Structural Analysis of Multistorey (G+4) Commercial Building using FEM Software (ETAB'S)

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Abstract - *The design process of structural planning and design requires not only imagination and conceptual thinking but also sound knowledge of science of structural engineering besides the knowledge of practical aspects, such as recent design codes, bye laws, backed up by ample experience, intuition and judgment. In the present study G+4 commercial building at Chevella, Telangana, India is designed using ETABS software. The modeling and analysis is carried out considering all the loads and designed the sections manually by referring design aids in the IS:456-2000 and SP16-1978. The principle objective of this work is taking forces in terms of shear force and bending moment to give adequate structural sections. Finally, the sections must be checked for all the four components with regard to strength and serviceability.*

***Keywords* – Beams, columns, footings, slab, ETAB software**

I. INTRODUCTION

Buildings come in a wide amount of shapes and functions, and have been adapted throughout history for a wide number of factors, from building materials available, to weather conditions, to land prices, ground conditions, specific uses and aesthetic reasons. A Multi-Stored is a building that has multiple floors above ground in the building. Multi-storey buildings aim to increase the floor area of the building without increasing the area of the land the building is built on, hence saving land and, in most cases, money (depending on material used and land prices in the area). The building is designed as a framed structure with brick walls as infill walls. All the exterior walls are one brick-wall while all the partition walls are half brick walls. We propose use M25, M30 and M35 concrete and Fe415 and Fe500 bars for all structural components like slabs, beams columns and foundation.

Regarding their structural features, they are rectangular buildings. All the columns are arranged in such a way that they form typical frames in length and width direction. The longitudinal and transverse frames are analyzed and taken the forces of building gas shear force and bending moment and designed the structural elements on the basis of limit state method of collapse using IS: 456-2000, and SP-16 have been adopted for the design of all structural components like slabs, beams, columns and foundations.

II. OBJECTIVES

The principal objective of commercial building design is considering the forces acting on the structure are calculated and give the safe and adequate structural elements by keeping in view of strength and serviceability through the life span of the building.

The objectives of the study are:-

1. Identification of structural arrangement of the plan.
2. Learn the concept of lateral and vertical loadings on the building.
3. Analyzing the building using FEM software ETABS under vertical and lateral loading conditions.
4. Determining the different forces and reactions on the structure.
5. Analyzing and designing of slab.
6. Sectional design of structural components.
7. Structural detailing of members and the system.

A. STATEMENT OF THE PROJECT

Salient Features: The design data shall be as follows
1. Utility of Buildings: Commercial Building
2. No of Storey: (G+4)
3. Shape of the Building: Rectangular
4. No. of Staircases: One
6. Types of Walls: 300mm brick wall
7. Geometric Details
   a) Floor-To-Floor Height: 3.5m
   b) Height of Plinth: 0.6m above G.L
   c) Depth of Foundation: 2.5m below G.L
8. Material Details
a) Concrete Grade: M25, M30, M35 (columns and beams)
b) All Steel Grades: HYSD Fe415, Fe500
c) Bearing Capacity of Soil: 350 kN/m2
d) Size of column = 300mmx650mm
e) Size of beam = 300mmx600mm
f) Size of slab =150mm and 125mm
9. Type of construction: R.C.C framed structure.

III METHODOLOGY

There are different types of loads are acting on the structures and these loads develops the stresses. When stress level reaches the ultimate point cracks will develop in the building therefore by giving proper structural sections to compensate the stresses by internal stress of the sections. The following loads are calculated from IS code books.

A. Types of Loads

Loads are primary consideration in any buildings design because they define the nature and magnitude of hazards or external forces that a building must resist to provide reasonable performance (i.e.; safety and serviceability) throughout the structure's useful life. The anticipated loads are influenced by a building's intended use (occupancy and function), configuration (shape and size) and location (climate and site conditions). Ultimately, the type and magnitude of the design loads affect critical decisions such has the Material selection, construction details, and architectural configuration. Thus to optimize the value (i.e. performance versus economy) of the finished product, it is essential to apply design loads realistically.
In general, the design loads recommended are as follows.

1. Dead load: The dead load comprises of the weights of walls, partitions floor finishes, false ceilings, false floors and the other permanent constructions in the buildings. The dead load loads may be calculated from the dimensions of various members and their unit weights.

