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"Analysis & Design of Structural Elements of Residential Building Located at Spencer Road, Bangalore"

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Abstract: An RCC framed structure is basically an assembly of slabs, beams, columns and foundation inter - connected to each other as a unit. The end goal of the structural analysis is to develop the necessary appreciation of behavior and to compare expected performance with the stated requirements. The purpose of standards is to ensure and enhance the safety, keeping careful balance between economy and safety. Th main purpose of the article is to design the loads structural components with the primary loads with structural stability and serviceability of the design effort which involves the validation of defection.

Keywords: Beam, Slab, Column, RCC Design

1. Introduction

To safely carry gravity and lateral loads, high-rise building design entails a conceptual design, approximate analysis, preliminary design, and optimization. Strength, serviceability, stability, and human comfort are the design criteria. A high-rise building is one that is 35 metres or higher in height and is divided at regular intervals. High-rise buildings are generally preferred because they reduce the cost of land in congested areas and where space is limited. High rises are now proliferating, particularly in cities, due to increased demand for high rises and decreased availability of space.

Engineers, researchers, and decision makers have generally used linear static elastic finite element analysis, including summations of vertical column loads, to determine the behaviour of structures. As the height of the building increases during the construction phase, the structural responses, i.e. axial loads, bending moments, and displacements, of such typical analysis may diverge from actual behaviour. Time-dependent, long-term deformations in response to the construction sequence can cause redistribution of responses that conventional methods would not compute and consider. This analysis was complex in nature, and many parameters had to be considered during the analysis. However, advances in finite element modelling and simulation have made nonlinear analysis simple, well-managed, and popular among engineers, researchers, and decision makers, thereby accelerating the proper design of structures, particularly high-rise structures. Construction sequential analysis is becoming an essential part of analysis, with many well-known analysis software packages including this feature in their analysis and design packages. However, this nonlinear static analysis is not widely used due to a lack of understanding about its importance and scope.

Construction sequential analysis, like many other types of analysis, serves a specific purpose during the design phase of a structure. As previously stated, it deals with nonlinear behaviour under static loads in the form of sequential load increment and its effects on structure, taking into account that structural members begin to react to load prior to completing the entire structure. For finite element analysis, one of the industry's leading analyses software's, "ETABS Version 18.1.1," is used, and all moment and axial load outcomes are measured in KN-m and KN, respectively.

2. LITERATURE REVIEW

P.P. Chandurkar et. al. (2013)[1] focuses on the G+9 building study: Had presented a study of a G+9 building with each storey three metres tall. The entire building design was carried out in accordance with the IS code for seismic resistant design, and the structure was considered fixed at the base. The design structural element was assumed to be square or rectangular in section. They modelled the building using ETAB software, and four different models were studied with different shear wall positions.

Varalakshmi V et.al (2014)[2] analysed and designed a G+5 storey residential building's various components such as beam, slab, column, and foundation The loads, namely dead load and live load, were calculated in accordance with IS 875(Part I & II)-1987[3], and HYSD bars, namely Fe

415, were used in accordance with IS 1986- 1985. They came to the conclusion that the safety of a reinforced concrete building is determined by the initial architectural and structural configuration of the entire structure, the quality of the structural analysis, design, and reinforcement detailing of the building frame to achieve element stability and ductile performance.

Prof. S .Vijaya Bhaskar Reddy et. al (2018)[4] primary goal of this research is to conduct a thorough examination of the simulation tools ETABS and STAAD PRO, which were used for the analysis and design of a rectangular plan with vertical regular and rectangular plan with vertical geometrically irregular multi-story building.

Barkha Verma, Anurag Wahane (2019)[5] studied to analyze the seismic response of a G+9 storey RCC frame structure with varying soil conditions (Hard, Medium, and Soft soil) for seismic Zone V was studied and compared using the latest software package STAAD Pro.

3. OBJECTIVES

The entire process of structural planning and design necessitates not only imagination and conceptual thinking (which constitute the art of designing), but also solid knowledge of structural engineering science, as well as practical aspects such as relevant design codes and bye-laws, backed up by ample experience, intuition, and judgement. The goal of structural design is to plan a structure that meets the basic structural design requirements. Serviceability, safety, durability, economy, aesthetic value, feasibility, practicability, and acceptability are all factors considered during the design process.

4. METHODOLOGY

This article is based on pre-existing plan of residential building proposed to construct at Spencer Road, Bangalore.A general description of the project is such that, there are 2 basements which are used for parking ang utilities with G+17 upper floors with lift core and overhead tank, staircase, gym room etc. The soil under building site is designed for raft foundation for which 200mm piles to be drilled and filled with the lean concrete at 75mm c/c.

