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A Comparative Study of Analysis and Design of Flat Slab and Hollow Block Slab and construction cost of RC Buildings

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Abstract :

Concrete-framed buildings with reinforcement are commonly favored over other building types in Sudan. These buildings often utilize flat and hollow block slabs. When designing these structures, it is necessary to determine the most suitable slab type that can withstand both gravitational and lateral loads while keeping costs to a minimum. However, the selection of slab type is often overlooked by designers, who tend to focus more on other structural elements like beams, columns, and walls. As a result, the structural contribution of floors in building design is often not adequately assessed. It is crucial to thoroughly examine this aspect from the very beginning of the design process. This study aims to evaluate the effects of two types of slabs on multi-story reinforced concrete buildings, exploring their structural behaviors in an effort to reduce overall costs. A total of 18 structural models were created, analyzed, and designed according to the BS 8110 and UBC97 standards. In these analysis, the important factors taken into account were the type of slab system (either flat or hollow block), the number of floors (10, 15, and 20), and the span length (5, 7.5, and 9 meters). The buildings were assumed to be residential buildings located in a seismic zone 2A in Atbara, Sudan. The results showed that buildings with flat slabs generally have longer periods, higher base shear forces, and larger rooftop displacements compared to those with hollow block slabs. The hollow block slab consistently emerged as a cost-effective option, while the flat slab proved to be a less economical choice.

Keywords: *Concrete buildings, re-enforcement, flat block slabs, hollow block slabs,*

دراسة مقارنة لتحليل وتصميم البلاطة المسطحة والبلاطة المجوفة وتكلفة إنشاء المباني الخرسانية المسلحة

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المستخلص

تُفضَّل المباني ذات الإطارات الخرسانية المسلحة عادةً على أنواع المباني الأخرى في السودان. غالبًا ما تستخدم هذه المباني ألواحًا مسطحة اوكتل مجوفة. عند تصميم هذه الهياكل، من الضروري تحديد نوع اللوحة الأنسب الذي يمكنه مقاومة الأحمال الجذبية والأفقية مع الحفاظ على تقليل التكاليف إلى الحد الأدنى. ومع ذلك، غالبًا ما يتم تجاهل اختيار نوع البلاطة من قبل المصممين، الذين يميلون إلى التركيز أكثر على العناصر الهيكلية الأخرى مثل الكمرات والأعمدة والجدران. ونتيجة لذلك، غالبًا ما لا يتم تقييم الإسهام الهيكلي للأرضيات في تصميم المباني بشكل كافٍ. من الضروري فحص هذا الجانب بدقة منذ البداية في عملية التصميم. تهدف هذه الدراسة إلى تقييم تأثير نوعين من البلاطات على المباني الخرسانية المسلحة متعددة الطوابق، مع استكشاف سلوكياتها الهيكلية في محاولة لتقليل التكاليف الإجمالية. تم إنشاء 18 نموذجًا هيكليًا وتحليلها وتصميمها وفقًا لمعايير BS 8110 و UBC97. في هذه التحليلات، كانت العوامل المهمة التي تم أخذها في الاعتبار هي نوع نظام البلاطة (سواء كانت بلاطة مسطحة أو بلوك مجوف)، وعدد الطوابق (10 و15 و20)، وطول الامتداد (5 و7.5 و9 أمتار). وافترض أن المباني مبانٍ سكنية تقع في منطقة زلزالية A2 في عطبرة، السودان. أظهرت النتائج أن المباني ذات البلاطات المسطحة تتمتع عمومًا بفترات أطول، وقوى القص الأساس أعلى، وإزاحات أكبر في السطح مقارنة بتلك المزودة ببلاطات البلوك المجوف. ظهرت بلاطة البلوك المجوف باستمرار كخيار اقتصادي، بينما ثبت أن البلاطة المسطحة خيار أقل اقتصادية.

***كلمات مفتاحية:** المباني الخرسانية، التسليح، البلاطات المسطحة، البلاطات المجوفة*

Introduction:

This article, based on a Master's level study at Nile Valley University in Atbara, Sudan, examines the impact of two different types of slabs on seismic performance and cost in reinforced concrete multi-story buildings. The article highlights the importance of assessing all possible slabs to choose the best option for building strength and cost. The study provides a comprehensive analysis of the research subject, emphasizing the need for careful consideration of two slab types in the construction of reinforced concrete multi-story buildings.

This article aims to evaluate the seismic performance of two slab types and their influence on the overall construction cost. The goals were achieved by creating 18 reinforced concrete models using Robot structural analysis software. The models comprised of two types of slabs: flat slabs and hollow block slabs. The buildings were designed in accordance with the British standard (BS 8110 1997) and the American uniform seismic code (UBC97-1997) [Hajek (2005) and Climent and Ávila (2013)]. All 18 residential buildings in Atbara city, Sudan, were assumed to be in seismic zone (2A) and only earthquake loads were considered for lateral loads.

Multi-story RC buildings often have slabs that require more construction materials than other structural components due to their large area and complexity. Standard RC buildings often use slabs to account for over 50% of the overall embodied energy, which includes the energy spent in material extraction, processing, manufacturing, and transportation. Approximately 30% of this 50% embodied energy is attributed to steel rebar [Apostolska *et al*., 2008].

The study suggests that prioritizing cost reduction for floor slabs is more important than focusing on column number and dimensions. This because the amount of concrete volume occupied by the columns is restricted in the range of 2.5-14% of floor slab concrete volume [Hossen and Anam, 2010]. Consequently, reducing floor slab weight can decrease concrete volume and environmental impact, leading to cost savings in construction [Bakale and Viswanathan 2017].

In building construction, there are multiple types of reinforced concrete slabs. This study focuses on analyzing the two most commonly used types of slabs in Sudan: flat slab and hollow block slab. Hollow block slabs provide numerous advantages. The presence of voids in this type of slabs reduces dead weight, thereby decreasing the amount of concrete below the neutral axis. However, these slabs have limitations in seismic regions due to their low rigidity and ductility [Tunc and Al-Ageedi, 2020].

