

Structural Design of a High-Rise Structure Using Protostructure Software

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Abstract

ProtaStructure Software developed by Prota Software used for the design of structural members such as beams, columns, slabs, foundations, shear walls, steel members, BIM coordination, 3D structural modelling of reinforced concrete, reinforcement detailing and drawings through the Prota suite. This study focuses on the structural analysis and reinforcement detailing of a Highrise structure using ProtaStructure software. It covers the analysis and design of major structural elements, and also provides detailed reinforcement drawings and demonstrates the importance of appropriate structural design and detailing in preventing structural failures and ensuring the safety, stability, serviceability, and long-term performance of a Highrise structure. The methodology adopted involved the selection of an appropriate building layout, preparation of architectural and structural drawings, identification of design loads, and application of the relevant provisions of BS 8110. The structural members were subsequently analysed and designed using ProtaStructure software. Based on the analysis results, appropriate reinforcement sizes, spacing, anchorage lengths, and other detailing requirements were determined. Deflection checks were also carried out to ensure compliance with the specified design requirements. Following the analysis and design of all structural elements, the reinforcement details were generated using ProtaDetails, an extension of ProtaStructure software. The resulting drawings provide comprehensive reinforcement details for the slabs, beams, columns, and foundation system, thereby providing a clear basis for the construction of the proposed Highrise structure that is safe, economical and stable.

Keywords: *ProtaStructure Software, Reinforcement, Highrise structure, Structural design.*

1. Introduction

Structural engineering plays an important role in the design, construction, and safety of buildings and other civil engineering infrastructure. The structural engineer is responsible for ensuring that

structures such as residential buildings, bridges, dams, and transportation facilities can safely resist the loads imposed on them throughout their service life. Structural design commonly begins with preliminary sketches, which are developed into clear working drawings for construction and statutory approval [1]. Technical drawings provide an effective means of communication among engineers, contractors, and other construction professionals by presenting construction requirements in a precise visual form [2]. The design of reinforced concrete buildings involves the analysis and design of major structural elements such as slabs, beams, columns, and foundations. These elements work together to transfer imposed loads safely to the ground. Structural design therefore requires appropriate consideration of dead and imposed loads while ensuring that the structural members satisfy strength, serviceability, and durability requirements[1] noted that reinforced concrete design is an important stage in building construction because it contributes significantly to structural safety and integrity. Reinforcement detailing provides the link between structural calculations and actual construction. It involves clearly specifying the size, number, spacing, location, anchorage, and arrangement of reinforcement bars within structural members. Proper detailing ensures that the reinforcement is placed correctly and that the intended interaction between concrete and steel can be achieved during the service life of the structure. [2] reported that effective structural detailing helps translate engineering calculations into practical construction information. [3] also identified technical drawings as an important means of communicating complex engineering information during construction. The importance of proper structural design and detailing is further demonstrated by the occurrence of building failures. Inadequate structural design, inferior construction materials, insufficient reinforcement, poor detailing, and improper interpretation of drawings have been identified as factors associated with structural failures [4]. Residential buildings may be particularly affected when pressure to reduce construction time and cost compromises technical requirements [5]. Even single-storey residential buildings require appropriate structural analysis because inadequate design can result in excessive cracking, deflection, partial collapse, or total structural failure [6]. The application of computer-aided structural design software can improve the efficiency and consistency of structural analysis and reinforcement detailing. However, software application must be supported by engineering judgement and compliance with established design standards. Software-generated results require appropriate interpretation and verification to ensure that structural members satisfy relevant design requirements. Consequently, integrating engineering principles, design codes, and structural design software provides a systematic approach to improving structural safety and construction accuracy. This study focuses on the structural analysis and reinforcement detailing of a single-storey residential building using ProtaStructure software in accordance with BS 8110. The study covers the analysis and design of slabs, beams, columns, and foundations, including the determination of internal forces, bending moments, support reactions, member dimensions, and reinforcement requirements. Following the structural analysis and design, detailed reinforcement drawings are generated using ProtaDetails, an extension of ProtaStructure software. The drawings provide information on reinforcement sizes, spacing, anchorage, and arrangement required for construction. The study demonstrates the application of structural design software alongside engineering principles and standard design provisions to achieve accurate and practical reinforcement detailing for Highrise structure.

