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Comparative Study of Analysis and Cost of Flat Slab and Conventional Slab Structures in Somalia-Mogadishu

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Abstract: All Somalian cities favor vertical growth over lateral growth due to a combination of rapid population growth, fast urbanization, lack of urban infrastructures, and rising land prices. The use of conventional slabs has been common in Somalia, but nowadays flat slabs are widely used due to their advantages such as reduced story height, ease of formwork installation, and shorter construction period, all of which affect the cost of construction projects. However, accurate analysis and design are required for flat slabs since they are susceptible to punching shear. This study aims to investigate the performance and behavior of flat slab and conventional slab floor systems subjected to gravity loads and to compare the total cost of flat slab floor systems and conventional slab floor systems for formwork, required concrete, and steel reinforcement in Somalia. 8-story residential buildings with flat slab and conventional slab floor systems have been analyzed using ETABS software as per ACI 318-14 and ASCE 7-16. The results show that flat slab structures have obvious architectural and structural advantages and in addition, the cost of a conventional slab floor system is 18.3% to 19.9% higher compared to a flat slab floor system. Based on the cost analysis results obtained from this case study, it could be concluded that the flat slab floor system is economical compared to the conventional slab floor system in Somalia.

Keywords: Conventional slab, Cost, ETABS, Flat slab, Somalia

Introduction

The idea and desire to build multi-story buildings have changed throughout history, and today the growth of cities has increased the construction of mid-rise and high-rise buildings. In fact, factors such as high population density, lack of land, and the increase in land prices are among the factors that have led to the preference for vertical structures over horizontally expanded structures. In emerging countries such as Somalia, the urbanization process began with the industrial revolution and is still ongoing, with people moving to urban areas where more work opportunities are available as a result of industrialization. In Somalia, the construction of 5-story to 12-story buildings is widespread. These buildings are often residential or commercial or in some cases a combination of the two.

The slab system commonly used in Somalia is conventional slab structures. On the other hand, flat slab systems have been widely used in Somalia in recent years. This reinforced concrete floor system has many advantages which accelerate construction, architectural flexibility, easier formwork, and use of space. However, flat slab structures need further attention.

The estimated cost of an engineering project can be determined using a scientific method before actually starting. Although the actual cost of the project upon completion differs from the estimated cost, it should not fluctuate significantly from the estimated cost, assuming there are no unexpected or unforeseen circumstances. Cost estimation requires talent, expertise, foresight, and good judgment in addition to a thorough understanding of building procedures and material and labor costs. Estimating the approximate cost of the project helps to assess its affordability and ensure financial resources (Peurifoy & Oberlender, 2014, Serbanoiu et al., 2020)

Problem Statement

- Population growth has put pressure on the limited land area in Somalia.
- Lack of prior information, lack of a database that includes housing prices, lack of proper resources, and lack of project management affected Somalia.
- A comparative study of the analysis and cost of flat slabs and conventional slabs in Somalia has not been studied yet.

Research Objective

The main objectives of this study are listed below:

- Investigating the performance of flat slab and conventional slab structures subjected to gravity loads.
- Evaluation of the behavior of flat slab and conventional slab structures for parameters such as bending moment, shearing force, etc.
- Comparison of the analysis results of the flat slab and conventional slab structures.
- Comparison of the required amount of concrete, steel, and formwork material.
- Comparison of the total cost of the structure with flat slab and conventional slab structures for concrete, steel, and formwork.

Literature Review

There are several previous studies and academic research mainly on the comparative study of analysis and cost of the flat slab and conventional slab structures. These articles and works have been reviewed as part of this study. Sawwalakhe, et al., (2021) investigated that modern architecture often supports the normal slab with a deep beam and a thin slab, which transfers the load to the column, due to its popularity, affordability, and ability to reduce weight and speed up growth. It also offers advantages including greater stiffness and weight-carrying capacity. Grid slabs are able to carry heavier loads over longer spans and reduce void-related dead load. The goal of this experiment was to determine the most affordable slab type among grid slab, flat slab with a drop, and standard slab. Story drift, shearing force, and story displacement were some of the measurements that were made. 18 distinct constructions were examined and the dead load, live load, and seismic load have been determined. A flat slab performs better than a standard slab or grid slab when the shearing force, bending moment, displacement, and drift are taken into account (Sawwalakhe & Pachpor, 2021).

