Original Research Article

COMPARATIVE COST AND DESIGN OF SOLID, RIBBED AND WAFFLE SLAB FOR A THREE-STOREY SHOPPING COMPLEX USING PROCTA, ORION AND SPREADSHEET

ABSTRACT

Cost is an important factor in choosing the type of floor or slab used in any construction. When a large space within a building needs to be covered without hindrance and supports, waffle or ribbed slabs are used. For all slab systems, the cost constitutes a significant portion of the overall cost of the structure. This research is therefore aimed at selecting a preferable slab system with the least cost of construction for a shopping mall. Computer-aided design software such as Prota 2018, and Orion 2018 were used for analysis and design, and RCC spreadsheets were used as a manual check for the slabs. The results reveal that the Solid floor slab has more concrete volume and steel compared to the waffle, and the rib consumes the least volume of concrete and steel among the three slab systems. Therefore, the rib slab is the most economical of the three slab systems since it uses up the least amount of concrete and reinforcement. The cost of a floor slab system ranges from 12 to 17% of the structural cost in building works, the percentages of the cost of the slab in a floor system is 17.84% for solid slabs system, 13.65% for rib slabs and 12.48% for waffle slabs of the total cost of a structure. It can therefore be concluded that using rib slab saves 17.95% and 7.46% of the construction sum when compared to solid slab and waffle slab construction systems respectively. In conclusion, it is recommended that ribbed slabs should be used for commercial building construction with more than 5KN/m^2 live load and spans up to 15m.

Keywords: Slab, Cost, Design

1. INTRODUCTION

Cost estimation in construction projects is an important factor for decision-making in all the project phases. The cost estimating for a construction project starts in the planning phase or in a feasibility study to determine the required financial requirements. Then in the construction phase, the actual cost is estimated and compared with the planned cost to assess the variation cost. The successful estimating process essentially depends upon the estimator's experience and acquaintance with achieving an accurate cost assessment; which shouldn't be different a lot from the actual cost [1]. Accurate estimation of costs in a construction project is one of the major functions of Project Managers.

Structure refers to a system formed by the interconnection of structural members built to support or transfer forces and to safely withstand the loads applied to it or prevent buildings from being collapsed. A structure supports the building by using a framed arrangement known as structural members. [2]

A slab is a flat two-dimensional planar structural element having a thickness small compared to its other two dimensions. It provides a working flat surface or a covering shelter in buildings and primarily transfers the load by bending in one or two directions. Reinforced concrete slabs behave basically as flexural members and the design is similar to that of beams. The floor system of a structure can take many forms of slabs such as in-situ solid slabs, ribbed slabs or pre-cast units and waffle slabs. Slabs may be supported on monolithic concrete beams, steel beams, walls or directly over the columns. The design and construction of floor slabs are usually solid, adequately reinforced in 2-direction and concreted. The construction of these slabs requires much formwork, a high number of reinforcements in both ways (top and bottom) and a high volume of concrete which resulted in an ample time or duration of construction. Research over the years has brought forward designs that have led to novel construction techniques for floor slabs. [3]

With increased population and land requirements for residential and commercial purposes in urban areas, multi-storey buildings are becoming common in the construction industry. When compared to low-rise buildings, multi-storey buildings accommodate more people per unit area of land and also decrease the cost per unit area of construction. The quantity of steel and concrete requirements for footings, beams, columns and slabs contribute mostly to the overall cost of the structure. Further, these quantities are variable while the cost of finishing and building services is constant. Hence, from an economic point of view, it is important to reduce the quantities of both steel and concrete without compromising on quality and design requirements [4]. The total quantity of steel and concrete requirements depends on the spacing of the columns which is the panel size of the slab. Hence, if the spacing of the column is more, the number of columns is less. [4]
Therefore, this research is aimed at selecting a preferable slab system with the least cost of construction for a shopping mall.