2. Methods

2.1 Experimental setup

This study involved the structural analysis, design, and reinforcement detailing of a Highrise structure. The building was designed as a reinforced concrete framed structure comprising slabs, beams, columns, and pad foundations. The architectural drawings in figure 1 and 2 provide the basis for developing the structural layout and locating the major structural elements. AutoCAD was used to prepare the structural general arrangement, while ProtaStructure was employed for structural modelling, analysis, and design in accordance with the selected provisions of BS 8110.



Figure 1. Architectural ground floor plan



Figure 2. Architectural first floor plan



Figure 3. Architectural typical second floor plan



Figure 4. South Elevation

2.2 Numerical model

2.2.1. Structural Layout and Design Parameters

The structural general arrangement was prepared in AutoCAD using the architectural plan as a reference. The layout in figure 3 identified the positions of the columns, beams, slab panels, and foundations. The drawing was organised using layers to distinguish the structural elements and was saved in DXF format for importation into ProtaStructure. The principal structural dimensions and design parameters were defined before analysis. The columns had a cross-sectional dimension of 225×225 mm. The floor beams measured 225×450 mm, while the roof beams measured 225×300 mm. The reinforced concrete slab was assigned a thickness of 150 mm and a concrete cover of 25 mm. A concrete unit weight of 24.0 kN/m^3 and a blockwork unit weight of 4.50 kN/m^3 were adopted. The characteristic slab dead load and imposed load were 3.47 kN/m^2 and 1.5 kN/m^2 , respectively.

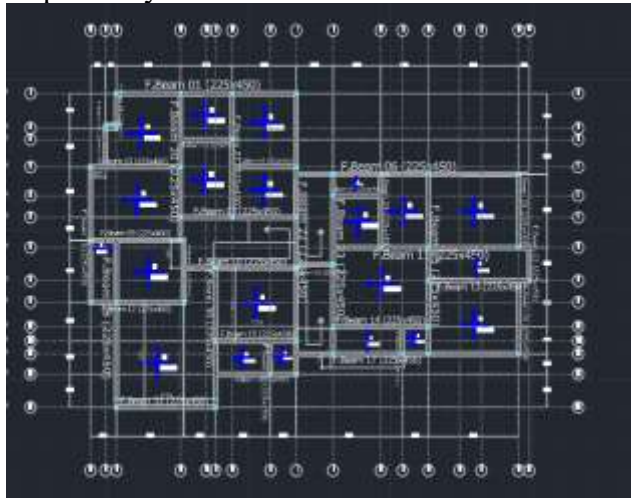


Figure 5. Structural general arrangement prepared in AutoCAD.

2.2.2. Structural Modelling Using ProtaStructure

The DXF drawing shown in figure 4 was generated in AutoCAD and imported into ProtaStructure used as a reference for developing the structural model. The structural elements were modelled according to their positions and dimensions in the general arrangement. Columns were positioned to provide load-transfer paths from the beams and slabs to the foundation system. Beams were modelled along the specified structural lines, while slab panels were defined within the beam layout. The slab panels were assigned the specified thickness and loading parameters. Slab strips were defined where required for slab analysis and reinforcement design. Partition walls were treated as non-structural elements and were excluded from the structural model. The physical three-dimensional model provided in figure 5 and 6 was subsequently converted into an analytical model for structural analysis.