2. Imposed Loads: Imposed load is produced by the intended use or occupancy of a building including the weight of movable partitions, distributed and concentrated loads, load due to impact and vibration and dust loads. Imposed loads do not include.

B. Loading standards

1. The dead loads
   a) Floor finis for typical floor =1 kN/m^2
   b) Floor finish for terrace = 1 kN/m^2
   c) Water proofing load = 2 kN/m^2
   d) Wall load on external wall = 15.39 kN/m
   e) Wall load on internal wall = 13.11 kN/m
   f) Parapet wall load = 3.75 kN/m
   g) Stair case wall load = 0.825 kN/m

2. Live loads
   a) Live load on typical floor = 4 kN/m^2
   b) Live load on Terrace = 1.5 kN/m^2

3. *Earthquake Load:*
Seismic motions consist of horizontal and vertical ground motions, with the vertical motion usually having a much smaller magnitude. The factor of safety provided against gravity loads usually can accommodate additional forces due to vertical acceleration due to earthquakes. So, the horizontal motion of the ground causes the most significant effect on the structure by shaking the foundation back and forth. However in practice all structures are flexible to some degree but a very flexible structure will be subjected to a much longer force under repetitive ground motion. This shows the magnitude of the lateral force on a structure is not only dependent on the acceleration of the ground but it will also depend on the type of structure (F=Ma). The earthquake load is estimated by static method in the project and is as specified by the provisions in IS 1893. In the earthquake resistant design focus is on the ductility and energy absorption by the material used (steel) for construction. It was shown repeatedly that no static analysis can assure a good dissipation of energy and favorable distribution of damage in irregular structures and in general the more slender a structure, the worse the overturning effect of an earthquake Seismic load can be calculated taking the view of acceleration response of the ground to the super structure. According to the severity of earthquake intensity they are divided into 4 zones.

4. *Load Combinations*
For seismic load analysis of a building the code refers following load combinations.
1. 1.5(DL + IL)
2. 1.2(DL + IL ± EL)
3. 1.5(DL ± EL)
4. 0.9 DL ± 1.5 EL

IV STRUCTURAL ANALYSIS

The procedure of structural analysis is simple in concept but complex in detail, it involves the analysis of a proposed structure to show that its resistance or strength will meet or exceed a reasonable expectation. This expectation is usually expressed by a specified load or the demand and an acceptable margined of safety that constitutes a performance goal for a structure. The performance goals structural design is multifaceted. Foremost, a structure must perform its intended function safely over its useful life. The concept of useful life implies consideration of durability and established the basis for considering the cumulative exposure to time varying risks (i.e. corrosive environments, that performance is inextricably linked to cost, owners, builders, and designer must considers economic limit to the primary goal of safety and durability. In the view of the above discussion, structural designer may appear to have little control over the fundamental goals of structural design except to comply with or exceed the minimum limits established by law. While this is generally true, a designer can still do much to optimize the design through alternative means and methods that can for more efficient analysis techniques, creative design detailing, and the use of innovative construction materials and methods. In summary the goal of structural design are defined by law and reflect the collective interpretation of general public welfare by those involved in the development and local adoption of building could.

A. Design of Slabs

Dimension = 12.5mx2.45m
Ly/lx=12.5m/2.45m=5.10m
Hence design is as one way slab
Effective span= 2.15m
Loads :-
Self-weight of slab = 0.15x25 = 3.75KN/m
Floor thickness = 1.0KN/m
Live load = 5KN/m
Service load = 9.75KN/m
Factored load = 14.625KN/m

Ultimate moment and shear forces:-

Mu = Wul2/8
= 14.625x2.152/8
Mu = 8.45 kN-m
Vu = W_ul/2 = 14.625x2.15/2 = 15.72kN
M_{ulim} = 0.133fckbd2
= 0.133x30x1000x1252
= 62.34x106
Mu <M_{ulim}
Hence section is under reinforced

Main reinforcement:-

Mu = 0.87 fy*Ast* [1-(Ast*fy/fck*b*d)]
8.45x106 = 0.87x500xAst [1-(Astx500/20x1000x125)]
Ast = 150.44mm2 say 150mm2
Using 10mm dia bars, spacing = 100 Ast/150
= 100x (π/4) x10x10/150
= 523 mm2
Provide using 10mm dia bars at 300mm c/c

Distribution reinforcement:-

c0.12% gross c/s area
= 0.012x103x150 = 180mm2
Provide 8mm dia at 250mm c

Check for shear:-

τ_v = V_u/bd = 14.91x103/1000x125
= 0.119 say 0.1N/mm2
P_t = 100xAst/bd Astpr 1000x(π/4)x10x10/300 = 100x261.7/1000x125 = 261.7mm2
= 0.209
K x τ_c = 1.3x0.3356= 0.436N/mm2>τ_v
Hence safe in shear and hence no shear reinforcement.

