

Analysis and Design of a G+5 Apartment Building Using ETABS: Geotechnical Investigation, Structural Analysis and Manual Design Verification

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Abstract - This paper presents the geotechnical investigation, structural analysis and design of a Ground-plus-five (G+5) apartment building using ETABS software. Site investigation and laboratory soil testing, comprising sieve analysis, standard Proctor compaction and direct shear tests, classified the founding soil and determined its safe bearing capacity using Terzaghi's theory. The building was modelled as a three-dimensional reinforced concrete space frame and analysed for dead and live load combinations per IS 456:2000, with wind and seismic loads evaluated per IS 875 (Part 3):1987 and IS 1893:2002 respectively, though found not to govern the design for this building height and zone. The ETABS concrete frame design module proportioned the beams and columns, and results were independently verified through manual design of a representative two-way slab, doubly reinforced beam, column, isolated footing and dog-legged staircase. The soil was classified as well-graded sand with a design safe bearing capacity of 169 kN/m², and all structural elements designed using M20/M25 concrete and Fe550 steel were found safe, with manual and software-based reinforcement quantities in close agreement. The study confirms that ETABS, combined with a systematic geotechnical investigation, provides a reliable basis for the analysis and design of multi-storeyed apartment buildings.

Key Words: ETABS, geotechnical investigation, bearing capacity, reinforced concrete building, limit state design, seismic load.

1. INTRODUCTION

Rapid urbanisation and the scarcity of land in densely populated cities have made vertical expansion, in the form of multi-storeyed apartment buildings, the practical solution to the growing demand for housing. Structural design of such buildings begins with the architectural plan, from which beam and column layouts are fixed; thereafter dead and live loads are computed, and the slabs, beams, columns and footings are proportioned in that load-transfer sequence, with due regard to serviceability and strength requirements at every stage.

ETABS (Extended Three-Dimensional Analysis of Building Systems), developed by Computers and Structures Inc., integrates three-dimensional object-based modelling, linear and nonlinear analysis, and code-based concrete design within a single environment, and is widely used for the analysis and

design of building structures ranging from single-storey industrial sheds to tall commercial towers. The present study applies this workflow to a G+5 apartment building, with the specific objectives of: (i) investigating the founding soil to determine its classification and safe bearing capacity; (ii) analysing and designing the building using ETABS; (iii) manually designing representative structural components — beam, slab, column, footing and staircase; (iv) comparing the ETABS and manual design results; and (v) preparing reinforcement detailing drawings using AutoCAD.

2. STUDY AREA

The building considered is a G+5 apartment structure with a stilt/ground floor used for common parking, and five identical residential floors above. The overall building footprint is 10.97 m × 21.03 m, with each residential floor comprising a living hall, kitchen, pooja room, store room, three bedrooms with attached toilets, a sit-out, balcony, lawn, lift and a dog-legged staircase, as shown in the key plan (Fig. 1). The centerline layout used for structural planning is shown in Fig. 2.

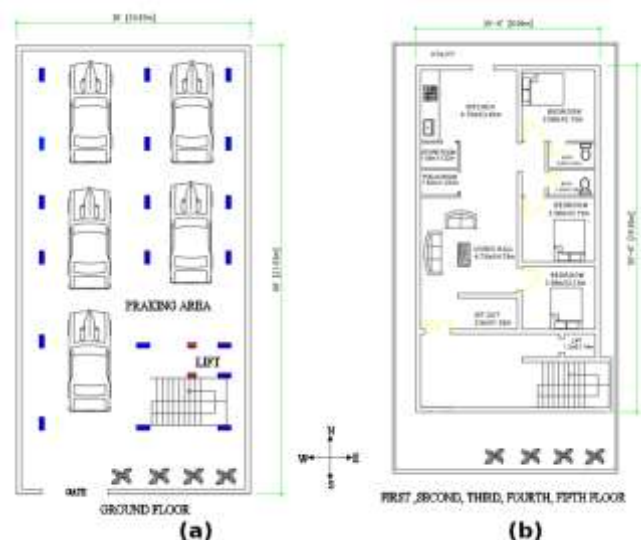


Fig -1: Key plan of the building — (a) ground/stilt floor parking layout; (b) typical residential floor plan (first to fifth floor)