The study is frame analysis and detailing STAAD Pro, ETABS, Framewin, SAFE, SAP2000. The size of column in frame is 0.2 X 0.65 m. The size of beams is taken as 0.2 X 0.45 m. The Slab thickness of each frame cases is 125 mm. In this study, the material used in RCC frame is concrete of M25, M30, M35, M40, M45 Grade & steel of Fe415 Grade.

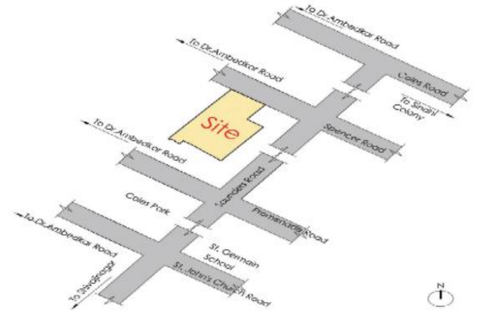


Fig. 1 Location Map of Spencer

Fig.2 Architectural & Software Modelling of Existing Study Plan

4.1 Load Calculation for the Analysis

The load considered in the software is primary loads & their load combinations according to IS 456:2000[6] & SP 16[7]. The primary loads commonly used such as Dead Load, Super dead Load, Live Load (LL), Roof Live load (RLL). The total Super Dead Load (SDL) on Slab is 1.33 KN/m^2. Stair Case Load Calculation with R = 150 mm and T = 250 mm, the inclined length of each step = {(150)^2 + (250)2} ½ = 291.54 mm. Self-weight of waist-slab = 25(0.15) (291.54)/250 = 4.20kN/m^2, Self-weight of steps = 25(0.5) (0.15) = 1.8kN/m^2, finishes (given) = 1.0 KN/m^2.

5. RESULTS AND DISCUSSIONS

5.1 Design of Beam

The beams size considered is 200 x 650 mm, the assumed characteristic strength of concrete and steel is 25 N/mm^2 & 500 N/mm^2.From ETABS, analysis

Ultimate Moment, M_u=135.779 KN-m

Torsional Moment, T_u = 10.91 KN-m

Shear force, V_u = 162.91 KN

As we known, $M_t = (T_u/1.7)\{1 + (D/b)\}$ ………………(1) $M_t = (10.91/1.7)*\{1+(800/200)\} = 35.29$KNm

Since, Equivalent Moment,

$M_{e1} = M_u + M_t$ ……………………(2)

$M_{el} = 135.779 + 35.29 = 171.077$KNm

$D_{required} = \sqrt{((171.077X10^6)/(0.1336x25x200))}$

$=506.066 < d_{provided}$

Therefore, section is designed as singly reinforced beam.

$M_{e1}/bd^2 = (171.077*10^6) / (200*850*850) = 1.18$

From Table 3 of SP-16, corresponding to

$M_u/bd^2 = 1.18$, we have $p_t = 0.2878$. So,

$A_{st} = 0.2878(200) *(850)/100 = 491.07\ mm^2$.

Provide 3-10 mm dia. in tension and 2-10 mm dia. in compression

$V_e = V_u + 1.6(T_u/b) = 162.90 + 1.6(10.91/0.20) = 249.28$ KN

Equivalent shear stress, $\tau_{ve} = (V_e/ bd) = (249.28x10^3) /(200 x 850) = 1.466N/mm^2$

From (Table 20: IS 456), $\tau_{c\ max} = 3.1\ N/mm^2$. Section does not need revision. Since $\tau_{ve} < \tau_{cmax}$

From Table 19, for value of pt = 1.18, $f_{ck} = 25$ we get, $\tau_c = 0.37\ N/mm^2$ and concluded that $\tau_c < \tau_{ve}$

- **Shear reinforcement required**

Assuming 2L stirrups of 10mm dia

$V_{us} = (\tau_{ve} - \tau_c)*b*d = (1.466-0.37)*200*850 = 186.32$ KN

$S_V = (0.87*f_y*A_{sv}*d)/V_e$

$V_{us} = (0.87x415x2x50.2x850)/(249.27x10^3) = 123$ mm (Minimum=120mm)