Check for deflection:-

(L/d)basic = 20
Pt = 0.209
Kt = 1.05x20=21
(L/d)max = 20x1.6 = 32
(L/d)provi = 2150/125 = 17.2 <21
Hence safe

II. Etab's Modeling, Analysis and Design procedure

1. General

ETABS is a special-purpose computer program developed specifically for building structures. It provides the Structural Engineer with all the tools necessary to create, modify, analyze, design, and optimize building models. These features are fully integrated in a single, Windows-based, graphical user interface that is unmatched in terms of ease-of use, productivity, and capability. The innovative and revolutionary new ETABS is the ultimate integrated software package for the structural analysis and design of buildings. Incorporating 40 years of continuous research and development, this latest ETABS offers unmatched 3D object based modeling and visualization tools, blazingly fast linear and nonlinear analytical power, sophisticated and comprehensive design capabilities for a wide-range of materials, and insightful graphic displays, reports, and schematic drawings that allow users to quickly and easily decipher and understand analysis and design results.

In this work modeled commercial G+4 building, analyzed by taking necessary design data and designed beams, columns, footings.

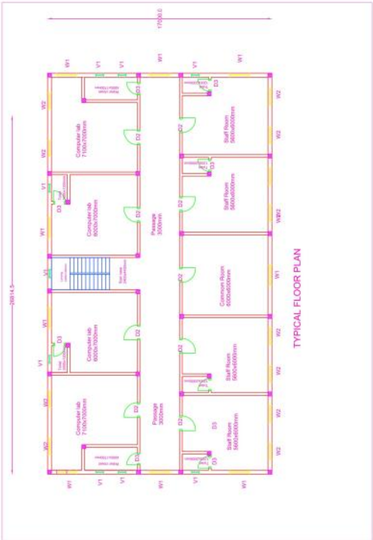

Fig. 1 Typical Floor Plan

2. Design of Beams

The beams are defined as the structural members subjected to transverse loads that cause bending moments and shear forces along their length. The plane of transverse loads is parallel to the plane of symmetry of the cross section of the beam and it passes through the shear center, so that the simple bending of the beam occurs. The bending moment and shear forces produced by the transverse loads are called as internal forces. The beams are called as simply supported, overhanging, cantilever, fixed and continuous depending upon the nature of supports and end conditions. The cross-section of most simple reinforced concrete beams is rectangular in shape.

Beam 1 (300x600)

M_u= 188 kN.m

V_u= 235 kN

b= 300 mm

D= 600 mm

d= 575 mm

$\frac{M_u}{bd^2} = \frac{188*10^6}{300*575^2}$ = 1.89

From SP 16 page no. 48,

1.85= 0.584 and 1.90= 0.602

P_t= 0.5984 %

$A_{st\ provided} = \frac{P_t * b * d}{100}$

$A_{st\ provided} = \frac{0.5984*300*600}{100}$

$A_{st\ provided}$ = 1077.12 mm^2

Assume 20mmφ bars,

$A_{st\ required} = \frac{\pi}{4}$x20x20= 314.16 mm^2

No. of bars= $\frac{1077.12}{314.16}$= 3.42= 4

Use 4 nos. of 20mmφ bars

Check and design of shear:

V_u= 235 kN

$\tau_v = \frac{V_u}{bd} = \frac{235*10^3}{300*575}$= 1.36 N/mm^2

From IS: 456-2000 table no. 19 page 73

$P_t = \frac{100*A_{st\ provided}}{bd}$

$P_t = \frac{100*1077.12}{300*575}$

P_t= 0.62

0.50= 0.49

0.75= 0.57

τ_c= 0.5284 N/mm^2

$\tau_v > \tau_c$. Hence, shear reinforcement must be provided.

