -1.899 | -13.566 | -2.858 | 165.023 |
| A4 | 142.022 | 0.966 | -1.899 | -13.566 | 3.849 | 171.502 |
| A5 | 142.022 | 0.966 | -1.899 | -13.566 | 10.304 | 177.737 |
| B2 | 142.022 | 0.966 | -1.899 | -5.486 | -10.417 | 142.377 |
| B3 | 142.022 | 0.966 | -1.899 | -5.486 | -2.858 | 149.679 |
| B4 | 142.022 | 0.966 | -1.899 | -5.486 | 3.849 | 156.158 |
| B5 | 142.022 | 0.966 | -1.899 | -5.486 | 10.304 | 162.394 |
| C3 | 142.022 | 0.966 | -1.899 | 0 | -2.858 | 139.261 |
| C4 | 142.022 | 0.966 | -1.899 | 0 | 3.849 | 145.740 |
| C5 | 142.022 | 0.966 | -1.899 | 0 | 10.304 | 151.976 |
| D2 | 142.022 | 0.966 | -1.899 | 5.486 | -10.417 | 121.541 |
| D3 | 142.022 | 0.966 | -1.899 | 5.486 | -2.858 | 128.843 |
| D4 | 142.022 | 0.966 | -1.899 | 5.486 | 3.849 | 135.322 |
| D5 | 142.022 | 0.966 | -1.899 | 5.486 | 10.304 | 141.558 |
| E2 | 142.022 | 0.966 | -1.899 | 13.466 | -10.417 | 106.387 |
| E3 | 142.022 | 0.966 | -1.899 | 13.466 | -2.858 | 113.689 |
| E4 | 142.022 | 0.966 | -1.899 | 13.466 | 3.849 | 120.168 |
| E5 | 142.022 | 0.966 | -1.899 | 13.466 | 10.304 | 126.404 |



Lateral force in y direction
For rocky, or hard soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15T; & 0.00 \leq T \leq 0.10 \\ 2.50 & 0.10 \leq T \leq 0.40 \\ 1.00/T & 0.40 \leq T \leq 4.00 \end{cases}$$

For medium soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15T; & 0.00 \leq T \leq 0.10 \\ 2.50 & 0.10 \leq T \leq 0.55 \\ 1.36/T & 0.55 \leq T \leq 4.00 \end{cases}$$

For soft soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15T; & 0.00 \leq T \leq 0.10 \\ 2.50 & 0.10 \leq T \leq 0.67 \\ 1.67/T & 0.67 \leq T \leq 4.00 \end{cases}$$

Lateral load calculations

| S.N | Floor | Wi (KN) | Hi (m) | WiHi ² (KN-m ²) | $W h^2 = V \sum_{j=1}^{B_{yn}} W h_j^2$ (KN) | $W h^2 = V \sum_{j=1}^{i_i} W h_j^2$ (KN) |
|-----|--------------|------------|-----------|---|---|--|
| 1 | Roof/Dome | 866.526 | 29.947 | 777120.281 | 423.573 | 423.573 |
| 2 | 7th floor | 4702.074 | 26.137 | 3212187.767 | 1750.816 | 1750.816 |
| 3 | 6th floor | 6697.462 | 22.403 | 3361418.921 | 1832.155 | 1832.155 |
| 4 | 5th floor | 6670.949 | 18.669 | 2325036.138 | 1267.271 | 1267.271 |
| 5 | 4th floor | 6517.787 | 14.935 | 1453819.844 | 792.411 | 792.411 |
| 6 | 3rd floor | 6517.787 | 11.201 | 817737.159 | 445.711 | 445.711 |
| 7 | 2nd floor | 5799.919 | 7.468 | 323467.429 | 176.307 | 176.307 |
| 8 | 1st floor | 5770.620 | 3.734 | 80458.345 | 43.854 | 43.854 |
| 9 | Ground floor | 6344.560 | 0.890 | 5025.526 | 2.739 | 2.739 |
| | | | Total = | 12356271.410 | | |

