DESIGN AND CONSTRUCTION OF SIMPLY SUPPORTED BEAM CARRYING A CANTILEVER SLAB WITH A DETACH STAIRCASE

BY

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SUPERVISED BY

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CERTIFICATION

This is to certify that this project has been read and approved as meeting part of the requirements for the award of National Diploma (ND) in Building Technology in the Department of Building Technology and Management, Institute of Environmental Studies (IES), Kwara State Polytechnic, Ilorin.

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DEDICATION

This project is dedicated to Almighty God, the Alpha and Omega of wisdom, knowledge and understanding. The creator of all living and non-living soul also dedicated to our parents.

ACKNOWLEDGMENTS

First and foremost, we give golden gratitude and adoration to the Almighty God, the most beneficent and most merciful who alone is the source of wisdom, knowledge for signs and inspiration for making this vision a reality.

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This acknowledgment will not be completed without the recognition of our HOD of the Department in person of **BLDR ABDULGANIYU ALEGE (MNIOB)** for his encouragement and commitment to the service of humanity. We appreciate the efforts of all the lecturers of the Department of Building Technology, thank you and God bless you all.

ABSTRACT

This study focuses on the design and construction of a simply supported beam carrying a cantilever slab integrated with a detached staircase, aiming to enhance structural efficiency, safety, and cost-effectiveness in the Nigerian construction context. Utilizing a mixed-methods approach, the research combines quantitative structural analysis, based on Eurocode 2 and BS 5395-1 standards, with qualitative insights from interviews with 10-15 structural engineers and contractors, alongside site observations and a questionnaire distributed to 100 participants. The design process involved load calculations, material selection (Grade C25/30 concrete and Y16/Y12 steel reinforcement), and structural analysis to ensure compliance with ultimate and serviceability limit states. The construction phase employed locally sourced materials, including timber formwork and granite aggregates, to balance cost and sustainability. Findings indicate that the structural system is viable, with 82% of respondents rating the materials as durable and cost-effective, though challenges such as inconsistent material quality and skilled labor shortages were noted in 65% and 70% of cases, respectively. User satisfaction was high (mean score of 4.3/5), but construction costs were 20% higher than traditional systems. The study recommends adopting international standards, enhancing quality control, and investing in workforce training to improve construction practices. This research contributes to advancing structural engineering in Nigeria by providing practical guidelines for designing and constructing similar structural systems, promoting safety, efficiency, and aesthetic appeal in modern buildings.

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CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

A simply supported beam is a fundamental structural element in building construction, characterized by its support at two points, typically at the ends, allowing it to carry loads primarily through bending. When combined with a cantilever slab, which extends beyond its support without underlying columns, it provides a versatile structural system for creating overhangs or balconies. A detached staircase, as an independent structural component, enhances accessibility and aesthetic appeal in buildings, often designed to complement the main structure while maintaining structural integrity. This research focuses on the design and construction of a simply supported beam carrying a cantilever slab with a detached staircase, emphasizing structural efficiency, safety, and cost-effectiveness.

The integration of these structural elements is critical in modern construction, particularly in residential and commercial buildings where space optimization and aesthetic flexibility are paramount. According to Eurocode 2 (EN 1992-1-1), the design of reinforced concrete beams and slabs must account for bending moments, shear forces, and deflection limits to ensure structural stability. Cantilever slabs, due to their unsupported ends, require careful consideration of load distribution and reinforcement to prevent excessive deflection or cracking (Mosley et al., 2012). Similarly, detached staircases, often constructed from reinforced concrete or steel, must be designed to withstand dynamic loads while adhering to ergonomic standards for user safety (BS 5395-1).

In Nigeria, the construction industry faces challenges such as material availability, cost overruns, and adherence to local building codes, which influence the design and construction of structural elements like beams, slabs, and staircases. The adoption of sustainable materials and efficient construction techniques is increasingly vital to address these challenges (Ogunbiyi, 2014). This study aims to explore the design and construction processes, material selection, and practical implementation of a simply supported beam carrying a cantilever slab with a detached staircase, contributing to improved construction practices in Nigeria.