Borkar, et al., (2021) examined that selecting an appropriate type of building for a specific purpose is essential for architectural engineers since multistory structures are becoming more and more required as the need for space in living arrangements increases. This research aimed to investigate the response of flat slab structures for a variety of heights and designs using ETABS, in terms of story shear, base shear, and story drift, in seismic loads for several zones (Borkar, et al., 2021). Sayli, et al., (2020) studied that classic slab systems, including flat slabs and grid slabs, have been evaluated using ETABS and STAAD.Pro. This study aimed to examine the impacts of vertical and horizontal force, displacement, shearing force, bending moment, flexibility, and slab behavior for conventional slabs, flat slabs, and grid slabs in various earthquake zones (Sayli & Madavi, 2020).

Sathawane, et al., (2012) have presented a comparison of Grid Slab, Flat Slab with Drop, and Flat Slab without Drop researchers found that Grid Slab is the most cost-effective option. The analyses of flat slabs, flat slabs without drops, and grid slabs were conducted manually, and also by using STAAD PRO V8i, IS 456-2000 programs. This study found that compared to other slabs considered, a flat slab with a drop is more reasonably priced. More concrete is needed for a grid slab and the amount of steel needed for a flat slab with a drop is also greater than for a flat slab without a drop (Sathawane & Deotale, 2012).

Methodology

A total of 6 models were modeled, 3 of which were developed with a flat slab floor system, and the other 3 models were developed with a conventional slab floor system. The difference between the models with the same type of slab is the grid spacing, which varies between 5, 6, and 7 meters. The height of each story is typically 3.2 meters and the selected buildings are assumed to be used as residential buildings. The location of the buildings is assumed to be in Mogadishu city which is the capital and the most populous city of Somalia. In the capital region, Mogadishu, the earthquake risk is classified as very low.

Buildings were modeled using ETABS and linear analysis was conducted. ACI 318-14 (Building Code Requirements for Structural Concrete) and ASCE (Minimum design loads for buildings and other structures) were adopted. The properties of materials are shown in Table 1.

Table 1. Properties of materials

Parameter	Value
Weight per unit volume of concrete, γ_c	25 kN/m^3
Weight per unit volume of steel, γ_s	78.5 kN/m^3
Modulus of Elasticity of steel, E_s	200,000MPa
Modulus of Elasticity of concrete, E_c	24870 MPa
Compressive strength of concrete, f_c	28 MPa
Yield strength of steel, f_y	420 MPa

Design Procedure

Preliminary measurements were taken to analyze building elements (beams, slabs, and columns). The initial slab and beam sizes were calculated, and the estimated sizes of the columns were determined according to the axial loads transmitted by the slab and beams as a result of live loads and dead loads. The appropriate member sizes and minimum thickness for different slab systems were calculated as per ACI 318-14.

Loads

Load Patterns

In this study, the considered loads are dead load and live load. The dead load is the structure self-weight, which is automatically calculated by ETABS software. Super dead load is the additional load on the structures; it represents the weight of the finishing materials and partition walls of a building which is considered 2.11 kN/m^2 in this study. The live load for residential buildings is considered 2 kN/m^2 and is assumed for all floors. The minimum design dead loads and live loads were taken from ASCE/SEI 7-10.

Load Combination

Commonly, a load combination is composed of various loads, such as dead loads and live loads, which are then combined to form a strength design. The load combination was developed in accordance with ASCE 7-10 as follows, where DL is dead load and LL is live load.

$$W_u = 1{,}2DL + 1{,}6\,LL$$

Modeling by ETABS

The building parameter details for types A, B, and C, and their plans are shown below in detail. The factors considered in this work were slab type, length of span in X and Y directions, story height, slab thickness, and the size of the columns.

