DESIGN AND ANALYSIS OF G+3 RESIDENTIAL BUILDING USING STAAD-Pro

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Abstract: In recent years, the exponential increase of population has led to overcrowding of people within a very small space. Plans and design to overcome the issues related to densely populated areas have resulted in significant increase in the number of high-rise residential buildings. Presently, there are numerous factors influencing the design and selection of building structures. More importantly, since the structural design and analysis is an art and science of designing with durable, economical, serviceable as well as safe structure, it is very important for a designer to acquire imagination, science knowledge and thinking capability during the structural planning. In order to compete in the fast-growing competitive market, it is equally important for a structure engineer to save time. So, the main objective of this project is to design and analyze a multi-storied building using STAAD Pro. Since, manual designing and analysis of any structures; be it buildings or bridges, takes very huge amount of time and resources, it is very efficient to use a computer-based software like AutoCAD, STAAD-Pro, Sketch-Up, etc. The design involves manual calculations of load and analyzing of whole structure by STAAD-Pro. With the help of the software, analyzing of the building was fast and efficient because it provides easy-to-use and accurate platform for analyzing a multi-story building. In this project, the manual design of beams, columns, slabs, etc. are calculated by "Limit State Method" using IS: 456-2000 code book. Loads on the members are considered according to IS: 875-1987 (Part I, II and III). Hence, the Residential Building is properly planned in accordance with National Building Code of India.

***Index Terms* – STAAD-Pro, Building, Design, Analysis.**

I. INTRODUCTION

Migration of huge number of populations from rural areas to urban places have led to construction of multi-storied building over a small area have become common these days. Due to this reason, the determination of general shape, size and dimension know as structure analysis is very important aspect, so that the structure will perform its functions safely withstanding all the influencing factors throughout its life.

The process of planning and design not only requires the imagination and calculations, but also the science knowledge of every minute aspect used during the process. Since functional designing of any structures has become requisite and the requirements ranges from buildings to buildings, every civil engineer must have good ideas about the usage of the building and its varying functions.

In recent years, the building construction has become the major task for the social progression. Plus, new innovative ideas and techniques are being developed for the economical and efficient progression of the work fulfilling the Building By-Laws of the particular country.

Therefore, in this project, the task of designing and analyzing of the building is done with the help of fast and efficient platforms offered by the STAAD Pro software for the completion of the task assigned on time.

II. OBJECTIVE

The main objective of this project is to design and analyze a residential building using STAAD-Pro. The software is easy-to-use, it is fast and can save lot of time. STAAD-Pro or STAAD software is so efficient and accurate as it can give every minute data of the design and analysis.

This project can help prepare to compete in this fast-growing competitive world by providing the knowledge of how to use the software more accurately and efficiently so that one can manage the time. Since the manual design of any structure takes huge amount of time, the software does this work within a short period of time.

The most important traits that every engineer should have is to be handy with every engineering software when it comes handy. This project's purpose is to recollect what one learnt during early years of his course both technically and manually.

III. MATERIALS AND METHODOLOGY

This chapter deals with the methods and materials used during the process of this project. This building is considered as low-rise G+3 Residential Building with the floor height of 3.048m or 10 feet. Consideration of all the load that can possibly act on the building is done except for snow load. All methods were followed as per Indian Standards.

3.1 Material Used

i. STAAD.Pro v8i
The software used for modelling, designing and analysis was STAAD.Pro v8i

ii. AutoCAD 2020
This software is used to draw the plan and the building plan was then exported to STAAD Pro.

iii. MS Excel 2019
It is used for the sorting of Axial Load on the columns which can be used for the grouping of columns.

iv. MS Word 2019
This is used for the preparation of report and other important documents if the project

v. IS 456-2000 and IS 875 (Part I, II & III)

3.2 Methodology

3.2.1 Modelling

G+3 Residential Building
Building Dimensions = 27.364m x 18.975m
Floor Height = 3.048m (10 Feet)