1.1 Review

A floor is an integral part of practically every modern industrial, commercial or residential building. As the expectation of building user, who is in everyday contact with the floors, rises, the performance of floor structure in day-to-day service is becoming increasingly important. The choice of type of slab for a particular floor depends on many factors. The economy of construction is an important consideration, but this is a qualitative argument until specific cases are discussed, and is a geographical variable. The design loads, required spans, serviceability requirements, and strength requirements are all important. [5]

1.1.1 Loading, Structural Analysis and Design Loading

The transfer of loads from a slab to a beam is controlled by the slab's geometrical dimension and the direction of reinforcements. The load of the slab, including self-weight, live load, and imposed dead load, is distributed over the beams on their sides. The slab loads are expressed in weight per unit area, whereas loads of beams are expressed in units of weight per length of the beam.
The load of the one-way slab, which has a rectangular shape, is divided equally between adjacent beams. The interior beam takes half of the total load of a slab on each side.
If a slab is supported on two sides only or supported on all four sides, but the longer side to shorter side ratio is greater than 2, it is termed a one-way slab [6].

Loads on a two-way slab are transferred to all beams on all sides. So, each beam supports an amount of the load from the slab. The slab is commonly divided into trapezoidal and triangular areas by drawing lines from each corner of the rectangle at 45 degrees. The beam's distributed load is computed by multiplying the segment area (trapezoidal or triangular area) by the slab's unit load divided by the beam length. For an interior beam, the portion of the other side's slab weight is estimated similarly and added to the previous one, i.e., the slab's load from the other side of the beam. So, interior beams take loads from both sides. Finite element modelling should be used to distribute the load of a slab with complex geometry to a beam. For this purpose, computer programs like SAP200, SAFE, and ETABS can be used. This method can also be considered for slabs with regular geometry. [6]

1.1.2 Structural Analysis and Design

Structural analysis is the prediction of the performance of a given structure under prescribed loads and other external effects, such as support movements and temperature changes. (Prashant, 2011 cited in) Movements and shear forces are considered the most common effects and are calculated from complicated formula and chart, and sometimes requires the use of computer software as well as trained and experienced engineers. The structure is analyzed to ensure that it has its required strength and rigidity [2]

Structural design is the methodical investigation of the stability, strength and rigidity of structures. The basic objective in structural analysis and design is to produce a structure capable of resisting all applied loads without failure during its intended life. The primary purpose of a structure is to transmit or support loads. If the structure is improperly designed or fabricated, or if the actual applied, loads exceed the design specifications, the device will probably fail to perform its intended function, with possible serious consequences. A well-engineered structure greatly minimizes the possibility of costly failures.
In Structural Design, we select or create suitable structural members to the given impact load obtained from the analysis of the structure. The reinforcement steel and member sizes especially (in the case of RC structures) are proposed and selected. In which a particular code of practice is considered fundamental for the design work. In this case, compliance with the local requirement and the design will be standardized [2].

When designing a structure to serve a particular function for public use, the engineer must account for its safety, aesthetics, and serviceability, while taking into consideration economic and environmental constraints. This design process is both creative and technical and requires a fundamental knowledge of material proportions and the laws of mechanics, which govern material response [7].

1.1.3 Structural Detailing

Structural detailing is the transformation of the works of the structural Engineer into working drawing for the builders to use without any cumbersome. The methods, symbols and notations used are standardized for uniformity despite the multi-diversity natures of the construction industry. The standard method of measurement and notations of detailing a building should be understood before carrying out the exercise. The purpose of their written account is to present a straightforward introduction to the basic standard method of detailing the reinforced concrete structure and its parts. Here a structural detailing of three storeys commercial structure will be designed and fully detailed following BS8110 standards. For this discussion, structural detailing is understood as determining the form of and the shaping and finishing of structural members and their connections. Structural detailing, as a design process, comprises the design of the cross-section, elevational profile and the connections of a structural member to achieve the structural engineering requirements of stability, strength and stiffness. Detailing begins after the structural form for a given design is chosen. For example, if designers decide in principle to adopt an exposed timber post-and-beam system, they can select details from many possible combinations of differently detailed beams, columns, joints and finishes. A similar range of alternatives has been suggested for the detailing of structural steel members [8].

