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Comparative Study of RCC Flat Slab and RCC Beam-and-Slab Floor Systems

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Abstract
A number of researchers have focused on comparative study of reinforced concrete flat slabs with post-tensioned and prestressed concrete flat slab and other types of floor systems. However, this research is focused on comparative study of RCC flat slab and RCC beam-and-slab floor systems. This topic was chosen because the RCC flat slab floor system has more benefits compared to the RCC beam-and-slab floor system but besides these benefits, it is less popular with designers in Ghana. There is however, no comparative cost analysis available to convince designers to adopt this option. This Research is therefore aimed to provide such information. These include the design of RCC Flat slab as well as RCC beam-and-slab floor systems and then comparing the results. Structural Designing Software (CSC TEDDS & RCC Excel Spreadsheet) and manual method were used for the analysis and design of both floor systems in accordance with BS 8110. From the analysis and design results of the office building, the total estimation for the quantities for a typical floor system is calculated. The procedure includes finding the quantities of concrete, reinforcing steel and formwork, and their cost according to the current unit rate for both cases. Results revealed that RCC flat slab floor system is +6.07% cost saving in floor construction and +2.42% in column construction, hence the most economic floor system. It was also found that the major cost significant saving item is formwork in case of RCC flat slab floor system compared to RCC beam-and-slab floor system.

Keywords: RCC Flat Slab floor system, RCC Beam-and-slab floor system, Flat Slab.

1.0 Introduction

Reinforced concrete system of construction over the years has being the most common practicing construction system and method. Most buildings in Ghana include commercial, industrial and residential buildings are constructed by the traditional reinforced concrete system. The RCC beam-and-slab system is the most common floor system used in Ghana.

As inflation and interest rate keep changing in an increasing order, there would be the need to introduce new or alternative construction methods to reduce the duration of contract among other reasons in order to maximise profit. Common practice of design and construction is to support the slabs by beams and support the beams by columns. This method of construction is referred to as Beam-and-Slab construction (Kandale and Patil, 2013). The beams reduce the available net clear ceiling height, hence, in warehouses, offices and public halls sometimes beams are avoided and slabs are directly supported on columns. This type of construction is referred to as Flat Slab construction (Kandale and Patil, 2013).

RCC flat slab floor is a reinforced concrete slab supported directly by concrete columns without the use of intermediary beams (Mosely and Bungey, 1990). The flat floor slab has many advantages over the beam-and-slab floor. These include simple construction and formwork and a flat ceiling, the latter of which reduces ceiling finishing costs, since the architectural finish can be applied directly to the underside of the slab (Deb, 2012). Even more significant are the cost savings associated with the low-storey heights made possible by the shallow floor system. Smaller vertical runs of cladding, partition walls, mechanical systems, plumbing, and a large number of other items of construction translate to large cost savings, especially for medium and high-rise buildings (Deb, 2012). Moreover, where the total height of a building is restricted, using a flat slab will result in more stories accommodated within the set height. Windows can extend up to the underside of the slab and there are no beams to obstruct the light and the circulation of air (Mosely and Bungey, 1990).

2.0 Problem Statement

The RCC flat slab floor system has more benefits compared to the RCC beam-and-slab floor system but besides these benefits, it is less popular with designers in Ghana. There is however, no comparative cost analysis available to convince designers to adopt this option. This Research is therefore aimed to provide such information.

3.0 Objectives of the Study

The aim of this paper is to investigate the cost effectiveness of Flat Slab floor systems over the Traditional Beam-and-Slab floor systems. The specific objectives of the study were:

1. To bring to light the benefits of using flat slab floor system.

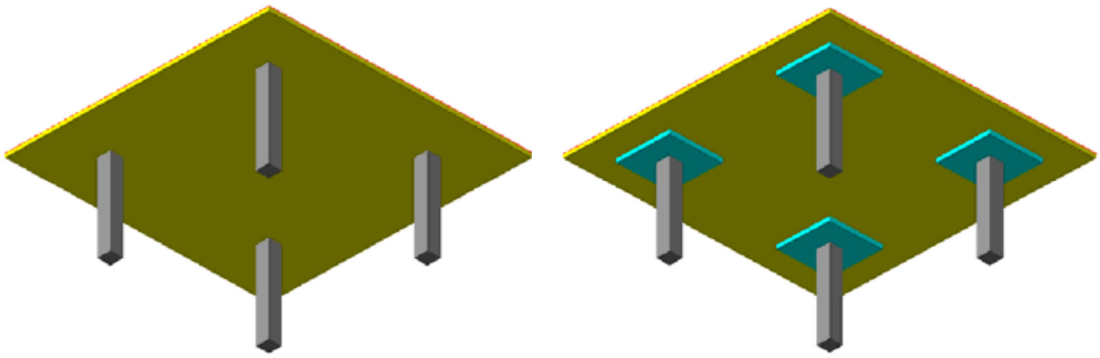
2. To assess the various components of RCC flat slab and RCC beam-and-slab floor systems.
3. To highlight the major cost significant items in both systems of floor construction.