Table 2. Building parameters (Type A)

Parameter	Slab Systems Conventional Slab	Flat Slab
Dimension of the building (Length and width)	25m×25m	25m×25m
Length of each span (X-direction)	5m	5m
Length of each span (Y-direction)	5m	5m
Number of spans	5 Rows & 5 Columns	5 Rows & 5 Columns
Story height	3.2m	3.2m
Number of stories	8	8
Slab thickness	160mm	180mm
Beam size	200mm×310mm	--------
Column size (corner)	460mm×460mm	400mm×400mm
Column size (exterior)	500mm×500mm	440mm×440mm
Column size (interior)	570mm×570mm	520mm×520mm

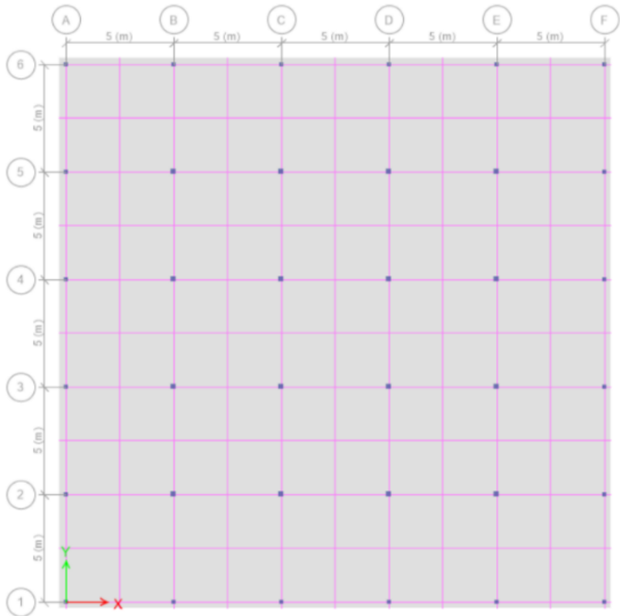

Figure 1. Plan of 8-story building (Flat slab/ Type A)

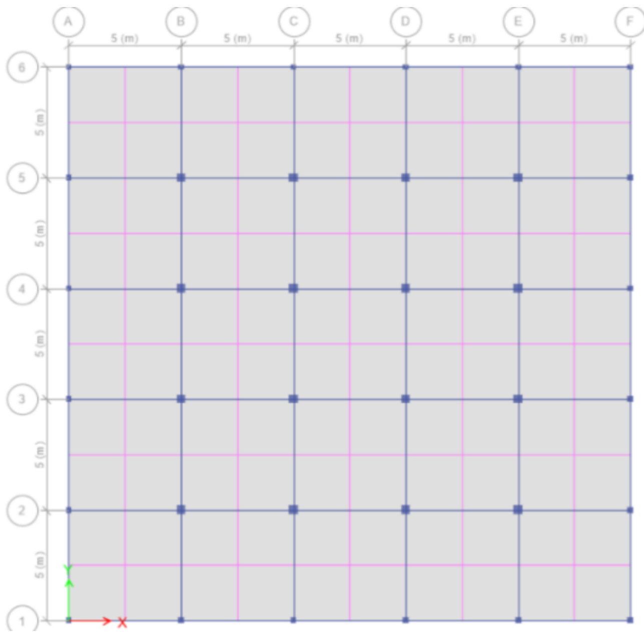

Figure 2. Plan of 8-story building (Conventional slab/ Type A)

Table 3. Building parameters (Type B)

Parameter	Slab Systems	
	Conventional Slab	Flat Slab
Dimension of the building (Length and width)	30m×30m	30m×30m
Length of each span (X-direction)	6m	6m
Length of each span (Y-direction)	6m	6m
Number of spans	5 Row & 5 Column	5 Row & 5 Column
Story height	3.2m	3.2m
Number of stories	8	8
Slab thickness	180mm	210mm
Beam size	350mm×450mm	--------
Column size (corner)	470mm×470mm	410mm×410mm
Column size (exterior)	510mm×510mm	450mm×450mm
Column size (interior)	590mm×590mm	530mm×530mm