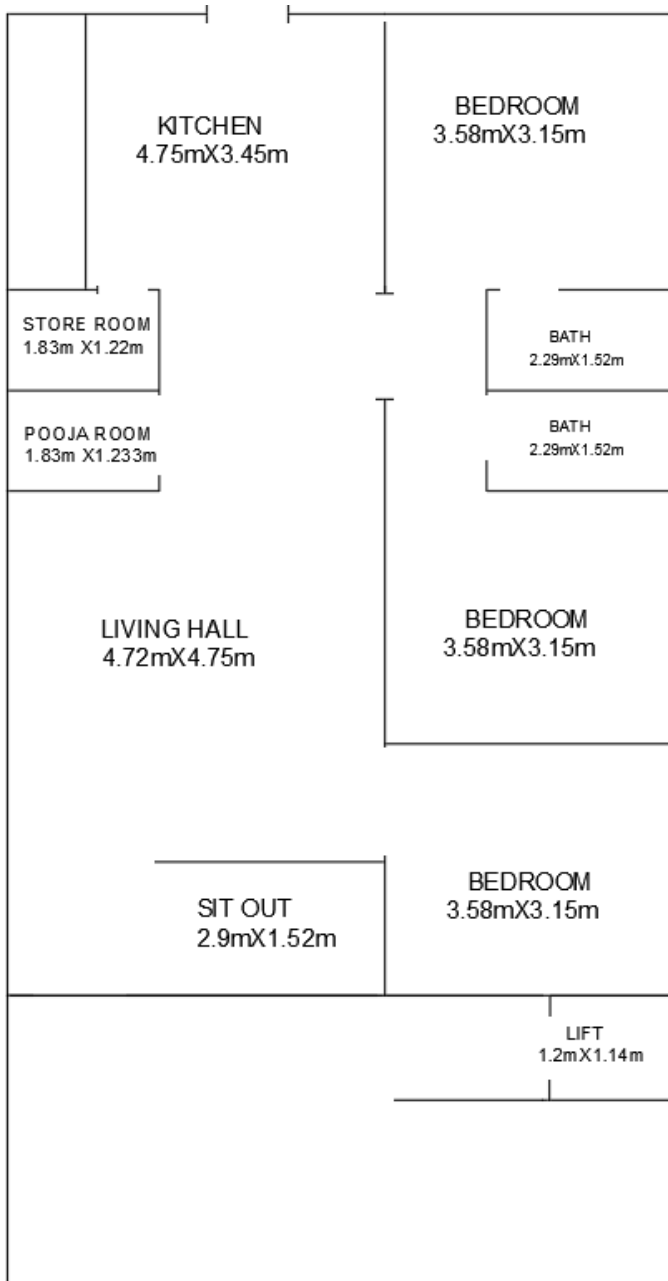


Fig -2: Centerline diagram of the apartment building used for structural planning

2.1 Geotechnical Investigation

A geotechnical site investigation was carried out to determine the soil properties and safe bearing capacity (SBC) required for foundation design, comprising reconnaissance, study of maps and collection of soil samples from trial pits, followed by laboratory testing (Fig. 3): sieve analysis, standard Proctor compaction and direct shear testing.



Fig -3: Geotechnical laboratory tests performed on the collected soil sample — (a) sieve analysis; (b) weighing of the compacted soil specimen for the standard Proctor test; (c) direct shear test in progress

Sieve analysis, carried out in accordance with IS 2720 (Part 4), gave a coefficient of uniformity $C_u = 7.72$ and a coefficient of curvature $C_c = 0.99$, and the soil was classified as well-graded sand (Table 1, Fig. 4a). The standard Proctor compaction test (light compaction, IS 2720 (Part 7)) gave a maximum dry density of 1.86 g/cc at an optimum moisture content of 14.12% (Table 2, Fig. 4b). The direct shear test gave an angle of shearing resistance $\phi = 29^\circ$ and cohesion $c = 0.15 \text{ kg/cm}^2$ (Table 3, Fig. 4c).

