ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1051

Structural Design Considerations for a Large Single Span Reinforced Concrete Monolithic Beam-Column Structures

Ogonna Samuel Nwokoye
Department of Civil Engineering, Federal polytechnic Oko, Nigeria

Abstract:- Large-span reinforced concrete structures present unique design challenges that necessitate meticulous consideration of load-bearing capacity, deflection control, reinforcement, and material choices. For spans exceeding 10 meters, structural engineers must carefully apply the principles and recommendations of Eurocode 2 to ensure that the structure is safe, functional, and durable. This paper explores the critical aspects of designing large single spans in reinforced concrete beam-column systems using Eurocode, with a focus on load distribution, reinforcement detailing, deflection limits, and material properties. Practical insights into the implementation of these guidelines are provided through examples, offering structural engineers in Nigeria a comprehensive approach to achieving safe and cost-effective long-span structures.

I. INTRODUCTION

Reinforced concrete (RC) beam-column structures are essential in many modern applications due to their robustness, durability, and versatility. However, when the span of a structure exceeds 10 meters, the design becomes more complex, requiring advanced engineering considerations to ensure both safety and serviceability. Large-span structures are common in applications such as auditoriums, bridges, warehouses, and industrial buildings where uninterrupted space is essential.The Eurocode, specifically Eurocode 2 (EN 1992-1-1), provides a framework for the design of reinforced concrete structures. It sets out detailed guidelines that address key structural concerns such as deflection, reinforcement, and load-bearing capacity. This paper aims to discuss the design considerations for large-span reinforced concrete beam-column structures (spans above 10 meters) using Eurocode principles, with a particular emphasis on Nigerian structural engineering applications. Some building have space requirement that necessitate single large span such as the event hall that exist in hotels where the ground floor of the hotel building will be a single span space of above 10m while the upper floors will be partitioned into hotel rooms. Such buildings have columns only on the either side of the floor width except where there are intervening stair halls.

II. CHALLENGES OF LARGE-SPAN REINFORCED CONCRETE STRUCTURES

A. Increased Loads and Moments

In large-span structures, the load distribution becomes a critical factor. As the span length increases, so do the bending moments and shear forces. According to the flexural design principles outlined in Eurocode 2, large-span beams experience greater moments and deflections, requiring more robust sections to resist these forces (British Standards Institution [BSI], 2004). The design must account for dead loads (self-weight), live loads (use-specific), and environmental factors such as wind and seismic activity.The bending moment for a simply supported beam can be calculated using the following equation:

$M = nL/8$

Where:
M is the maximum bending moment,
n is the design load per unit length,
L is the span length.

For spans above 10 meters, this equation highlights the exponential increase in moment with span length. Therefore, it becomes essential to optimize the section size and reinforcement to resist these forces efficiently (Mosley, Bungey, & Hulse, 2012).

B. Deflection Control

Excessive deflection is a common issue in long-span beams and can lead to aesthetic, functional, and structural problems such as cracking of finishes, sagging, and loss of structural integrity. Eurocode 2 places significant emphasis on deflection control to ensure that the serviceability of the structure is not compromised. According to Eurocode 2, deflection can be controlled by adhering to span-to-depth ratio recommendations. For reinforced concrete beams, the span-to-depth ratio should typically be between 15 and 20 (depending on the support condition) for spans greater than 10 meters (BSI, 2004). This ratio helps limit deflections within acceptable limits. However, the exact ratio may vary depending on the nature of the loads and material properties.

➢ *Other Methods of Controlling Deflection Include:*

- Increasing the beam depth: Increasing the depth of the beam directly enhances its stiffness, thereby reducing deflection.
- Pre-stressing and post-tensioning: These techniques involve the application of tensile forces to counteract the loads on the beam, effectively reducing deflection (Beeby & Narayanan, 1995).

C. Shear Forces and Reinforcement

In large-span beams, shear forces increase due to the longer distances over which loads are transferred. Eurocode 2 recommends the use of transverse reinforcement, such as stirrups or closed ties, to resist these forces and prevent shear failure. The design must ensure that the shear capacity of the section is adequate to handle the applied loads (BSI, 2004).

The shear capacity (V) can be estimated using the formula:

$$V_{Rd} = \alpha.f_{ck}\,b.z$$

Where:
V_{Rd} is the design shear resistance,
α is a factor for long-term effects,
f_{ck} is the characteristic compressive strength of concrete,
b is the section width,
z is the internal lever arm.