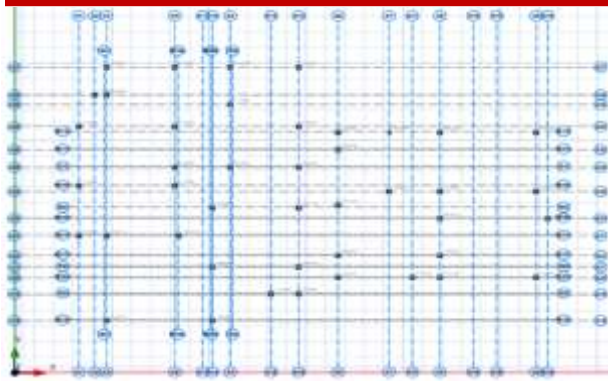


Figure 6: DXF file on Protastructure

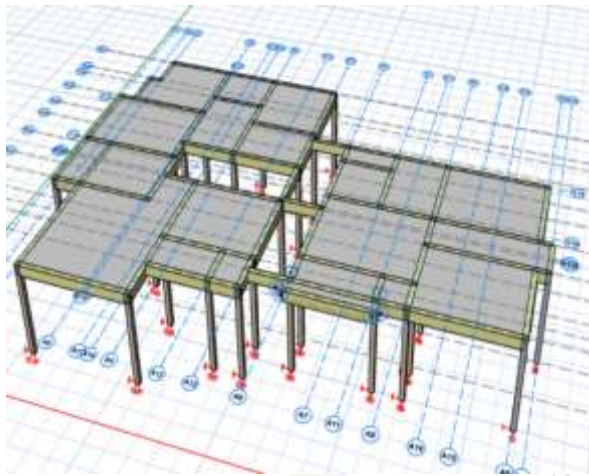


Figure 7. Three-dimensional ground floor structural model developed in ProtaStructure.



Figure 8. Three-dimensional first floor structural model developed in ProtaStructure

2.3 Data reduction and metrics

2.3.1 Structural Analysis and Design

The structural model was analysed using ProtaStructure as shown in figure 7, Material properties and reinforcement parameters were assigned to the relevant structural members. The loading information was entered, and the required load combinations were generated for the analysis. The analysis was used to determine the structural response under the applied loads, including bending moments, shear forces, axial forces, and deflections. The design process covered the reinforced concrete beams, columns, slabs, and pad foundations. The software's design functions were used to determine the reinforcement requirements for the individual members. Following the initial analysis and design, the results were reviewed to identify members requiring further design attention. The post-analysis checks included the assessment of deflection and serviceability requirements. Where necessary, member reinforcement was reviewed and adjusted before the design was finalised.

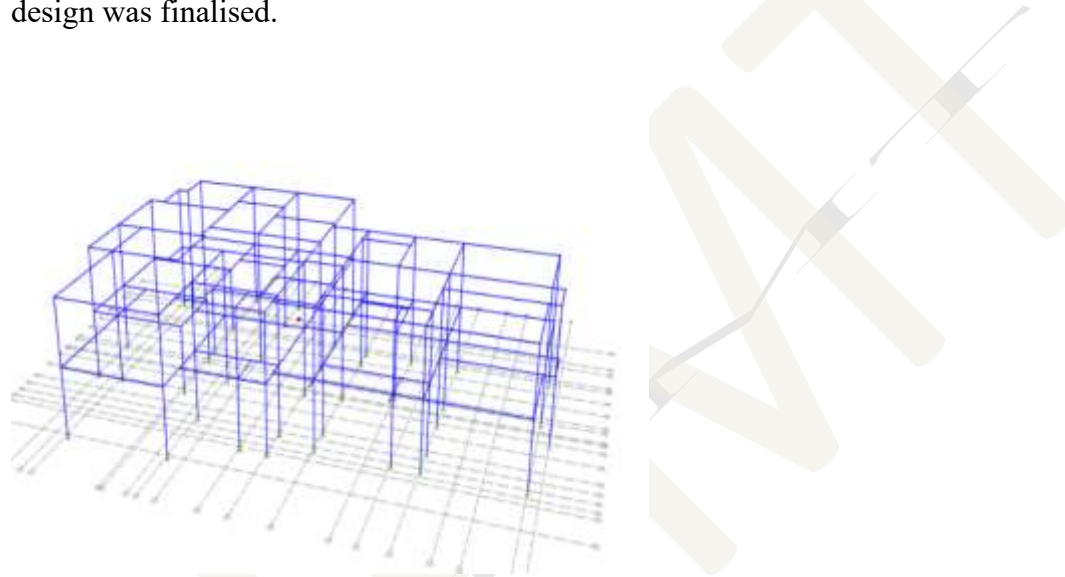


Figure 9. ProtaStructure analysis results or analytical model.