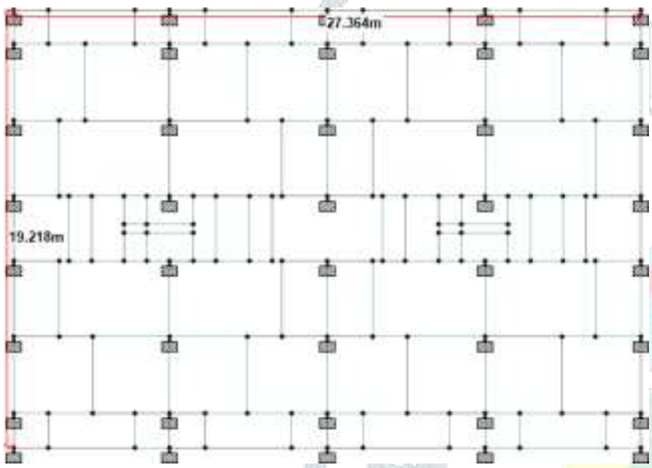


Figure 3.1: Building Plan

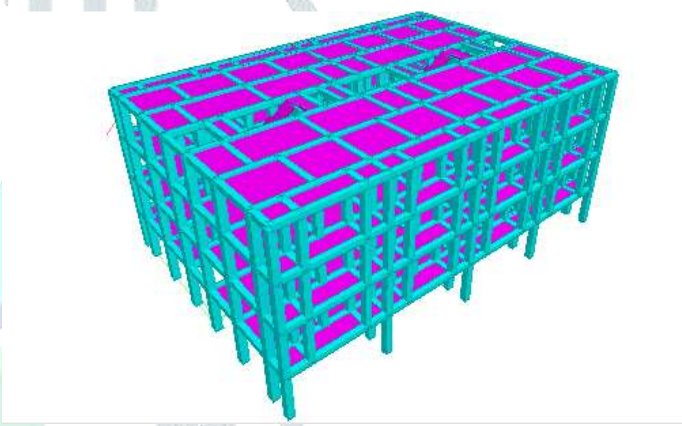


Figure 3.2: 3-D View of the Building

3.2.1 Loadings

3.2.1.1 Seismic or Earthquake load

The definition of seismic load is done considering the ZONE IV and Reduction Response of Special RC Moment Resisting Frame (SMRF).

Parameters	Value	Unit
Zone	0.24	
Response reduction Factor (RF)	0.05	
Importance factor (I)	1	
Rock and soil site factor (SS)	2	
* Type of structure (ST)	1	
Damping ratio (DM)	0	
* Period in X Direction (PX)	0.21	seconds
* Period in Z Direction (PZ)	0.25	seconds

Figure 3.2.1.1: Seismic Parameters Table

3.2.1.2 Dead load

Wall Load – 15.24 kN/m (Outer walls)
7.62 kN/m (Inner walls)
6.25 kN/m (Paraphet wall)
Floor load – 5 kN/m2

Figure 3.2.1.2: Dead Load Intensity Applied on the Building

3.2.1.3 Live load

Live Load – 2 kN/m2 for Residential Building as per Indian Standard.

2 : LL

YRANGE 3.048 12.192 FLOAD -2 GY

3.2.1.4 Wind load

Intensity – 1.4752 kN/m^2

Wind Load intensity was calculated manually considering the building is in Punjab. The application wind load acts upon the top floor of the building with the height of 9.144m to 12.192m.

3.2.2 Design

Design of beams, columns and slabs are done in STAAD Pro as well as manually as per IS 456-2000.

Geometric Parameters

Beams – 0.35m x 0.35m (all beams)

Columns: C1- 0.46m x 0.46m

C2 – 0.46m x 0.40m

C3 – 0.40m x 0.40m

Slabs – 120mm thick

Section | Beta Angle

Ref	Section	Material
1	Plate Thickness	CONCRETE
2	Rect 0.40x0.40	CONCRETE
3	Rect 0.46x0.40	CONCRETE
4	Rect 0.46x0.46	CONCRETE
5	Rect 0.46x0.46	CONCRETE
6	Rect 0.35x0.35	CONCRETE

Load Combinations

9 : 1.5(DL+LL)
10 : 1.2(DL+WLX+EQX)
11 : 1.2(DL+WL-X+EQX)
12 : 1.2(DL+WLZ+EQZ)
13 : 1.2(DL+WL-Z+EQZ)
14 : 0.9DL+1.5EQX
15 : 0.9DL+1.5EQZ
16 : 0.9DL+1.5WLX
17 : 0.9DL+1.5WL-X
18 : 0.9DL+1.5WLZ
19 : 0.9DL+1.5WL-Z
22 : 1.2(DL+WLX+EQ-X)
23 : 1.2(DL+WL-X+EQ-X)
24 : 1.2(DL+WLZ+EQ-Z)
25 : 1.2(DL+WL-Z+EQ-Z)

IV. Data Analysis And Results

Real structural system was considered during the design and analysis of this project with the following of the Indian Standards and IS Codes. During the times of design and analysis, one must have the understanding and knowledge of structure, and ways one how to do or how to apply the methods.

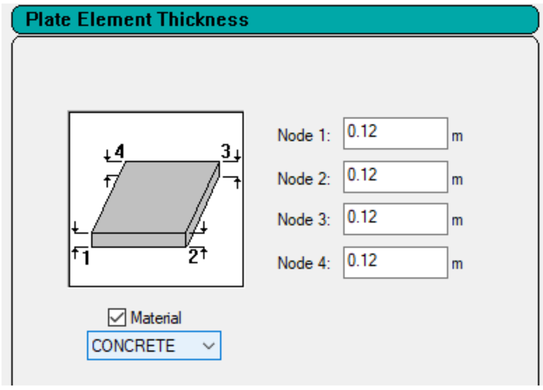
4.1 Modelling Considerations

4.1.1 Definition of Material Properties

The materials that are used in the design are concrete and steel. The concrete is defined as M25 and the steel of Fe415.