4.0 Literature Review

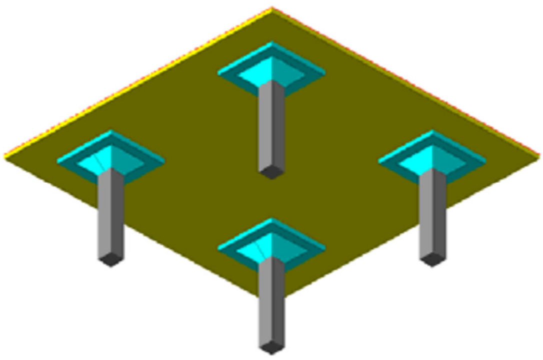
4.1 RCC Flat Slab Floor Systems

The flat slab is defined in BS8110: Part 1, clause 1.2.2.1, as a slab with or without drops, supported generally without beams by columns with or without column heads. In flat slab buildings, floors are directly supported by columns without the use of intermediary beams (Zandi *et al*., 2013). In general, normal frame construction utilizes columns, slabs & Beams. However, it may be possible to undertake construction without providing beams, in such a case the frame system would consist of slab and column without beams. These types of Slabs are called flat slab, since their behaviour resembles the bending of flat plates. To increase punching shear resistance of flat slabs, columns may be flared to form a column head (column capital) or the slab may be thickened around columns as a drop panel or both (Figure 2-1(b) and (c)) (Zandi *et al*., 2013).

According to Park *et al*. (2000) Flat slabs may have drop panels ((Figure 2-1 (b)) or drop panels with capitals (Figure 2-1 (c)) that allow the slabs to be thinner than those without drop panels and capitals. Flat slabs without drop panels and capitals or with capitals hidden in columns are called flat plates (Figure 2-1 (a)).



(a) Flat slabs without drop panels and capitals (b) Flat slabs with drop panels



(c) Flat slabs with capitals and drop panels

Figure 1: Flat slab systems in building construction (Wang, 2006)

4.1.1 Benefits of Using Flat Slab Floor Systems Over the Traditional Beam-And-Slab Floor System

The flat slab has overcome all the drawback of the traditional system of beams framing into columns and supporting slabs spanning between the beams. Though the relatively deep beams of traditional floor system provide a stiff floor which is capable of long spans, and which is able to resist lateral loads, yet the complications of beam formwork, coordination of services, and overall depth of floor have led to a decrease in the popularity of this type of floor (Deb, 2012).

The benefits of using flat slab floor systems over the traditional beam-and-slab floor system outlined by (Deb, 2012) include

- **Larger Span Length Achieved**: The span 'L' of a reinforced concrete flat-plate is approximately D x 28 for simply supported, D x 30 for an end span of a continuous system, to D x 32 for internal continuous spans (Deb, 2012). The economical span of a flat plate can be extended by prestressing to approximately D x 30, D x 37 and D x 40 respectively, where D is the depth of slab. Whereas for the traditional reinforced concrete floor has an economical span 'L' of D x 15 for a single span and D x 20 for a multi-span, where D is the depth of the slab plus beam. The depth of slab between the columns can be initially sized using the span-to-depth ratios for a flat slab.

- **Flat Soffit i.e. Flat Ceiling**: The main and unique feature of this system is that it provides a way for the architect to achieve the concept of high and completely flat ceiling with no beam protrusion. The services can be installed within or below the slab and there are flexibilities in relocating vertical small penetrations. The soffit is often flat and high ceiling height can be achieved. Whereas traditional beam column slab system, the ceiling is not flat and hence many locations it is required to use false ceiling to get a flat ceiling, which is again going to increase the cost of construction. Moreover, the lifespan of false ceiling is few years and hence it needs to be changed several times in the lifespan of the structure. This problem can be avoided with flat slab floor systems. As already the soffit of the slab is flat, there is no need of providing false ceiling. Because of this, flat slab system has found immense use in hotels, malls, public buildings.
- **Savings in Shuttering Cost**: Shuttering/ Formwork constitutes a major cost of construction of reinforced concrete structures. In a traditional beam column slab system, the need of shuttering area is more and so the cost of formwork is also more whereas flat slab system requires only soffit shuttering of slabs.
- **Savings in Construction Time**: As formwork and staging time is reduced, the overall construction time also gets reduced considerably in flat slab floor systems. Keeping in mind of the tight schedule of the projects these days, if construction time can be saved in some means, it will give the builder/ owner early commissioning time of the project, which in turn will reward them with early revenue generation.
- **Prestressing**: Prestressing is not possible in traditional beam column system, whereas post-tensioned flat plate/slabs are a common variation of the conventional plate structure where most of the reinforcement is replaced by post-tensioned strands of very high strength steel. The structural advantage of post tensioning over conventional RCC is that the slab is nearly crack free at full service load. This leads to a smaller deflection compared to conventional RCC because of the higher rigidity of the uncracked section. Hence, reduction in thickness of the slab compared to conventional RCC is the rationale for using post-tensioning system for spans over 10m and above. Further the lack of cracking leads to a watertight structure.
- **Building Height**: Traditional beam-and-slab floor system produces building/ structure higher than flat slab floor system. The reason behind is absence of beams in the flat slab system which is very much beneficial for malls, theatres, hotels etc. In malls, theatres, hotels, because of higher span requirement, the depth of beam is very high, which adds to the floor height making the overall height of each floor more. This again has cost impact as well as aesthetic impact on the structure. This problem can be avoided by adopting flat slab floor system. Also by adopting to suitable prestressing system, it is possible to do construction of higher span slabs without any increase in floor height, which is a major concern with beam-and-slab floor system.
- **Ease of installation of Mechanical and Electrical Services**: In traditional beam-and-slab floor system, penetration through beams for large ducts is difficult to handle. This is a common need in hotels, malls, public buildings, as the service lines are more in these types of buildings. Since making holes in large size beams is not feasible, the service lines needs to be taken through longer routes which again increases the cost of installation and affects the aesthetics by a great deal. With the adoption of flat slab floor system, the large and bulky sized beams are eliminated and service lines can be very easily taken through the slab by keeping suitable and required sized openings in the slab.