Flat slabs have less stiffness, causing longer vibration durations, but they offer numerous benefits over two-way slabs due to their quicker construction process.Time, architectural advantages, and economic benefits are important factors to consider in the construction of buildings. However, the absence of beams in flat slabs makes them more susceptible to punching shear failure.The structural behavior of this type of slabs can be enhanced in earthquake-prone areas by incorporating perimeter beams and/or reinforced concrete walls.

Bakale and Viswanathan's study compared seismic behaviors of various slab types in buildings with regular and irregular features. The story displacement in both orthogonal directions in regular buildings was consistent for all slab types, except for ribbed slabs, which caused more displacements perpendicular to the ribs. Compared to buildings with two-way slabs with beams, buildings with flat slabs had 37% and 24% greater story displacements in regular and irregular buildings, respectively. Compared to those with flat slabs, the story shear forces in buildings with flat plates were 17% and 11% higher in regular and irregular buildings, respectively. Bikçe *et al*. conducted a study on the cost and seismic behavior of lightweight hollow block slabs and two-way slabs using both theoretical and physical models. The study reveals that lightweight hollow block slabs are 10.5% to 21.9% more expensive than two-way slabs with beams, according to both theoretical and physical structural models. Additionally, the lightweight hollow block slab displayed higher values of base shear forces and periods.

Zakaria *et al*.'s study on seismic performance of RC buildings with grid slab and hollow block slab types found that grid slab is the most suitable type for seismic loads. This is due to its lower values of base shear forces and periods, which ranged from 9% to 12% in the base shear forces and 5% to 6% in the periods.

The structural behavior of low-rise RC buildings was investigated, focusing on different slab types like two-way, flat, and ribbed slabs, under earthquake loads. To achieve this, three 5-story buildings were designed and modeled in accordance with the Turkish Earthquake Code, 2007 (TEC 2007). The research revealed that flat slab buildings experienced the highest base shear forces, while two-way slab buildings with beams had the lowest. The study also found that, the ribbed slab had longer vibration periods, while the flat slab had shorter periods, and the ribbed slab had the highest average lateral displacement. Flat slabs consistently resulted in larger displacements, higher base shear forces, and longer periods compared to two-way slabs with beams. In contrast, the study suggests that regions with high seismic activities should use a two-way slab with beams due to its lower displacements, lower base shear forces, and shorter periods.

Structural Models:

Robot software was utilized to create 18 structural models, each featuring two slab types, three span lengths (5, 7.5, 9 meters), and three floor numbers (10, 15, and 20). All buildings were assumed to have square-shaped floor layouts, and the overall dimensions were determined based on the span lengths. The study analyzed 5 and 7.5-meters spans buildings with 60-meters overall dimensions, which commonly found in RC buildings. To better understand slabs' impact on seismic behavior, a slightly larger 72-meters by 72-meters dimension was also studied. The study aimed to evaluate the impact of span length and floor number on the seismic behavior of buildings with two types of slabs, designed in accordance with BS 8110 requirements and American uniform building code (UBC97). The following sections will provide more detailed information about structural models. It was assumed that all 18 structures were residential buildings built in Atbara city, Sudan, and had a uniform floor height of 3.2 meters.

Characteristics of the Plan

Figures 1.a through 1.f show buildings layouts with identical span lengths for each floor number, except for the ten-story buildings which did not have shear walls along the perimeter. The study utilized three distinct square-shaped layouts for flat and hollow block slab types, each corresponding to a span length of 5, 7.5, and 9 meters. The study examined the effects of different slab types on structural behaviors and costs using layouts with minimum overall dimensions of 60 meters for 5 and 7.5-meters spans and 72 meters for 9-metersspans.Table 1 provides a summary of all buildings' slab details and designations, which are used interchangeably with their full descriptions in the text. Figures 1.a.1 to 1.a.2 show 60-meters-long buildings with 5 meters spans, featuring flat and hollow block slabs. The layouts in Sudan typically have a central wall with elevators, staircases, and utility shafts, a common arrangement. Figures 1.b.1 to 1.b.2 show the layouts of slab types in a 60-meters square-shaped building with a 7.5-metersspan.Similarly, Figures 1.c.1 to 1.c.2 display the layouts for buildings with an overall dimension of 72 meters and a span of 9 meters.

Three key factors were considered when selecting structural members' sizes: first, slab thicknesses slightly above BS 8110 minimum requirements to avoid deflection issues. Second, the calculation of flat plate thickness utilized punching shear calculations to eliminate the need for column capitals or dropped panels. Lastly, the shear wall areas were allocated in accordance with Tunc and Al-Ageedi's guidelines, ensuring continuity along the gridlines, with the maximum ratio ranging from 0.6% in the 10-story building to 2.6% in the 20-story building. Layouts with a 5-meter span used smallest wall areas, 7.5-meters used largest, and 9-meters required less wall area to avoid excessive wall areas.