Table -1: Grain size distribution values

IS sieve (mm)	Cumulative % finer
0.075	2.2
0.15	6.2
0.3	12.5
0.425	19.5
0.6	31.5
1.18	46.5
2.36	70.5
4.75	92.5

Table -2: Standard Proctor test values

Determination no.	1	2	3	4
Wt. cylinder+soil (g)	6287	6366	6419	6312
Wt. compacted soil (g)	2000	2079	2132	2025
Avg. moisture (%)	10	12	14	16
Wet density (g/cc)	2.00	2.08	2.13	2.03
Dry density (g/cc)	1.80	1.84	1.86	1.75
Moisture content (%)	11.1	13.21	14.12	16.38

Table -3: Direct shear test values

Sl.no.	Normal stress (kg/cm ²)	Shear stress (kg/cm ²)
1	0.5	0.35908
2	1.0	0.49308
3	1.5	0.62708

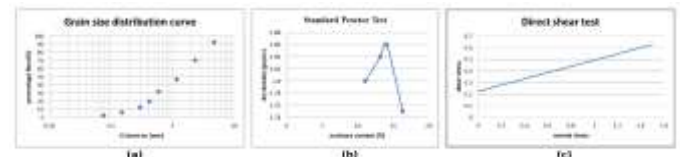


Fig -4: Laboratory test results — (a) grain size distribution curve; (b) standard Proctor compaction curve; (c) direct shear stress–normal stress curve

The safe bearing capacity of the soil was computed using Terzaghi's bearing capacity theory for a square footing, using the bearing capacity factors given in Table 4 for $\phi = 29^\circ$ (interpolated). The ultimate bearing capacity was found to be $q_u \approx 500 \text{ kN/m}^2$, and applying a factor of safety of 3 together with the overburden term, the design safe bearing capacity was obtained as 169 kN/m^2 , which was adopted for the foundation design.

Table -4: Terzaghi's bearing capacity factors (selected values)

ϕ (deg)	N_c	N_q	N_γ
0	5.7	1.0	0
10	9.6	2.7	1.2
20	17.7	7.4	5.0
25	25.1	12.7	9.7
30	37.2	22.5	19.7
35	57.8	41.4	42.4

The overall technical data, materials and specifications adopted for the building are summarised in Tables 5–7.

Table -5: Technical data of the building

Parameter	Value
Number of storeys	G+5
Width of building	10.97 m
Length of building	21.03 m
Floor height	3.0 m
Design SBC of soil	169 kN/m ²
Type of foundation	Isolated/combined footing

Live load	4 kN/m ²
Partition wall load	1.5 kN/m ²
Floor finish load	1 kN/m ²
Grade of concrete	M20 (20 N/mm ²)
Grade of steel	Fe550 (550 N/mm ²)

Table -6: Details of materials used

Material	Unit weight
Reinforced concrete	25 kN/m ³
Brick masonry	20 kN/m ³

Table -7: Specification of the building

Parameter	Value
Area of building	152.28 m ²
Shape of building	Rectangular

3. LITERATURE REVIEW

Varalakshmi et al. [1] analysed and designed a G+5 storey residential building, sizing beam, slab, column and foundation elements for dead and live loads computed as per IS 875 (Parts I & II):1987, using Fe415 HYSD reinforcement as per IS 1786:1985, and concluded that the safety of an RC building depends strongly on the initial architectural and structural configuration and on the quality of analysis, design and detailing.

Chandrashekar and Rajasekar [2] analysed and designed a G+5 storey building under wind and earthquake loading using ETABS, also considering fire-safety aspects of the construction material, and concluded that ETABS is an innovative and time-efficient tool for high-rise building design.