1.1.4 Cost Analysis in Construction Industry

The construction industry, under the system of industrial classification used for statistical and government purposes, is defined as an industry that includes only companies that are involved with building and civil engineering. [9]

Reliable estimates of construction costs and schedules presented by contemporary construction companies, their consultants and suppliers at the time of project approval are important for justifying a project on economic grounds and for planning the means of financing it. The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical for creating policies within sustainable development based on economic costs. The financial impact of a cost overrun results also in demand for construction investment credits. [9]

A construction cost analysis is an analysis performed by a construction company or its workers to accurately identify where the company or project is using or spending its money and resources and whether or not this money is being well spent. To perform a building construction cost analysis, the construction company will likely break down the costs into major categories like labour, materials and supplies. They may also look at performance in terms of functions or phases or something else. The company will then reconcile all of their cost data, probably compare it to what was estimated or forecast, and then talk about and discuss what they were able to achieve by spending that money in that area [10].

Construction projects are considered to be the most important pillars of any society therefore it is necessary to pay attention to them and examine their constantly changing circumstances, The construction projects sector is one of the most vulnerable to changing circumstances because it is directly related to changing social, economic and cultural conditions, and the construction projects are based on three pillars: cost, quality and time, so the success of any project is based on these pillars. The project is considered successful if it is constructed with the highest quality, the lowest time and the lowest cost, hence, the success of the project is closely related to the cost estimate of the project. projects and construction projects, in particular, may be subject to financial loss or economic failure due to inaccuracy in the calculation and estimation of the costs expected, when the implementation of the project may be the real costs greater than the expected costs and therefore the financial loss of the project, must be understood and study the cost estimate which is an important aspect of the project cost management [11].

Cost means expenses incurred by the contractor for labour, material, services, utilities etc., plus overheads and contractor's profits. Cost Management is the process by which costs (expenses) incurred on a project are formally identified, approved and paid. Cost control is the deliberations, actions and reactions to project cost fluctuations during a project to maintain the project cost within the project budget [12].

Cost is a crucial metric that is defined as how much the overall environment favours finishing a project within the projected budget. Typically, the cost is limited to the amount stated in the tender documents. It is the total cost incurred by a project from start to finish. Therefore, it covers any expenses brought on by changes or alterations made during the building phase as well as the price of defending against legal claims in court or through arbitration. Unit costs and percentages of net variation over final costs are two ways that costs can be measured. [13]

The Project cost management is to ensure that the project achieves the objectives required in a condition of financial performance, the managers, contractors and designers are responsible for all aspects of the project to ensure that the performance does not exceed the budget [14].

The process of estimating, planning, and controlling expenses to complete the project without going over budget was included in project cost management. The following processes are part of the cost management process, as shown below by [15], cited in [13]:

1) Estimate cost: Is the description Approximate of financial resources needed to complete project activities.

2) Determine the budget: the processes of gathering the estimated costs of individual activities or packaging the work to establish a licensed cost baseline.

3) Control cost: the processes of monitoring the project's state to develop the project budget and managing changes to the cost baseline.

1.1.5 Methods of Cost Estimation in Projects.

Reliable cost estimates are necessary for all projects. Without a cost estimate, it would be impossible to prepare a business plan, establish detailed budgets, predict resources requirement or control project costs.

According to [16], in the process of estimation, the Project Cost Engineer uses either one or a combination of the following tools and techniques:

1.1.5.1 Experts Judgement

In order to estimate the project's cost, specialists use their experience and knowledge. This method can take into account particular project-specific elements that are unique. But it might also be partial.

1.1.5.2 Analogous Estimating

Using numbers from a previous, comparable project's scope, cost, budget, and duration—or scale measures like size, weight, and complexity—as a starting point, analogous cost estimating estimates the same parameter or measurement for a current project. This method of cost estimation uses the actual cost of prior, comparable projects as the starting point for calculating the cost of the present project. It is most reliable when the prior projects were actually similar and not merely physically similar, and when the project team members who were responsible for creating the estimates had the necessary experience.

