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Analytical Study between Flat and Hollow Block Slabs in Sudan

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Abstract:

In this study, one of a structural member which called slabs are studied as general and in particular, one of these types hollow block and flat slab are investigated as a structural system. These structural systems are methods of construction for flooring system which are used in Sudan, and this research is covering the analysis and design of hollow block and flat slab using Safe program according to British code (BS 8110-1997). The results of analysis and design are compared together to find the best system and cost-effectiveness. The methodology comprises of the method and the design that was used to conduct the case studied and explain the way of analysis and design of hollow block and flat slab for a residential building in Sudan. There were two models with variable plan areas (13m×23m) and (14m×23m) analyzed and designed according to British code 8110. The result obtained from the study shows that the hollow block slab has a lightweight and zero punching shear making it more preferable choice for residential building. Considering from the economical point of view it is less expensive than that of the flat slab using hollow concrete block; hence the total quantity of steel reinforcement and concrete used is less. In model 1 for the cost of materials and the total cost increased for the flat slab is (27.31% - 21.54%) and on other hand In model 2 for the cost of materials and the total cost increased for the flat slab is (35.63% - 29.17%). To conclude, hollow block slab is the best alternative method in frame structures due to its capability to reduce the self-weight of the slab then the cost especially in long spans and have a good overall behavior in hot countries like Sudan.

Keywords: Hollow block slab, flat slab, analysis and design, Safe software, British code (BS 8110-1997)

1. Introduction

Slabs are the structural elements that convey the additional dead and imposed loads in different structures. They are used in buildings, paths, and bridges. Usually, they can be classified to one way and two ways systems. One way slabs with beams used are commonly for small spans not exceed six meters in one direction. Two-way slabs with beams and without beams are used for longer spans. Two-way slab systems are fundamentally used when there are long spans to reduce the slab thickness and to decrease the internal forces and the slab deflection (Ibrahim Mohammad Arman, 2014). Flat slab structures are used ultimately which have economical and functional advantages of the structural system and the architectural flexibility. The behavior and design of flat slab structures for gravity loads are well created. Their behavior under lateral displacements, however, is not well understood and lateral design methods are not well created (Laurel M. Dovich and James K. Wight; 2005).

Hollow block slab is designed to reduce a dead load of the slab and to facilitate formwork. It is a common and significant type of voided slab used in large span floor system. The portions of the slab thickness are full by the hollow blocks; this will conduct to give a deeper arm for the reinforcement while saving concrete and hence decreasing slab self-weight. The ribs reinforcement bars in the slab are located between the blocks. The blocks that used in slabs may be Styrofoam or concrete blocks. (Adel A. Al-Azzawi, Abbas J and Al-Asdi; 2017).

1.1. Problem Statement

Due to the different types of concrete slabs systems, it is necessary to determine the appropriate type of structure, whether residential, commercial, or otherwise, to give architectural and structural flexibility and economically. In this research, we could study the difference between hollow block slab and flat slab, as well as, which slab is more economical and suitable to applied in Sudan.

1.2. Research Questions and Hypothesis

- What type of slab is economical?

- How to calculate the design parameters of the hollow block and flat slab according to British standard code?
- What is the suitable program for analysis and design the both slabs.
- What are the major differences between the two slabs?