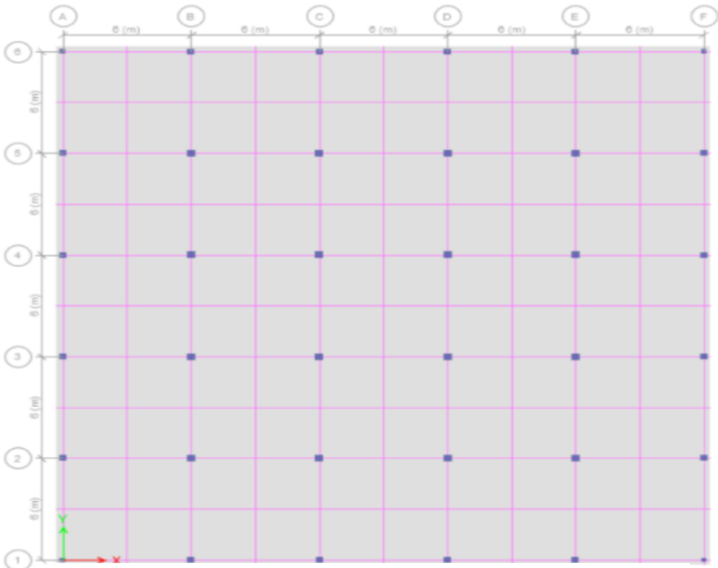

Figure 3. Plan of 8-story building (Flat slab/ Type B)

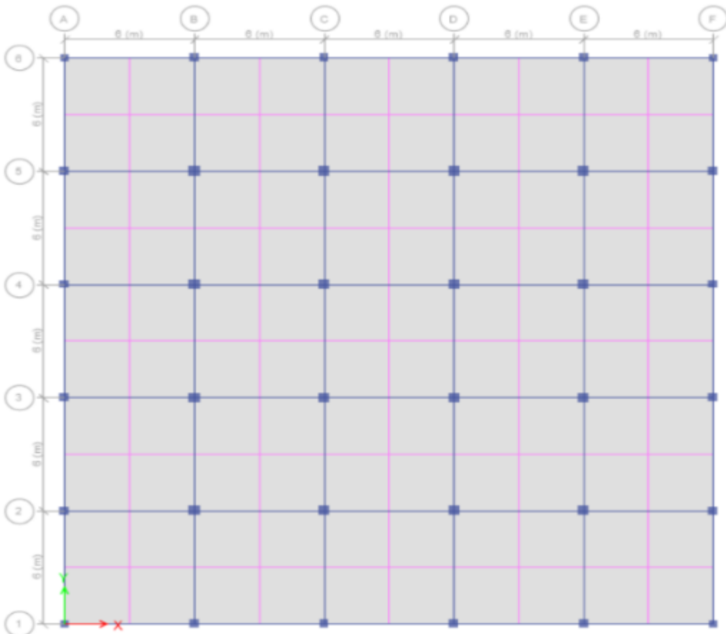

Figure 4. Plan of 8-story building (Convectional slab/ Type B)

Table 4. Building parameters (Type C)

Parameter	Slab Systems	
	Conventional Slab	Flat Slab
Dimension of the building (Length and width)	35m×35m	35m×35m
Length of each span (X-direction)	7m	7m
Length of each span (Y-direction)	7m	7m
Number of spans	5 Rows & 5 Columns	5 Rows & 5 Columns
Story height	3.2m	3.2m
Number of stories	8	8
Slab thickness	210mm	240mm
Beam size	390mm×490mm	--------
Column size (corner)	500mm×500mm	440mm×440mm
Column size (exterior)	540mm×540mm	480mm×480mm
Column size (interior)	620mm×620mm	560mm×560mm