The overall procedure integrated architectural planning, structural drafting, three-dimensional modelling, load application, structural analysis, member design, foundation design, and reinforcement detailing. The final outputs comprised the structural model, analysis and design results, and reinforcement drawings for the proposed residential building.

2.3.2 Foundation Design and Reinforcement Detailing

Pad foundations were introduced beneath the columns and designed using the foundation-design functions in ProtaStructure. The footing properties and design status were reviewed to establish whether the foundations satisfied the adopted design requirements. Reinforcement detailing was then prepared for the structural members. The detailing outputs included reinforcement bar diameters, spacing, arrangement, and anchorage information for the beams, columns, slabs, and foundations. These details were used to produce the structural reinforcement drawings required for construction.

3. Results

3.1 Foundation Footing Results

The structural analysis produced a pad footing of 1000 mm × 1000 mm with a thickness of 400 mm to support the 225 mm × 225 mm reinforced concrete column. The footing was designed using C16/20 concrete and 385 MPa reinforcement steel. The reinforcement detailing shown in figure 8 was generated by ProtaStructure/ProtaDetails comprised 5Y16 bars at 250 mm spacing in both directions at the top and bottom of the footing.

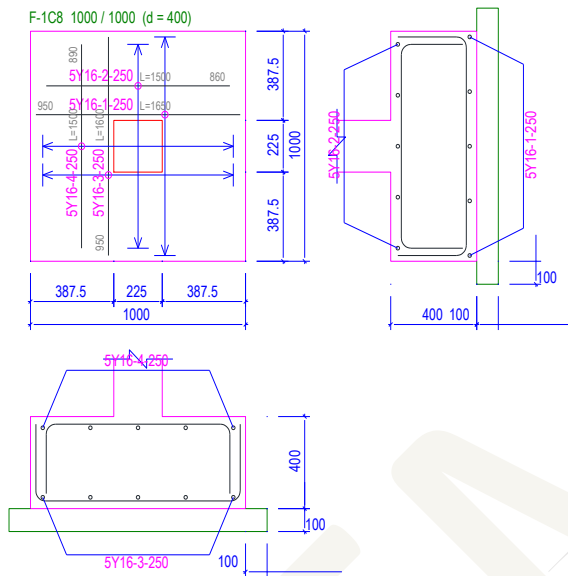


Figure 10. Reinforcement detail of the designed pad footing.

The calculated corner soil stresses ranged from 76.56 to 92.15 kN/m², indicating a slightly non-uniform pressure distribution beneath the footing. The maximum soil stress of 92.15 kN/m² was below the assumed allowable bearing capacity of 280 kN/m². This gives a substantial margin between the applied soil pressure and the assumed allowable capacity. The total vertical load used in the soil bearing assessment was 84.36 kN, including the column load and the additional weights of the footing and overlying soil. The footing self-weight was 9.6 kN, while the weight of the soil above the footing was 12.6 kN, giving a combined additional load of 22.2 kN.

Table 1. Summary of foundation footing results

Parameter	Result
Column size	225 × 225 mm
Footing size	1000 × 1000 × 400 mm
Concrete	C16/20
Reinforcement	385 MPa
Maximum soil stress	92.15 kN/m ²
Allowable soil stress	280.00 kN/m ²
Total vertical load	84.36 Kn
Reinforcement provided	5Y16 @ 250 mm
Required steel area	507.86 mm ²

Provided steel area	804.25 mm ²
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The eccentricity assessment also satisfied the specified limit. The calculated eccentricities were 0.31 mm and 15.09 mm in the X- and Y-directions, respectively, compared with the corresponding limiting value of 166.67 mm. The results indicate that the resultant load remained within the allowable central zone of the footing. The punching shear and one-way shear checks were also satisfactory. At the effective perimeter, the punching shear demand was 170.9 kN compared with a capacity of 982.5 kN, while at the column face the demand was 92.2 kN compared with a capacity of 1189.0 kN. Similarly, the one-way shear demands of 34.6 and 35.7 kN at the column faces were considerably lower than the capacity of 336.2 kN. The flexural design required 507.86 mm² of reinforcement in each principal direction, while 804.25 mm² was provided. Therefore, the reinforcement provided exceeded the calculated requirement in both directions.

