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COMPARISON OF THE POST-TENSIONED, SOLID, HOLLOW BLOCK, AND FLAT SLABS IN TERMS OF ECONOMY CONSIDERING DIFFERENT SPAN LENGTHS

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From among the several types of slabs, there is uncertainty about the most cost-effective one for structures with short, medium, and long spans. A study comparing the cost of the solid, flat, hollow block (HB), and post-tensioned (PT) slabs for *4*, *6*, and *8m* spans was conducted using SAFE software. For each span length, the total quantities of concrete and steel bars were found and compared for *4* slabs. Then, the total cost of steel bars, concrete, blocks, tendons, and formwork was tabulated and compared. The findings revealed that the quantity of concrete in slabs with *4* and *6m* spans is the least in the HB slabs, while for slabs with *8m* spans, the quantity of concrete is the least in the PT slab. Besides, the quantity of steel bars in slabs with *4*, *6*, and *8* spans is the least in PT slabs. In terms of economy, the most cost-effective option is the flat slab for *4m* spans, with savings of about *14*, *9*, and *17*% compared to solid, HB, and PT slabs, respectively. On the other hand, for *6* and *8m* spans, the most cost-effective option is the PT slab, with savings of about *10*, *6*, and *6*% for the *6m* span, and *10*, *20*, and *22*% for *8m* span compared to solid, HB, and flat slabs, respectively. Therefore, for *6m* spans and more, PT slabs offer significant cost savings.

Key words: solid slab, HB slab, flat slab, PT slab, cost.

1. Introduction

Selecting the appropriate type of slab for the structure is one of the crucial decisions in the design phase. Park and Gamble [1] stated that one of the factors to consider when selecting the type of slab for the structure is the span length. Among the several types of slabs, there is uncertainty about the most cost-effective one for structures with short, medium, and long spans.

Kiran and Issac [2] stated that solid slabs are a cost-effective option for short or medium-spans structures that are well-known to the local market and contractors. This slab has a number of drawbacks, including a higher floor-to-floor height, a negative impact on electrical or mechanical services fixation, a high slab thickness that makes it difficult to handle any duct penetrations through the beams over long spans, and a high total cost. Harish *et al.* [3] stated that the structures with grid slabs are monolithic, stiffer, have a good shape appearance and have less cost maintenance. Sulaibi and Al-Amiery [4] mentioned that waffle slabs (two-way ribbed slabs) reduce the weight of the slab, as well as reduce the quantities of steel and concrete in them. Soghair *et al*. [5] reported that ribbed slabs reduce the floor height, reduce the own weight, and exhibit greater stiffness and lesser deflection. Climent and Ávila [6] said that waffle slabs have limited ductility and low stiffness when used in seismic regions. Girish and Lingeshwaran [7] stated that flat slabs have their own advantages such as simple formwork, good architectural appearance, faster construction, and lower building height. However, larger spans are not possible in the flat slab system. Patil *et al*. [8] stateded that flat plate slabs are cost-effective because they lack beams and thus reduce floor height by *10-15*%. Furthermore, the formwork is easier, and the structure is more elegant. According to Singh *et al*. [9], PT slabs reduce deflection and shorten construction time. They also offer perfect corrosion protection for steel bars, consistent serviceability, longer spans, and cost savings in concrete and steel materials. Khot *et al*. [10] reported that solid

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slabs are more recommended for spans with short lengths, flat slabs are recommended for medium span length, and waffle slabs are better than flat and solid slabs where it is suitable for longer spans, heavier loads and more cost-effective in repetitive work. Mishra and Bajpai [11] found that conventional slabs (solid slabs) are not a good choice for large-span areas, but waffle slabs are ideal for large-span areas from the point of view of deflection and economic aspects. Idrizi and Idrizi [12] experimentally verified that the advantage of using a waffle slab system over a solid slab system is important not only in terms of achieving a lighter and more cost-effective structure but also in terms of providing a relatively safer structure. Devi *et al*. [13] compared flat and PT slabs and found that PT slabs are preferable for long spans. Gupta *et al*. [14] stated that a PT slab is not economical for short spans while for long spans it is more cost-effective than conventional slabs. Desai and Shaikh [15] reported that PT slabs are a better option compared to flat slabs in terms of cost, durability and stability. Mashri, [16] found that it is more economical to construct a building with short spans with an HB slab than with a solid slab.