4.1.2 Drawbacks of Flat Slab Floor System

The Flat slab floor system promises a world of benefits over the traditional beam-and-slab floor system; however, there are some drawbacks with this floor system. The main drawbacks with flat slabs are that they may deflect excessively and are vulnerable to punching failure (Arya, 2009). The relatively thin slab of the structure makes it susceptible to excessive deflections and floor vibrations. Excessive deflection can be avoided by deepening slabs or by thickening the slab near the columns, using drop panels (Arya, 2009). The uniformity of the flat slab system may lend itself to an ease of construction, however, it is not very efficient at resisting shear forces at critical locations, namely columns (Deb, 2013). If the slab is found to be inadequate to resist punching shear, certain measures can be introduced to strengthen these locations. These include increasing the depth of the slab over the entire panel, increasing the column size, adding a shear capital, or adding shear reinforcement (Deb, 2013).

4.1.3 General Consideration for Use of Flat Slab Floor System

The following are the key factors to be considered before adopting the use of the concrete flat slab with steel/concrete column system (Deb, 2012):

- Architectural layout should be well planned to fully enhance the main area where high flat ceiling with neatly arranged steel/concrete columns are required in the design

- ❖ Spacing of columns
- ❖ Punching shear checks at column areas
- ❖ Long term deflection of the flat plate
- ❖ Early planning of routing for Plumbing, Mechanical and Electrical services, opening for voids and location of staircase

4.1.4 Punching Shear

Reinforced concrete (RC) flat slab floors lead to architecturally pleasing buildings and bridges as well as simplify and accelerate site operations (Pilakoutas and Li, 2003). They allow easy and flexible partitioning of space and reduce the overall height of tall buildings. However, flat slab construction can lead to high shear stresses around supporting columns, which can cause abrupt punching shear failures at loads well below the slab flexural strength. Punching failure arises from the fact that high live loads results in high shear stresses at the supports, which may allow the columns to punch through the slab unless appropriate steps are taken (Arya, 2009). According to Pilakoutas and Li (2003), at the design stage there are several ways of avoiding punching shear failure, such as:

- ❖ reducing the applied loads,
- ❖ reducing the effective length of the slab,
- ❖ increasing the overall thickness of the slab,
- ❖ increasing the thickness of the slab locally with a drop panel or an inverted cone,
- ❖ increasing the column head dimensions and
- ❖ providing some kind of shear reinforcement.

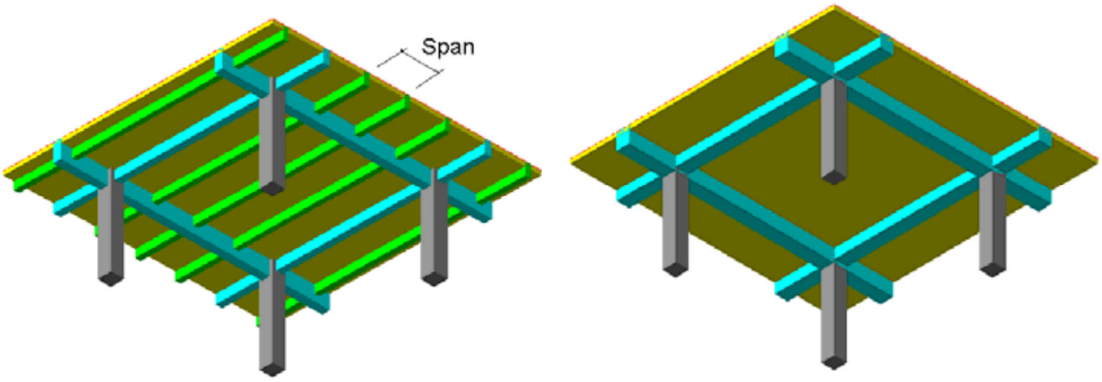
However, all these methods have drawbacks, and research effort has therefore been directed at finding alternative solutions. A few of the alternative solutions to punching shear that have been proposed over recent years include the use of shear hoops, ACI shear stirrups, shear ladders and stud rails (Arya, 2009). All are designed to overcome the problem of fixing individual shear links, which is both labour intensive and a practical difficulty.