3.2 Column Analysis and Reinforcement

The column analysis in figure 9 produced 225 mm × 225 mm reinforced concrete columns. Most columns were detailed with four 16 mm diameter longitudinal bars and 8 mm links at 175 mm spacing. Columns 1C4 and 2C4 required four 18 mm diameter longitudinal bars. The adopted concrete and reinforcement materials were C16/20 and 385 MPa, respectively, with a 25 mm concrete cover. The critical loading condition produced an axial force of 49.9 kN, with bending moments of approximately 0.0 kN·m and 4.2 kN·m about the principal axes. The column was therefore subjected to combined axial compression and biaxial bending. The interaction assessment showed that the selected reinforcement was adequate for the applied combination. The shear assessment also indicated satisfactory performance. The maximum shear stress reported was 0.04 N/mm², compared with a concrete shear capacity of 0.81 N/mm². The calculated slenderness ratios were 8.7 and 8.6 in the two principal directions, both below 15, indicating that the assessed column behaved as a short column. The provided longitudinal reinforcement area of 804.25 mm² exceeded the minimum required area of 202.50 mm².

Table 2. Summary of column design results

Parameter	Result
Column size	225 × 225 mm
Concrete grade	C16/20
Reinforcement grade	385 MPa
Concrete cover	25 mm
Typical longitudinal reinforcement	4Y16
Critical columns	4Y18
Links	Y8 @ 175 mm
Required steel area	202.50 mm ²
Provided steel area	804.25 mm ²
Maximum reported shear stress	0.04 N/mm ²
Concrete shear capacity	0.81 N/mm ²
Maximum slenderness ratio	8.7

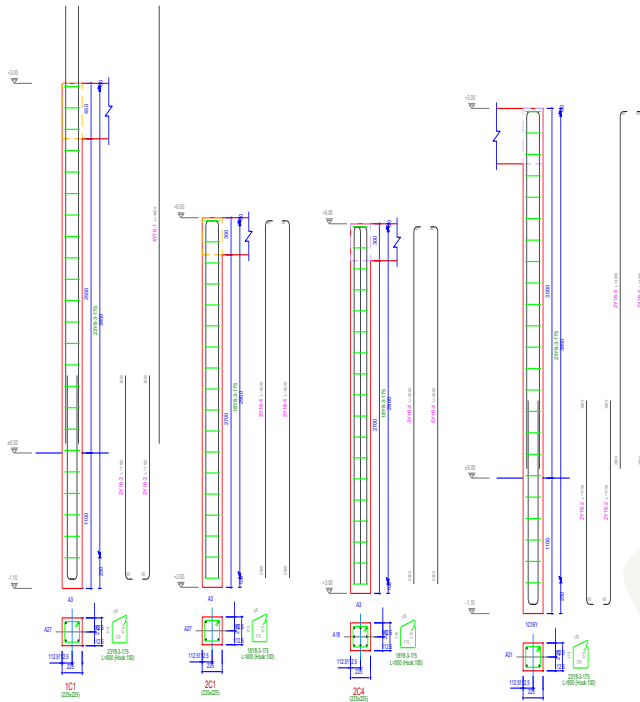


Figure 11. Column reinforcement and interaction diagram generated from ProtaStructure.

3.3 Beam Analysis and Reinforcement

The analysis produced two principal beam sizes as seen in figure 10. The floor beams had dimensions of 225×450 mm, while the roof beams had dimensions of 225×300 mm. The larger floor-beam depth reflects the greater loading associated with the floor system, whereas the roof beams primarily support roof-level loads. The beam reinforcement schedule generally consisted of 16 mm diameter longitudinal reinforcement and 8 mm diameter links. Floor beam links were provided at 300 mm spacing, while roof beam links were provided at 175 mm spacing. A typical floor beam, 1B1, was designed with a section of 225×450 mm. For beam 1B1, the reported bending moments ranged from 0.2 to 0.9 kN·m at the bottom and up to 0.7 kN·m at the top. The calculated required steel areas were relatively small, ranging from 1.22 to 7.33 mm² at the bottom and 5.29 mm² at the top. However, the provided reinforcement area was 402.12 mm². This indicates that the reinforcement provided was greater than the calculated flexural steel requirement.