Balaji and Selvarasan [3] carried out static and dynamic analysis of a G+13 storey residential building in ETABS under severe seismic zone and Type II soil conditions, studying storey displacement and base shear for different load cases.

Geethu et al. [4] presented a comparative study of multi-storeyed building analysis and design using STAAD.Pro and ETABS, with planning done as per the National Building Code, and concluded that ETABS predicts higher bending moment and axial force values than STAAD.Pro for the same configuration.

These studies consistently identify ETABS as an efficient platform for three-dimensional analysis and code-based design of RC buildings, which motivates its use in the present study, extended here with a full geotechnical investigation of the founding soil.

4. DATA AND METHODOLOGY

The methodology comprised: site survey and soil investigation (Section 2.1); structural planning and preparation of the centerline diagram in AutoCAD; three-dimensional modelling, loading and code-based design of the building in ETABS; manual verification of representative members; and reinforcement detailing in AutoCAD, as summarised in Fig. 5.

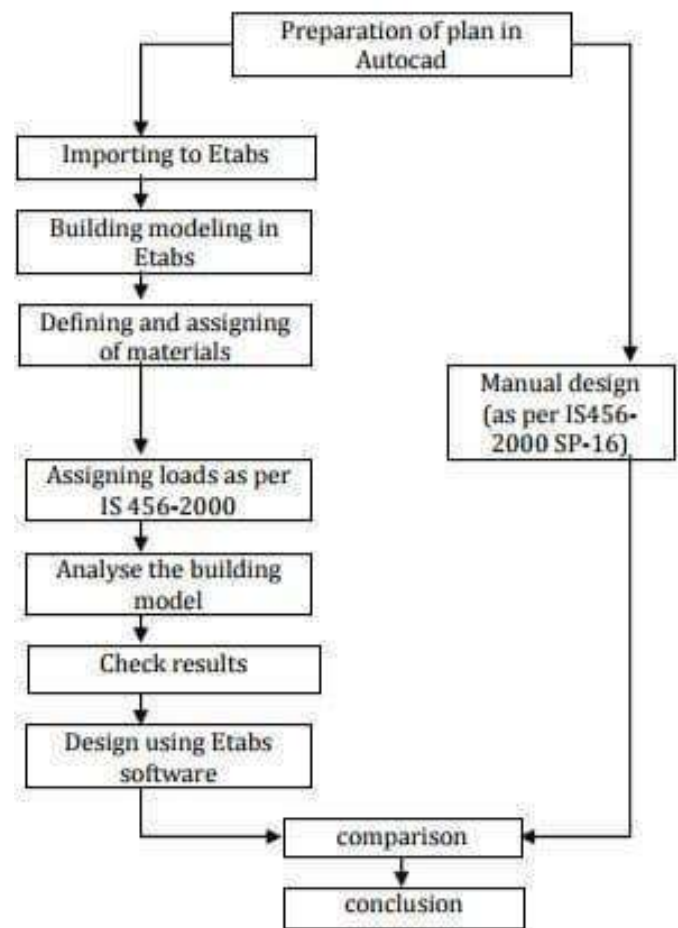


Fig -5: Methodology adopted for the analysis and design of the apartment building

4.1 Design Philosophy and Loads

All members were designed by the limit state method of IS 456:2000, using the design aids of SP-16 and detailing provisions of SP-34. Loads considered were dead loads, imposed (live) loads of 4 kN/m² as per IS 875 (Part 2):1987, wind loads as per IS 875 (Part 3):1987 (basic wind speed 33 m/s, $k_1 = k_3 = 1.0$) and seismic loads as per IS 1893 (Part 1):2002 (Zone II, zone factor 0.10, importance factor 1.0, response reduction factor 3.0). As the building height is within the limits for which wind and seismic loads do not govern low/mid-rise residential buildings up to G+5 in Zone II, gravity load combinations (1.5(DL+LL)) were found to govern the design of all members; snow and temperature loads were not applicable.