- ❖ ***Shear hoops*** are prefabricated cages of shear reinforcement which are attached to the main steel. They are available in a range of diameters and are suitable for use with internal and edge columns. Although superficially attractive, use of this system has declined significantly over recent years.
- ❖ ***ACI shear stirrup*** is potentially the simplest and cheapest method of preventing punching shear in flat slabs. The shear stirrups are arrangements of conventional straight bars and links that form a '**+**', '**T**' or '**L**' shape for an internal, edge or corner column respectively. The stirrups work in exactly the same way as conventional shear reinforcement but can simply be attached to the main steel via the straight bars.
- ❖ ***Shear ladders*** are rows of traditional links that are welded to lacer bars. The links resist the shear stresses and the lacer bars anchor the links to the main steel. Whilst they are simple to design and use they can cause problems of congestion of reinforcement.
- ❖ ***Stud rails*** are prefabricated high tensile ribbed headed studs, which are held at standard centres by a welded spacer bar. These rails are arranged in a radial pattern and held in position during the concrete pour by tying to either the top or bottom reinforcement. The studs work through direct mechanical anchorage provided by their heads. They are easy to install but quite expensive.

4.2 RCC Beam-And-Slab Floor Systems

This method of construction is to support the slabs by beams and support the beams by columns. Reinforced concrete floor systems can be classified in many ways, but the common classification of the slabs is by their structural actions (Park et al., 2000). The RCC beam-and-slab floors are categorised into two types: one-way spanning slabs and two-way spanning slabs. Many factors affect the choice of the type of slabs for a particular floor system, such as the economy of construction, design loads, required spans, serviceability requirements, and strength requirements (Park et al., 2000).

The general definition of the one-way slab is that the slab spans in one direction between beams or walls, as shown in Figure 2 (a) and (b). The two-way slab is the slab supported on beams or walls on all sides of each panel, as shown in Figure 2 (b). When the aspect ratio (i.e. the longer supported length against the shorter supported length) is less than 2, the slab is treated as a two-way slab in normal conditions (Figure 2 (b)).



(a) One-way slabs (cast-in-situ) (b) Two-way slabs (cast-in-situ)
Figure 2: Classification of RCC beam-and-slab floor systems (Wang, 2006)

5.0 Design Methodology
5.1 Scope of Design
The scope of the work consists of the design and detailing of a typical floor of a three-storey Office Block for the two cases considered (i.e. RCC Flat Slab and RCC Beam-and-Slab floor systems). Bill of Quantities were prepared based on a typical design and detailing of structural members of the two cases considered. The design example consists of a three-storey office block with a typical floor plan consisting of three bays in both X and Y directions, each bay measuring 5m x 4m resulting in an overall plan size of 15m x 12m.