2. Literature Review

(Bikçe and Akyol, 2017) have studied ten buildings with up to 16 floors, five of those buildings with solid slabs and the other with lightweight hollow block slabs, which have been designed in accordance with updated earthquake regulations. As a result of the study, it has been determined that the cost difference varies between 1.33 and 15.37% when one slab various replaced with the other.(Al-Azzawi and Abed 2017) have studied experimentally the behavior of reinforced concrete slabs with hollow cores under varying study parameters. The experimental part covered testing 8 slab samples of hollow-core and solid models with (2.05 m) length, (0.6 m) width, and (25 cm) thickness under two monotonic line loads.(NavjotKaur Bhatia, June 2016) have examined the dynamic behavior of the flat slab and grid slab in comparison to the conventional slab. In the study of the project the writer performs the dynamic analysis for seismic and wind forces of multistory RC building with different plans like square, orthogonal hexagonal, orthogonal for the flat slab, grid slab, and conventional slab. The above have analyzed for different stories like 10, 20, and 30 and also for the different earthquake zone according to the Indian standard code of practice (1893 – 2002). They made the relation between earthquake responses and strengths. It is detected from the study that the behavior and structural behavior of flat slab and grid slab is preferable in comparison to a conventional slab. It is shown in term of deflection and cost of the material. (Salman I. Khan and Ashok R. Mundhada 2015) have conducted a comparative study between flat and grid slab on Reinforced cement concrete buildings. The dynamic analysis method is response spectrum using Etabs software for three buildings having different high rise (12,15,18) stories the study can represent that flat slab has lower performance than the grid slab based upon flat slab has 4% more base shear and lateral displacement additional to flat slab has significantly more story drift. (Makode R K and Akhtar 2014) have compared the seismic response of multistoried structures (12-story building) with flat and grid slabs using the response spectrum method, the study concludes that at the columns in the center of the plan was less in grid slab as compared to the building with the flat slab, moreover, at each storey the building with grid performed less storey drift than flat slab.(Allawi 2014) have carried out experimental tests on the one-way voided slab to investigate the structural behavior of the reinforced concrete slabs containing cavities. (Rahman, Vakas K., and A. R. Mundhada'2013) have worked on the design of reinforced cement concrete in addition to pre-stressed concrete flat slabs for different spans and then compare the results Programming in Microsoft Excel is done to design both types of flat slabs. . The idea is to reach a definite conclusion regarding which one of the two techniques is more suitable for another. Results reveal that a pre-stressed concrete flat slab is more expensive than reinforced cement concrete flat slab for smaller spans but for longer span pre-stressed concrete flat slab is more economic. (Alzanen, A.H.M, 2012) have included the analysis and design of hollow block slab according to different provisions codes: Egyptian cod (EPC 203-2007), American code (ACI 318-2005), and British code (BS 8110-1997).In addition to reinforcement detailing and construction method. The results of analysis and design by codes are compared to find the code designable achieving economical and safety.

The economical and safety code is used to analyze and design two floors system manually; flat and hollow block slab and compare results to reach a definite conclusion regarding the superiority of the two-floor systems over one another. There are other features that make it a suitable structural system for hot places like Sudan. (Amit A. Sathwane2011) have investigated that the among flat slab, grid slab, and flat slab with the drop which is economical for the nexus point opposite+e to vidhanbhavan and beside the NMC office. The analysis of flat slab, grid slab, and flat slab without drop done both manually using STAAD PRO V8i software according to IS 456-2000. It is conducted in this study that a flat slab with a drop is economical compare to other considered slab for the nexus point. It has also appeared in the study that concrete required for the flat slab with and without drop is less than the grid slab and steel required for the flat slab with drop and grid slab is less than the flat slab without a drop. (Ghoneim and El-Mihilmy, 2008)Other advantages include reduction of loads on the foundation thereby allowing more storeies to be built on the same foundation, low reinforcement per square meter and high acoustic and thermal insulation. Hollow block floors proved economic for spans of more than 5m with light or moderate live loads, such as hospitals, office, or residential buildings. They are not suitable for structures having heavy live loads such as warehouses or parking.

3. Research Methodology

The design method which used in this study is the Finite elements [Safe program]. In conventional structural analysis, numerous approximations are introduced and the engineer is normally content to accept the resulting facilitation. Actual elements are considered as idealized one-dimensional linear members; deformations due to axial force and shear are assumed to be adequately small to be neglected; and so on. In general, such assumptions are valid and the results of the analysis are adequately close to the values that would occur in the actual structure to be acceptable.

The finite element is that a body or continuum is divided into smaller elements of finite dimensions called finite elements connected at a lot of joints called nodal points or nodes. The displacements of these nodal points will be the basic unknown parameters of the problem. The original body or structure is then idealized as an assemblage of these elements connected at nodal points. In the most popular procedure, a simple displacement purpose at the specified nodal points of elements is assumed in terms of the displacements at the prescribed nodal points of elements (Kai, Cheung Yau, and Olgierd Cecil Zienkiewicz 1967).