4.2 ETABS Modelling and Analysis

The AutoCAD centerline diagram was imported into ETABS as a DXF file to generate the structural grid, following which storey data, material properties (M20/M25 concrete, Fe550 steel) and frame/slab sections were defined and assigned to the model. Support conditions were assigned as fixed at the foundation level, and dead, live and wall loads were applied before running the static analysis. The resulting three-dimensional model is shown in Fig. 6.



Fig -6: ETABS structural model of the apartment building — (a) beam-column-slab assignment in plan and 3D; (b) three-dimensional rendered wireframe view of the full building

Once verified to be free of geometric errors, the model was analysed and the ETABS concrete frame design module was used to proportion longitudinal and shear reinforcement for every beam and column as per IS 456:2000.

5. RESULTS AND DISCUSSION

5.1 Bending Moment and Shear Force Response

The bending moment diagrams obtained from ETABS for the building frame under the governing gravity load combination are shown in Fig. 7, exhibiting the expected hogging moments over supports and sagging moments at midspan. The corresponding member force and shear force diagrams are shown in Fig. 8, and the bending moment, shear force and deflected profile of a representative single beam are shown in Fig. 9, confirming physically consistent analysis output suitable for member design.

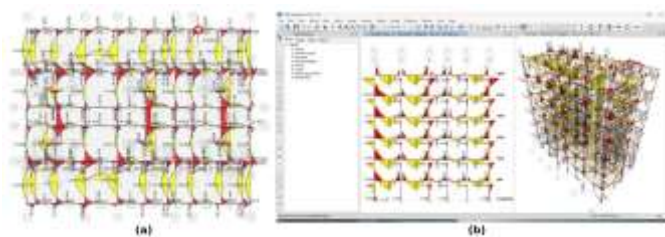


Fig -7: Bending moment diagrams for the building frame obtained from ETABS — (a) plan and 3-D view; (b) elevation view of a representative frame



Fig -8: (a) Member force (axial force) diagram; (b) shear force diagram for the building frame

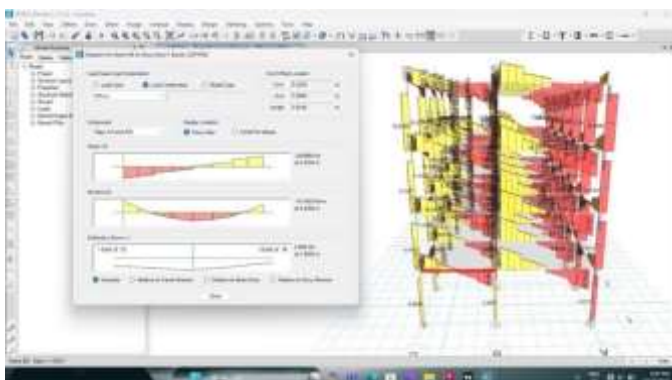


Fig -9: Bending moment, shear force and deflected profile of a representative single beam

5.2 ETABS Column and Beam Design Output

Table 8 summarises the ETABS design output for a critical 230×450 mm column under combined axial load and biaxial bending, and Table 9 summarises the corresponding output for a critical 230×450 mm beam under flexure, shear and torsion, both designed as per IS 456:2000. The column reinforcement percentage of 0.8% and the beam reinforcement close to the minimum prescribed value indicate an economical design within the code limits.

Table -8: ETABS column design output (230×450 mm section, Story 1)

Parameter	Value
Design axial force, P_u	177.11 kN
Design moment, M_{u2}	7.147 kN·m
Design moment, M_{u3}	-54.429 kN·m
Required rebar area	828 mm ²
Reinforcement percentage	0.80%
Shear V_{u2} / V_{u3}	2.02 kN / 29.81 kN

Table -9: ETABS beam design output (230×450 mm section, Story 1)