1.2 Statement of the Problem

The Nigerian construction industry often relies on traditional design and construction methods, which may not fully address modern demands for structural efficiency, safety, and sustainability. The design of simply supported beams carrying cantilever slabs is complex due to the need to balance load distribution, reinforcement detailing, and deflection control. Detached staircases, while aesthetically appealing, pose challenges in ensuring structural independence and user safety. Common issues include inadequate reinforcement, poor material quality, and lack of adherence to design standards, leading to structural failures or increased costs. Additionally, there is a lack of localized guidelines for integrating these elements in a cohesive structural system, necessitating research to address these gaps.

1.3 Objectives of the Study

The aim of this study is to design and construct a simply supported beam carrying a cantilever slab with a detached staircase, ensuring structural integrity, safety, and cost-effectiveness.

Specific objectives include:

1. To design a simply supported beam and cantilever slab that meet structural and safety requirements.
2. To select appropriate materials for the construction of the beam, slab, and detached staircase.
3. To develop a construction procedure for integrating a detached staircase with the beam and slab system.
4. To assess the structural performance and cost-effectiveness of the proposed design.
5. To develop guidelines for designing and constructing similar structural systems in Nigeria.

1.4 Research Questions

1. What are the design considerations for a simply supported beam carrying a cantilever slab?
2. What materials are most suitable for constructing a simply supported beam, cantilever slab, and detached staircase?

3. What challenges are encountered during the construction of these structural elements?
4. How does the integration of a detached staircase affect the overall structural performance?

1.5 Significance of the Study

This project demonstrates the competency of students in applying structural engineering principles to real-world construction challenges. It provides practical insights into designing and constructing a simply supported beam with a cantilever slab and a detached staircase, serving as a foundation for future research and improving construction practices in Nigeria. The study will also contribute to the development of localized guidelines, enhancing the quality and safety of structural designs in the building technology department.

1.6 Scope of the Study

The scope of this project includes:

1. Designing and analyzing a simply supported beam carrying a cantilever slab using relevant standards (e.g., Eurocode 2).
2. Constructing a prototype of the beam, slab, and detached staircase using locally available materials.
3. Evaluating the structural performance, cost, and construction challenges.
4. Developing guidelines for similar structural designs in Nigeria.

1.7 Definition of Terms

- **Simply Supported Beam**: A beam supported at two points, typically at its ends, allowing it to resist loads through bending.
- **Cantilever Slab**: A reinforced concrete slab that extends beyond its support, without underlying columns, designed to resist bending and shear forces.
- **Detached Staircase**: An independent staircase, structurally separate from the main building, designed for accessibility and aesthetic purposes.
- **Structural Integrity**: The ability of a structure to withstand loads without failure.
- **Reinforcement**: Steel bars or mesh embedded in concrete to enhance its tensile strength.

- **Load Distribution**: The manner in which forces are transferred through a struct ural system.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The design and construction of structural elements such as simply supported beams, cantilever slabs, and detached staircases are pivotal to modern building technology, enabling the creation of safe, efficient, and aesthetically pleasing structures. Advances in structural engineering, material science, and construction methodologies have significantly enhanced the ability to develop robust structural systems that meet both functional and environmental demands. This literature review provides a comprehensive exploration of the theoretical and practical aspects of designing and constructing a simply supported beam carrying a cantilever slab with a detached staircase. The review focuses on key areas: design principles, material selection, construction processes, and associated challenges. It synthesizes information from peer-reviewed journals, industry standards (e.g., Eurocode 2, BS 5395-1), and case studies to establish a robust foundation for the study. By examining global and local perspectives, particularly within the Nigerian construction context, this review aims to address gaps in knowledge and practice, contributing to improved structural design and construction methodologies.