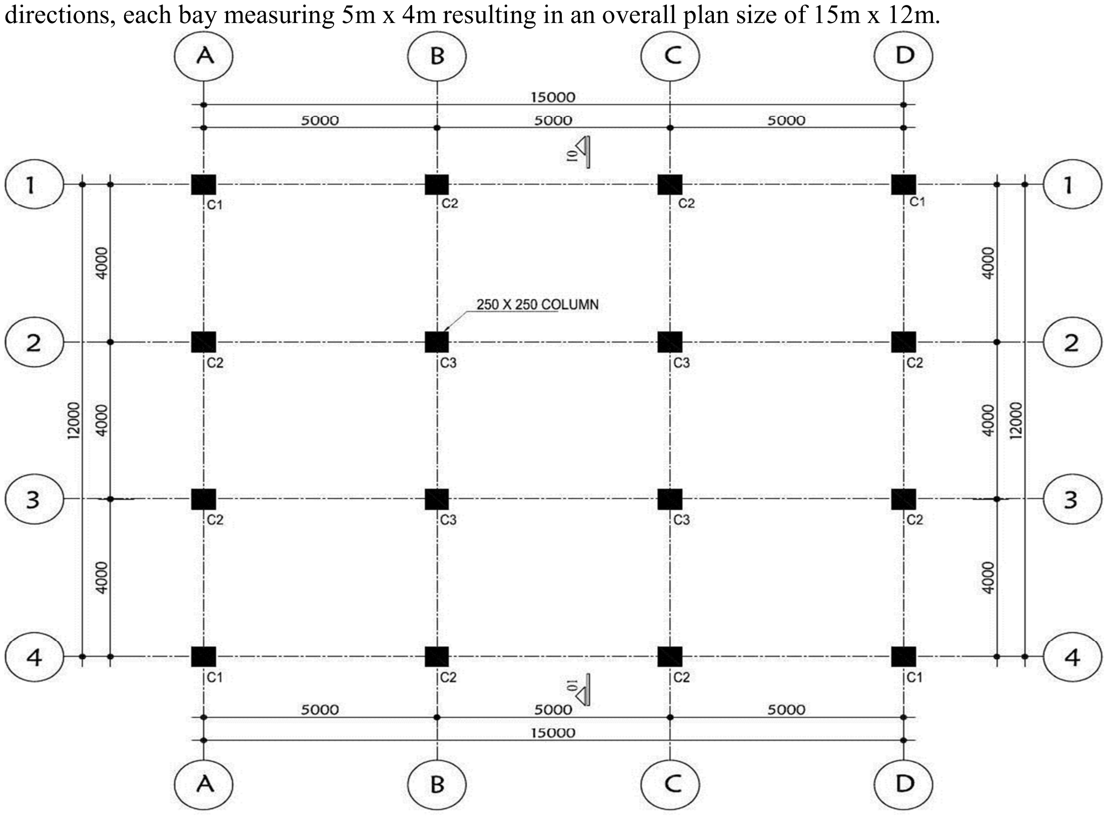


Figure 3: Typical Floor Plan

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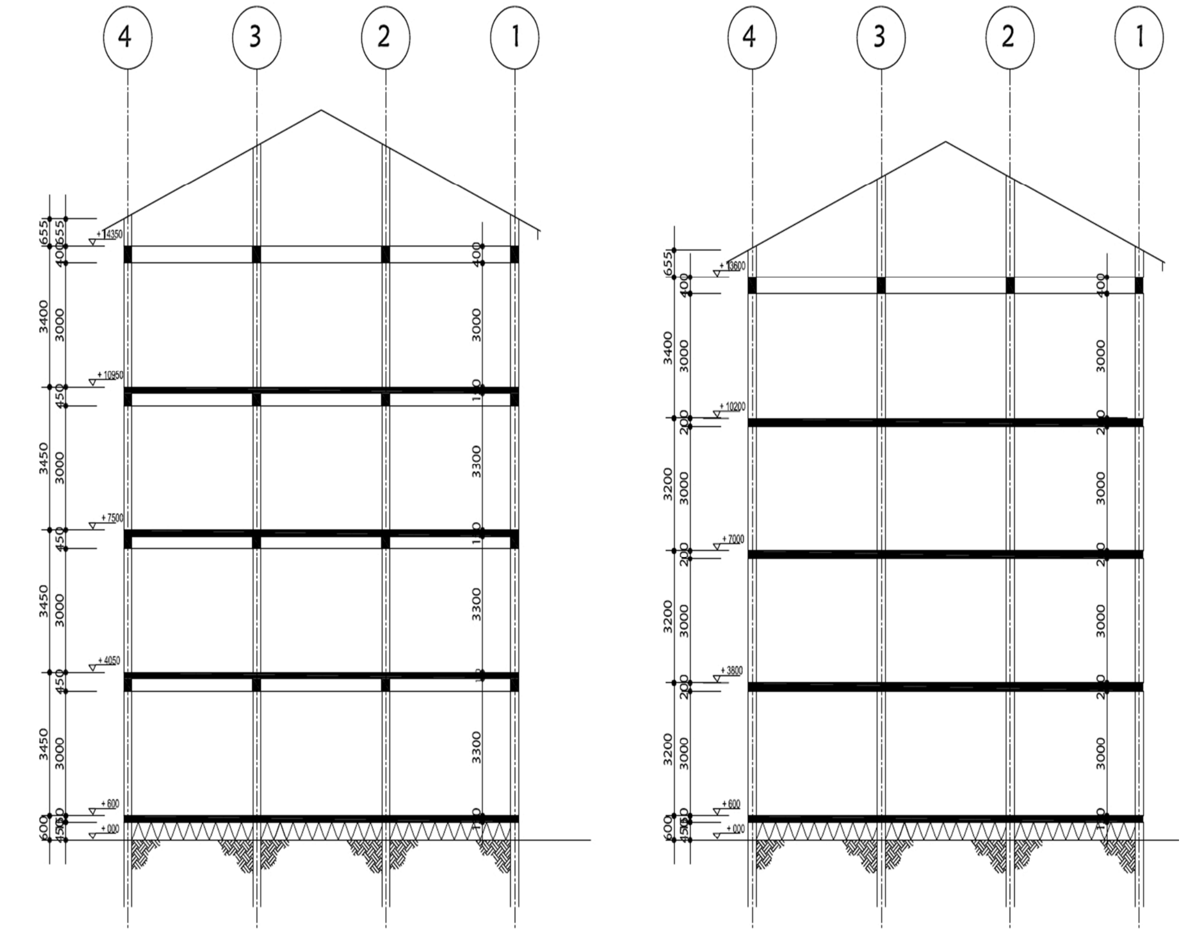

(a) Cross-Section – RCC Beam-and-Slab Floor System (b) Cross-Section – RCC Flat Slab Floor System

Figure 4: Cross-Sections through RCC Flat Slab and RCC Beam-and-Slab Floor Systems

5.2 Analysis and Design

Structural Designing Software (CSC TEDDS & RCC Excel Spreadsheet) and manual method were used for the analysis and design of both floor systems. The design was based on the Equivalent Frame Method of Analysis. The code(s) used for the design is the BS8110, BS6399 and other relevant codes of practice. The design loadings considered were both dead load and imposed load. The imposed load used for the design is 2.5KN/m^2 with reference to BS6399. The design information consists of a concrete grade of C30 and reinforcement steel (i.e. high yield, f_y = 460 N/mm^2 and mild steel, f_y = 250 N/mm^2).