1.1.5.3 Parametric Estimating

Based on historical data and project characteristics, a formula or statistical relationship between historical data and other variables (such as square footage in construction) is used in parametric estimating to determine the number of resources required for an activity.

1.1.5.4 Bottom-up Estimating

Bottom-up estimating employs the estimates of individual work packages, which are then "rolled up" or summarized to get the project's total cost estimate. Since it examines prices in greater detail, this kind of estimate is typically more accurate than other approaches.

1.1.5.6 Three-Point Estimating

The accuracy of single-point activity cost estimates may be improved by considering estimation uncertainty and risk and using three estimates to define an approximate range for an activity's cost:

i. Most likely (M): The cost of activity, based on realistic effort assessment for the required work and any predicted expenses.
ii. Optimistic (O): The activity cost is based on an analysis of the best-case scenario for the activity.
iii. Pessimistic (P): The activity cost based on analysis of the worst-case scenario for the activity.

Cost estimates based on three points with an assumed distribution provide an expected cost and clarify the range of uncertainty around the expected cost.

1.1.5.7 Reserve Analysis

Reserve analysis is used to determine how much contingency reserve, if any, should be allocated to the project. This funding is used to account for cost uncertainty.

1.1.5.8 Project Management Information System Method of Estimating

Project management information systems can include resource management software that can plan, organize, and manage resource pools and develop resource estimates. Depending on the sophistication of the software, is especially useful for looking at cost estimation alternatives.

1.1.5.9 Cost of Quality

Cost of Quality (COQ) includes money spent during the project to avoid failures and money spent during and after the project due to failures. During cost estimation, assumptions about the COQ can be included in the project cost estimate.

1.1.5.10 Vendor Bid Analysis

Vendor analysis can be used to estimate what the project should cost by comparing the bids submitted by multiple vendors.

2. MATERIAL AND METHODS

2.1 Materials

The materials used for this research work are as follows:

i. AutoCAD for generating the architectural and structural drawings and layouts used.
ii. Prota 2018 and Orion 2018; an analysis and design software for determining the structural behaviour of the structure under the applied live load.
iii. Reinforced Cement Concrete (RCC) spreadsheet; a manual spreadsheet for the analysis results obtained from (ii) above.

2.2 Methods

Several analysis methods; Orion 2018, Prota 2018 and the latest versions, Visual Basics, Tekla, RCC spreadsheets etc. are used to predict the structural behaviour of the structure. In this project we are working on a three-storey shopping complex structure and analyzed with the help of Prota 2018 and Orion 2018 under different slab types and the slabs will be cross-checked with RCC spreadsheets as a manual calculation for both. From the study of analysis, the structural behaviour and cost comparison should be done. The rectitude of the program was checked by first designing the slabs using the programs and comparing the results obtained.

To obtain strong and reliable findings after the literature study the research methodology was workout as follows:

2.2.1 Assumptions Made in Modelling, Design and Analysis

The assumptions made or properties of the different types of floor systems used are described in the table below:

Table 1: Material Properties

Material Properties	
Modulus of Elasticity of concrete, E_c	23×10^3 MPa
Compressive strength of concrete, fc	24 MPa
Modulus of Elasticity of steel, E_s	200 GPa
Yield Strength	420 MPa

***Material Constants

Table 2: Design Information

Design Information	
Relevant Codes:	BS8110-1997, BS6399, BS 5950
Design Stresses:	Concrete, fcu = 25N/mm2 and Steel, fy = 410N/mm2
Fire Resistance:	One hour for all elements
Exposure Condition:	Mild for all elements.
	Cover: Slab and Stair – 20mm Beam and Column – 25mm Foundation – 50mm
Soil Condition:	Firm gravely lateritic clay (Assumed)
General Loading Condition:	Live load: - 5.0KN/m2
	Roof load (live and dead): - 1.50KN/m2

Floor finishes: - 1.20KN/m2

Weight of Blockwall: -

3.3KN/m2

Partition load: - 1.0KN/m2

*Design information from BS Codes

Step I

The model of the structure was generated using Proto 2018 and Orion 2018 design software and analyzed for different slab systems in accordance with the layouts in Figures 1 and 2.