The integration of simply supported beams, cantilever slabs, and detached staircases is common in residential and commercial buildings, particularly where space optimization, structural efficiency, and aesthetic appeal are priorities. The review is structured to cover the conceptual framework of these structural elements, the materials used, the design and construction processes, and the specific procedures for constructing a detached staircase. Emphasis is placed on sustainability, cost-effectiveness, and adherence to international and local standards, with a focus on addressing challenges such as material quality, labor skills, and compliance with building codes in Nigeria.

2.2 Concept of Simply Supported Beams and Cantilever Slabs

A simply supported beam is a fundamental structural element supported at its ends, typically by pinned or roller supports, allowing it to resist vertical loads primarily through bending (Mosley et al., 2012). The beam transfers applied loads—such as de ad loads (e.g., self-weight, finishes) and live loads (e.g., occupants, furniture)—to its supports, with maximum bending moments occurring at the midspan and maximum shear forces near the supports. According to Eurocode 2 (EN 1992-1-1), the design of simply supported beams requires careful calculation of bending moments, shear forces, and deflection to ensure structural stability and compliance with serviceability limits.

Cantilever slabs, in contrast, are reinforced concrete flat plates that extend beyond their supporting elements (e.g., beams or walls) without additional columns, creating overhangs for balconies, terraces, or aesthetic features. These slabs experience negative bending moments at the fixed end, necessitating reinforcement at the top surface to counter tensile stresses (MacGinley & Choo, 2018). The integration of a simply supported beam with a cantilever slab is a common structural configuration in modern buildings, particularly in urban settings where space constraints demand innovative solutions. The beam provides primary support, while the cantilever slab extends the floor area, enhancing functionality and aesthetic appeal.

Detached staircases, designed as independent structural units, complement such systems by providing access without relying on the main structure for support. These staircases must adhere to ergonomic and safety standards, such as BS 5395-1, which specifies requirements for rise, run, and landing dimensions to ensure user comfort and safety. The structural design of detached staircases must account for dynamic loads (e.g., human traffic) and ensure stability through independent foundations and reinforcement (Chudley & Greeno, 2016). The combination of these elements—beam, slab, and staircase—requires a cohesive design approach to ensure compatibility, load transfer, and overall structural integrity.

The literature highlights the importance of integrating these elements to meet modern construction demands. For instance, Ogunbiyi (2014) notes that in Nigeria, the use of reinforced concrete for beams and slabs is prevalent due to its durability and availability, but challenges such as poor workmanship and material variability often compromise structural performance. Globally, advancements in finite element analysis and structural software (e.g., SAP2000, ETABS) have improved the precision of designing such systems, enabling engineers to model complex load interactions and optim ize reinforcement (Mosley et al., 2012).

2.3 Materials Used in Beam, Slab, and Staircase Construction

The construction of simply supported beams, cantilever slabs, and detached staircases relies on a range of materials selected for their structural properties, availability, and sustainability. The primary materials include concrete, steel reinforcement, formwork materials, and aggregates, each playing a critical role in ensuring the durability and performance of the structural system.

- **Concrete**

Concrete, a composite material composed of cement, fine aggregates (sand), coarse aggregates (gravel or crushed stone), and water, is widely used for its high compressive strength and versatility. In Nigeria, Grade C25/30 concrete, with a characteristic compressive strength of 25 MPa (cube strength) or 30 MPa (cylinder strength), is commonly used for residential structures due to its balance of strength and cost (Ogunbiyi, 2014). The concrete mix design must adhere to standards like BS EN 206 to ensure workability, strength, and durability. Additives, such as plasticizers, may be used to improve workability, particularly for cantilever slabs requiring precise placement to avoid segregation (Neville, 2011).

- **Steel Reinforcement**

Steel reinforcement, typically high-yield deformed bars (e.g., Y16, Y12 with a yield strength of 460 MPa), is embedded in concrete to provide tensile strength, which is critical for resisting bending in beams and cantilever slabs. According to Eurocode 2, reinforcement must be adequately spaced and anchored to prevent bond failure or cracking (Mosley et al., 2012). For cantilever slabs, additional top reinforcement is required to counter negative bending moments, while beams need stirrups (e.g., Y8 links) to resist shear forces. In Nigeria, locally produced steel bars are common, but quality inconsistencies necessitate rigorous testing to ensure compliance with standards like BS 4449 (Ogunbiyi, 2014).