Eurocode 2 emphasizes detailing the shear reinforcement properly to avoid brittle shear failure, which can occur in large spans due to increased shear forces (BSI, 2004).

D. Material Considerations

For large-span concrete structures, the selection of appropriate materials is critical. Eurocode 2 provides detailed guidance on the strength and durability requirements of both concrete and reinforcement. For spans above 15 meters, the following material properties are recommended:

- Concrete Strength Class: Eurocode 2 suggests using a minimum concrete strength class of C30 for large spans, though higher-strength classes such as C40 may be required depending on the load conditions (BSI, 2004).
- Reinforcement Steel: High-yield steel (characteristic strength of 500 MPa) is typically recommended for large-span beams. This steel provides the necessary tensile strength while minimizing the size and number of reinforcing bars required (BSI, 2004).

III. STRUCTURAL DESIGN USING EUROCODE 2

A. Load-Bearing Capacity

The load-bearing capacity of a beam-column structure depends on the combined action of the beam and column elements. In large-span structures, the beam takes on most of the horizontal load, while the columns support the vertical loads. Eurocode 2 recommends calculating the ultimate load-bearing capacity by combining dead loads, live loads, and environmental factors.

The Ultimate Limit State (ULS) design is used to ensure that the structure can support the maximum anticipated loads. The ULS for bending moments is given by:

$$M_{Rd} = \alpha_{cc} f_{ck} b d^2$$

Where:
M_{Rd} is the design moment of resistance,
α_{cc} is a factor that accounts for long-term effects,
f_{ck} is the characteristic compressive strength of concrete,
b is the width of the section,
d is the effective depth.

For large spans, the cross-sectional dimensions must be optimized to ensure that the beam can resist these forces without excessive deflection or failure (Park & Paulay, 1975).

B. Reinforcement Detailing

Proper reinforcement detailing is essential for large-span beams to ensure that the structural elements can carry the applied loads safely. Eurocode 2 provides guidance on the spacing, anchorage, and placement of reinforcement bars.

➢ *Longitudinal Reinforcement*

The longitudinal reinforcement must resist the tensile forces in the beam. For large spans, high-yield steel reinforcement bars (500 MPa) should be used, with sufficient cross-sectional area to handle the applied tensile stresses.

➢ *Shear Reinforcement*

Transverse reinforcement, typically in the form of stirrups, is required to prevent shear failure. The spacing and size of the stirrups are dictated by the shear forces in the beam. Eurocode 2 provides detailed formulas for determining the required shear reinforcement for large-span structures (BSI, 2004).

C. Deflection Limits

As discussed earlier, deflection limits are a critical consideration in large-span structures. Eurocode 2 specifies limits for both short-term and long-term deflections to ensure that the structure remains serviceable throughout its lifespan.The span-to-depth ratio should be carefully considered, and if necessary, additional measures such as pre-stressing or post-tensioning should be employed to control deflection (Beeby & Narayanan, 1995).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1051