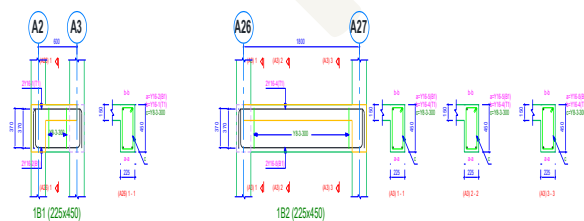


Figure 10. Typical beam reinforcement generated by ProtaStructure.

The shear assessment of beam 1B1 produced design shear forces of 5.4 and 3.2 kN, corresponding to shear stresses of 0.06 and 0.03 MPa. These values were below the reported concrete shear capacity of 0.48 MPa and the maximum allowable shear stress of 3.58 MPa. The nominal shear capacity was 93.3 kN, substantially exceeding the applied shear forces. The reported torsional moment was 0.2 kN·m, with negligible torsional stress. The beam deflection check also satisfied the specified limit, with an L/d ratio of 1.47 compared with a limiting value of 45.09. The results therefore indicate satisfactory flexural, shear, torsional and serviceability performance for the assessed beam.

Table 3. Summary of beam 1B1 design results

Parameter	Result
Beam size	225 × 450 mm
Design moment	0.2–0.9 kN·m
Maximum shear force	5.4 kN
Maximum shear stress	0.06 MPa
Concrete shear capacity	0.48 MPa
Maximum allowable shear stress	3.58 MPa
Nominal shear capacity	93.3 kN
Torsional moment	0.2 kN·m
Provided steel area	402.12 mm ²
Typical hanger reinforcement	2Y16
Typical bottom reinforcement	2Y16
Link reinforcement	Y8 @ 300 mm
L/d ratio	1.47
Allowable L/d	45.09

3.4 Slab Analysis

Figure 11 is the slab analysis considered the different slab types within the building, including room slabs, flat roof areas, terrace/balcony slabs and lowered slab areas. The software calculated the contribution of the individual material layers, including screed, grout, finishing materials and lightweight concrete, to establish the additional dead loads acting on the slab system.