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IV. SAILENT FEATURES OF SAP2000 USED FOR ANALYSIS

Sap 2000 represents the most sophisticated and user friendly releases of the SAP series of computer programs. Creation and modification of the model, execution of the analysis, and checking and optimization of the design are all done through this interface. Graphical displays of the results, including real time display of the time history displacements, are easily produced. The finite element library consists of different elements out of which the three dimensional frame elements were used in this analysis. The Frame element uses a general, three dimensional beam-column formulations which include the effect of biaxial bending, torsion, axial deformation and biaxial shear deformation.

Structures that can be modeled with this element include:

1. Three-dimensional frames
2. Three-dimensional truss
3. Planar frames
4. Planar grillages
5. Planar trusses

A frame element is modeled as a straight line connecting two joints. Each element has its own local coordinate system for defining section properties and loads, and for interpreting output. Loading option allows for gravity, thermal and pre-stress condition in addition to the usual nodal loading with specified forces and or displacements. Dynamic loading can be in the form of a base acceleration response spectrum, or varying loads and base accelerations.

| Calculation of Load | | | | | | | | | | | | |
|---------------------|--------------|-----------|-------------|-----------|-----------|----------------|-------------------|--------------|----------------|----------------------|----------------|-------------|
| S.N | Description | Slab (KN) | Column (KN) | Beam (KN) | Wall (KN) | Staircase (KN) | Floor Finish (KN) | Plaster (KN) | Escalator (KN) | Total Dead load (KN) | Live load (KN) | DL + 0.5 LL |
| 1 | Roof/Dome | 402.11 | | 418.826 | | | | 45.590 | | 866.526 | | 866.526 |
| 2 | 7th floor | 1028.685 | 146.626 | 1605.858 | 412.670 | | 517.252 | 50.568 | | 3761.659 | 1880.830 | 4702.074 |
| 3 | 6th floor | 1050.253 | 548.163 | 1605.858 | 1474.431 | 66.980 | 474.768 | 137.517 | | 5357.970 | 2678.985 | 6697.462 |
| 4 | 5th floor | 1050.253 | 548.163 | 1605.858 | 1331.149 | 192.379 | 474.768 | 134.189 | | 5336.759 | 2668.379 | 6670.949 |
| 5 | 4th floor | 1050.253 | 548.163 | 1483.328 | 1331.149 | 192.379 | 474.768 | 134.189 | | 5214.229 | 2607.115 | 6517.787 |
| 6 | 3rd floor | 1050.253 | 548.163 | 1483.328 | 1331.149 | 192.379 | 474.768 | 134.189 | | 5214.229 | 2607.115 | 6517.787 |
| 7 | 2nd floor | 990.924 | 548.163 | 1483.328 | 834.425 | 192.379 | 437.448 | 104.218 | 49.050 | 4639.935 | 2319.968 | 5799.919 |
| 8 | 1st floor | 847.91 | 548.163 | 1605.858 | 834.425 | 192.379 | 385.443 | 104.218 | 98.100 | 4616.496 | 2308.248 | 5770.620 |
| 9 | Ground floor | 1050.253 | 548.163 | 1605.858 | 1022.296 | 192.379 | 474.768 | 132.881 | 49.050 | 5075.648 | 2537.824 | 6344.560 |
| | | | | | | | | | | | Total load, W | 49887.683 |

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INPUTS AND OUTPUTS

The design of earthquake resistant structure should aim at providing appropriate dynamic and structural characteristics so that acceptable response level results under the design earthquake.

For the purpose of seismic analysis of our building we use the structural analysis program SAP 2000 V14, which has a special option for modeling horizontal rigid floor diaphragm system. A floor diaphragm is modeled as a rigid horizontal plane parallel to global X-Y plane, so that all points on any floor diaphragm cannot displace relative to each other in X-Y plane.