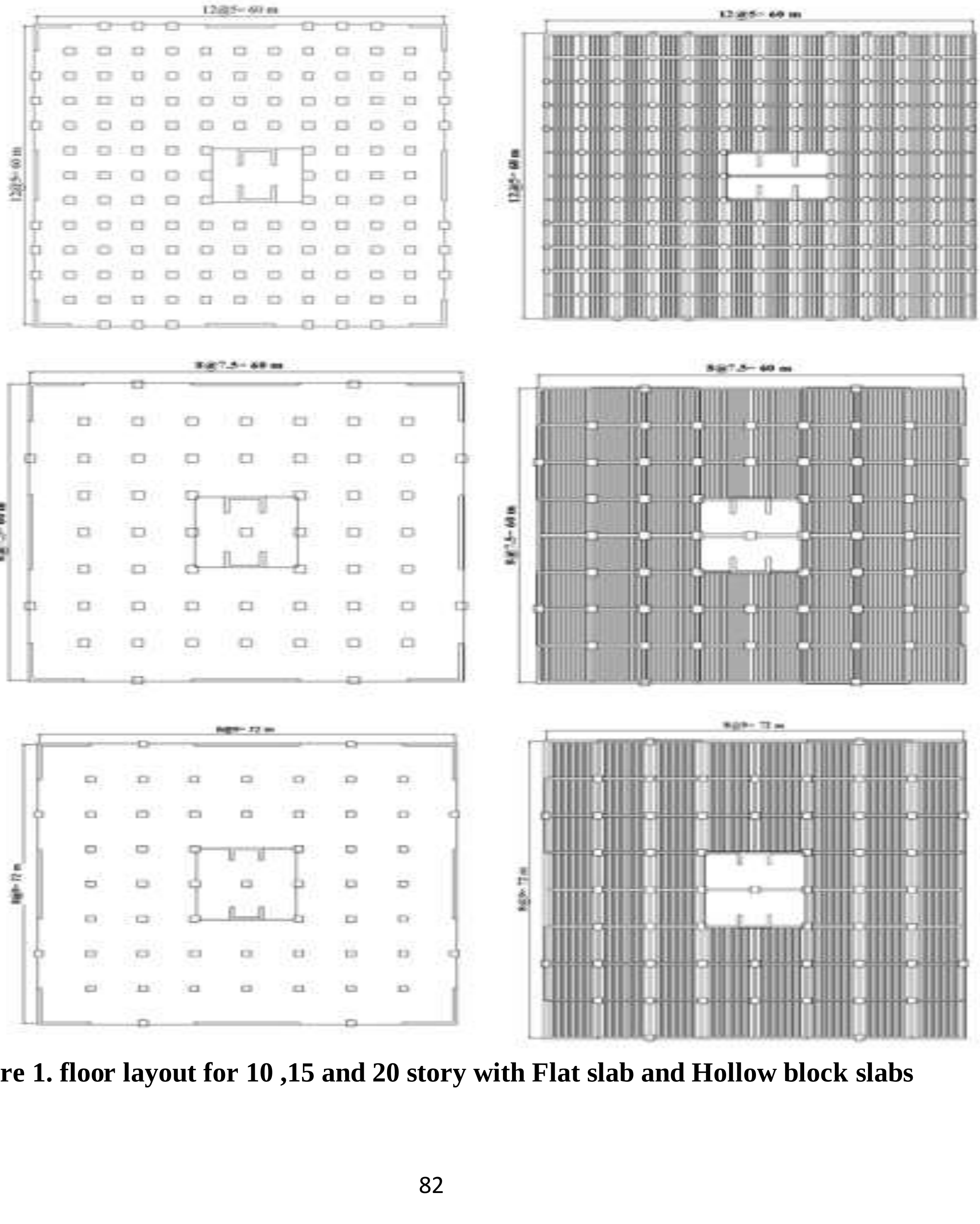


Figure 1. floor layout for 10 ,15 and 20 story with Flat slab and Hollow block slabs

Table 1: Buildings Layout and Dimensions for Flat and Hollow Block Slab

Layout	Model Properties				Column Dimensions (cm)		Beam Dimensions (cm)		Shear Wall Thickness (cm)	Slab Thickness (cm)	
	Parameters		Total Story Nos.	Story Nos.	Interior	Exterior	Flat	Hollow Block		Flat	Hollow Block
FS1, HBS1 (5)	Story Height (m)	3.20	10	1 to 5	70 x 70	60 x 60	40 x 50	40 x 50	30	20	30
				6 to 10	60 x 60	50 x 50			40		
	Plan Dim. $(m \times m)$	60x60	15	1 to 5	90 x 90	80 x 80	40 x 50	40 x 50	30	20	30
				6 to 10	80 x 80	70 x 70			40		
				11to15	70 x 70	60 x 60			50		
	Slab Span	5	20	1 to 5	120x120	100x100	40 x 50	40 x 50	30	20	30
				6 to10	100x100	90 x 90			40		
				11to15	90 x 90	80 x 80			50		
				16to20	80 x 80	70 x 70			60		
FS2, HBS2 (7.5)	Story Height	3.20	10	1 to 5	80 x 80	70 x 70	40 x 60	50 x 50	30	25	40
				6 to 10	70 x 70	60 x 60			40		
	Plan Dim. $(m \times m)$	60x60	15	1 to 5	100x100	90 x 90	40 x 60	50 x 50	30	25	40
				6 to10	90 x 90	80 x 80			40		
				11to15	80 x 80	70 x 70			50		
	Slab Span	7.5	20	1 to 5	140x140	120x120	40 x 60	50 x 50	30	25	40
				6 to 10	120x120	100x100			40		
				11to15	100x100	90 x 90			50		
				16to20	90 x 90	80 x 80			60		
FS3, HBS3 (9)	Story Height	3.20	10	1 to 5	90 x 90	80 x 80	40 x 70	50 x 60	30	30	50
				6 to 10	80 x 80	70 x 70			40		
	Plan Dim. $(m \times m)$	72x72	15	1 to 5	130x130	100x100	40 x 70	50 x 60	30	30	50
				6 to 10	110x110	90 x 90			40		
				11to15	90 x 90	80 x 80			50		
	Slab Span	9	20	1 to 5	160x160	150x150	40 x 70	50 x 60	30	30	50
				6 to 10	150x150	140x140			40		
				11to15	140x140	120x120			50		
				16to20	120x120	100x100			60		

Dimensions of Structural Members:

All The structural members were dimensioned in accordance with the minimum requirements of BS 8110-1997. The practice of reducing column and shear wall dimensions every 5 floors, a common practice in RC building construction, was also applied. However, the dimensions of beams and floor thicknesses remained constant throughout the height of each building, unlike columns and shear walls. The coupling beams in all structural models had identical cross-sectional dimensions, measuring 0.4 meters in width and 0.6 meters in depth. The coupling beam depth was determined to be adequate for 10 and 15-story buildings and maintained for 20-story buildings to facilitate comparison of results.Table1 provides detailed information on the layouts for the three sets of floor numbers (10, 15, and 20-story). The hollow block slab's topping thickness is 0.1 meters, with joists parallel to the "X" direction, 0.2 meters wide, and 0.7 meters apart. The slab types used in each span length were designed with identical cross-sectional dimensions for columns and shear walls, as well as the same thicknesses. This decision was justified based on the fact that the volume of concrete used for columns typically ranges from 2.5% to 14% of the volume of concrete used for floor slabs according to a previous study [10]. For all structural members, including columns, shear walls, and slabs, concrete class C30 was used. The concrete, with a Poisson's ratio of 0.2, was assumed to have a modulus of elasticity of 31,000 MPa in accordance with BS 8110 guidelines. The steel reinforcement bars utilized were of 460 MPa grade, with a minimum yield strength of 420 MPa, a modulus of elasticity of $2x10^5$ MPa, and a Poisson's ratio of 0.3.

Seismic Loads:

The study assumed that the local site class for all structural models was 2A.According to UBC 97-1997, established a seismic importance factor of one for residential buildings, resulting in an occupancy class of four. The total seismic weight was calculated using a live load participation factor of 0.55. All the buildings were designed with a high ductile system. The response modification factor (R) was 4.5 in both "X" and "Y" directions. The response spectrum method (RSM) was used for 10, 15, and 20-story buildings with a 5% damping ratio and assumed concrete cracks as per BS 8110 (Refer to Table 2).

Finite Element Modeling:

The structural models were created, analyzed, and designed using Robot structural analysis software, a commercially available engineering software capable of designing multi-story buildings under both static and dynamic loading conditions. The system comprises modeling tools, templates, code-based load prescriptions, analysis methods, and solution techniques that are synchronized with the unique grid-like geometry of this structure. Robot provides advanced tools for slab modeling, analysis, and design, incorporating elements like soil types, ramps, columns, braces, walls, and interfacial elements. The software integrates with Autodesk Rivet, enabling users to import models, loading, and displacement fields for advanced local assessments of slab systems in larger structures.For the structural models, RSM analysis conducted following the methodology described in UBC97.During the analysis, self-weight, superimposed, and live gravity loads were applied to the buildings.The program automatically incorporated self-weights of structural members into the analysis.It was assumed that all buildings had a superimposed dead load and a uniformly distributed live load (including partition walls) as shown in table 2.The supports at the base of the buildings were fixed to prevent translation and rotation. The floor slabs were modeled using a semi-rigid diaphragm to prevent any negative effects on the rigid diaphragm approach. The maximum reinforcement for slabs was determined by analyzing results at both top and bottom of slabs within each designated strip, considering the corresponding load combination.

Table 2: Specification of Loading

Gravity Loads	
Dead load	Default values taken by Robot structural Analysis based on the variable dimensions taking the unit weight of concrete is 24 kN/m^3
Live load	1.5kN/m^2
Floor load	1kN/m^2
Wall load	11kN/m^2
Lateral Loads Earthquake Loads	
Seismic Zone	2A
Zone Factor, Z	0.15
Importance Factor, I	1
Over Strength (Reduction) Factor (R)	4.5
Type of soil	SD

RESULTS

The structural performance of two slab types in structural models is evaluated based on their structural responses and overall costs. The study analyzes and discusses findings for different story numbers (10, 15, and 20 stories) considering fundamental periods, base shear forces, maximum lateral displacements, and overall costs. In the cost estimation phase, the amount of concrete and steel rebar is calculated separately for beams, columns, and slabs. The total cost calculation assumes a cost of 1200000 SDG per ton for grade 460 Mpa steel rebar and 90000 SDG per cubic meter for C30 concrete. The total cost of each building, calculated in Sudanese pounds at January 2024, excludes formwork, labor fees, and foundation costs. For almost all columns, a minimum reinforcement ratio was considered necessary in the cost analysis as per the minimum column capacity requirement stated in BS 8110.Consequently, the plan to customize column sizes for each slab type was abandoned, and the same column sizes were utilized in all sets, irrespective of the slab types. The beam reinforcements' determination was established by analyzing the maximum and minimum positive and negative moments at their mid-spans and supports, respectively.

Ten Story Buildings

The subsequent subsections present the outcomes derived from ten levels of structural models.

Layouts with 5-meters spans

Building mode shapes with 5 meters span exhibit movement in "X", "Y", and rotational direction "Z", with the first period always in "Z" direction. Figure 2a shows that the fundamental period of a building with a flat slab is longer, while that of a building with a hollow block slab is shorter. Figure 2b shows that a building with flat slab has higher base shear value, while the building with a hollow block slab has lower value. This is due to the relatively larger thickness of the flat slab, which prevents excessive deflection and punching shear. Figure 2c illustrate that the building with the flat slab exhibits higher rooftop displacement, while the building with the hollow block exhibits lower displacement. The study reveals that a hollow block slab building is the costly-effective option, while a flat slab building is the less economical choice (Figure 2d), where the cost of FS1 exceeds the cost of HBS1 by 11%.