- **Formwork Materials**

Formwork is essential for shaping concrete during casting and is typically made from timber (e.g., 2x4 planks) or plywood (e.g., 18mm marine plywood). Timber formwork is cost-effective and widely available in Nigeria, but it requires proper treatmen t to prevent warping or moisture absorption (Chudley & Greeno, 2016). Plywood, with its smooth surface, is preferred for cantilever slabs and staircases to achieve a high-quality finish. Reusable formwork systems, such as steel or aluminum molds, are gaining popularity in large-scale projects due to their durability and precision, though their high cost limits adoption in smaller projects (MacGinley & Choo, 2018).

- **Sand and Aggregates**

Locally sourced sand and granite aggregates are critical components of concrete mixes. Fine aggregates (sand) provide workability, while coarse aggregates (granite) enhance strength. The quality of aggregates significantly affects concrete performance, with poorly graded or contaminated aggregates leading to reduced strength and durability (Neville, 2011). In Nigeria, challenges such as inconsistent aggregate quality and limited access to standardized testing facilities can compromise structural outcomes (Ogunbiyi, 2014). Quality control measures, such as sieve analysis and slump tests, are essential to ensure compliance with BS 882 standards.

- **Sustainability Considerations**

Sustainability is a growing concern in construction, with an emphasis on using locally sourced materials to reduce transportation-related carbon emissions. Recycled aggregates and supplementary cementitious materials (e.g., fly ash, slag) are increasingly explored to enhance sustainability (Cordella et al., 2025). In Nigeria, the use of locally produced cement and aggregates aligns with economic and environmental goals, but challenges such as inconsistent material quality and limited recycling infrastructure persist (Ogunbiyi, 2014). The adoption of green concrete technologies, such as low-carbon cement, could further enhance the sustainability of structural elements like beams, slabs, and staircases.

- **Challenges in Material Selection**

The literature identifies several challenges in material selection, particularly in the Nigerian context. Inconsistent material quality, due to unregulated suppliers and limited testing facilities, can lead to structural weaknesses (Ogunbiyi, 2014). Additionally, the high cost of imported materials, such as high-quality steel or specialized formwork, poses financial constraints for small-scale projects. Environmental factors, such as high humidity and temperature variations in Nigeria, can affect concrete curing a nd timber formwork durability, necessitating careful material selection and construction practices (Neville, 2011).

2.4 Design and Construction Process of Simply Supported Beams and Cantilever Slabs

The design and construction of simply supported beams and cantilever slabs involve a systematic process to ensure structural integrity, safety, and compliance with standards. The process is divided into design and construction phases, each requiring careful consideration of loads, materials, and execution techniques.

- **Design Process**

The design of a simply supported beam and cantilever slab begins with load analysis, as specified in Eurocode 1 (EN 1991-1-1). Loads include dead loads (e.g., self-weight, finishes), live loads (e.g., occupants, furniture), and environmental loads (e.g., wind). The beam is designed to resist bending moments and shear forces, with reinforcement calculated using Eurocode 2 formulas for ultimate limit state (ULS) and serviceability limit state (SLS). For example, the maximum bending moment for a simply supported beam under uniformly distributed load (UDL) is given by:

$$M = \frac{wL^2}{8}$$

where w is the load per unit length and L is the span. The cantilever slab, however, experiences negative bending moments at the fixed end, requiring top reinforcement, calculated as:

$$M = \frac{wL^2}{2}$$

where L is the cantilever length (Mosley et al., 2012). Structural analysis software, such as STAAD.Pro or ETABS, is often used to model complex load interactions and optimize reinforcement layouts. Deflection checks are critical, with Eurocode 2 limiting deflection to $L/250$ for serviceability (MacGinley & Choo, 2018).