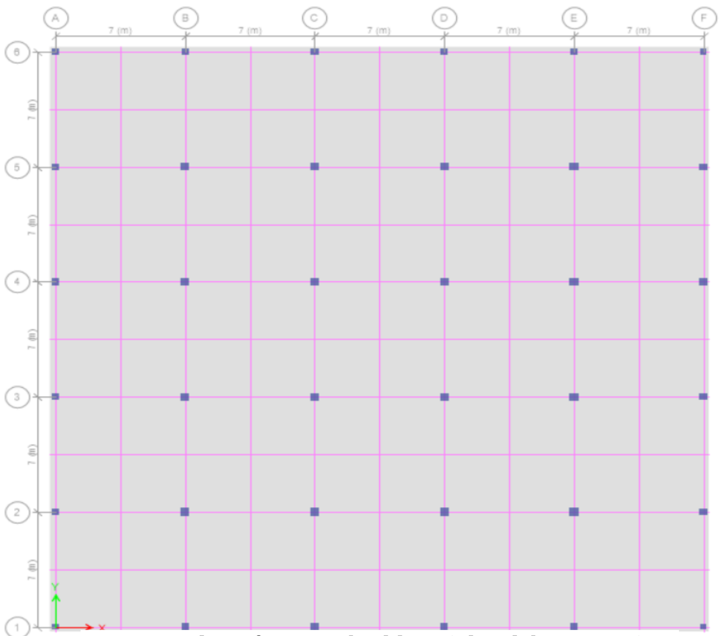

Figure 3. Plan of 8-story building (Flat slab/ Type C)

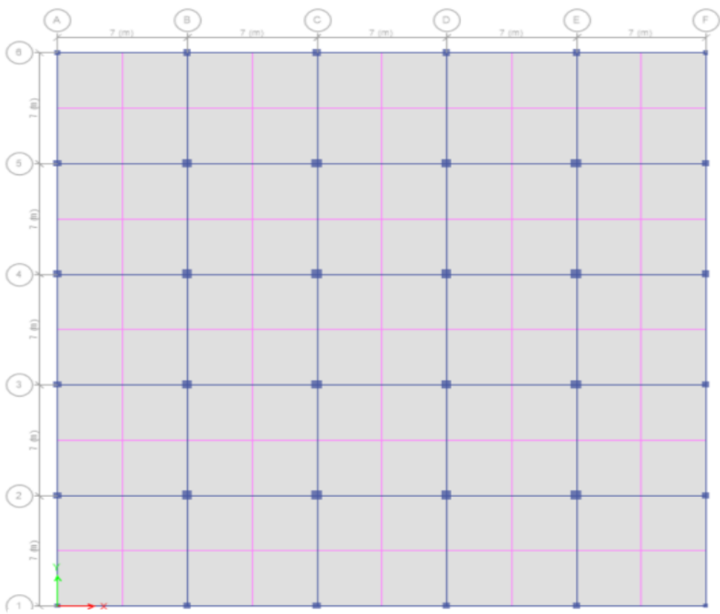

Figure 4. Plan of 8-story building (Conventional slab/ Type C)

Results and Discussion

The results include bending moment, shearing force, punching shear force, and deflection of different models shown in Table 5. As shown in Table 5, all plot sizes of the flat slab structures have greater bending moment, shearing force, and deflection with respect to conventional slab structures. Increasing the span length/plot size increases the punching shear in flat slab structures. It should be noted that the punching shear value is within the permissible limit for all plot size models in this study. The required weight of steel reinforcement, the required volume of concrete, and the required area of the formwork have been evaluated for all cases. The results are shown in the following figures.