Fig.: 3D model of building without slab for analysis in SAP Fig.: 3D model of building with slab for analysis in SAP

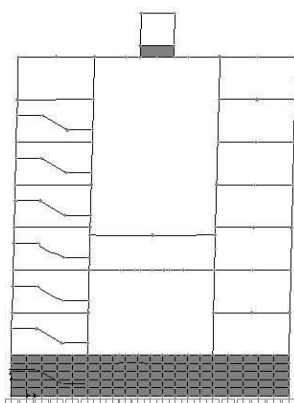
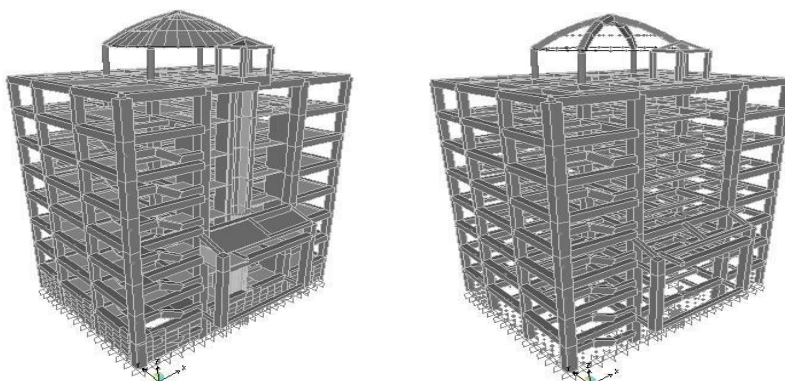


Fig.: Deformed shape at XZ plane at grid 2-2

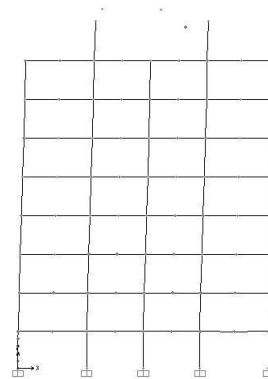


Fig.: Deformed shape at XZ plane at grid 4-4

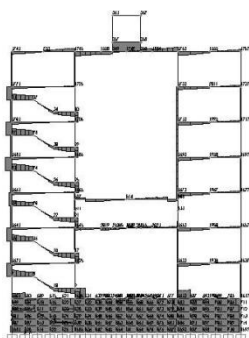


Fig.: Shear force diagram at XZ plane at grid 2-2

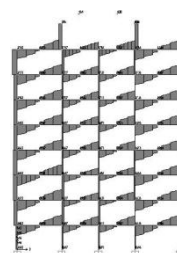


Fig.: Shear force diagram at XZ plane at grid 4-4

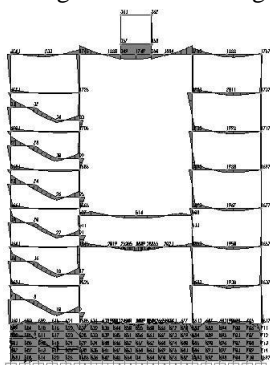


Fig.: Bending moment diagram at XZ plane at grid 2-2

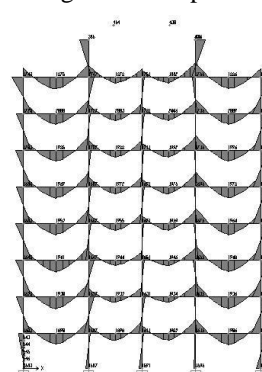


Fig.: Bending moment diagram at XZ plane at grid 4-4

VI. CONCLUSION

The seismic coefficient method is used to analysis the building due to more practicable and easy. SAP 2000 V14 provided to be helpful tools in the analysis of frame for various loading condition. In this project, the analysis, design and detailing of all require element of building were done based on 3-D frame analysis by SAP 2000 V14. Finally i hope that efforts and coordination for the project work will prove much useful in my career and project will be helpful in providing information on the earthquake resistant design and its safe practice and i hope, this project will help me in similar jobs that i might have in our hands in the future.

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