4.1.2 Definition of Slab/Element Thickness

The slab thickness provided was 120mm thick for all the slabs and elements, and the material is concrete.



4.1.3 Definition of Load

Dead Load includes the Self-Weight of the structure along with wall loads, floor load and parapet wall load. The unit weight of each material is considered as per IS.

- Exterior wall (230mm thick + 20mm wall finish) = 15.24 kN/m
- Interior wall (115mm thick + 20mm wall finish) = 7.62 kN/m
- Parapet wall (230mm thick + 20mm wall finish, 1m height) = 6.25 kN/m

- Floor load = 5kN/m2
  - Slab load (120mm thick) = 3 kN/m2
  - Floor finish load = 1kN/m2
  - Furniture load = 1kN/m2

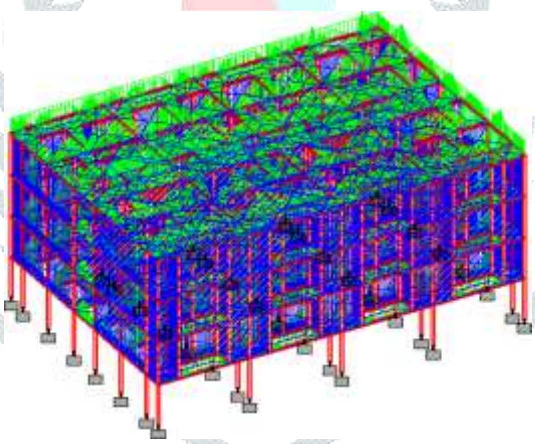


Figure 4.1.3(a): Dead Load acting upon the Building

Live Load is applied as per the IS 875 Part II: 1987. The intensity of the live load for the residential building is given as 2kN/m2.

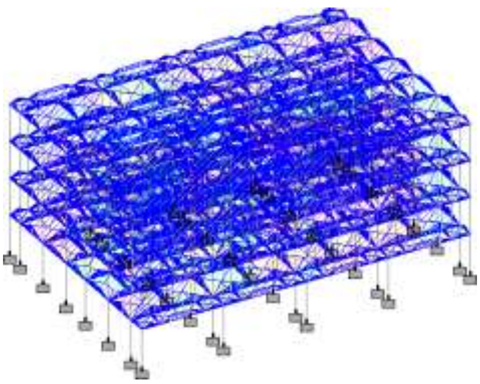
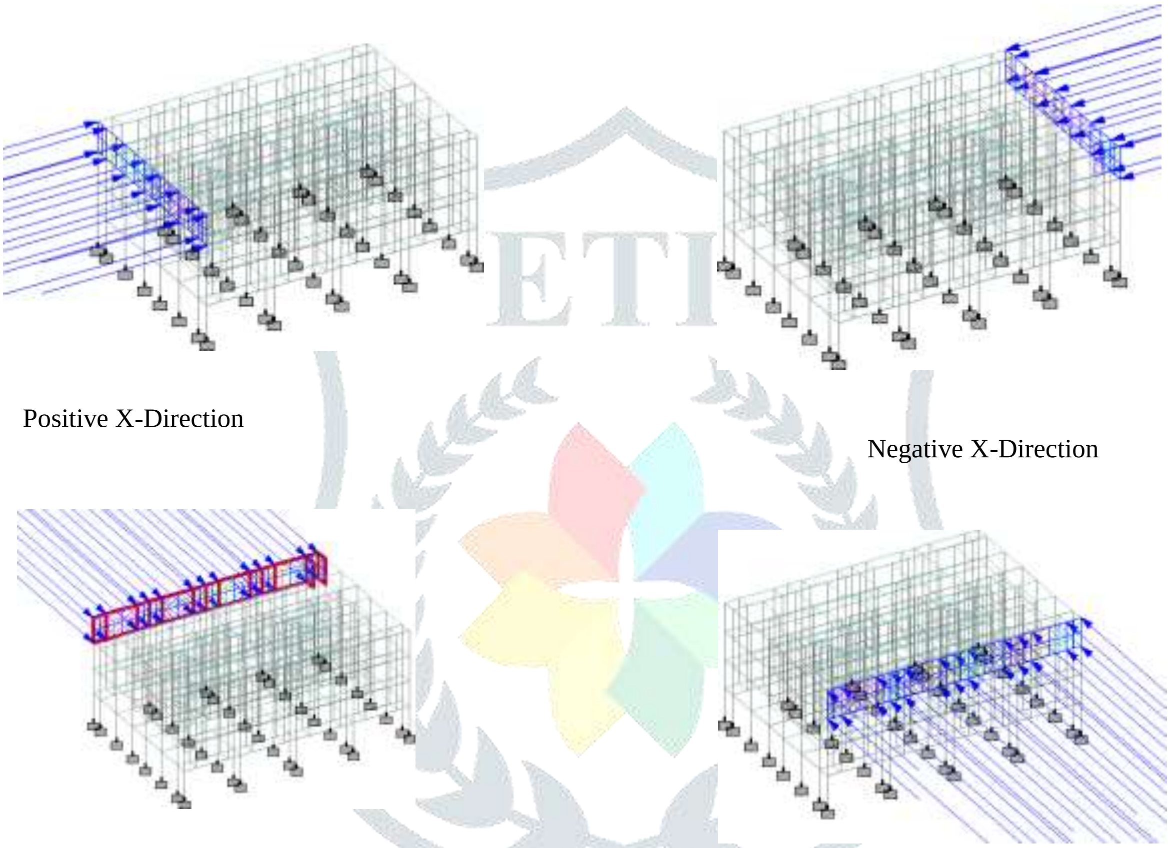