Table 5. Analysis of results for all cases

Parameter `	Slab Systems					
	Conventional Slab			Flat Slab		
Plot Size	25m×25m	30m×30m	35m×35m	25m×25m	30m×30m	35m×35m
Span Length (m)	5	6	7	5	6	7
Slab Thickness (mm)	160	180	210	180	210	240
Bending Moment (kN.m)	38.1	66.8	92	52.6	94.3	149.7
Shearing Force (kN)	41.6	90.4	93.3	96.8	156.2	160.5
Punching Shear (kN)	-------	------	------	0.74	0.84	0.99
Deflection (mm)	1.927	2.230	3.427	3.874	5.045	5.719

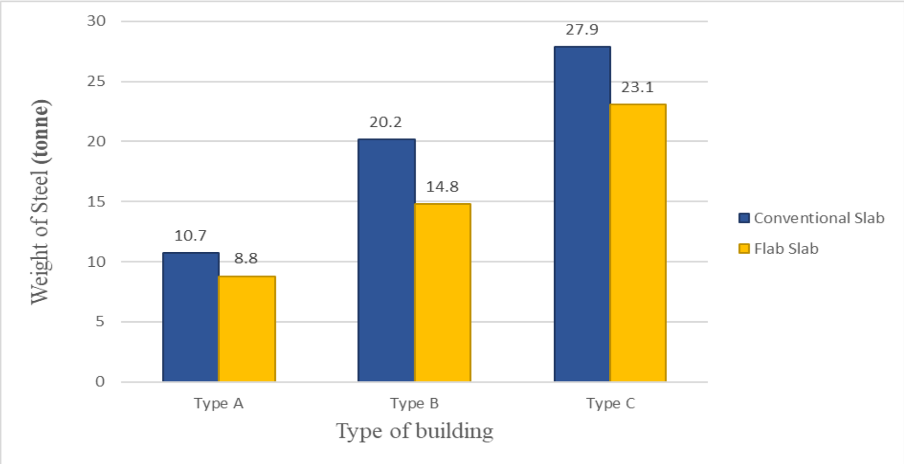

Figure 7. Weight of required steel for all cases

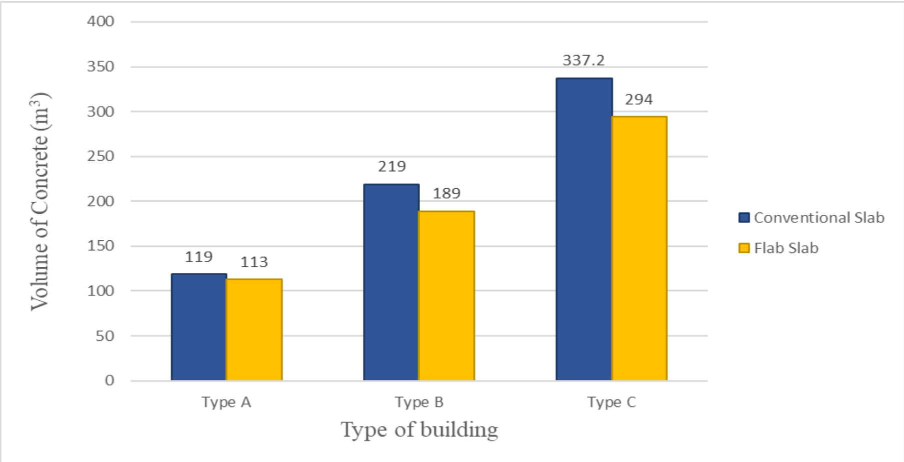

Figure 8. The volume of required concrete for all cases

As shown in the figures, the volume of concrete for a flat slab is 5% to 14% less than that of a conventional slab structure, and the required weight of steel reinforcement for a flat slab is 18% to 27% less than that of a conventional slab structure, and the required area of formwork for a flat slab is 22% to 25% less than that of a conventional slab structure. Market rates are used to calculate the total cost of steel, concrete, and formwork used in flat slab and conventional slab systems. The price of steel and concrete in the Somali market is 950 $/ton and 135 $/m^3$ respectively and the formwork rate is 25 $/m^2$. Figure 10 shows the total cost of the conventional slab and flat slab structures for all cases.