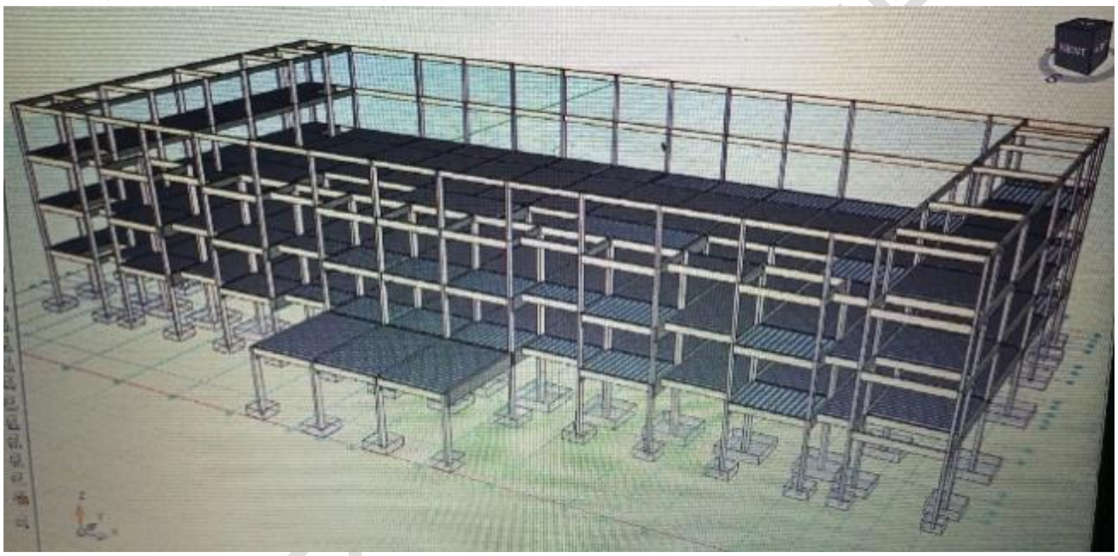

Figure 1: Prota 2018 3D Model

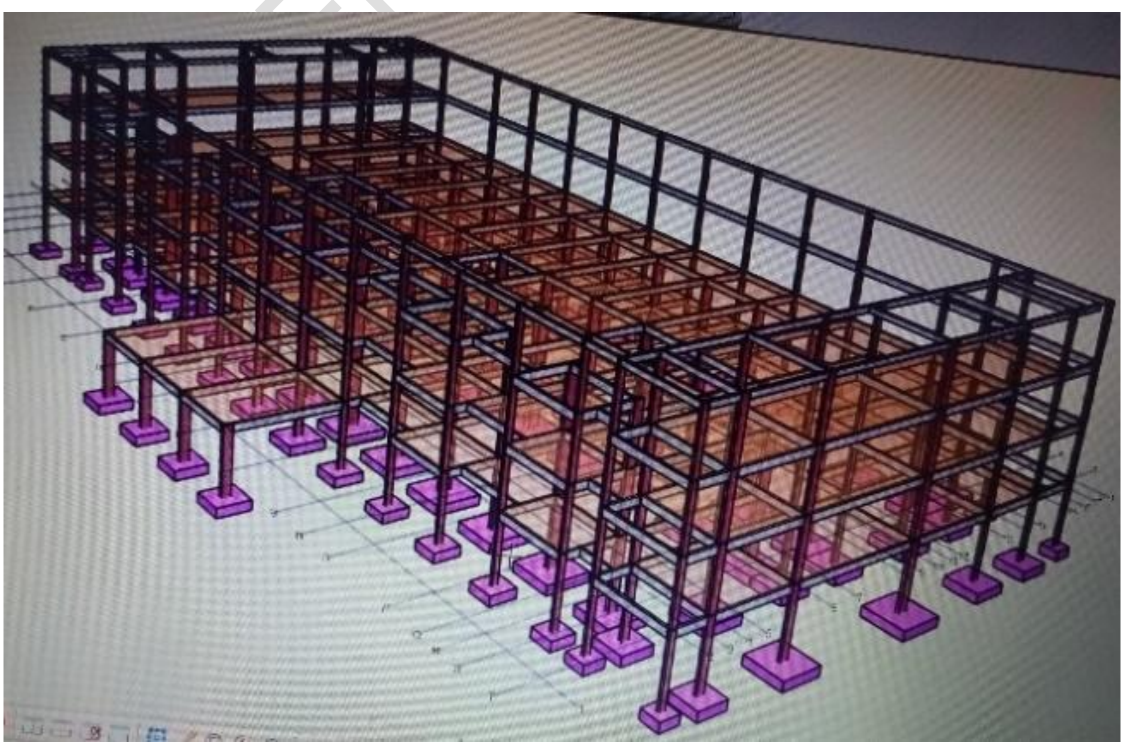

Figure 2: Orion 2018 3D Model

Step II

The structure was analysed in accordance with BS codes and the results for each slab system are extracted as shown below.

Table 3: Results of Floor Type System

Solid Slab Floor System Properties	
Thickness of Slab	175mm to 250mm
Size of drop beams	600x230mm – 1200x300mm
Size of columns	00x300 – 700x600mm
Sizes of footing	3700x3700x800mm max
Ribbed Slab Floor System Properties	
Thickness of Slab	300mm
Width of web	125 - 200mm
	400mm x 250mm x 270mm
Block Dimensions	
Size rib beams	450x200mm - 700x200mm
Size of columns	600x300mm – 600x400mm
Sizes of footing	4100x4100x1000mm max
Waffle Slab Floor System Properties	
Thickness of Slab	300mm
Width of web	125 - 200mm
Block Dimensions	400mm x 250mm x 270mm
Size rib beams	450x200mm - 700x200mm
Size of columns	600x300mm – 600x400mm
Sizes of footing	4100x4100x1000mm max

*****Values from Orion and Prota Design

Table 4: Critical Values extracted from the design