Programs that work on the analysis and design of high buildings contributed to save time and effort and high accuracy in the results. These programs work on the system of finite elements, where the origin is divided into small elements in the form of a network and examples of these programs are (Sap, Safe, Etabs, Staadprog). It is worth

mentioning that the elements for columns, beams, and ties are known in these programs as frame elements, and those for slabs, shear walls, and ramps as shell elements [Tayseer Ismail Hasb ALLA 2018].

3.1. Safe Program

Safe is a sophisticated, yet easy to use, special purpose analysis, design, and detailing program developed especially for the concrete slab and base mat systems. Safe version-2016 couples powerful object-based modeling tools with an intuitive graphical interface, allowing the efficient and quick modeling of slabs of arbitrary or regular geometry with post-tensioning, drop panels, openings, edge beams, ribs, and slip joints, supported by columns, walls, or soil. Design is seamlessly integrated with the modeling and analysis, and provides extensively reporting of the required rebar calculated based on a chosen design code. Detailed drawings may be produced easily for slabs and beams designed using Safe. Safe may be used as a stand-alone application, or may be used in connection with Etabs to complete analysis, design, and detailing of concrete floor plates.

Safe offers the widest group of analysis and design tools available for the structural engineer working on concrete slabs. The list exemplifies just a part of the varieties of systems and analyses that Safe can easily handle slabs as following:

- Flat slabs.
- Waffle slabs.
- Ribbed slabs.
- Rectangular or circular slabs.
- Slabs subjected to any number of vertical load patterns and combinations.
- Slab reinforcement calculated based on user-defined design strips.

User controlled placement of slab rebar.

- Punching shear checks and punching reinforcement design.
- Dynamic analysis of floor systems and foundations by exporting response spectrum analysis results from Etabs to Safe.
- Reinforcement contours calculated using Finite Element forces.

3.2. Scope of Case Study

The scope of the work consists of the design and detailing of floor slab for a single storey office Block for the two cases considered (flat slab and hollow block slab). A Bill of quantities was prepared based on a typical design and detailing of structural members of the two cases considered. The design model consists of a single storey office block with a plan consisting of plan areas of (23 m × 13 m) and (23 m × 14 m) as follows in Figures (3.1) and (3.2).

Figure 1: Layout of Plan [1]

Figure 2: Layout of Plan [2]

Figure 3: Model-1 Fat slab

Figure 4: Model-1 Hollow Block Slab

Figure 5: Model-2 Flat Slab

Figure 6: Model-2 Hollow Block Slab

3.3. Analysis and Design

Structural design software (Safe) was used for the analysis and design of both floor systems. The design was based on the finite element method of Analysis. The code used for the design is the BS8110, BS6399, and other relevant codes of practice. The design loadings considered were both dead and imposed loads. The material and geometric properties of the single-storey building are presented in Tables 1, 2, and 3.

Standards	BS 8110 : 1997
Material name	Concrete
Type of material	Isotropic
Mass per unit volume	2.4 KN/m ³
Modulus of elasticity	22.454 KN/mm ²
Poisson ratio	0.2
Grade of concrete	25 N/mm ²
Grade of steel	
F_y	460 N/mm ²
F_{ys}	250 N/mm ²

Table 1: Description of Material Properties

The loading condition in the building is defined as follows; the dead load is considered:

- Own weight from the slab is calculated based on the variable dimensions taking the unit weight of concrete is 24 kN/m³.
- [Finishes+partitions]loads = 5.7kN/m².
- Live load =1.5 kN/m²
- Load combinations =1.4 dead + 1.6 live (1.4 Gk + 1.6 QK)

Structure Type	Flat Slab
Structure Function	Residential building floor
1-Length in X-direction	23 m
2-Length in Y-direction	13 m
3-Floor to floor height	3 m
4-Number of stories	1
5-Total height of building	3 m
Slab thickness	200 mm
7-Size of the column	250 mm×450 mm
8-Grade of concrete	25 N/mm ²
9-cover	25 mm