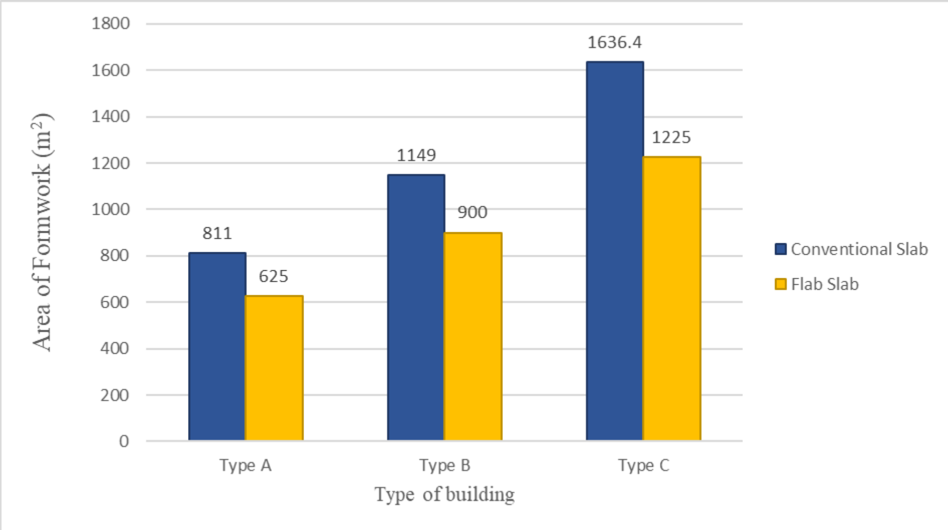

Figure 9. Area of required formwork for all cases

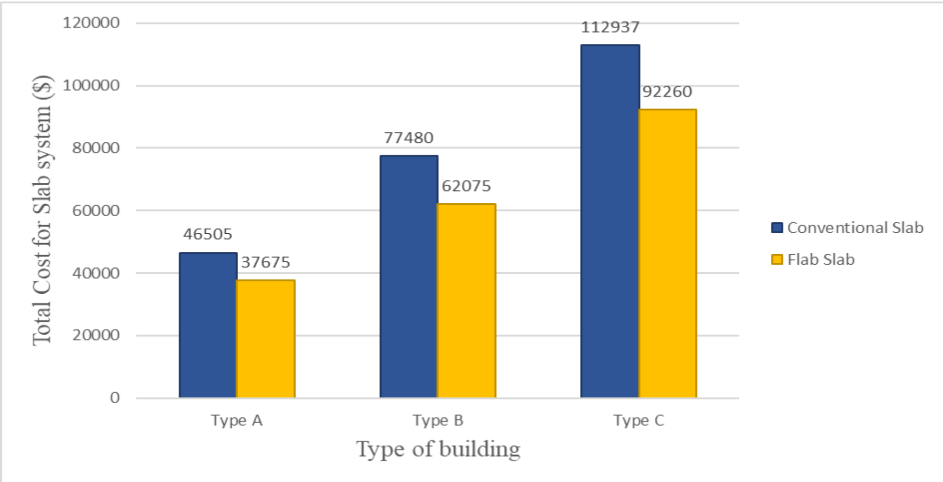

Figure 10. The total cost of the slab system for all cases

As shown in Figure 10, the total cost of flat slab structures is about 18.3% to 19.9% lower compared to conventional slab structures. Therefore, flat slab structures are more economical in terms of the cost of materials compared to conventional slab structures.

Conclusions

The results of the analysis lead to the following conclusions:

- Compared to conventional slab structures, flat slab structures are subjected to higher bending moment, shearing force, and deflection.
- The punching shear value is within the permissible limit. Therefore, the depth of the slab is sufficient for flat slab systems.
- The punching shear failure in flat slab structures is not critical in this study, but if punching shear becomes critical, drop panels, shear reinforcement, and increasing the sections of slab and column are required.
- As the span length increases, bending moment, shearing force, and deflection increase.

- A flat slab structure is more economical than a conventional slab structure. The cost of a flat slab system is 18.3% to 19.9% less than a conventional slab.
- For high-rise buildings, flat slab structures are preferable over conventional slab structures in the architectural aspect. In addition, flat slab structures provide formwork flexibility, flexural reinforcement insertion ease, concrete casting simplicity, and open space for water, air, and other piping, and enhance visual appeal.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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