Values from Orion 2018

Type of Slab	**Critical Load (KN)**	**Axis**	**Column Size**	**Footing**
Rib	2640	J5	400x600mm	3400x3400x800mm
Waffle	3118	J5	400x600mm	3800x3800x800mm
Solid	2903	G5	400x600mm	3400x3400x800mm

Values from Prota 2018

Type of Slab	**Critical Load (KN)**	**Axis**	**Column Size**	**Footing**
Rib	2893	T11	400x600mm	3500x3500x800mm
Waffle	3740	J5	500x600mm	4100x4100x800mm
Solid	2939	G5	400x600mm	3700x3700x800mm

**Values from Orion and Prota Design*

3.0 RESULTS AND DISCUSSION

3.1 Results

Tables 5a to 5f present the quantities for each element of the building with different floor systems. The quantities summaries obtained from the taking-off sheets are shown below.

Table 5a: Quantities Estimation of Solid Slab System

Type of Member	**Concrete Volume (m3)**	**Steel Bar (kg)**	**Formwork (m2)**	**No. of Block (m3)**	**Percentage (%)**
Footing	726	25636	959		7.53
Column	320	96832	2881		27.56
Floor Slab	1292	93998	6250		27.97
Drop Beam	486	129589	4057		36.95
Total	**2823**	**346055**	**14146**		