V_{us}= (V_u-τ_c x b x d)

V_{us}= (235x1000-0.5284x300x575) = 144.472 kN.

Spacing:

$S_v = \frac{0.87*f_y*A_{sv}*d}{V_{us}}$

Assuming 2-legged 8mmφ bars

$A_{sv} = \frac{3.14}{4} * 8^2 * 2$= 100.544

$S_v = \frac{0.87*415*100.544*575}{144.472*10^3}$

S_v= 144.48 mm = 200 mm

But maximum spacing provided is,

(a) 0.75xd = 0.75x575 = 431.25 mm
(b) 300 mm

Hence, provide 8mmφ 2-legged stirrups @200 mm $^c/_c$.

Check for deflection:

$\frac{L}{D_{max}} = F_1 * F_2 * F_3$

$P_t = \frac{100*A_{st\ provided}}{b*d}$

$P_t = \frac{100*1077.12}{300*575}$ = 0.62

F_s= 0.58 x f_y($A_{st\ required}/A_{st\ provided}$)

F_s=0.58x415x(314.16/1077.12) = 70.204

In IS: 456, from fig. 4 page 38,

F_1 = 1

In IS: 456, from fig. 5 page 39,

F_2 = 1.1

In IS: 456, from fig. 6 page 39,

F_3 = 1

$\frac{L}{D_{max}} = F_1 * F_2 * F_3$ = 1x1.1x1x7 = 7.7

$\frac{L}{D_{provided}}$= 6200/1000 = 6.2

$\frac{L}{D_{max}} > \frac{L}{D_{provided}}$.

Hence, it is safe, deflection control is satisfactory.

Beam 36

M_u= 167 kN.m

V_u= 231 kN

b= 300 mm
D= 600 mm
d= 575 mm

$$\frac{M_u}{bd^2} = \frac{167*10^6}{300*575^2} = 1.68$$

From SP 16 page no. 48,
1.65= 0.512 and 1.70= 0.530

P_t= 0.5228 %

$$A_{st\ provided} = \frac{P_t*b*d}{100}$$

$$A_{st\ provided} = \frac{0.5228*300*600}{100}$$

$$A_{st\ provided} = 941.04\ mm^2$$

Assume 20mmφ bars,

$$A_{st\ required} = \frac{\pi}{4}x20x20 = 314.16\ mm^2$$

$$\text{No. of bars} = \frac{941.04}{314.16} = 2.99 = 4$$

Use 4 nos. of 20mmφ bars.

Check and design of shear:

V_u= 231 kN

$$\tau_v = \frac{V_u}{bd} = \frac{231*10^3}{300*575} = 1.34\ N/mm^2$$

From IS: 456-2000 table no. 19 page 73

$$P_t = \frac{100*A_{st\ provided}}{bd}$$

$$P_t = \frac{100*941.04}{300*575}$$

P_t= 0.54
0.50= 0.49
0.75= 0.57

τ_c= 0.5028 N/mm^2

$\tau_v > \tau_c$. Hence, shear reinforcement must be provided.

V_{us}= (V_u-τ_c x b x d)

V_{us}= (231x1000-0.5028x300x575) = 144.267 kN.

Spacing:

$$S_v = \frac{0.87*f_y*A_{sv}*d}{V_{us}}$$

Assuming 2-legged 8mmφ bars

$$A_{sv} = \frac{3.14}{4} * 8^2 * 2 = 100.544$$

$$S_v = \frac{0.87*415*100.544*575}{144.267*10^3}$$

S_v= 144.68 mm = 200 mm

But maximum spacing provided is,
(a) 0.75xd = 0.75x575 = 431.25 mm
(b) 300 mm

Hence, provide 8mmφ 2-legged stirrups @200 mm $^c/_c$.