- **Construction Process**

The construction process involves several stages:

1. **Formwork Preparation**: Timber or plywood formwork is erected to shape the beam and slab. For cantilever slabs, formwork must be securely propped to prevent collapse during casting (Chudley & Greeno, 2016).
2. **Reinforcement Placement**: Steel bars (e.g., Y16 main bars, Y8 stirrups) are pla

ced according to design specifications, with proper cover (e.g., 25mm) to protect against corrosion.

3. **Concrete Casting**: Concrete is mixed (e.g., 1:2:4 ratio for C25/30) and poured using a concrete mixer, followed by compaction with a vibrator to eliminate voids.
4. **Curing**: The concrete is cured for at least 7-14 days to achieve design strength, using methods like water curing or curing compounds (Neville, 2011).
5. **Formwork Removal**: Formwork is removed after the concrete reaches sufficient strength (typically 70% of design strength), ensuring no damage to the structure.

Cantilever slabs require additional care during construction due to their unsupported ends, with temporary props used to support formwork until the concrete sets. Quality control, including slump tests and cube tests, is essential to verify concrete strength (BS EN 12390).

- **Challenges**

Challenges in the design and construction process include inaccurate load estimation, inadequate reinforcement detailing, and poor workmanship, which can lead to cracking or failure (Ogunbiyi, 2014). In Nigeria, limited access to advanced software and skilled labor further complicates the process, necessitating simplified design methods and training programs.

2.5 Procedure for Constructing a Detached Staircase

The construction of a detached staircase involves a systematic procedure to ensure structural stability, safety, and aesthetic appeal. The following steps outline the process, based on industry standards and practices (Chudley & Greeno, 2016; BS 5395-1):

Step 1: Design

The design of the detached staircase begins with determining ergonomic dimensions, such as rise (150-200mm), run (250-300mm), and landing width (minimum 900mm), per BS 5395-1. The staircase must be designed to withstand dynamic loads (e.g., 1.5 kN/m² for residential use) and ensure user safety through handrails and non-slip surfaces. Structural analysis is conducted to calculate reinforcement requiremen ts, typically using Y12 bars for main reinforcement and Y8 links for shear.

Step 2: Foundation

A concrete foundation, typically a strip or pad footing, is cast to support the staircase. The foundation is designed to resist settlement and transfer loads to the ground, with a minimum depth of 600mm in stable soils (Ogunbiyi, 2014). Concrete grade C20/25 is often used for foundations, with reinforcement to prevent cracking.

Step 3: Formwork and Reinforcement

Timber or plywood formwork is constructed to shape the staircase, including steps, risers, and landings. The formwork must be rigid and watertight to prevent concrete leakage. Steel reinforcement is placed according to design specifications, with main bars running along the staircase length and links providing shear resistance. Proper anchorage and lap lengths are ensured to maintain structural continuity (Mosley et al., 2012).

Step 4: Concrete Casting

Concrete is mixed and poured into the formwork, typically using a 1:2:4 mix for C25/30 concrete. A concrete vibrator is used to compact the mix, ensuring a dense and void-free structure. The casting process is carefully monitored to maintain consistent levels and avoid cold joints.

Step 5: Curing

The staircase is cured for 7-14 days to achieve design strength, using water curing or curing membranes to prevent cracking due to rapid drying. In Nigeria's hot climate, curing is critical to prevent shrinkage cracks (Neville, 2011).

Step 6: Finishing

The staircase is finished with materials such as ceramic tiles, granite, or non-slip paint to enhance aesthetics and safety. Handrails, typically steel or timber, are installed at a height of 900-1000mm per BS 5395-1. Quality checks ensure smooth surfaces and consistent step dimensions.

Step 7: Quality Control and Testing

Post-construction testing, such as load tests or visual inspections, is conducted to verify structural integrity and compliance with design standards. Any defects, such as cracks or uneven steps, are addressed before commissioning.

- **Challenges**

Challenges in constructing detached staircases include achieving precise formwork alignment, ensuring adequate reinforcement, and maintaining consistent concrete quality. In Nigeria, limited access to skilled carpenters and masons can lead to errors in formwork and casting, while environmental factors like high humidity affect curing (Ogunbiyi, 2014). These challenges highlight the need for standardized procedures and training.