Figure 4.1.3(b): Live Load

Seismic or Earthquake Load is applied along positive X-direction, negative X-direction, positive Z-direction and negative Z-direction as per IS1893 Part I. During the definition of load, Zone IV was considered.

- 4 : EQX
  - 1893 LOAD X 1
- 5 : EQZ
  - 1893 LOAD Z 1
- 20 : EQ-X
  - 1893 LOAD X -1
- 21 : EQ-Z
  - 1893 LOAD Z -1

Wind Load is also applied in all four directions like seismic load (+X, -X, +Z & -Z directions), but the application of the load is only on the top floor of the building (height of 9.144m to 12.192m).
The intensity of wind is 1.4752 kN/m2 calculated considering the location of the building as Punjab, India.



Positive X-Direction

Negative X-Direction

Positive Z-Direction

Negative Z-Direction

Figure 4.1.3(c): Wind Load Applied on Building

4.2 Application of Load Combination
Following are the 15 Load Combinations that could possibly act on the building.

- 9 : 1.5(DL+LL)
- 10 : 1.2(DL+WLX+EQX)
- 11 : 1.2(DL+WL-X+EQX)
- 12 : 1.2(DL+WLZ+EQZ)
- 13 : 1.2(DL+WL-Z+EQZ)
- 14 : 0.9DL+1.5EQX
- 15 : 0.9DL+1.5EQZ
- 16 : 0.9DL+1.5WLX
- 17 : 0.9DL+1.5WL-X
- 18 : 0.9DL+1.5WLZ
- 19 : 0.9DL+1.5WL-Z
- 22 : 1.2(DL+WLX+EQ-X)
- 23 : 1.2(DL+WL-X+EQ-X)
- 24 : 1.2(DL+WLZ+EQ-Z)
- 25 : 1.2(DL+WL-Z+EQ-Z)

After the addition of load combination, following are the Deflections, Bending Moment Diagram and Shear Force Diagram.