6.0 Results and Discussion

6.1 Estimating and Costing

From the analysis and design results of the office building, the total estimation for the quantities for a typical floor system is calculated in accordance with the Standard Method of Measurement of Building Works (SMM7). The quantities of concrete, reinforcing steel, and the formwork and their cost according to the current unit rate for both cases are given in Table 1 and 2 for a typical floor. The rate per square meter for a typical floor of the building in each case is based on the values calculated from the detailed estimation.

Table 1: Rate analysis for the cases considered – Typical Floor Slab

Item	**Element**	**RCC Flat Slab**		**RCC Beam-and-Slab**	
		Qty	Cost (GH¢)	Qty	Cost (GH¢)
Concrete (m^3)	Slab	37	22,200.00	28	16,800.00
	Beams	-	-	8	4,800.00
Reinforcement (kg)	Slab	3,444	19,251.96	2,318	12,957.62
	Beams	-	-	1,183	6612.97
Formwork (m^2)	Slab	198	11,682.00	159	9,381.00
	Beams	-	-	102	6,018.00
Total cost			**53,133.96**		**56,569.59**
Cost per sqm.			**334.18**		**355.78**
Cost saving			**6.07%**		-

Table 2: Rate analysis for the cases considered – Typical Floor Columns

Item	**Element**	**RCC Flat Slab**		**RCC Beam-and-Slab**	
		Qty	Cost (GH¢)	Qty	Cost (GH¢)
Concrete (m^3)	Columns	3	1,800.00	3	1,800.00
Reinforcement (kg)	Columns	704	3,935.36	742	4,147.78
Formwork (m^2)	Columns	48	2,832.00	48	2,832.00
Total cost			**8,567.36**		**8,779.78**
Cost saving			**2.42%**		-

6.2 Data Presentation

The analysis, design and the estimation of the office building for the two different floor systems is done and finally the total cost of each floor system is found out. The Figures 5 to 8 shows the variation of cost elements and items of both floor systems considered.