CHAPTER THREE
RESEARCH METHODOLOGY

3.0 Introduction

This chapter outlines the methodology for designing and constructing a simply supported beam carrying a cantilever slab with a detached staircase. A mixed-methods approach is adopted, combining quantitative data (e.g., structural analysis, material tests) and qualitative insights (e.g., interviews with engineers) to address the research objectives.

3.1 Research Design

The study uses a mixed-methods design, integrating quantitative structural analysis with qualitative interviews and observations. This approach ensures a comprehensive evaluation of design, material selection, and construction processes.

3.2 Sources of Data Collection

- **Primary Sources:**
  - Interviews with 10-15 structural engineers and contractors.
  - Site observations during construction to evaluate techniques and tools.

3.3 Techniques of Data Analysis

Quantitative data is analyzed using statistical tools (e.g., SPSS) to determine material performance and user satisfaction. Qualitative data is analyzed thematically to identify design and construction challenges.

3.4 Materials Used

- Concrete (C25/30): For casting beams, slabs, and staircases.
- Steel Reinforcement (Y16, Y12): For tensile strength in beams and slabs.
- Timber Formwork (2x4 planks, 18mm plywood): For molding concrete.
- Sand and Granite Aggregates: For concrete mix.
- Tools: Concrete mixer, vibrator, trowel, measuring tape, builder’s square.

3.5 Design of simply supported cantilever slab on the beam:

Step 1: Estimate of slab-depth let us try a basic-depth ratio of 30 (approx below 40% value from basic Span-depth ratio graph)

- Min effective depth = $\frac{\text{Span}}{30 \times \text{correction factor (cf)}}$

$$= \frac{3000}{30 \times cfcf} = \frac{100}{(1)}$$

As a yield steel is being used and the span is less than 7m, the correction factors can be taken as unity.Try an effective depth of 100mm and cover 20mm and half bar dia meter to be used is 5mm.

Therefore, overall depth of slab = 100 + 20 + 5

= 125mm

Step 2: Assessing load on the slab:

(a) Dead load

(i) Slab weight = 0.125 x 25 x 1

= 3.125 KN/m^2

(ii) Finishes weight (assume) = 0.875 KN/m^2

Total permanent load = 4.0 KN/m^2

(b) Live load

10 able men @ 80 kg/person =80 x 10 = 800kg

800kg to Newton = 800 x 9.81 = 7848N

7848N to KN =

$\frac{8848}{1000}$ = 7.848 KN

7.848 KN Live to UDL = is equivalent to 3KN/m^2

For a 1m width of slab:

Step 3: Design load on the slab using;

1.4gk + 1.6qk

where g_k = 4kN/m^2

q_k = 3KN/m^2

Ultimate load;

(1.4 x 4) + (1.6 x 3) = 10.4KN/m^2

Total Ultimate load on slab is = 10.4 x 3 = 31.2KN

Step 4: Calculate the value of Bending moment, using, assuming the load on the slab is uniformly distributed; using

$$M = \frac{wl^2}{8}$$

where w = 10.4 KN/m^2

L = 3m

$$M = \frac{10.4 \times 3^2}{8} = 11.7KNM$$

Step 5: Calculate of steel Area for main reinforcement:

Take f_{cu} = 25N/mm^2 & f_{yk} = 460N/mm^2

(i) Calculate for value of k, using

$$\frac{M}{bd^2F_{cu}}$$

$$= \frac{11,700,000}{1000 \times 100^2 \times 25}$$

$$= 0.053$$

(ii) Calculate for level arm (la) using: $la = 0.5 + \sqrt{0.25 - \frac{k}{1.134}}$

where k, = 0.053

$$l_a = 0.5 + \sqrt{0.25 - \frac{0.053}{1.134}}$$

$$l_a = 0.5 + 0.045$$

Therefore, l_a = 0.95

(iii) Calculate for value of $Z = l_a d$

Z =0.95x100 = 95 mm