Check for deflection:

$$\frac{L}{D_{max}} = F_1 * F_2 * F_3$$

$$P_t = \frac{100*A_{st\ provided}}{b*d}$$

$$P_t = \frac{100*941.04}{300*575} = 0.54$$

F_s= 0.58 x f_y($A_{st\ required}$ / $A_{st\ provided}$)

F_s=0.58x415x(314.16/941.04) = 80.35

In IS: 456, from fig. 4 page 38,
F_1 = 1
In IS: 456, from fig. 5 page 39,
F_2 = 1.1
In IS: 456, from fig. 6 page 39,
F_3 = 1

$$\frac{L}{D_{max}} = F_1 * F_2 * F_3 = 1x1.1x1x7 = 7.7$$

$$\frac{L}{D_{provided}} = 6200/1000 = 6.2$$

$$\frac{L}{D_{max}} > \frac{L}{D_{provided}}.$$

Hence, it is safe, deflection control is satisfactory.

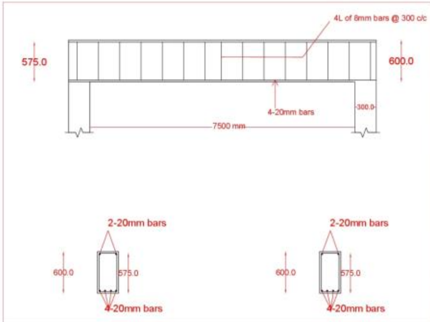

Fig. 1 Beam reinforcement details

TABLE 1 BEAM DESIGN AND DETAILS

Beam No.	Forces in beam	A_{st} provided	No. of bars	stirrups
B1	v_u=235 m_u=188	1002.79	4	4L@ 300mm
B2	v_u=233 m_u=169	890.82	4	4L@ 300mm
B3	v_u=116 m_u=77	385.38	2	4L@ 300mm
B7	v_u=322 m_u=327	1936.94	6	4L@ 300mm
B11	v_u=233 m_u=156	815.86	3	4L@ 300mm

3. Design of columns

In reinforced concrete construction, a compression member having its effective length greater than 3 times its least lateral dimension is called as a column or a strut. A vertical compression member coming under above definition is usually called a column, while that in any other direction, as in case of frames and trusses, and is called a strut. A column with an effective length less than three times the least lateral dimension is called a pedestal.

Table 2: column reinforcement

Column type	Mix	Size (mm)	Main Steel
C1-storey1	M-35	300X650	6-#32
C2-storey2	M-35	300X650	6-#32
C3-storey3	M-35	300X650	4-#32
C4-storey4	M-35	300X650	4-#32
C4-storey5	M-35	300X650	4#32

4. Foundation design

The foundation is a structure is the part of the structure which transfers the load to the soil on the soil on which it rests. It forms a very important part of the structure. The ground surface in contact with the lower surface of the foundation is called foundation. The ground on which soil rests is called the sub grade. A stresses induced in the soil are within the load of the structure on to a sufficient area of the soil so that the stresses induced in the soil are within the safe limit. If a soil is overstressed, it may lead to shear failure resulting in the sliding of the soil along a plane of rupture and thus in the collapse of the structure.

Table 2 Footing design and details

Footing type	Column size (m)	Footing depth (m)	Long span steel	Short span steel
F1	5x1.8	750	20φ@ 80 mm	20φ@ 200mm c/c
F2	6.4x2.5	1050	20φ@ 100 mm c/c	20φ@ 150 mm c/c
F3	7.7x4	1000	20φ@ 90 mm c/c	20φ@ 200 mm c/c
F4	9.2x5	1600	20φ@ 150 mm c/c	20φ@ 180mm c/c

CONCLUSION

1. ETAB has the capability to calculate the reinforcement needed for any concrete section. The program contains a number of parameters which are designed as per IS: 456(2000). Beams are designed for flexure, shear and torsion.
2. Maximum sagging and hogging moments are calculated for all active load cases at each of the above mentioned sections. Each of these sections is designed to resist both of these critical sagging and hogging moments. Where ever the rectangular section is inadequate as singly reinforced section, doubly reinforced section is tried.
3. Shear reinforcement is calculated to resist both shear forces and torsional moments. Shear capacity calculation at different sections without the shear reinforcement is based on the actual tensile reinforcement provided by ETAB program.
4. In this project we have designed slabs as two way slabs depending upon the end condition, corresponding bending moment. The coefficients have been calculated as per I.S. code methods for corresponding lx/ly ratio.
5. Here we have designed isolated footing based on the bearing pressure.

II. SCOPE OF THIS STUDY

1. Increase the storey heights and carried out analysis and design.
2. Analysis and design by taking substitute manual method.
3. Carried out analysis and design by using different FEM software.

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