IV. CASE STUDY: A 12-METER SPAN EVENT HALL SITUATED ON THE GROUND FLOOR OF A 2-STOREY HOTEL BUILDING

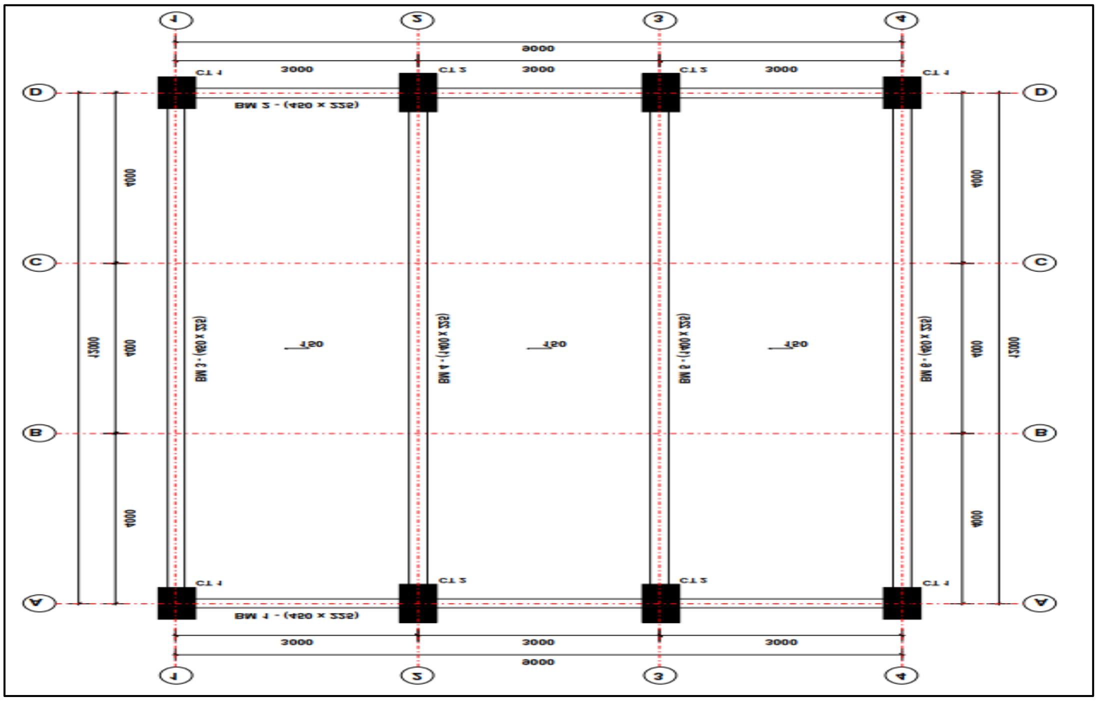

Fig 1.0 First Floor General Arrangement of Beams and Columns

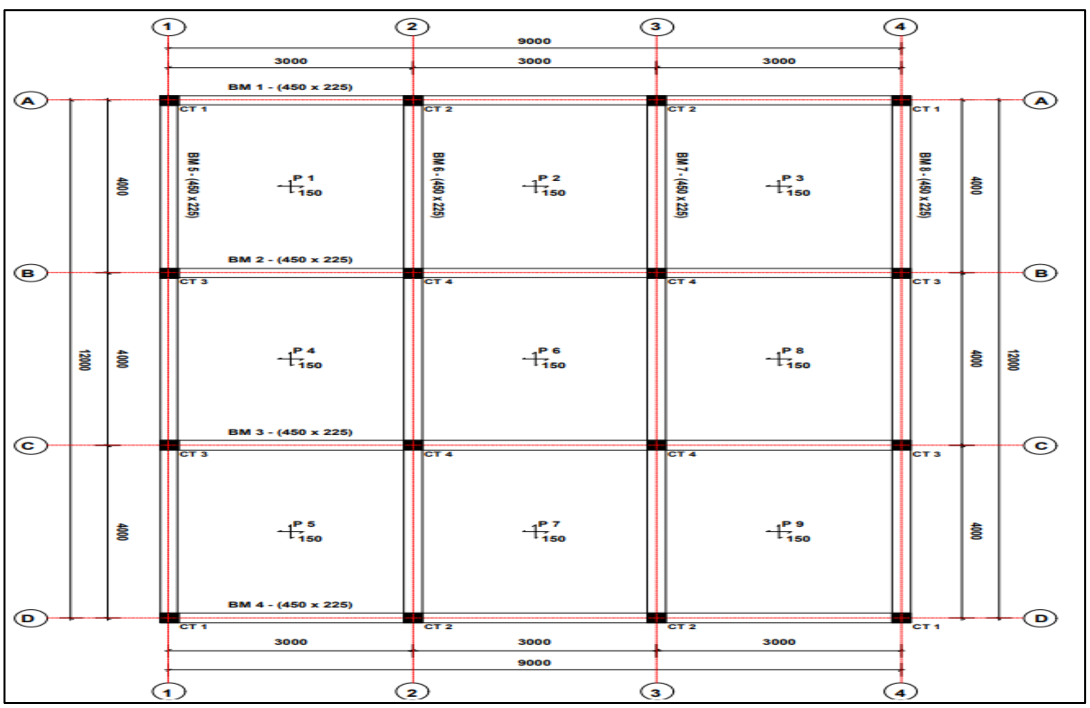

Fig 3.0 Second Floor General Arrangement General Arrangement of Beams and Columns