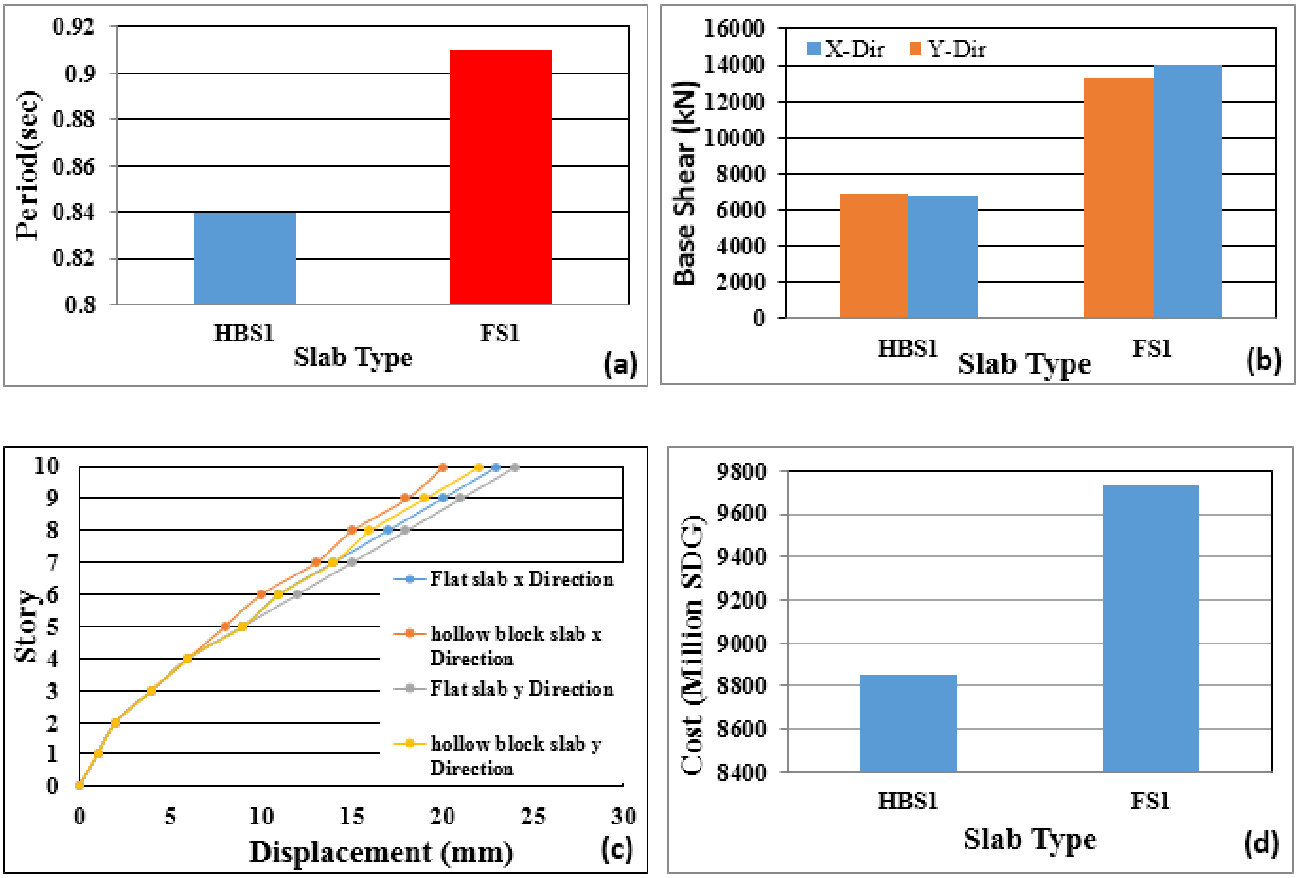


Figure 2:10 story building with 5-meter span: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) Total cost

Layouts with 7.5-meters spans

From the data presented in Figure. 3a, it can be observed that the building with hollow block slabs experienced the shorter period. The flat slab experienced higher base shear force, while the building with a hollow block slab experienced lower shear force (Figure. 3b).The building with the flat slab experienced higher rooftop displacement, while the building with the hollow block slab had the lower displacement (Figure. 3c).The hollow block slab was found to be more cost-effective slab type for buildings with 7.5-meters spans, similar to its use in 5-meters spans buildings. Still, the flat slab remained the more expensive type of slab and exceeds HBS2 cost by 13% (Figure. 3d).