Provide 8mm Dia. 2L @120mm C/C

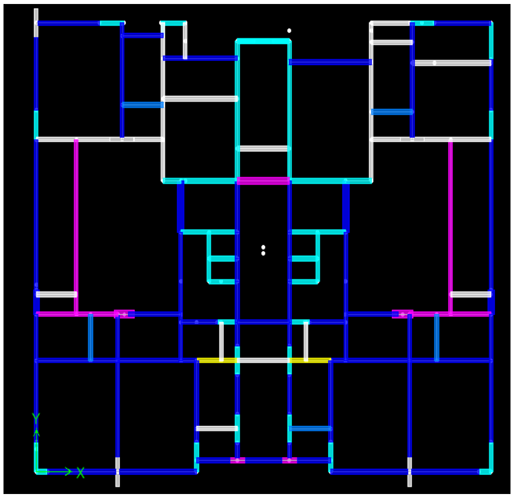


Fig. 3 Plan View of Beam Placement

5.2 Design of Slab

$L_x = 4.05$ m , $L_y = 4.6$ m

$(L_y/L_x) = (4.60 / 4.05) = 1.13 < 2$

F_{ck} = 25 N/mm2
F_Y = 500 N/mm2
Self-weight of the slab = (0.15 x 25) = 3.75 KN/m²
Floor Finish = 1.33 KN/m²
Live Load = 2 KN/m²
Total service load = w = 7.75 KN/m²
Ultimate Load = wu = (1.5 x 8.75) = 11.63 KN/m²

- **Short Span Moments**

At Continuous Edge:

$M_x = 0.056X11.63X4.05^2 = -10.68$KN-m

At Mid Span:

$M_x = 0.042 x 11.63x4.05^2 = +8.011$ KN-m

- **Long Span Moments**

At Continuous Edge:

$M_x = 0.047 x 11.63X4.05^2 = -8.96$KN-m

At Mid Span:

$M_x = 0.035 x 11.63X 4.05^2 = +6.68$ KN-m

❖ Check for effective depth required:

M_u = 10.68 KN-m , $d_{req} = \sqrt{\frac{Mu}{0.138 f_{ck} b}}$

d_{req}= 55.63 mm < Provided 150 mm(Safe)

❖ Calculation of Reinforcements:

M_{ux} - ve = - 10.68KN-m ,M_{ux} + ve = + 8.011 KN-m

M_{uy} - ve = -8.96KN-m , M_{uy} + ve = + 6.68 KN-m

At Continuous Edge of short span

M_u/bd^2 =0.73 , From SP 16, P_t = 0.178%

A_{St} = 215.38 mm^2, Assuming #8 mmBars

c/c spacing = (50.26 x 1000 / 215.38) = 233.35 mm

Spacing should exceed:

- 3d = 3 x 125 = 375 mm
- 300 mm

Therefore, Provide #8 @ 220 mm c/c

At mid span of short span

M_u/bd^2 = 0.55, From SP 16, Pt = 0.13 %

A_{st} = 157 mm^2, Min. % of reinforcement required= 0.12 %

$A_{st\ min.}$ = 0.12 x 1000 x 150 / 100 = 180 mm^2

Assuming #8 mm Bars

Therefore, Provide #8 @ 275 mm c/c

At Continuous Edge of long span

M_u/bd^2 = 0.7, From SP 16, Pt=0.167 %

A_{st}= 202.07 mm^2

Therefore, Provide #8 @ 225mm c/c

At mid span of long span

M_u/bd^2 = 0.52 , From SP 16, Pt = 0.11 %,

A_{st}= 133 mm^2 , Min. % of reinforcement = 0.12 %

$A_{st\ min.}$ = 0.12 x 1000 x 150 / 100 = 180 mm^2

A_{st} = 180 mm^2

Therefore, Provide #8 @ 275 mm c/c

❖ Check for shear

$M_{ux} = w_u l^2/8$

10.8 = w_u*(4.05^2) / 8

w_u = 5.26 KN

Therefore, $V_{ux} = w_u l / 2$ = 5.26*4.05 / 2= 10.65KN

$\tau_u = V_{ux}$ / bd= 10.65*10^3 / (1000*121) = 0.088 N/mm^2

From IS: 456, , P_t= 215.38*100 / (1000*121) = 0.178%

τ_c = 0.78 N/mm^2 , Here $\tau_u < \tau_c$ * ok

Hence safe in shear.

❖ Check for deflection

Pt=0.12%

F_s = (0.58 X f_y X Area of c/s steel required) / Area of c/s steel provided

F_s = (0.58 X 500 X 180) / 215 =242

For Pt=0.12, Modification factor Kt =1.769

(L/D) max=26 X Kt=20x1.769=45mm

(Lx/D) provided=4050/150=27mm

(Lx/D) provided < (L/D) max. Hence, Safe in deflection.