This study is primarily concerned with selecting out of solid, flat, HB and PT slabs the most cost-effective ones for short, medium, and long spans. The design and cost analysis for the slabs have been carried out and compared.

2. Research methodology

The analysis and design for *4* slabs for *4*, *6*, and *8m* spans were performed using SAFE software as per ACI code. Then the total quantities of concrete and steel bars were tabulated and compared. Finally, the cost analysis considering concrete, steel, tendons, blocks, and formwork for the slabs was evaluated and compared.

2.1. Material properties

Table 1 shows the concrete compressive strength $\left(f_C^{'}\right)$, yield strength $\left(f_y\right)$ and ultimate tensile strength $\left(f_u\right)$ of steel bars and tendons. Furthermore, it shows the weight per unit volume and modulus of elasticity $\left(E\right)$ for all materials.

Table 1. Material properties [23].

Material	$f_C^{'}\left(MPa\right)$	$f_y\left(MPa\right)$	$f_u\left(MPa\right)$	$E\left(MPa\right)$	Weight per Unit Volume $\left(kN/m^3\right)$
Concrete	*30*	-	-	*25743*	*24*
Steel	-	*400*	*500*	*200000*	*76.98*
Tendon	-	*1690*	*1860*	*200000*	*76.98*

2.2. Modelling

The study of the slabs for different span lengths was carried out based on some assumptions. Both the superimposed dead load (*SIDL*) and live load (*LL*) were considered $3.5\ kN/m^2$. The dead load (*DL*) includes both self-weight of slabs and *SIDL*. The load combinations (U_1 and U_2) used for serviceability and for the ultimate design are shown in Eqs (2.1) and (2.2), respectively.

$$U_1 = DL + LL \tag{2.1}$$

$$U_2 = 1.2DL + 1.6LL \tag{2.2}$$

Figure 1. shows the models of solid, HB, flat, and PT slabs for *4m* spans, respectively.