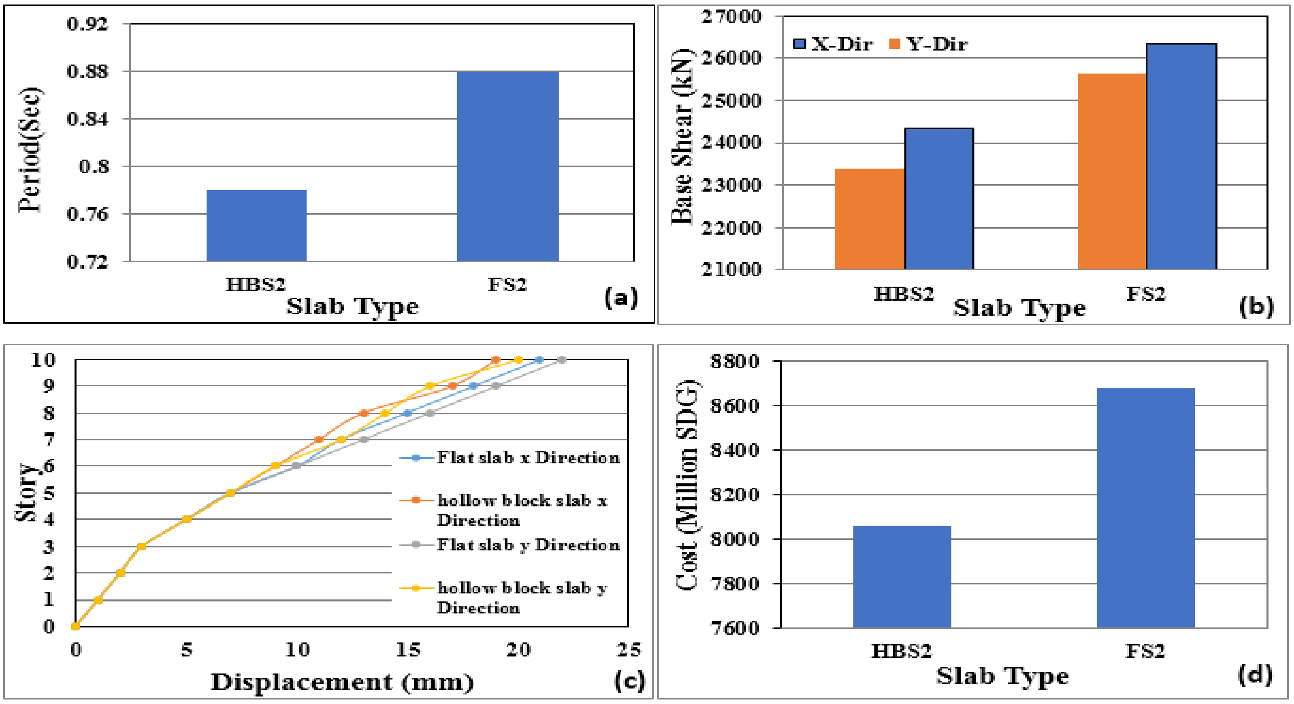


Figure 3. 10 story building with 7.5-meter span: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) Total cost

Layouts with 9-meter spans

From figure. 4a it can be seen that the flat slab structure had the longer period value among the two building types, while the hollow block slab had the shorter period value.Figures4b and 4c show that flat slab buildings experience higher base shear force and maximum rooftop displacement, while hollow block slab buildings have lower base shear force and minimum rooftop displacement, respectively. The hollow block slab was found to be costly-effective option for buildings with 7.5-meters spans, while the flat slab was the expensive one (Figure. 4d).

Comparison of layouts with 5 and 7.5 meter spans

A detailed investigation was conducted on the results of buildings with 5 and 7.5 meters dimensions, as their total in-plane sizes were the same. The comparison involved analyzing the variation in periods, base shear forces, maximum rooftop displacements, and overall cost of structural models, finding that 5-meter span buildings had longer periods.Figure.5a shows longer periods in 5-meter span buildings compared to 7.5-meter spans, while 7.5-meter span buildings have higher base shear forces, as shown in Figure. 5b. Increasing span length from 5 to 7.5 meters led to a 46% increase in base shear forces for flat slabs. Figure. 5c shows that layouts with 5-meter spans experienced higher rooftop displacements compared to layouts with 7.5-meter spans. As expected, the study found that buildings with 5-meter spans had higher construction costs, with 15% and 16% difference in flat slabs and hollow block slab respectively compared to 7.5-meter spans.

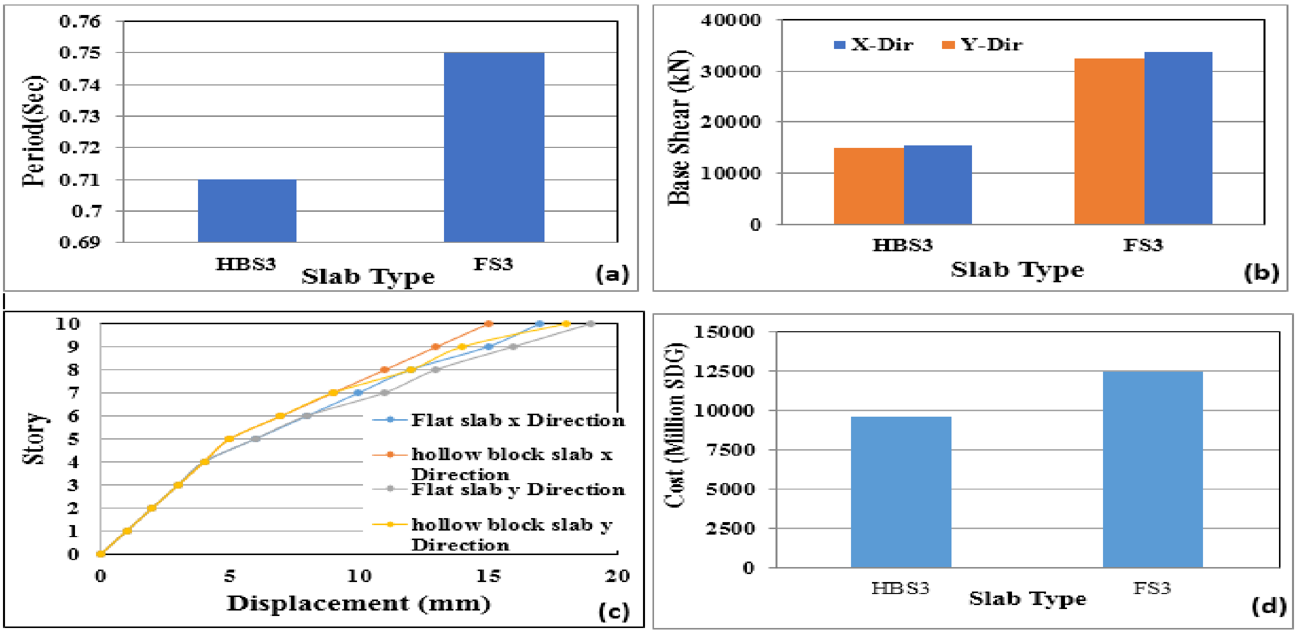


Figure 4. 10 story building with 9-meter span: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) Total cost