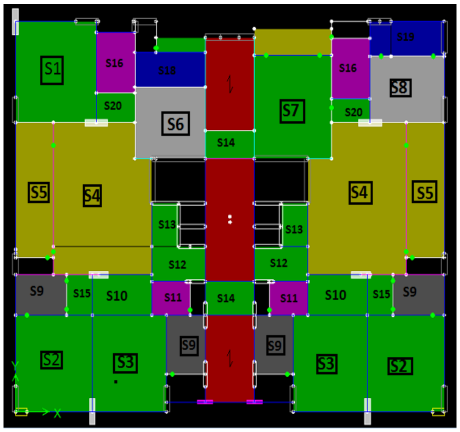


Fig. 4 Slab details

5.3 Design of Column

Location: PC (first floor) , cover: 50 mm

Column size: 300mmX1200mm, grade of concrete Fck = 45 N/mm^2 , Load Pu=1487.49KN & floor height = 3050 mm

- **Factored moments @ bottom**

Mux = 38.918KN-m, beam depth= 600mm

Muy= 75.56 KN-m , effective length of column= 2450 mm

- **Factored moments @ top**

Mux = 32.11KN-m

Muy= 86.31 KN-m

Length of the column Lx= 2450 mm, Ly=2450 mm.

Lx/Dx = 2450/300 =10.166<12 within the limit.

Ly/Dy =2450/1200 =2.54<12 within the limits.

- **Check for minimum eccentricity**

$e_x=(L_x/500)+(b/30)=(2450/500)+(300/30)=16.1<20mm$

$e_y=(L_y/500)+(d/30)=(2450/500)+(1200/30)=46.1<20mm$

- **Minimum eccentric moments**

$Mx=P*e_x=1487*20 /1000=29$ KN-m

$My= P*e_y =1487*46.1/1000=68.57$KN-m

Pu = 1487.49KN

Mu = 32.11KN-m

Mu= 86.31 KN-m

Trail 1: assume reinforcement percentage= 0.8%.

$Ac=B*D=300x1200=360000mm^2$

$As =(pt*B*D)/100= 2880\ mm^2$

Puz = 0.45fck*Ac+0.75*fyAst =8370KN

$Pt/f_{ck}= 0.8/45 =0.017$

$Pu/(f_{ck}bd) =1487.5*10^3/(45*300*1200) =0.0918$

Uniaxial moment of the section about X-X axis

d'/D =50/300 =0.15

From graph of Sp 16-page no. 139, take two side reinforcement,

$Mux1/fckbD^2 = 0.045$

$Mux1=0.045*45*300*1200^2=874.8$ KN-m

Uniaxial moment of the section about Y-Y axis

d'/D =50/1200 = 0.05

From graph of Sp16 page no. 132, take two side reinforcement,

$Muy1/fckbD^2 = 0.051$

$Muy1 = 0.051 *45*1200*300^2 = 247.86$KN-m

Pu/Puz =1487.5/8370=0.1778

From SP16, page no.104 we get, $\alpha_n =1$

$$\left(\frac{M_{ux}}{M_{ux1}}\right)^{\alpha_n} + \left(\frac{M_{uy}}{M_{uy1}}\right)^{\alpha_n} \leqslant 1{\cdot}0$$

$= (32.1/874.8)^1 +(86.31/247.86)^1<1$

= 0.3841< 1, Hence safe.

Hence adopt 0.8% of $BD=0.8*300*1200/100=2880mm^2$

Provide 16T of 12 no's two sides equally.

- **Stirrup reinforcement calculations**

As per IS: 456, Clause 26.5.3.2 c, For Compression members, Diameter of lateral ties shall not be less than 1/4th of the largest longitudinal bars and in no case less than 6mm.

The Pitch of transverse reinforcement shall not more than the least of the following distances-

- ❖ The least lateral dimension of the compression member =300mm
- ❖ Sixteen times the smallest diameter of the longitudinal bar to be tied= 16*20=320mm
- ❖ 300mm

Hence provide 8 mm dia at 250mm c/c.

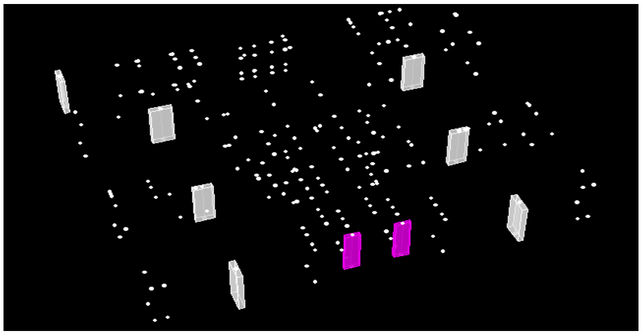


Fig. 5 Columns Position Assigned (3D View)

5.4 Design of Stair case:

Staircase room= 2.6x 4.75m

Floor height=3.05m

Live load =3 KN/m^2

Treads = 300 mm

Rise =145.2mm

Height of each flight=3.05 /2=1.525m

No of rises in each flight = 1500/145.2=11

No of treads in each flight =11-1 =10

Width of landing = 1.2m

Effective span = Going + landing + bearing/2

= (0.3 x 10) + (1.2) + (0.15/2) = 4.3 m

Assuming the waist slab thickness = 150mm

To meet durability of concrete in moderate condition and 2 hrs fire resistance [from table 16 and 16 A of IS 456-2000 pg 47] nominal cover required 30mm.