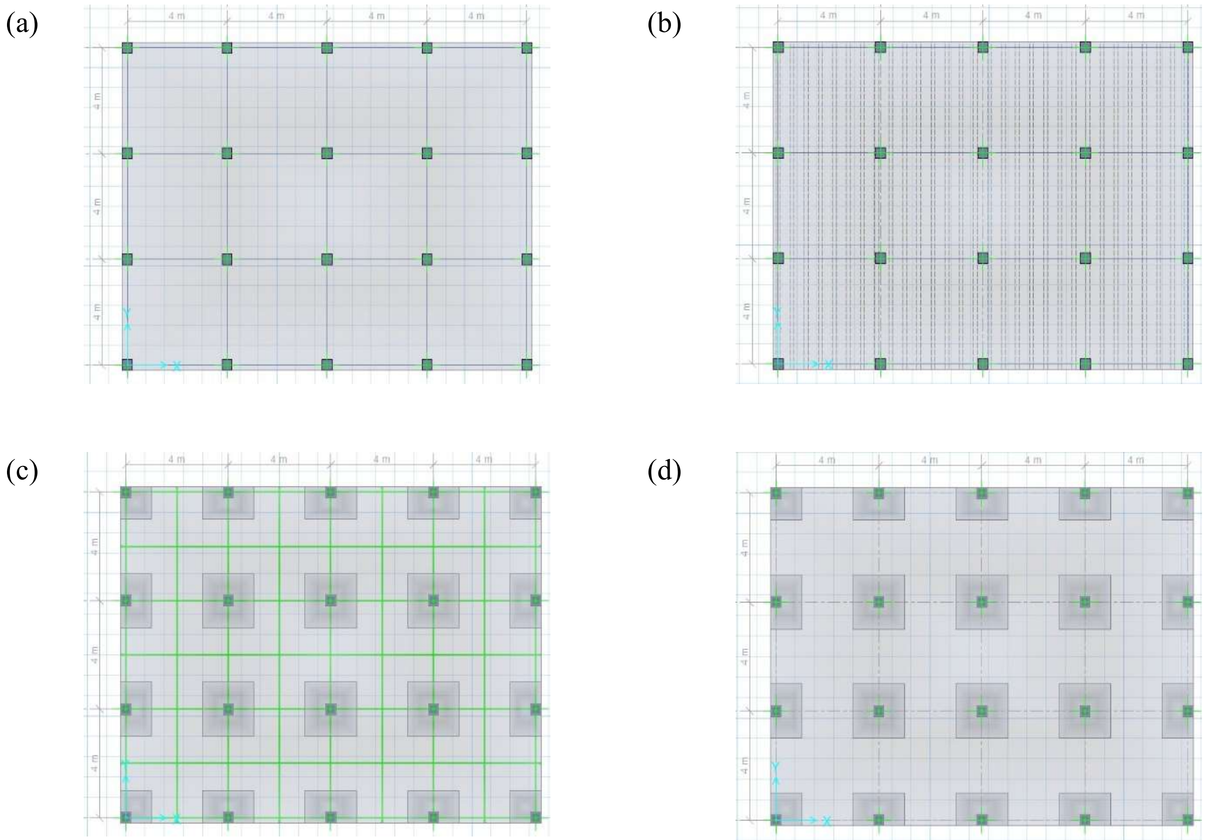

Fig.1. Slabs models for *4m* spans: (a) solid slab, (b) HB slab, (c) flat slab, (d) PT slab [23].

3. Results and discussions

3.1. Check for deflection

The maximum deflection in each slab was checked according to the service load combination. Table 2 illustrates the maximum deflection in each slab for different span lengths.

Table 2. Maximum deflection in slabs.

Span length (*m*)	Maximum deflection (*mm*)			
	Solid	HB	Flat	PT
4	*1.94*	*1.52*	*1.66*	*1.06*
6	*5.88*	*9.13*	*5.95*	*6.46*
8	*10.44*	*19.7*	*10.51*	*12.49*

As per the ACI code, the greatest permissible deflection is a span length over *240*, so the maximum permissible deflection is around *16.67*, *25*, and *33.33mm* for *4*, *6*, and *8m* spans, respectively. All the deflections of the slabs are less than the maximum permissible deflection, this implies that the deflections in slabs for all spans are controlled. Figure 2 illustrates the deflection in slabs for the *4m* spans.