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1051

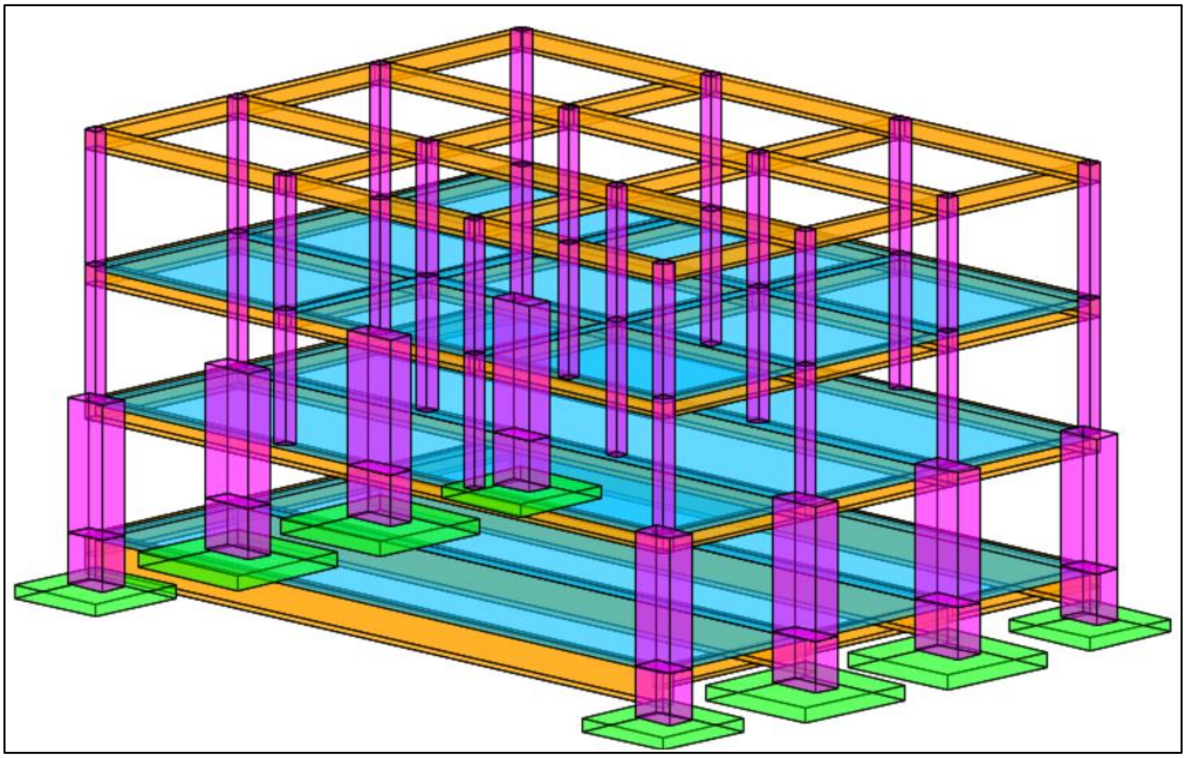

Fig 3.0 3D Model Showing Part of the 12m Single Span Slab-Beam-Column Structure

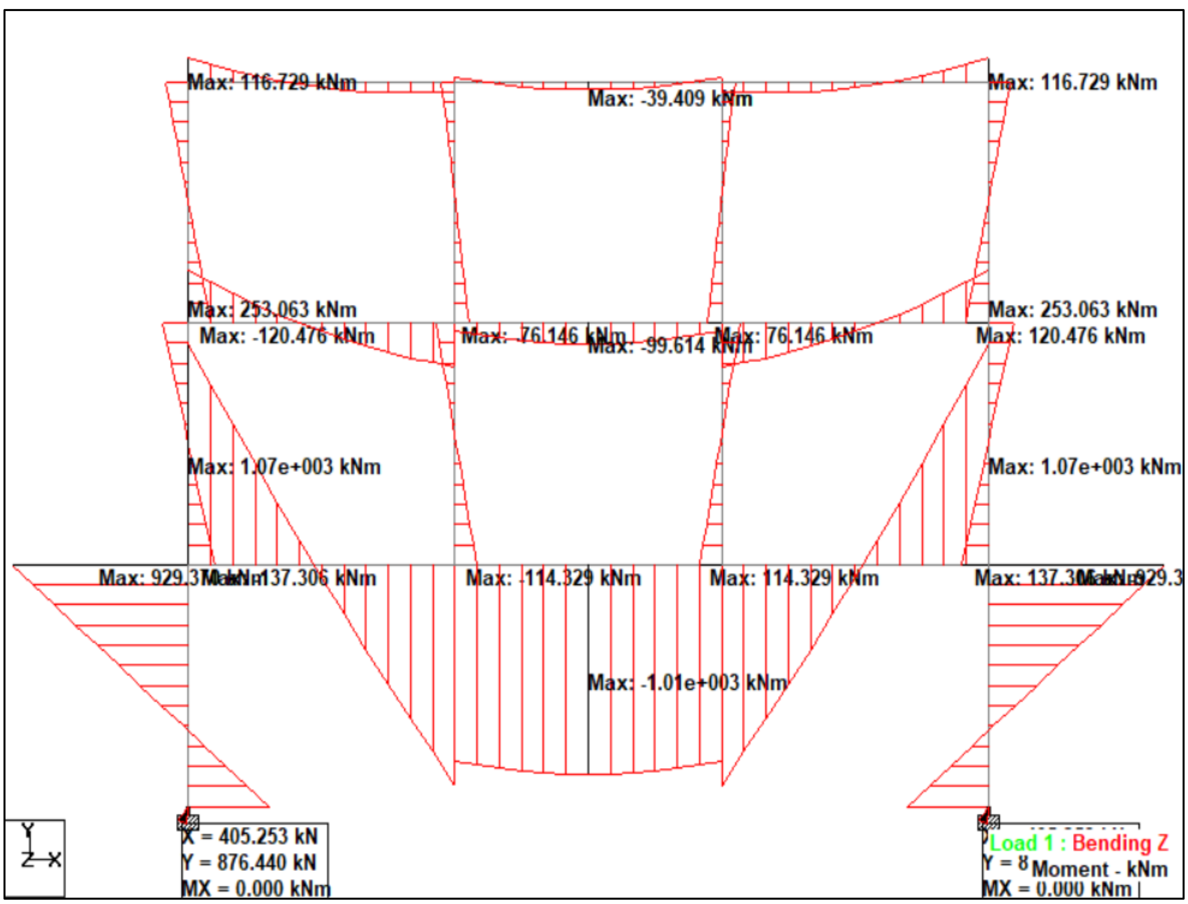

Fig 4.0 Bending Moment Diagrams For The 2d Frame

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1051

V. DESIGN OF REINFORCED CONCRETE MEMBERS:

A reinforced concrete floor beam was designed for the first floor housing hotel room accommodation spaces, with a span of 12 meters. The design was based on Eurocode 2 guidelines and focused on deflection control, load-bearing capacity, and material selection.

- Beam Depth: A depth of 1.2 meter was chosen to limit deflection, following the span-to-depth ratio recommended by Eurocode.
- Reinforcement: High-yield steel reinforcement bars (500 MPa) were used, with transverse reinforcement spaced according to Eurocode's recommendations for shear control.
- Concrete Strength: C30 concrete was used to provide additional strength and durability.
- The bending moment diagram presented in fig 4.0 shows a maximum span moment of 1010kNm and the maximum support moment of -1070kNm. This indicates the critical nature of the beam
- The beam-column is such that hogging bending moment of -1070kNm exist at the column- beam connection such that the beam top reinforcement is detailed to resist that hogging moment near the supports

The design ensured that the beam remained within Eurocode's deflection limits while also providing sufficient load-bearing capacity.

- *Design of beam-4:*

Beam-4 is on gridline-2 as shown in fig 2.0 for span reinforcement M_{max}= 1010kNm, b=300mm, h=1200mm, cover=35mm, f_{cu}=30N/mm2, width of flange b_f= (300+12000/5) = 2700mm. effective depth d=1200-35-25/2-8= 1,144.5mm, k=M/(bd^{2}fcu), $K = \frac{1010E6}{2700*1144.5*1144.5*30}$ = 0.0095, La=0.95, $As = \frac{M}{0.87fyz}$, $As = \frac{1,010,000,000}{(0.87*500*1144.5*0.95)}$ = 2,135mm^2