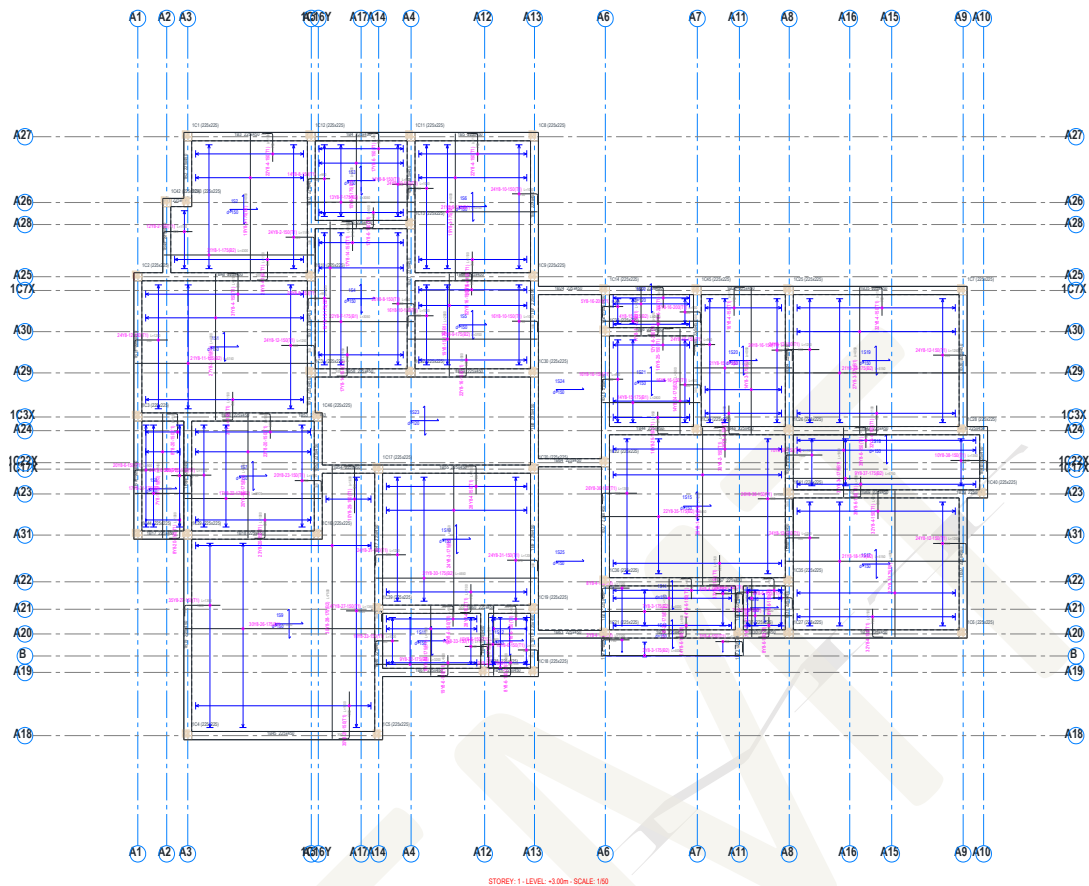


Figure 12. Slab layout and reinforcement generated by ProtaStructure.

The slab loading results formed the basis for the subsequent structural analysis and reinforcement design. The adopted slab thickness was 150 mm with a concrete cover of 25 mm. The characteristic dead load applied to the slab was 3.47 kN/m², while the characteristic imposed load was 1.50 kN/m². These loads were incorporated into the structural model for the analysis of the slab panels and their supporting beams.

4. Discussion

The results obtained from the structural analysis indicate that the major reinforced concrete components of the proposed Highrise structure satisfied the reported design checks. The foundation footing satisfied the soil bearing, eccentricity, punching shear, one-way shear and flexural reinforcement checks. The columns satisfied the reported axial, bending and shear requirements, while the assessed beam satisfied the reported flexural, shear, torsional and deflection requirements. The reinforcement generated by ProtaStructure/ProtaDetails provided practical detailing information for the construction of the structural members. The results demonstrate the application of computer-aided structural analysis and design to the development of a reinforced concrete Highrise structure in accordance with the adopted British Standard design provisions.

5. Conclusion

Based on the research made, the following conclusions can be drawn:

1. Detailing with ProtaStructure software makes the design and analysis process faster.
2. When a structure is properly analysed, structural failures like cracking, uneven settlement and total collapse can be prevented.
3. The study proved that using Protastructure software improves accuracy and prevent under or over reinforcement.
4. The analysis results showed that the structure is safe, stable, and economical to build.

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Declarations

Funding

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Conflict of Interest

The authors declare that they have no competing interests.

Ethics Approval

Not applicable. This study did not involve human participants, identifiable human data, human biological materials, or animals.

Consent to Participate

Not applicable

Consent for Publication

Not applicable

Animal Ethics

Not applicable

Clinical Trial Registration

Not applicable

Data and Code Availability

The DXF drawing was generated in AutoCAD and imported into ProtaStructure used as a reference for developing the structural model. AutoCAD was used to prepare the structural general arrangement, while ProtaStructure was employed for structural modelling, analysis, and design in accordance with the selected provisions of BS 8110.

Author Contributions (CRediT)

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Taiwo Temitope. Adebayo: Formal Analysis, Investigation, Project administration, Writing – original draft

Oluwagbenga David Adegbola: Software, Formal Analysis and Validation

AI-Use Disclosure

The authors declare that no generative artificial intelligence or AI-assisted technologies were used in the preparation of this manuscript.

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