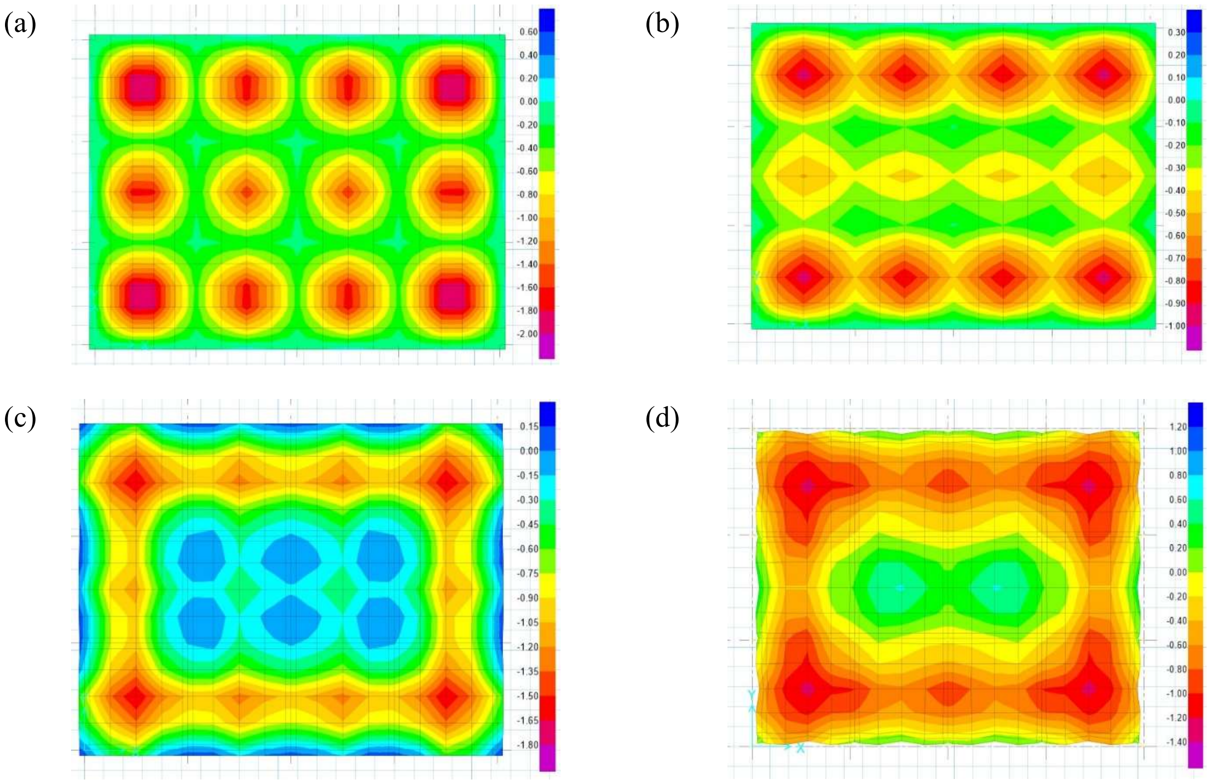

Fig.2. Deflections in slabs for 4 m spans: (a) solid slab, (b) HB slab, (c) flat slab, (d) PT slab [23].

3.2. Check for punching shear

The flat and PT slabs were initially designed without adding drop panels; however, because the punching shear ratios were greater than *1*, drop panels were required to reduce the punching shear failure. Figure 3 shows the punching shear ratios in flat and PT slabs for the *4m* span.

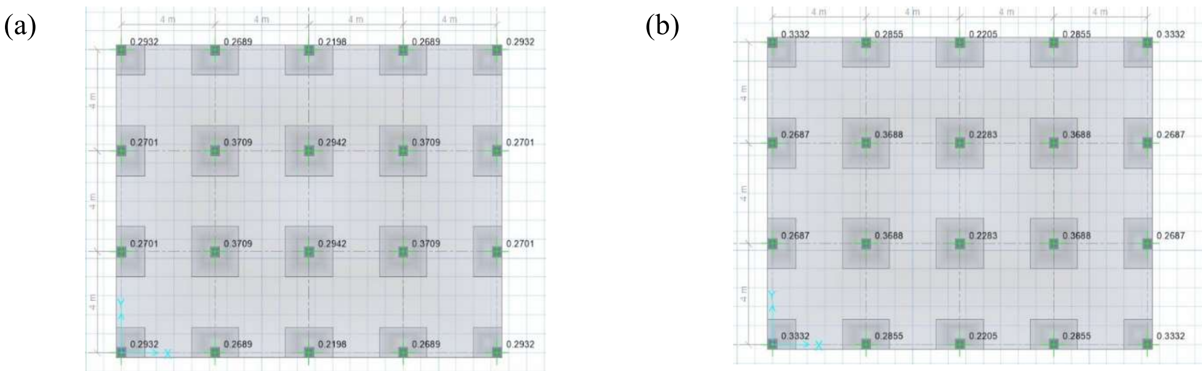

Fig.3. Punching shear ratios for *4m* spans: (a) flat slab, (b) PT slab [23].

3.3. Comparison of concrete quantities

The quantities of concrete were evaluated according to the quantities of concrete in slabs, beams for solid and HB slabs, and drop panels for flat and PT slabs. Table 3 demonstrates the total quantities of concrete in the slabs.

Table 3. Total quantities of concrete.

Slab	Span length (m)	Quantity of concrete (m^3)			
		Beams	Drop panels	Slab	Total
Solid	*4*	*22.32*	-	*19.2*	*41.52*
	6	*33.48*	-	*60.48*	*93.96*
	8	*44.64*	-	*153.6*	*198.24*
HB	*4*	*15.84*	-	*14.82*	*30.66*
	6	*23.76*	-	*47.65*	*71.41*
	8	*44.64*	-	*136.8*	*181.44*
Flat	*4*	-	*18.816*	*19.2*	*38.016*
	6	-	*18.816*	*73.44*	*92.256*
	8	-	*52.452*	*184.32*	*236.772*
PT	*4*	-	*18.816*	*19.2*	*38.016*
	6	-	*18.816*	*56.16*	*74.976*
	8	-	*52.452*	*115.2*	*167.652*