Table 2: Physical Properties of Single Story Flat Slab Building

1- Length in X-direction	23 m
2-Length in Y-direction	13 m
3-Floor to floor height	3 m
4-Number of stories	1
5-Total height of building	9 m
6-Hidden beam	
Main hidden beam	260 mm×600 mm
Outer hidden beam	260 mm×400 mm
Enterer hidden beam	260 mm×400 mm
Ribs	260 mm×125 mm
7-Slab thickness	70 mm
8-Size of the column	250 mm×450 mm
9-Grade of concrete	25 N/mm ²
10-cover	25 mm
11- weight of block	0.5 KN/m ²
12-density of block	6 KN/m ²

Table 3: Physical Properties of Single Story Hollow Block Slab

Figure 7: Flow Chart Shows Steps That Followed in Safe Program

4. Results and Discussion

From Table 4, the steel reinforcement of the flat slab for 50 m² is (1.67 ton) and on the other hand in the hollow block slab with the same area is (1.095 ton), with an increase in the steel reinforcement quantity for flat slab by (0.575 ton). In Addition, The concrete of the flat slab for 50 m² is (11 m³) but the concrete in the hollow block is (8.1 m³). So, the quantity of concrete for the flat slab increased by 26.36% than the hollow block slab. Furthermore, the total cost of the flat slab for 50 m² is (299,800 SDG) but the hollow block slab is (235,220 SDG), with an increase in the total cost of the flat slab by (64,580 SDG).

Concrete = 9,500 SDG/ m ³ , Steel = 90,000 SDG/ton, Block = 30 SDG/unit						
Flat slab with 0.22 m thickness						
Area (m ²)	50	100	150	200	250	300
Concrete (m ³)	11	22	33	44	55	66
Steel (Ton)	1.67	3.34	5.01	6.68	8.35	10.02
Cost of construction (SDG)/Area	45000	90000	135000	180000	225000	270000
Cost of materials (steel + concrete)/(SDG)	254800	509600	764400	1019200	1274000	1528800
Total (SDG)	299800	599600	899400	1199200	1499000	1798800
Hollow block slab with 0.26 m thickness						
Area (m ²)	50	100	150	200	250	300
Concrete (m ³)	8.1	16.2	24.3	32.4	40.5	48.6
Steel reinforcement (Ton)	1.095	2.19	3.285	4.38	5.475	6.57
Block (unit)	324	648	972	1298	1620	1944
Cost of construction (SDG)/Area	50000	100000	150000	200000	250000	300000
Cost of materials (steel reinforcement+concrete+block)/(SDG)	185220	370440	555660	740880	926100	1111320
Total (SDG)	235220	470440	705660	940880	1176100	1411320
Percentage Diff. (materials for hollow slab against flat slab)	27.31%	27.31%	27.31%	27.31%	27.31%	27.31%
Increase ratio(Cost of construction for hollow slab against flat slab)	10%	10%	10%	10%	10%	10%
Percentage Diff. (Total cost)	21.54%	21.54%	21.54%	21.54%	21.54%	21.54%

Table 4: Cost Effectiveness of Hollow Block and Flat Slab Model-1

Figure 8: Comparison of the Steel Reinforcement Quantity (Ton) in the Two Slabs

Figure 9: Comparison Of Concrete Quantity (M³) In The Two Slabs.

Figure 10: Comparison of the Total Cost (SDG) in the Two Slabs

As shown in Table 5 the steel reinforcement of the flat slab for 50 m² is (1.8 ton) and on the other hand in the hollow block is (1.045 ton), with an increase in the steel reinforcement of the flat slab by (0.755 ton). In Addition, the concrete quantity of the flat slab for 50 m² is (12.5 m³) but the concrete in the hollow block is (8.1 m³). So, the quantity of concrete for the flat slab increased by 35.2% than the hollow block slab. Moreover, the total cost of the flat slab for 50 m² is (325,750 SDG) but the hollow block slab is (230,720 SDG), with an increase in the total cost of the flat slab by (95,030 SDG).