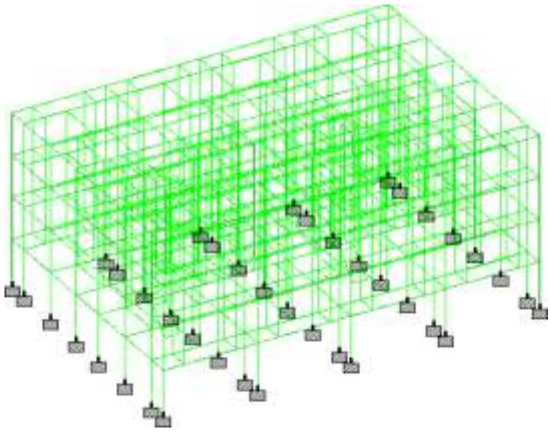


Figure 4.2.1: Deflection Diagram

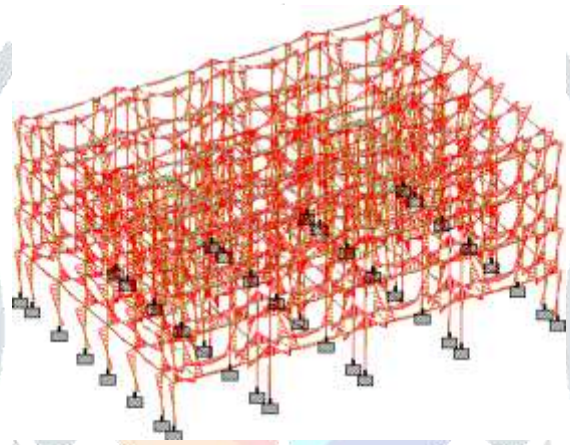


Figure 4.2.2: Bending Moment Diagram

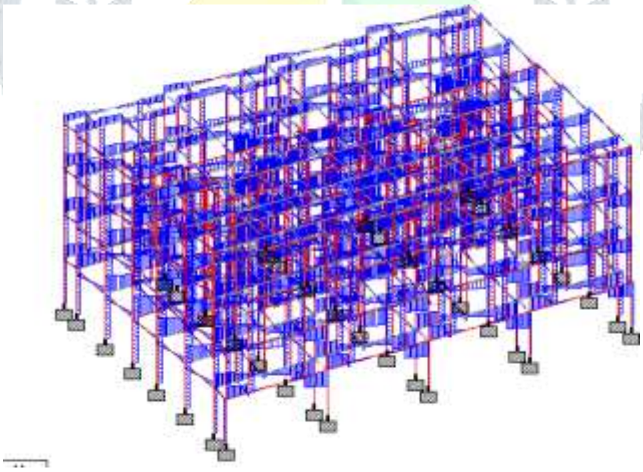


Figure4.2.3: Shear Force Diagram

4.2 Design of RCC Elements

Reinforced Cement Concrete elements includes Beams, Columns and Slabs. Following are the design of each elements from the software (STAAD.Pro)

4.2.1 Design of Beam

There are two types of Reinforced Concrete beams:

Singly Reinforced Beam: In this type of beam, steel bars are placed near to bottom of beams where they are effective in resisting of tensile bending stress.

Doubly Reinforced Beam: It is reinforced under the compression tension region. The necessities of steel of compression region arises when the depth of the beam is restricted and the strength availability singly reinforced beam is in adequate.

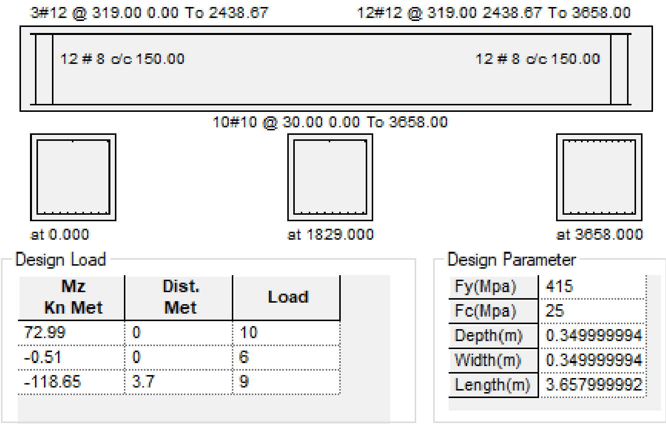


Figure 4.2.3: Beam Design

4.2.2 Design of Columns

A column may be defined as an element used primarily to support axial loads with a height of a least three times its lateral dimension. The strength of column depends upon the strength of materials, shape, cross-sectional area, length and degree of proportional and dedicational restrain at its end.

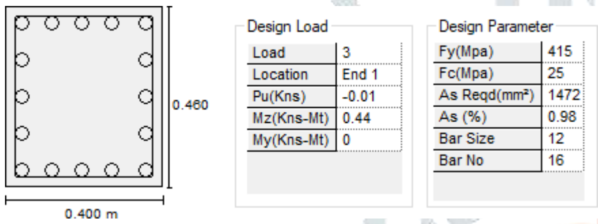


Figure 42.2(a): Column Design for C1

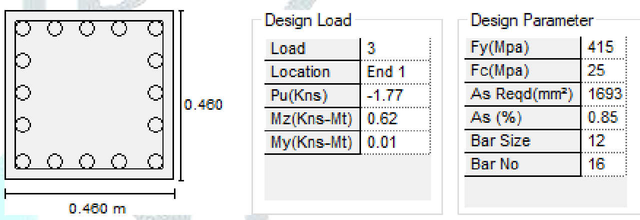


Figure 4.2.2(b): Column Design for C2

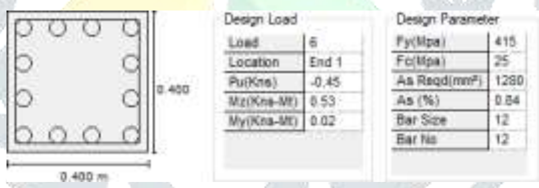


Figure 4.2.2(c): Column Design for C3

4.2.3 Slab Design

There two types of slaps classified as One-Way Slab and Two-Way Slab by the ratio of their longer length to the shorter length. Following are the differences between 1-way and 2-way slabs.

One Way Slab	Two Way Slab
One-way slab is supported by beams in only two sides.	Two-way slab is supported by beams in all four sides.
The ratio of longer length (ly) to shorter length (lx) is equal or greater than 2. (ly/lx>=2)	The ratio of longer length (ly) to shorter length (lx) is lesser than 2. (ly/lx<2)
Main reinforcement is provided in only one direction. It is found in balconies and staircases.	Main reinforcement is provided in both the directions.