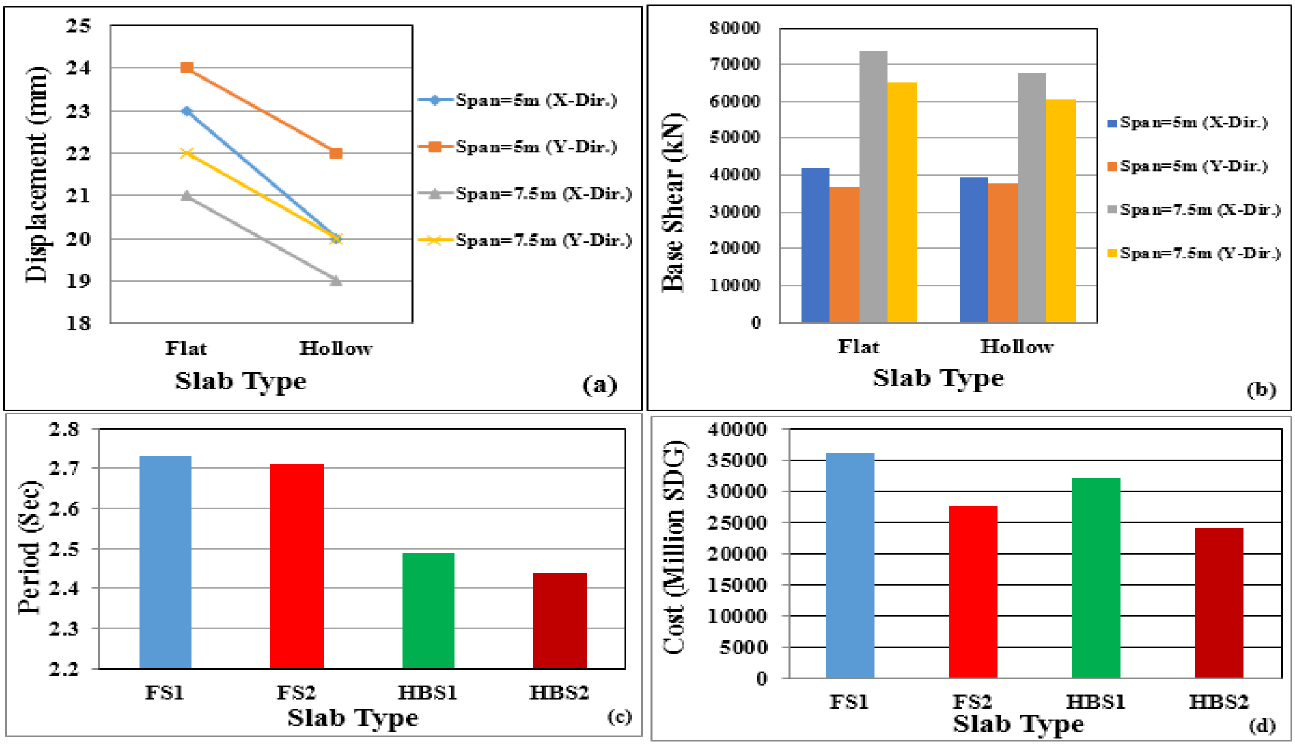


Figure 5. 10 story buildings with 5 to 7.5 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) overall cost

Fifteen Story Buildings

Layouts with 5-meters spans

The study found that the buildings with flat slabs had longer periods, while the buildings with hollow block slabs had the shortest period (Figure6a).The study reveals that a flat slab-based building has the highest base shear force and maximum rooftop displacement, while a hollow block-based building has the lowest (Figure6b and Figure6c) respectively. The hollow block slab was found to be more cost-effective option for buildings with 7.5-meter spans, while the flat slab was the expensive one (Figure 6d).

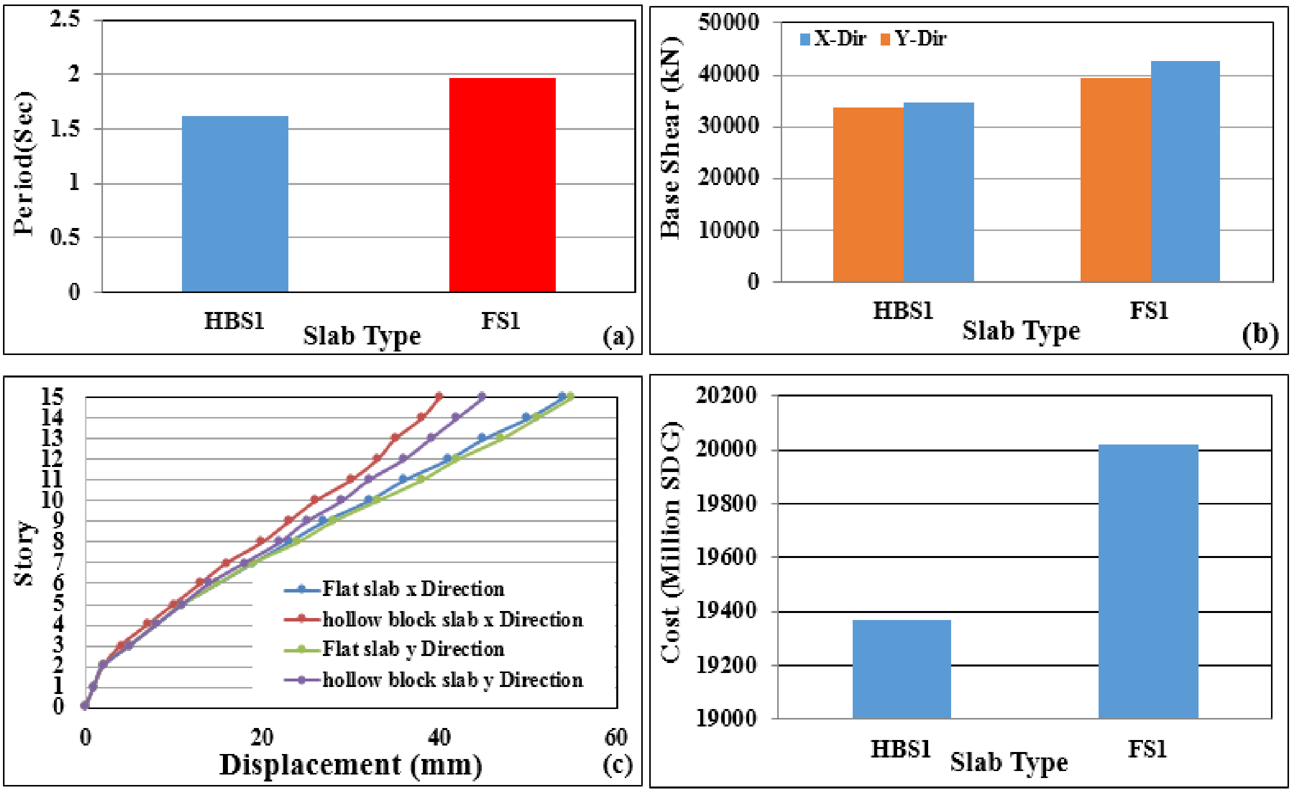


Figure 6. 15 story buildings with 5 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) overall cost