*Solid slab quantities using Prota 2018

Table 5b: Quantities Estimation of Ribbed Slab System

Type of Member	Concrete Volume (m3)	Steel Bar (kg)	Formwork (m2)	No. of Block (m3)	Percentage (%)
Footing	653	20847	919		7.90
Column	280	71659	2748		26.33
Floor Slab	138	10868	602		4.09
Ribbed Slab	702	87283	5716	1871	33.70
Drop Beam	410	76239	2695		27.97
Total	**2183**	**266896**	**12680**	**1871**	

*Ribbed slab quantities using Prota 2018

Table 5c: Quantities Estimation of Waffle Slab System

Type of Member	Concrete Volume (m3)	Steel Bar (kg)	Formwork (m2)	No. of Block (m3)	Percentage (%)
Footing	781	26275	1006		9.33
Column	308	73820	2840		25.59
Floor Slab	137	10868	596		3.86
Ribbed Slab	697	67933	5681	1860	25.32
Drop Beam	526	104121	3367		35.91
Total	**2447**	**283017**	**13489**	**1860**	

*Waffle slab quantities using Prota 2018

Table 5d: Quantities Estimation of Solid Slab System

Type of Member	Concrete Volume (m3)	Steel Bar (kg)	Formwork (m2)	No. of Block (m3)	Percentage (%)
Footing	730	25287	964		8.36
Column	314	60927	2860		19.86
Floor Slab	1258	93905	6261		31.43
Drop Beam	397	126439	3392		40.35
Total	**2699**	**306558**	**13477**		

*Solid slab quantities using Orion 2018

Table 5e: Quantities Estimation of Ribbed Slab System

Type of Member	Concrete Volume (m3)	Steel Bar (kg)	Formwork (m2)	No. of Block (m3)	Percentage (%)
Footing	630	20847	908		8.16
Column	294	61597	2893		23.63
Floor Slab	139	10868	604		4.24
Ribbed Slab	706	87283	5450	1882	34.77
Drop Beam	344	76943	2805		29.21
Total	**2113**	**257538**	**12634**	**1882**	

*Ribbed slab quantities using Orion 2018

Table 5f: Quantities Estimation of Waffle Slab System

Type of Member	Concrete Volume (m3)	Steel Bar (kg)	Formwork (m2)	No. of Block (m3)	Percentage (%)
Footing	630	24098	903		7.60
Column	304	87132	2826		26.75
Floor Slab	138	10868	604		3.44
Ribbed Slab	702	67933	5719	1872	22.59
Drop Beam	351	130971	2380		39.62
Total	**2125**	**321002**	**12432**	**1872**	

*Waffle slab quantities using Orion 2018

3.1.1 Cost Estimation for the Framed Structure

The results of the cost estimate and the percentage of the cost of the slab used are summarized in Tables 6a to 7b for each floor system as shown below.

Table 6a: Cost Estimation for Solid Slab System

Item no.	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Footing	726	m^3	32,000	23,232,000
2	Column	320	m^3	32,000	10,240,000
3	Floor Slab	1,292	m^3	32,000	41,344,000
4	Drop Beam	486	m^3	32,000	15,552,000
5	Filler Block	-	m^3	3,000	-
6	Steel Bar	346,055	m^3	300	103,816,500
7	Formwork	14,146	m^2	3,500	49,511,000
		Total			**243,695,500**

*Solid slab cost from Prota 2018

Table 6b: Cost Estimation for Ribbed Slab System

Item no.	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Footing	653	m^3	32,000	20,896,000
2	Column	280	m^3	32,000	8,960,000
3	Floor Slab	841	m^3	32,000	26,912,000
4	Drop Beam	410	m^3	32,000	13,120,000
5	Filler Block	1,871	m^3	3,000	5,613,000
6	Steel Bar		m^3	300	80,068,800
7	Formwork	12,678	m^2	3,500	44,737,000
		Total			**199,942,800**