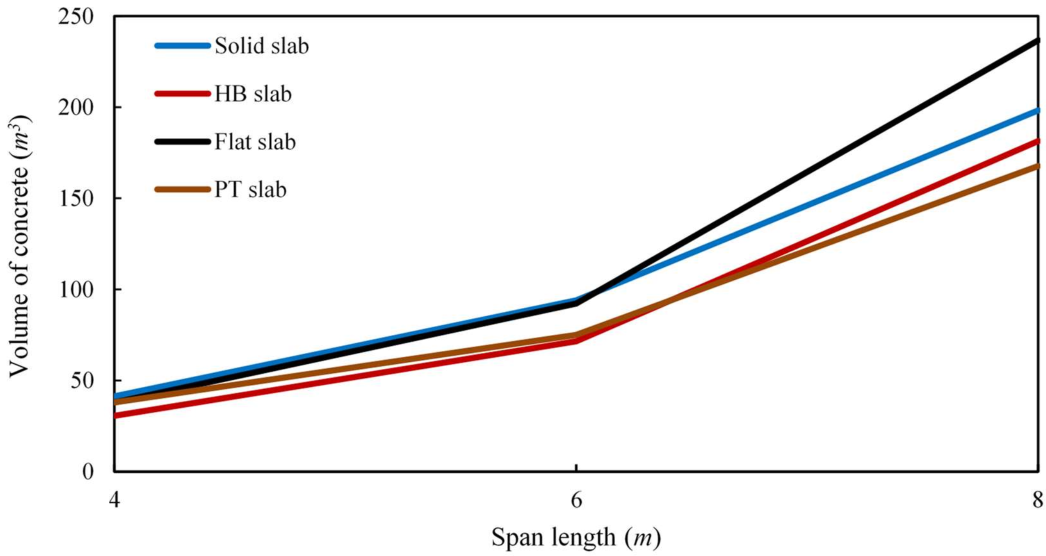

Fig.4. Total quantities of concrete in slabs.

Figure 4 reveals that for slabs with *4* and *6m* spans, the HB slab requires the least amount of concrete, which is around *26*%, *19*%, and *19*% less in the slabs with *4m* spans and around *24*%, *23*%, and *5*% less in the slabs with *6m* span than solid, flat, and PT slabs, respectively. Also, the PT slab needs the lowest quantity of concrete for *8m* spans, needing approximately *29*, *8*, and *15*% less than flat, HB, and solid slabs, respectively.

3.4. Comparison of steel quantities

The reinforcements of the slabs, beams and drop panels were determined by SAFE software and the results obtained from SAFE for each slab are shown in Tab.4.

Table 4. Bills of the quantity of steel bars.

Span length (*m*)	Total weight of steel bars (*ton*)			
	Solid	HB	Flat	PT
4	*2.403*	*3.51*	*1.6*	*0.67*
6	*6.15*	*8.71*	*5.5*	*1.03*
8	*14.35*	*23.34*	*14.41*	*3.32*