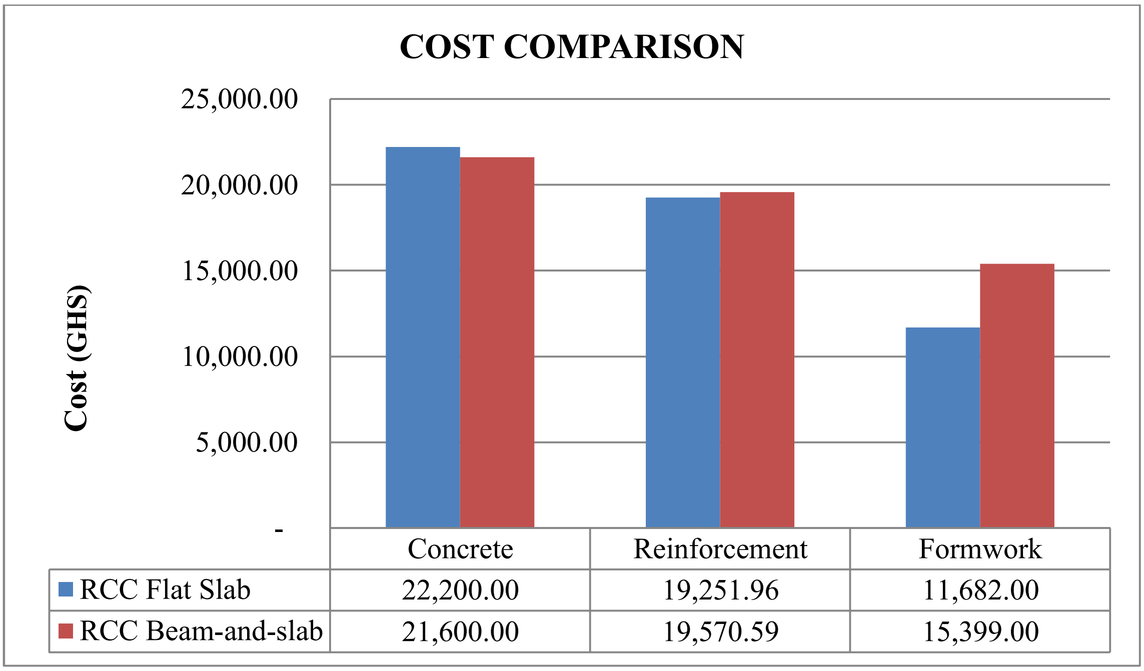

Figure 5: Variation of cost with each item -Typical Floor Slab

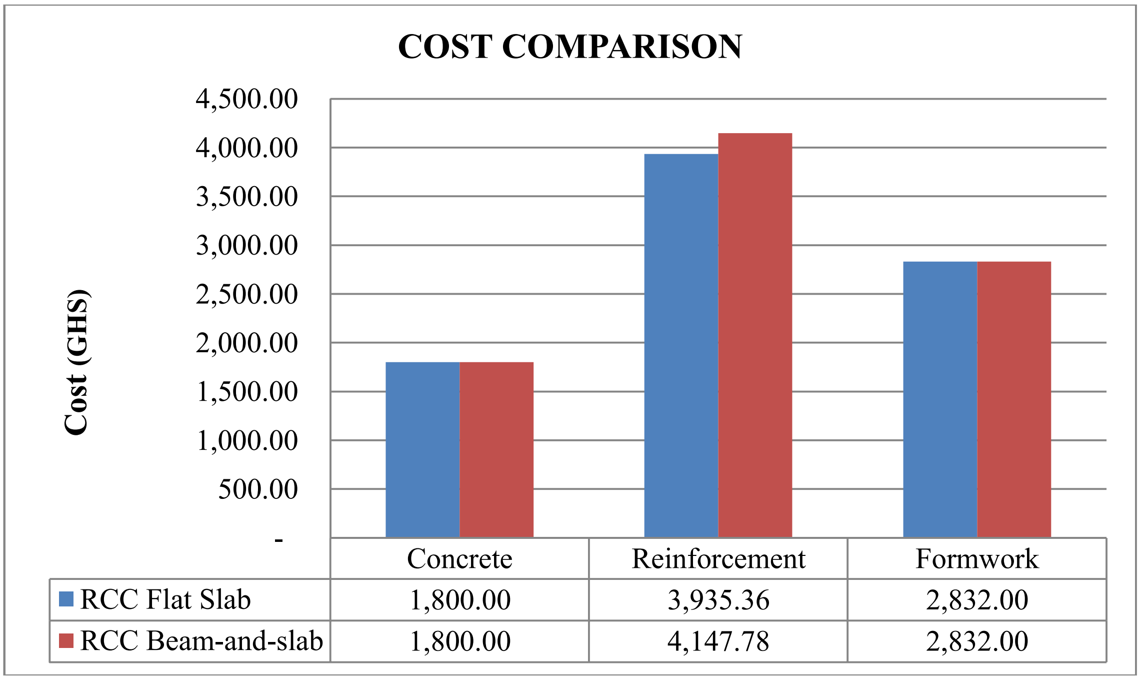

Figure 6: Variation of cost with each item – Typical Floor Columns

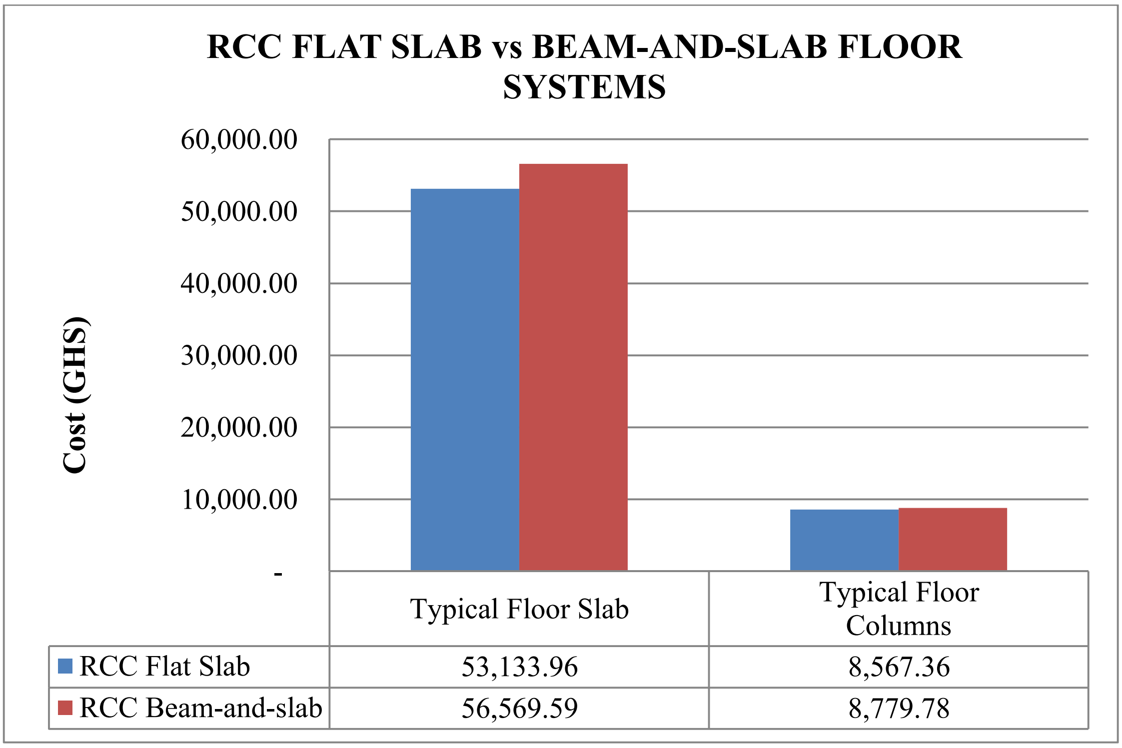

Figure 7: Variation of cost with each floor system – Elements

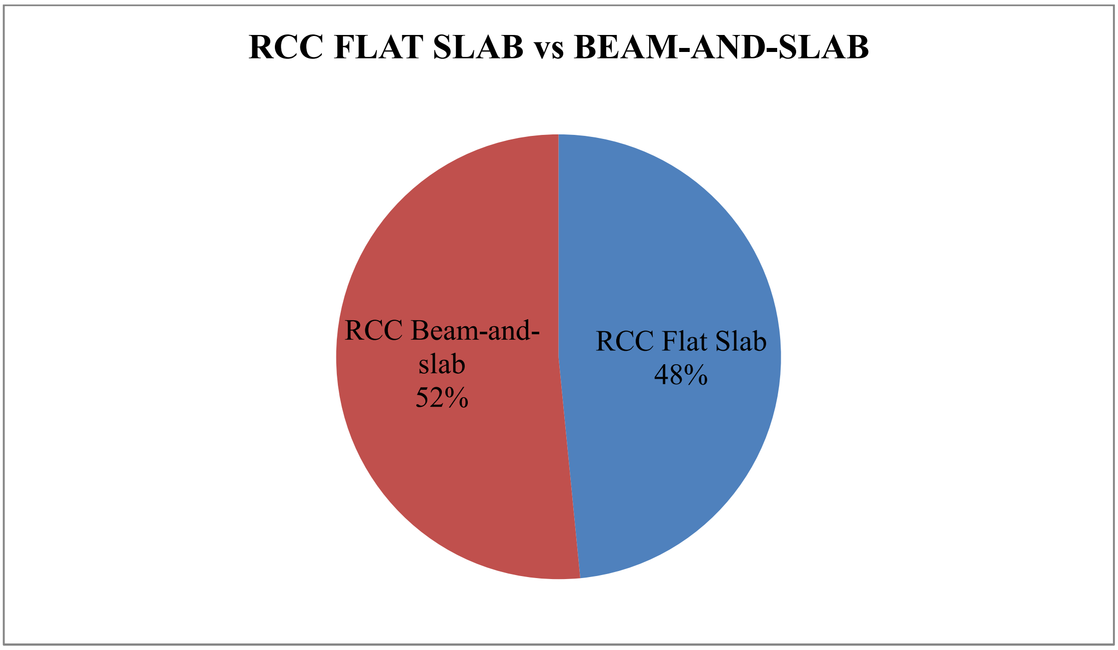

Figure 8: Variation of cost with each floor system

6.3 Findings

The summaries of findings from the above data presentation are as follows:

1. The benefits of using flat slab floor systems are as follows:
   i) The floor-to-floor height available in case of RCC flat slab floor system is 3.00m while in case of RCC Beam-and-slab floor system is 3.30m. These represent a height saving of 300mm, which will significantly reduce the overall height of the building or enables additional floors to be incorporated in buildings of a given height. This will however result in cost savings in terms of finishes.
   ii) The cost saving in Flat Slab floor systems is significant; +6.07% in floor construction and

+2.42% in column construction.

2. Assessing the various components of RCC flat slab and RCC beam-and-slab floor systems revealed the following:
    i) The cost of concrete required for a floor is 2.7% more in case of RCC flat slab compared to RCC Beam-and-slab floor system.
    ii) The cost of reinforcing steel required for a floor is 1.63% more in case of RCC Beam-and-slab compared to RCC flat slab floor system.
    iii) The cost of formwork required for a floor is 24.14% more in case of RCC Beam-and-slab, compared to RCC flat slab floor system.
    iv) The cost of reinforcing steel required in the columns is 5.12% more in case of RCC Beam-and-slab compared to RCC flat slab floor system.
3. The major cost significant items in both systems of floor construction were as follows:
    i) The major cost significant item in both floor systems is concrete followed by reinforcement steel and the least cost item is formwork. However, the most cost saving item is formwork in case of RCC flat slab floor system compared to RCC Beam-and-slab floor system.