Table 4.2.3: Difference between One-way and two-way slab.

4.3 Manual Design of Slab and Beam

4.3.1 Slab Design

Slab Panel = 6.782m x 8.078m

Live load = 2kN/m^2

f_{ck} = 25N/mm^2 f_y = 415N/mm^2

Step 1: Determination of type of slab

ly= 8.078m, lx=6.782m

Therefore, l_y/l_x=1.19 < 2, so it is two-way slab

Step 2: Fixing the depth of Slab

l/d =20 (for simply supported) --- IS456: 2000 (page 37)

therefore, l_x/20=d

d= (6.782x103)/20 = 169.55mm. So, assume d=170mm

Assuming Cover as 15mm = d'

D = d+d' = 170+15= 185mm

Step 3: Calculation of effective depth (Page 34, IS456)

(a) Effective span for lx
   a. Clear span + effective depth = 6.782 + 0.17 = 6.952m
   b. C/C distance between support = 0.15 + 6.782 + 0.15 = 7.082m (bearing= 300mm)
   So, l_x = 6.953m (least)

(b) Effective span for ly
   a. Clear span + effective depth = 8.078 + 0.17 = 8.248m
   b. C/C distance between supports = 0.15 + 8.078 + 0.15 = 8.378m
   So, l_y = 8.378m

Step 4: Load Calculations

i. Dead Load or Self weight of slab (W_D)
   W_D = 0.185 x 1 x 25 = 4.625kN/m^2

ii. Live Load (W_L) = 2kN/m^2

iii. Finishing (assuming thickness of slab = 120mm)

= 0.12 x 1 x 24 = 2.88kN/m^2 (Providing with plain cement finishing)

Therefore, total load (W) = 9.505kN/m^2, Ultimate load (Wu) = 1.5 x 9.505 = 14.2575 kN/m^2

Step 5: Calculation of Bending Moment

B. M along l_x = M_x, B. M along l_y = M_y

Using IS method (page 91)

$Mx = \alpha_x W_u l_x^{\,2}$

$My = \alpha_y W_u l_x^{\,2}$

For ly/lx = 1.19, (Table 27)

By interpolation,

αx = 0.083, αy = 0.0592

Therefore,

M_x = 0.082 x 14.2475 x 6.9522 = 56.503 kN-m

M_y = 0.0592 x 14.2475 x 6.9522 = 40.793 kN-m

Now, calculating effective depth required.

$d_{req} = \sqrt{\frac{\square\square}{0138\ \square\square\square\ \square}} = \sqrt{\frac{56.503\ \square\ 10^6}{0138\ \square\ 25\ \square\ 1000}}$ = 127.9mm < $d_{provided}$ (170mm). Hence safe.

Step 6: Calculation of Area of Reinforcement (A_{st})

- Use 8mm Dia bars along both span
- Shorter span steel will be kept below longer span steel as $M_x > M_y$

d_x = 170mm, $d_y = 170 - \frac{8}{2} - \frac{8}{2} = 162$mm

Steel along short span (Ast along lx)

$(Ast)_x = \frac{0.5\square\square\square}{\square\square}[1-\sqrt{1-\frac{4.6\square\square\square}{\square\square\square\ \square\ \square\square^2}}]$ bdx = 1023.27mm^2

$(Ast)_y = \frac{0.5\square\square\square}{\square\square}[1-\sqrt{1-\frac{4.6\square\square\square}{\square\square\square\ \square\ \square\square^2}}]$ bdy = 756.41mm^2

Check for Minimum A_{st}
$(Ast)_{min}$ = 0.12% bD (for Fe415 & Fe500)
$(Ast)_{min}$ = 222mm2
Therefore, $(Ast)_x$ and $(Ast)_y$ > $(Ast)_{min}$, hence safe.

Now, for 8mm Dia bar
$a_{st} = \frac{□}{4} d^2 = 50.26mm^2$

Spacing for short span
$S_x = \frac{ast}{(□□□)□}$ x b = $\frac{50.26}{1023.27}$ x 1000 = 49.11mm^2, therefore provide spacing of 50mm^2

<u>Step 7: Check for Shear</u>
$V_{ux} = W_u l_x / 2$ = (14.2575 x 6.952)/2 = 49.56kN
$V_{uy} = W_u l_x / 2$ = (14.2575 x 8.248)/2 = 58.79kN

Now, $\tau_{vx} = \frac{□□□}{□ □□}$ = 0.29 N/mm^2, $\tau_{vy} = \frac{□□□}{□ □□}$ = 0.36 N/mm^2