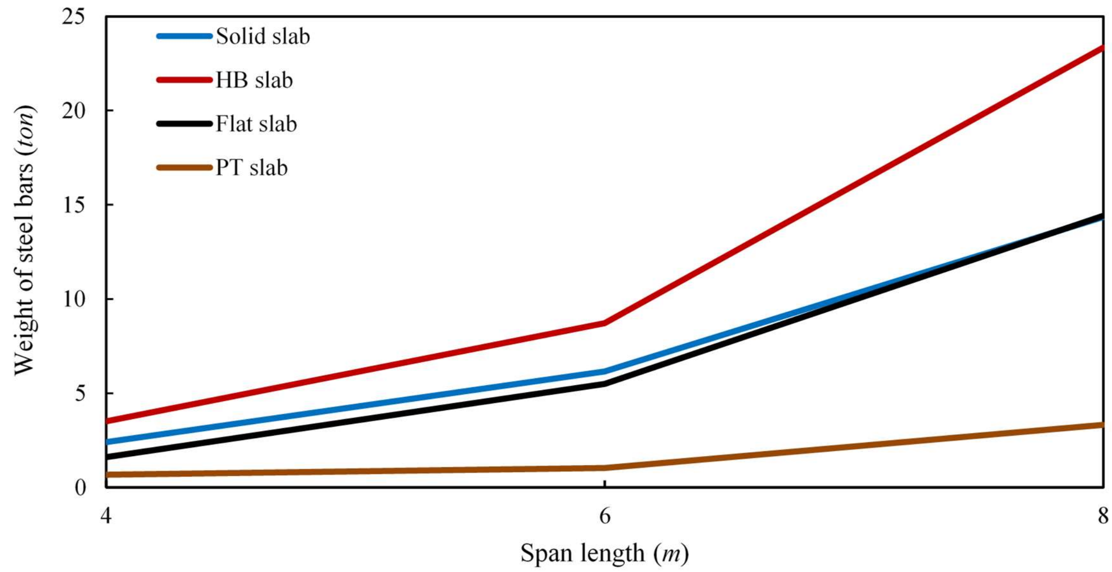

Fig.5. Total quantities of steel in slabs.

From Fig. 5, it is observed that PT slabs need a minimal quantity of steel bars at all spans, which is by around *58*%, *81*%, and *72*%, at spans *4m*, *81*%, *88*%, and *83*% at spans *6m* and *77*%, *86*%, and *77*% at spans *8m* when contrasted with flat, HB and solid slabs, respectively.

3.5. Comparison of the total cost

The total cost was evaluated including the cost of steel bars, concrete, blocks, tendons, and formwork. Tables 5 and 6 illustrate the unit prices of materials used in the study according to the Lebanese market and the total cost of slabs, respectively.

Table 5. Unit prices of materials.

Material	Unit price ($)
Concrete per m^3	*120*
Steel per *ton*	*800*
Each Block	*0.2*
Tendons per m^2	*12*
Formwork per m^3	*40*

Table 6. The total cost of slabs.

Slab	Span length (*m*)	Cost ($)					
		Concrete	Steel	Blocks	Tendons	Formwork	Total cost
Solid	*4*	*4982.4*	*1922.5*	-	-	*1660.8*	*8565.6*
	6	*11275.2*	*4920*	-	-	*3758.4*	*19953.6*
	8	*23788.8*	*11480*	-	-	*7929.6*	*43198.4*
HB	*4*	*3679.2*	*2808*	*350*	-	*1226.4*	*8063.6*
	6	*8569.2*	*6968*	*790*	-	*2856.4*	*19183.6*
	8	*21772.8*	*18672*	*880*	-	*7257.6*	*48582.4*
Flat	*4*	*4561.92*	*1280*	-	-	*1520.64*	*7362.56*
	6	*11070.72*	*4400*	-	-	*3690.24*	*19160.96*
	8	*28412.64*	*11528*	-	-	*9470.88*	*49411.52*
PT	*4*	*4561.92*	*536*	-	*2304*	*1520.64*	*8922.56*
	6	*8997.12*	*824*	-	*5184*	*2999.04*	*18004.16*
	8	*20118.24*	*2656*	-	*9216*	*6706.08*	*38696.32*