    ii) It is also observed that the major cost significant item in the construction of columns in both floor systems is reinforcement steel followed by formwork and the least cost item is concrete. However, the most cost saving item is reinforcement steel in case of RCC flat slab floor system compared RCC Beam-and-slab floor system.

7.0 Conclusions and Recommendations

7.1 Conclusions

In this study, comparative cost assessment has been carried out on RCC flat slab and RCC Beam-and-slab floor systems. Structural elements considered include floor slabs, beams and columns in both floor systems. It was revealed that the major cost advantage item of the RCC flat slab floor system over the RCC beam-and-slab floor system is formwork (+6.07% cost saving) in floor construction and reinforcement steel (+2.42% cost saving) in column construction. However, the additional height saving in the use of RCC flat slab floor system as an additional cost advantage cannot be overemphasized. Based on the study conducted, it could be concluded that from the economic point of view, the RCC Flat Slab floor system is the most economical compared to RCC Beam-and-slab floor system.

7.2 Recommendations

In recent years, flat slab construction has become quite popular for medium and high-rise buildings. In a developing country like Ghana, in order to optimise land use, it is recommended that flat slab construction should be preferred since it is very cost effective and have many advantages over the beam-and-slab floor system.

For future scope, it is recommended that further comparative study of RCC flat slab and RCC beam-and-slab floor systems should include different sizes of floor panels/bays in both systems. In addition, the complete structure could be analysed and costed with complete programme of works for both floor systems.

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