Concrete = 9,500 SDG/ m³, Steel = 90,000 SDG/ton, Block = 30 SDG/unit							
Flat slab with 0.25m thickness							
Area (m ²)	50	100	150	200	250	300	350
Concrete (m ³)	12.5	25	37.5	50	62.5	75	87.5
Steel (Tone)	1.8	3.6	5.4	7.2	9	10.8	12.6
Cost of construction (SDG)/Area	45000	90000	135000	180000	225000	270000	315000
Cost of materials (steel + concrete)/(SDG)	280750	561500	842250	1123000	1403750	1684500	1965250
Total (SDG)	325750	651500	977250	1303000	1628750	1954500	2280250
Hollow block slab with 0.26 m thickness							
Area (m ²)	50	100	150	200	250	300	350
Concrete (m ³)	8.1	16.2	24.3	32.4	40.5	48.6	56.7
Steel (Ton)	1.045	2.09	3.135	4.18	5.225	6.27	7.315
Block (unit)	324	648	972	1298	1620	1944	2268
Cost of construction (SDG)/Area	50000	100000	150000	200000	250000	300000	350000
Cost of materials (steel reinforcement + concrete+block)/(SDG)	180720	361440	542160	722880	903600	1084320	1265040
Total (SDG)	230720	461440	692160	922880	1153600	1384320	1615040
Percentage Diff. (materials for hollow slab against flat slab)	35.63%	35.63%	35.63%	35.63%	35.63%	35.63%	35.63%
Increase ratio(Cost of construction for hollow slab against flat slab)	10%	10%	10%	10%	10%	10%	10%
Percentage (total cost)	29.17%	29.17%	29.17%	29.17%	29.17%	29.17%	29.17%

Table 5: Cost Effectiveness of Hollow Block and Flat Slab Model-2

Figure 11: Comparison of the Steel Reinforcement Quantity (Ton) in the Two Slabs

Figure 12: Comparison of the Concrete Quantity (M³) in the Two Slabs

Figure 13: Comparison of the Total Cost (SDG) in the Two Slabs

Finally, Table 6 shows the comparative study between flat and hollow block slabs through model 1&2

Description	Flat Slab and Hollow Block Slab Model 1	Flat Slab and Hollow Block Slab Model 2
The increase in the steel reinforcement for flat slab	0.575 ton	0.755 ton
The increase in the concrete for flat slab	2.9 m ³	4.4 m ³
The increase in the total cost for flat slab	64,580 SDG	95,030 SDG

Table 6: Comparison between the Two Models [1&2]

5. Conclusion

In this paper, a comparative study is carried out between hollow block and flat slab using Safe program based on BS 8110-1997. The results depict that the analysis of hollow block slab in model 1 and model 2 have decreased the total cost by 21.54%, 29.17% respectively compared to that of flat slab models. Furthermore, we can conclude that when the span is longer than 7 m the difference in the total cost between hollow block and flat slab is increased due to the increase in the thickness of flat slab. Hence, the hollow block slab is suitable and economical. Moreover, both Hollow and flat slabs systems are very simple to construct and efficient in that require to minimize the building height. However, Reinforced concrete of hollow block slab is inherently fire resistant, and no additional cost for fireproofing that required to meet required ratings. Further, there is no punching shear in hollow block while high in the flat slab whenever the span is long.

6. Recommendation

For particulars:

- In the residential building that has lightweight using hollow block slab.
- Use these systems in another country like Yemen with the same volume of hollow block.
- How to convince the owner in Sudan for choice hollow block slab and explain for him the advantages.
- Check punching shear manually because the program does not calculate reinforcement steel

For future studies:

- Study the analysis and design of hollow block and flat slab system building under the influence of earthquakes.
- Study the analysis and design of hollow block and flat slab system building in other countries.
- Study the analysis and design of hollow block slab only under variable parameters.
- Study the analysis and design of flat slab only under variable parameters.
- Using cork as hollow blocks in a dropped ceiling.
- Study the analysis and design of hollow block and flat slab system building using Robot program according to British code (BS 8110-1997).
- Study the analysis and design of hollow block and flat slab system in the commercial building.

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