**Ribbed slab cost from Prota 2018

Table 6c: Cost Estimation for Waffle Slab System

Item no.	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Footing	781	m^3	32,000	24,992,000
2	Column	308	m^3	32,000	9,856,000
3	Floor Slab	834	m^3	32,000	26,688,000
4	Drop Beam	526	m^3	32,000	16,832,000
5	Filler Block	1,860	m^3	3,000	5,580,000
6	Steel Bar	283,017	m^3	300	84,905,100
7	Formwork	13,489	m^2	3,500	47,211,500
		Total			**216,064,6000**

*Waffle slab cost from Prota 2018

Table 6d: Cost Estimation for Solid Slab System

Item no.	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Footing	729	m^3	32,000	23,328,000
2	Column	314	m^3	32,000	10,048,000
3	Floor Slab	1,257	m^3	32,000	40,224,000
4	Drop Beam	397	m^3	32,000	12,704,000
5	Filler Block	-	m^3	3,000	-
6	Steel Bar	306,476	m^3	300	91,967,400
7	Formwork	13,476	m^2	3,500	47,166,000
		Total			**225,437,400**

*Solid slab cost from Orion 2018

Table 6e: Cost Estimation for Ribbed Slab System

Item no.	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Footing	630	m^3	32,000	20,160,000
2	Column	294	m^3	32,000	9,408,000
3	Floor Slab	845	m^3	32,000	27,040,000
4	Drop Beam	344	m^3	32,000	11,008,000
5	Filler Block	1,882	m^3	3,000	5,646,000
6	Steel Bar	257,538	m^3	300	77,261,400
7	Formwork	12,808	m^2	3,500	44,828,000
		Total			**195,351,400**

*Ribbed slab cost from Orion 2018

Table 6f: Cost Estimation for Waffle Slab System

Item no.	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Footing	630	m^3	32,000	20,160,000
2	Column	304	m^3	32,000	9,728,000
3	Floor Slab	841	m^3	32,000	26,912,000
4	Drop Beam	351	m^3	32,000	11,232,000
5	Filler Block	1,872	m^3	3,000	5,616,000
6	Steel Bar	321,002	m^3	300	96,300,600
7	Formwork	12,431	m^2	3,500	43,508,500
		Total			**213,457,100**

*Waffle slab cost from Orion 2018

Table 7a: Percentage of the cost of slab used in each floor system

Slab System	Percentage of Slab Cost (%)
Solid Slab (SS)	16.97
Ribbed Slab (RS)	13.46
Waffle Slab (WS)	12.35

*% cost from Prota 2018

Table 7b: Percentage of the cost of slab used in each floor system

Slab System	Percentage of Slab Cost (%)
Solid Slab (SS)	17.84
Ribbed Slab (RS)	13.84
Waffle Slab (WS)	12.61

*% cost from Orion 2018

3.2 Discussion

As seen in Tables 6a to 6f, for both methods of analysis and design, the results showed that the use of a ribbed slab system requires less quantity of reinforcement and concrete than that required for solid and waffle slab systems.

From Tables 7a and 7b, using rib slab saves between 17.95% and 8.85% of the construction sum when compared to solid and waffle slab construction systems respectively. From Table 4, it can be seen that the total axial load transferred to the foundation is higher in the waffle slab construction method due to the decomposition of additional dead loads from the two ways ribs in the slab.

4. CONCLUSION

Based on the cost analysis results obtained from this study, the following conclusions can be drawn:

i. Structural drawings are generally produced from architectural drawings.
ii. Solid floor slab has more concrete volume compared to waffle and ribbed consumes the least volume of concrete among the three slab systems. The quantities of concrete and steel required in a ribbed slab is less compared to that required for solid and waffle slab.
iii. In terms of overall cost, the ribbed slab is the most economical of the three slab systems since it uses up the least amount of concrete and reinforcement.
iv. For all slab systems, the cost constitutes the major part of the total structural cost of reinforced concrete structure, the cost of floor slab may range from 12 to 17% of the cost of a structure. The percentages are 17.84% for SS, 13.65% for RS and 12.48% for WS of the total cost of the structure.
v. Using a rib slab system saves 17.95% compared to a solid slab and 7.46% in terms of a waffle slab system.

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