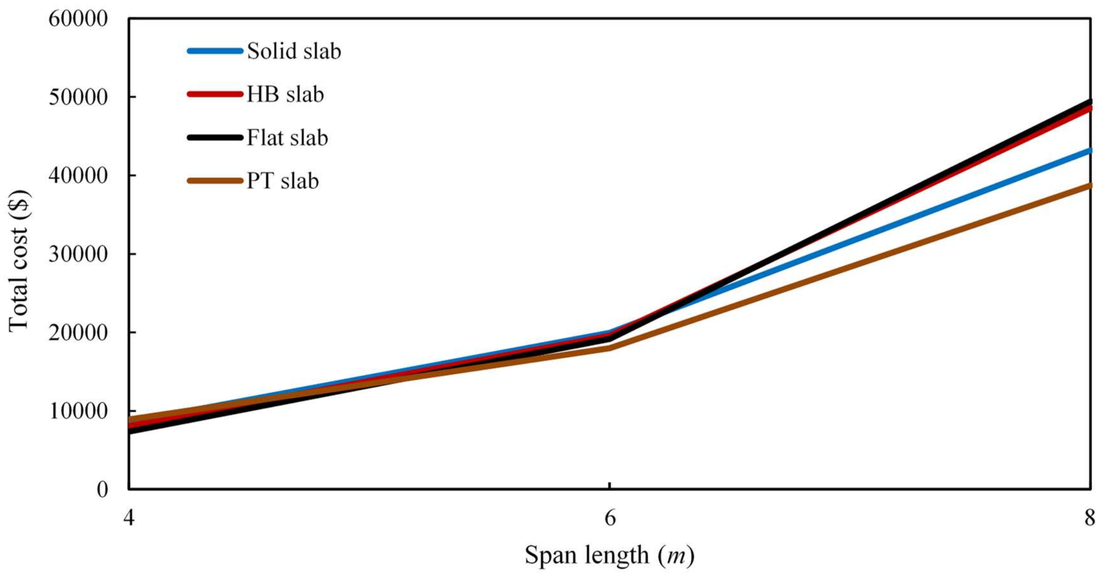

Fig.6. Total cost of the slabs.

Despite the fact that the PT slab requires fewer steel bars than other slabs and that the HB slab requires a minimal amount of concrete when all material costs are considered, the flat slab is the most cost-effective slab, with savings in the total cost of approximately *14*%, *9*%, and *17*% when contrasted with solid, HB, and PT slabs, respectively. In addition, even though the PT slab requires more concrete and has an extra cost of tendons, it is the most cost-effective option for a slab with *6m* spans. This saves about *10*%, *6*%, and *6*% of the total cost when contrasted with solid, HB, and flat slabs, respectively. Finally, PT slabs require fewer concrete and steel bars in slabs with *8m* spans than other slabs, making it the most cost-effective option with savings of *10*%, *20*%, and *22*% compared to solid, HB, and flat slabs, respectively (See Fig. 6).

Several studies have been conducted on comparison between different types of reinforced concrete slabs. Reddy and Pradeep [17] conducted a cost analysis of PT and reinforced concrete flat slabs with a span of *9.44m* and found that it is more economical to use a PT slab than a reinforced concrete flat slab. Ajay [18], as well as Thayapraba [19] verified that in panels of dimensions *9×9*, *10×10*, *11×11*, and *12×12m*, PT slabs are more cost-effective than reinforced concrete flat slabs. Ahmad [20] compared flat and PT slabs in a project with spans of up to *8m* and found that PT slabs are more cost-effective than reinforced concrete flat slabs. Rao *et al*. [21] conducted a study on the two-way solid and PT slab of *9.38m* span and reported that the PT slab is cheaper than the two-way solid slab by *15*%. Abdelaziz and Abdalla [22] analyzed multi-storey buildings with PT and flat slabs and noted that PT systems offer significant cost savings for spans greater than *6m*. Therefore, all these comparative studies match the results of the current study.

3. Conclusions

A comparative study of the material's quantities and cost of several slabs is presented. The conclusions made from the above work are as follows:

For slabs with *4* and *6m* spans, the HB slab requires a minimal amount of concrete, which is around *26*%, *19*%, and *19*% less for a *4m* span and around *24*%, *23*%, and *5%* less for a *6m* span than solid, flat, and PT slabs, respectively. Also, for slabs with *8m* spans, the PT slab needs the lowest quantity of concrete, approximately *29*%, *8*%, and *15*% less than flat, HB, and solid slabs, respectively.

PT slabs require minimal quantities of steel in *4*, *6*, and *8m* spans slabs where the saving of steel in percentage is around *58*%, *81*%, and *72*%, for *4m* span, *81*%, *88*%, and *83*% for *6m* spans, and *77*%, *86*%, and *77*% for *8m* spans, as compared to flat, HB and solid slabs, respectively.

In terms of economy, the most cost-effective option is the flat slab for *4m* span slabs, with savings of around *14*%, *9*%, and *17*% compared to solid, HB, and PT slabs, respectively. On the other hand, for *6* and *8* m spans slabs, the most cost-effective option is the PT slab, with savings of about *10*%, *6*%, and *6*% for *6m* spans slabs, and *10*%, *20*%, and *22*% for *8m* spans slabs, compared to solid, HB, and flat slabs, respectively. Therefore, for *6m* spans and more, PT slabs offer significant cost savings.

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Nomenclature

DL − dead load
E – modulus of elasticity
$f_C^{'}$ − concrete compressive strength
f_u − ultimate tensile strength of steel
f_y − yield strength of steel
HB − hollow block
LL − live load
PT – post-tensioned
$SIDL$ − superimposed dead load
U_1 – service load combination
U_2 − ultimate design load combination

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