Provide 5Y25B as main span reinforcement. As Provided = 2450mm^2

- *Check for deflection*

As provided= 2450mm^2
Basic span/effective depth ratio = 20, d=1144.5mm, mbd^2=1,010,000,000/(300x1144.5^2)=2.57
F_s=5.fy.A_{sreq}/8.$A_{sprov.}$ A_{sreq}= 2135mm2. Fs=5x500x2135/(8x2450)= 272.321
Modification factor = .55+(477-272.321)/(120x(0.9+2.57)= 1.0415
Allowable span/effective depth ratio=20x1= 20
Actual span/effective depth ratio= 12000/1144.5= 10.48

Since allowable ratio is greater than actual ratio: deflection check is satisfied

Longitudinal reinforcement for the negative bending moment at the end support of the single span. It will be a wrong model to assume that this beam is simply supported rather it has hogging bending moments at the end column supports. From fig 5.0, M= -1.070kNm.

$k = \frac{m}{bd^2 f_{cu}} = 1070 * \frac{1000000}{300*1144.5^2 *30}$ =0.0907, K= 0.0907< 0.156 hence compression reinforcement is not required

$z = 1144.5.(0.5 + \sqrt{0.25 - 0.0907/0.9})$= 1014.36

$A_s = \frac{m}{0.87fyz} = 1070 * \frac{10^6}{(0.87*500*1014.36)}$= 2424.9

Asreq= 2424.9mm^2, provide 5Y25T. As provided =2450mm^2

VI. CONCLUSION

The structural design of large-span reinforced concrete beam-column structures presents unique challenges due to the increased loads, moments, and deflections associated with spans above 10 meters. Eurocode 2 provides a comprehensive framework for addressing these challenges, with detailed guidelines on load-bearing capacity, deflection control, reinforcement detailing, and material selection. By adhering to Eurocode 2, engineers can ensure that large-span structures remain safe, durable, and functional. This paper has outlined the critical design considerations for spans exceeding 10 meters, emphasizing the importance of controlling deflection, properly detailing reinforcement, and selecting appropriate materials. The case study of the 12-meter span event hall on the ground floor of a 2 storey hotel building with the first floor slab partitioned into spaces for hotel room accommodations demonstrates the practical application of these principles, highlighting how careful adherence to Eurocode guidelines can result in a safe and efficient structure. In Nigerian structural engineering practice, the use of Eurocode 2 for the design of large-span reinforced concrete structures is essential, particularly as the country continues to modernize its infrastructure. The principles outlined in Eurocode not only ensure the stability and serviceability of these structures but also contribute to cost-effective construction by optimizing material use and reducing the likelihood of structural failures. Moving forward, it is recommended that structural engineers in Nigeria continue to familiarize themselves with Eurocode 2 and its application to large-span designs. As more structures in Nigeria, such as auditoriums, stadiums, and large industrial facilities, require long-span solutions, the guidance provided by Eurocode will become increasingly relevant. The use of advanced design techniques, such as pre-stressing and post-tensioning, alongside Eurocode recommendations, will further enhance the performance of these structures.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1051

REFERENCES

[1]. Beeby, A. W., & Narayanan, R. S. (1995). Designers' guide to EN 1992-1-1 and EN 1992-1-2: Eurocode 2: design of concrete structures: General rules and rules for buildings and structural fire design. Thomas Telford.
[2]. British Standards Institution. (2004). BS EN 1992-1-1: Eurocode 2: Design of concrete structures: General rules and rules for buildings. London, UK: BSI Group.
[3]. Mosley, W. H., Bungey, J. H., & Hulse, R. (2012). Reinforced concrete design: to Eurocode 2 (7th ed.). Palgrave Macmillan.
[4]. Nawy, E. G. (2009). Reinforced concrete: A fundamental approach. Pearson Education.
[5]. Neville, A. M. (2011). Properties of concrete (5th ed.). Pearson Education Limited.
[6]. Park, R., & Paulay, T. (1975). Reinforced concrete structures. John Wiley & Sons.
[7]. Sinha, S. N. (2002). Reinforced concrete design. Tata McGraw-Hill Education.
[8]. Taly, N. (2001). Design of reinforced concrete foundations. McGraw-Hill Professional.
[9]. Wight, J. K., & MacGregor, J. G. (2012). *Reinforced concrete: Mechanics and design (6th ed.). Pearson Higher Education.
[10]. Yunusa, I. (2007). Fundamentals of reinforced concrete design for engineers. Ahmadu Bello University Press.