Parameter	Value
Factored moment, M_{u3} (neg/pos)	-13.02 kN·m / 0 kN·m
Top/bottom rebar required	206 mm ² / 206 mm ² (min)
Factored shear, V_u	33.77 kN
Shear capacity of concrete, V_c	31.08 kN
Shear reinforcement, $A_{sv/s}$	254.94 mm ² /m
Factored torsion, T_u	3.39 kN·m

5.3 Manual Design Verification

A representative two-way slab ($4.75 \text{ m} \times 4.63 \text{ m}$, $L_y/L_x = 0.97 < 2$) was designed manually per IS 456:2000 Annex D, giving 10 mm diameter main bars at 200 mm centres along the shorter span and 10 mm diameter distribution bars at 300 mm centres along the longer span, with the depth check for deflection satisfied (l/d permissible = 24 > l/d provided of 24, within tolerance). The detailing is shown in Fig. 10.

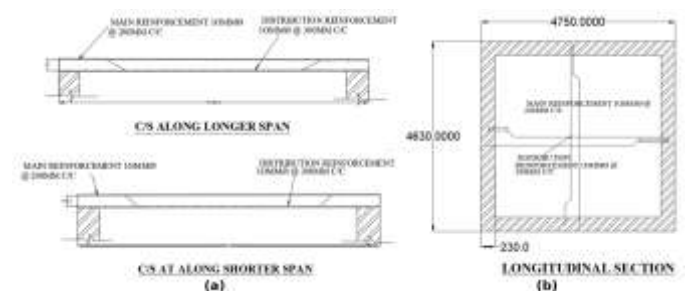


Fig -10: Detailing of the two-way slab — (a) longitudinal section showing main and distribution reinforcement; (b) cross-sections along the longer and shorter spans

A doubly reinforced beam of $230 \text{ mm} \times 450 \text{ mm}$ cross-section was designed for the critical span, providing 3 bars of 12 mm diameter (bottom, mid-span), 1 additional 16 mm bar at mid-span, 2–3 bars of 10 mm diameter (top), and 2-legged 8 mm stirrups at 230 mm centres, as detailed in Fig. 11.

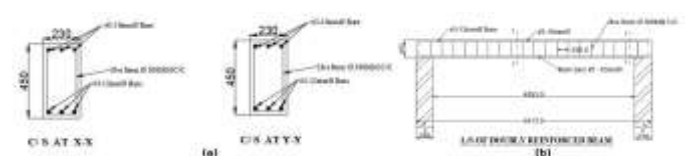


Fig -11: Detailing of the doubly reinforced beam — (a) longitudinal section; (b) cross-sections at X-X and Y-Y

A corner column (230 mm × 450 mm) subjected to axial load with biaxial bending was designed manually, giving a required steel area of 3147.98 mm², provided using 10 bars of 20 mm diameter with 8 mm diameter lateral ties at 230 mm centres, as detailed in Fig. 12.

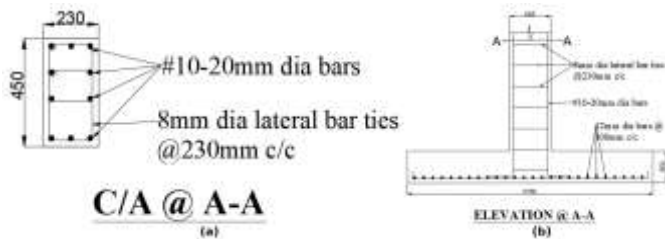


Fig -12: Column reinforcement detailing — (a) elevation @ A-A; (b) cross-section C/A @ A-A

An isolated square footing of 2.7 m × 2.7 m and 350 mm overall depth was designed manually for a factored column load of 1119.84 kN and the design SBC of 169 kN/m², providing 12 mm diameter bars at 60 mm centres in both directions, as detailed in Fig. 13.