Percentage of steel; = $\frac{□□□ (□□□□□□□□□)}{□ □□}$ x 100 = 0.6%
For 0.6% steel, (table 19)
From interpolation, design shear, τc = 0.522 N/mm^2
Therefore, τ_{vx} and τ_{vy} < τc. **Hence safe.**

4.3.2 Beam Design

Size = 350mm x 350mm
Load acting on the beam
Self-weight = 0.35 x 0.35 x 25 = 3.0525 kN/m^2
Dead Load = 15.24 kN/m^2 (outer wall load)
Live Load = 2 kN/m^2

Total load = 20.3025kN/m^2
Ultimate load, Wu = 1.5 x 20.3025 = 30.45kN/m^2

Effective length, le = 6.782m

<u>Moment of Resistance</u>
Md = $\frac{□□ □ □^2}{2} = \frac{30.45 □ 6.782^2}{2}$ = 700.4 kN-m

<u>Main Steel Area</u>

$(Ast)_{req} = \frac{0.5□□□}{□□}[1-\sqrt{1-\frac{4.6□□□}{□□□ □ □□^2}}]$ bd = 243.9mm^2
Using 8mm dia bars
Area of bar = 50.24mm^2
Number of bars = 243.9/50.24 = 5.45, so provide 6 number of bars

Therefore, $(Ast)_{provided}$ = 6 x 50.24 = 301.44 mm^2
Since, (Ast)req < (Ast)provided, design is safe.

<u>Design of shear</u>
$V_u = W_u$ x le = 30.45 x 6.782 = 206.5 kN
$\tau_v = \frac{□□}{□ □}$x100 = 0.16 N/mm^2

for $\frac{□□□ □ 100}{□ □}$ = 0.19, τmax is: (IS456, page 73)

τ_{max} = 0.28 N/mm^2
Since $\tau_{max} > \tau_c$, **the design is safe.**

V. RESULT AND DISCUSSIONS

5.1 Results

5.1.1 Bending Moment of the Regular Building

The figure below shows that the beams undergo sagging in the middle portion and hogging at the end portion due to self-weight. Hence, behaving like a continuous beam.

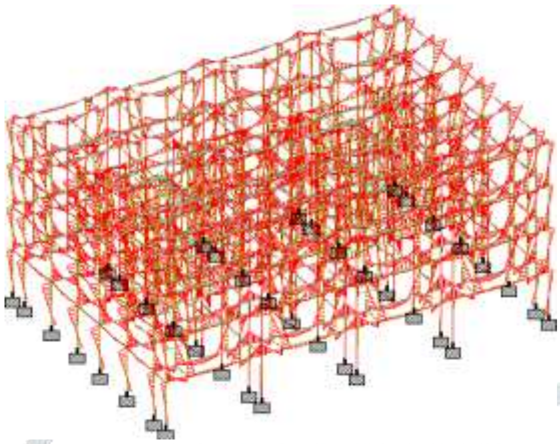


Figure 5.1.1: Bending Moment Diagram

5.1.2 Stress for Structure

The Absolute Maximum Stress diagram of each floor is given by the figure below.