Taking clear cover = 30 mm

Assuming bar diameter for main reinforcement as 10mm

Effective depth d= 150 - 30 – 10/2= 115 mm

Loads on-going:

Self-weight of slab = 0.150x 25 = 3.75 KN/m^2

Equivalent of this load in plan (on Horizontal plane)

= load on slope x $\frac{\sqrt{R^2+T^2}}{T}$

=3.75 x $\sqrt{}(300^2$+145.22)/300= 4.166KN/m^2

Self-weight of steps = average rise x density

= (0.145.2/2)x25 =1.815 KN/m^2

Live load = 3 KN/m^2

Floor finish (50mm thick) = 0.05 x 25 = 1 KN/m^2

Total load on stair = 4.166+1.815+1+3=9.99 KN/m^2

Factored load w1=1.5*10=15=20

- **Calculations for landing:**

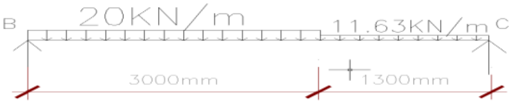
Provide landing slab thickness = waist slab thickness

Dead load of landing=0.15*25=3.75KN

Floor finishes =1 KN

Live load=3KN

Ultimate load w2=11.625



R_a=w_1a(2l-a)+w_2c^2/2L=41.2KN

R_b=w_2c(2l-c)+w_1a^2/2L=33.76KN

M max at X=R1/W1 when R1<w1a =R_1^2/2w

X=2.1 , M max = R_1^2/2w1=42.43 KN-m

❖ **Check for effective depth:**

For balanced section, M_U = $M_{U,lim}$= 0.133 $f_{ck}bd^2$

From SP-16, P_t=0.478 %

A_{St} = 717 mm^2

Main steel; provide 12 # @ 115 mm c/c

Distribution steel: 0.15% of goss area

Provide 8 # @ 200mm c/c.

❖ Check for shear:

Vu= reaction= 41.2KN

τ_u =Vu/bd=41200/(1000*125)=0.3296

Min % of steel 100Ast/bd=0.478, τ_c =0.49

Here $\tau_u < \tau_c$ * ok

$$d = \sqrt{\left(\frac{M_u}{0.133 \text{ X } f_{ck} \text{ X b X } d^2}\right)}$$

$$= \sqrt{\left(\frac{42.43 \text{ X}10^6}{0.133 \text{ X } 25 \text{ X } 1000}\right)} = 112.9\text{mm} < 150\text{mm}$$

Hence it is safe.

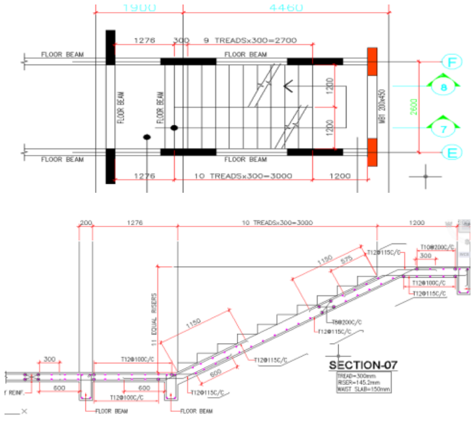


Fig. 6 Plan and elevation of Stair case

CONCLUSION

The study concludes that the need for nonlinear static analysis grows with increasing slenderness, and that each additional floor places a significant load on the columns. With increasing slenderness, the need for sequential analysis that takes into account P-Delta effects, material properties, and nonlinear behaviour of structures becomes a significant issue. Construction sequence analysis is required in both steel and RCC structures to improve analysis accuracy in terms of displacement, axial, moment, and shear force in supporting beams and columns nearby, as well as for the entire structure. Moments and shear in the supporting beam are higher in sequential analysis, which must be considered during the design phase of manual or computer-aided design to avoid cracking of the beam and column due to sequence effects. In addition, I compared the outcomes of linear static analysis and construction sequential analysis. Finally, I concluded that the results of the construction sequential analysis yielded favorable results for the high-rise building.

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