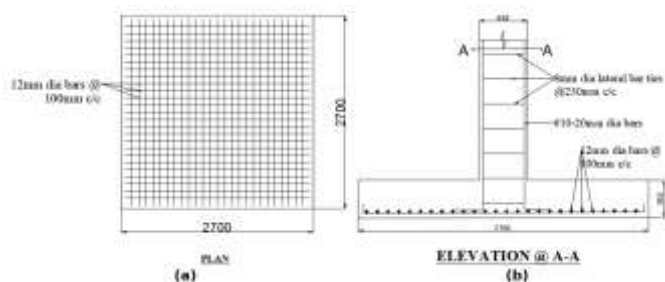


Fig -13: Isolated footing reinforcement detailing — (a) elevation @ A-A; (b) reinforcement layout (plan)

The dog-legged staircase, with a waist slab of 250 mm effective thickness, a 300 mm going and 150 mm rise, was designed as an inclined one-way slab spanning between landings, providing 12 mm diameter main bars at 150 mm centres and 10 mm diameter distribution bars at 230 mm centres, as detailed in Fig. 14.

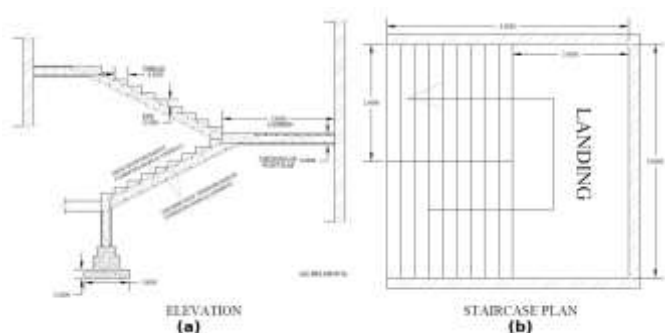


Fig -14: Staircase reinforcement detailing — (a) staircase plan; (b) sectional elevation

5.4 Comparison of ETABS and Manual Design Results

Table 10 compares the ETABS and manual design results for a representative beam and column. The reinforcement quantities obtained by the two methods are of the same order, with the manual method generally giving marginally higher reinforcement due to its more conservative, code-based hand-calculation assumptions, confirming the reliability of the ETABS-based design for this building.

Table -10: Comparison of ETABS design and manual design results

Element	Parameter	ETABS	Manual
Beam (B1)	Top reinf.	2ø12mm	3ø10mm
Beam (B1)	Bottom reinf.	3ø16mm	3ø12mm
Beam (B1)	Top Ast req/prov	158/320.29 mm ²	198.03/339 mm ²
Beam (B1)	Bottom Ast req/prov	289/330.29 mm ²	339.29/427.2 mm ²
Beam (B1)	Stirrups	8ø@300mm c/c	8ø@230mm c/c
Column (C1)	Ast required	1602.8 mm ²	1228.5 mm ²
Column (C1)	Main bars	6ø25mm	10ø20mm
Column (C1)	Ast provided	4228 mm ²	3147.98 mm ²
Column (C1)	Ties	8ø@230mm c/c	8ø@230mm c/c

6. CONCLUSIONS

- The founding soil at the site was classified as well-graded sand ($C_u = 7.72$, $C_c = 0.99$), with an angle of shearing resistance of 29° and a design safe bearing capacity of 169 kN/m², computed using Terzaghi's bearing capacity theory.
- The G+5 apartment building, modelled and analysed in ETABS using M20/M25 concrete and Fe550 steel, was found safe under the governing gravity load combinations, with reinforcement ratios within the limits prescribed by IS 456:2000.
- Wind and seismic loads did not govern the design of any member for this building height and Seismic Zone II location; gravity load combinations were critical throughout.
- Manual verification of a representative slab, beam, column, footing and staircase gave reinforcement quantities of the same order as the ETABS output, confirming the reliability of the software-based design.
- The integrated workflow — geotechnical investigation, architectural planning, ETABS modelling and design, manual verification, and AutoCAD detailing — provides a systematic and replicable methodology for the design of similar multi-storeyed apartment buildings.
- ETABS was confirmed to be an efficient, accurate tool for the analysis and design of multi-storeyed RC buildings, particularly for rapid evaluation of load combinations and automated code-checking.

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