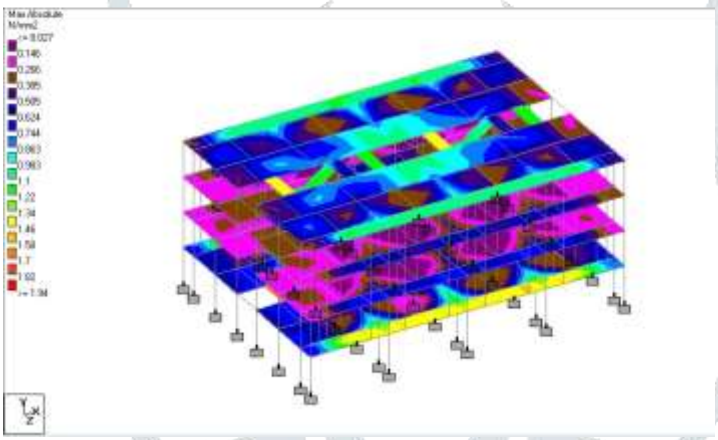


Figure 5.1.2: Absolute Maximum Stress Diagram

5.1.3 Shear Bending and Deflection of Beam

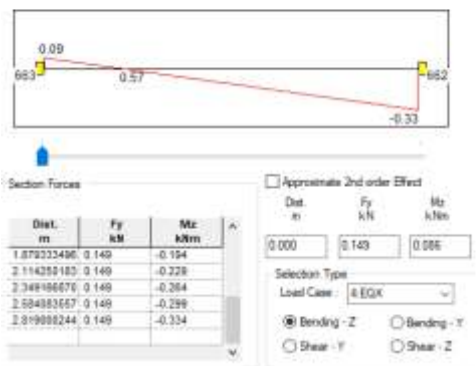


Figure 5.1.3(a): Shear Bending of Beam

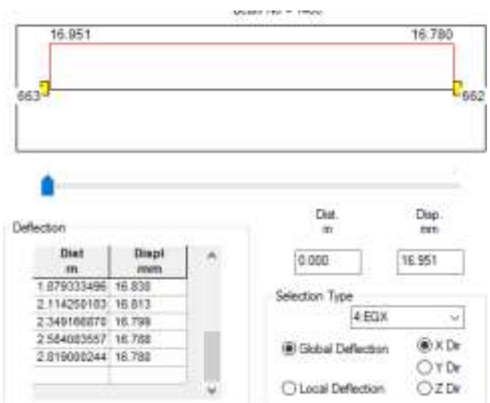


Figure 5.1.3(b): Deflection of Beam

5.1.4 Shear Bending and Deflection of Column

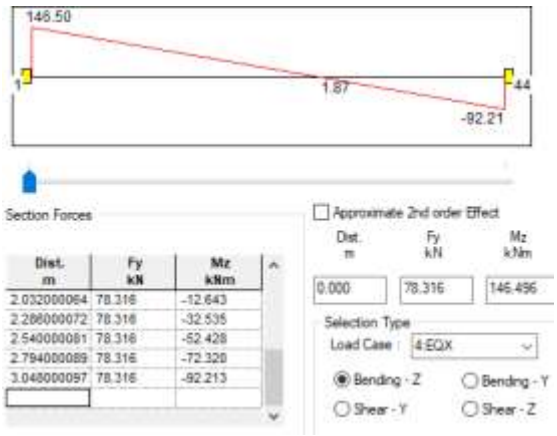


Figure 5.1.4(a): Shear Bending of Column

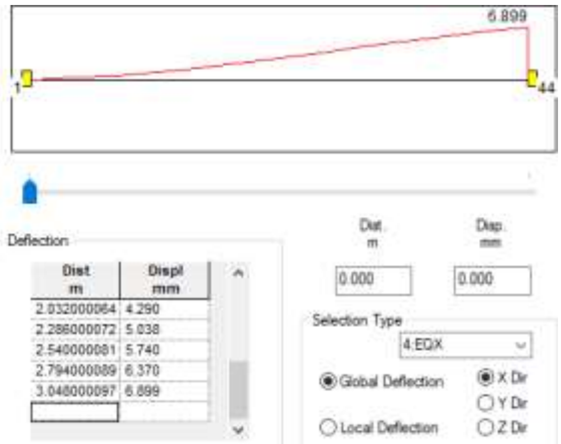


Figure 5.1.4(b): Deflection of Column

5.1.5 Storey Shear

It is found out that the shear decreases with increase in height.

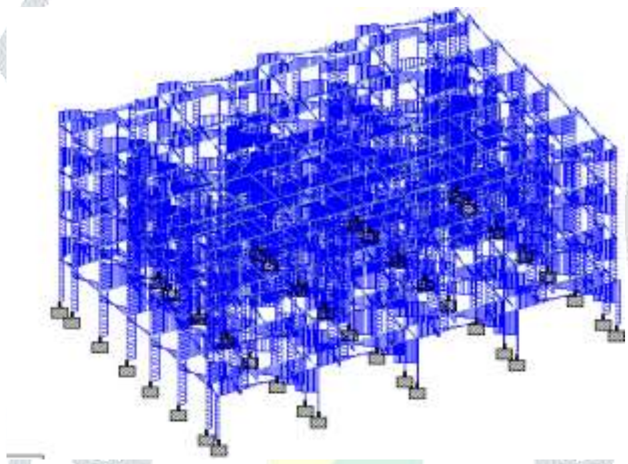


Figure 5.1.5: Shear Force acting on the Structure

VI. CONCLUSION

STAAD Pro software has become more and more critical in the analysis of any engineering structures as well as scientific problems. Much of the reason for this change from manual methods has been the advancement of computer techniques development by the research community and in particular universities taking advantages of its fast and efficient platform.

However, following are differences in result obtained from manual calculations and STAAD Pro.

1. Total Area of Reinforcement in Beams required was 229.4 mm2 given by the software whereas area of 243.9 mm2 was obtained manually.
2. Area of Reinforcement in Slabs obtained manually was 1023.7 mm2 in lx and 756.45 mm2 in ly direction. After the STAAD Pro design, the area of steel (reinforcement) to be provided was calculated to be 108 mm2 in both longer and shorter span.
3. The shear reinforces of 2 legged 8mm Dia @ 150mm c/c was provided for the beam.
4. The maximum Deflection of beam was found to be 17.082mm and 14.658mm in column.

Therefore, it is observed that the reinforcement area is more in case of manual design compared to software design. Thus, after the analyzing and discussing, it can be concluded that the structure has fulfilled the requirements of the structure in terms of serviceability and safety.

VII. ACKNOWLEDGMENT

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