Layouts with 7.5-meters spans

From figure 7 it can be observed that the flat slab exhibiting higher period value and lowest base shear force (Figure7a and 7b) respectively. The flat slab experienced the highest rooftop displacement (Figure7c), while the hollow block slab was more cost-effective solution for buildings with 5-meter spans (Figure7d).

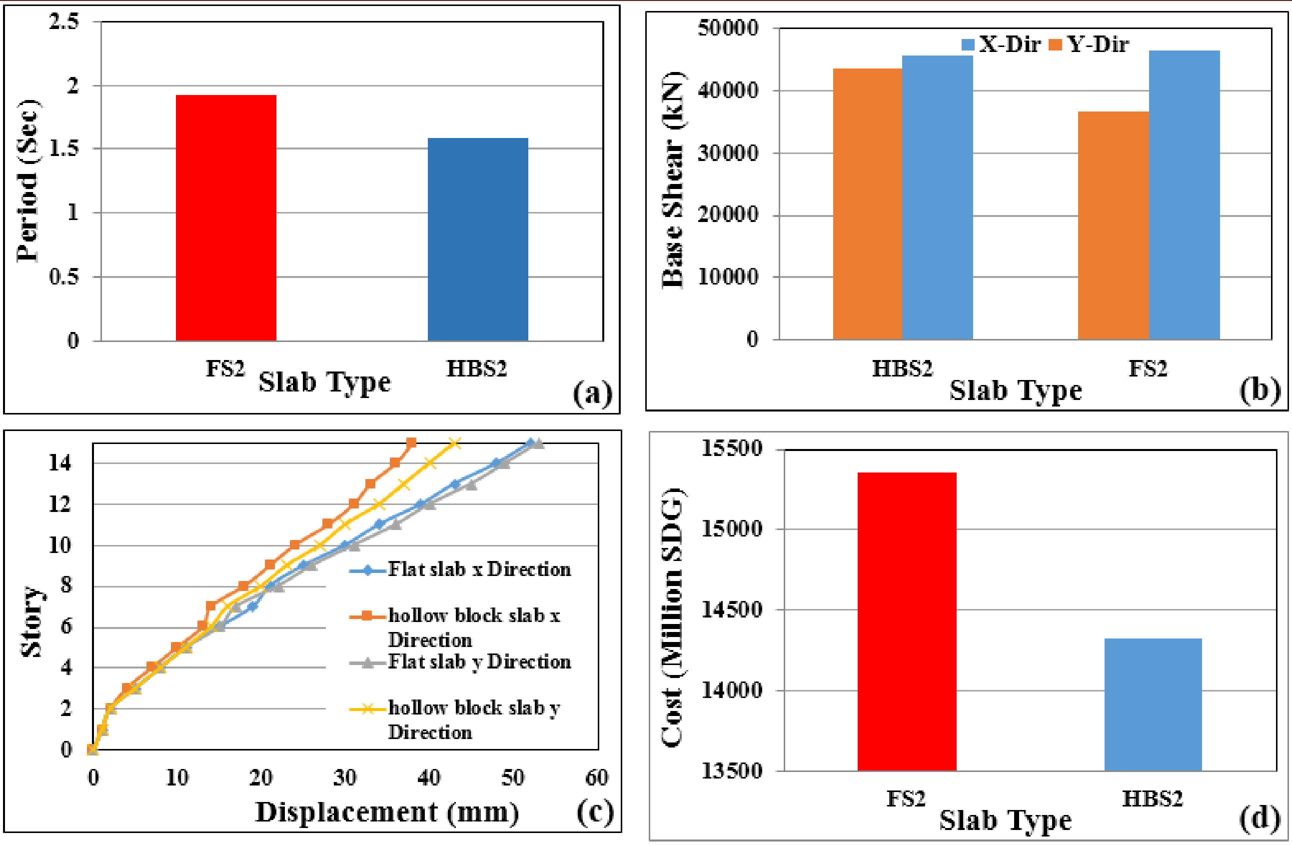


Figure 7. 15 story buildings with 7.5 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) overall cost

Layouts with 9-meter spans

The study reveals that buildings with flat slabs have longer periods and experience the highest base shear force (Figure 8a and 8b respectively), while those with hollow block slabs have the shortest periods (as depicted in Figure 8b). Flat slabs have the maximum rooftop displacement, while hollow block slabs have the minimum (as shown in Figure 8c). The hollow block slab option is the costly-effective for 9-meters spans (as illustrated in Figure 8d).

Comparison of layouts with 5 and 7.5 meters spans

According to Figure 9a, buildings with 5-meters spans had longer periods than those with 7.5-meters spans. The buildings with 7.5-meters spans had higher base shear forces (Figure 9b). Increasing the span length from 5 to 7.5 meters resulted in a 22%, and13% increase in the base shear force for buildings with hollow block slab, and flat slabs, respectively. Figure 9c indicated that buildings with 5-meters spans had greater rooftop displacements compared to those with 7.5-meter spans. The buildings with 7.5-meters spans had higher costs (Figure 9d).The cost difference relative to the layouts with 5-meter spans was 26% for buildings with hollow block slabs, and, and 24% for those with flat slabs

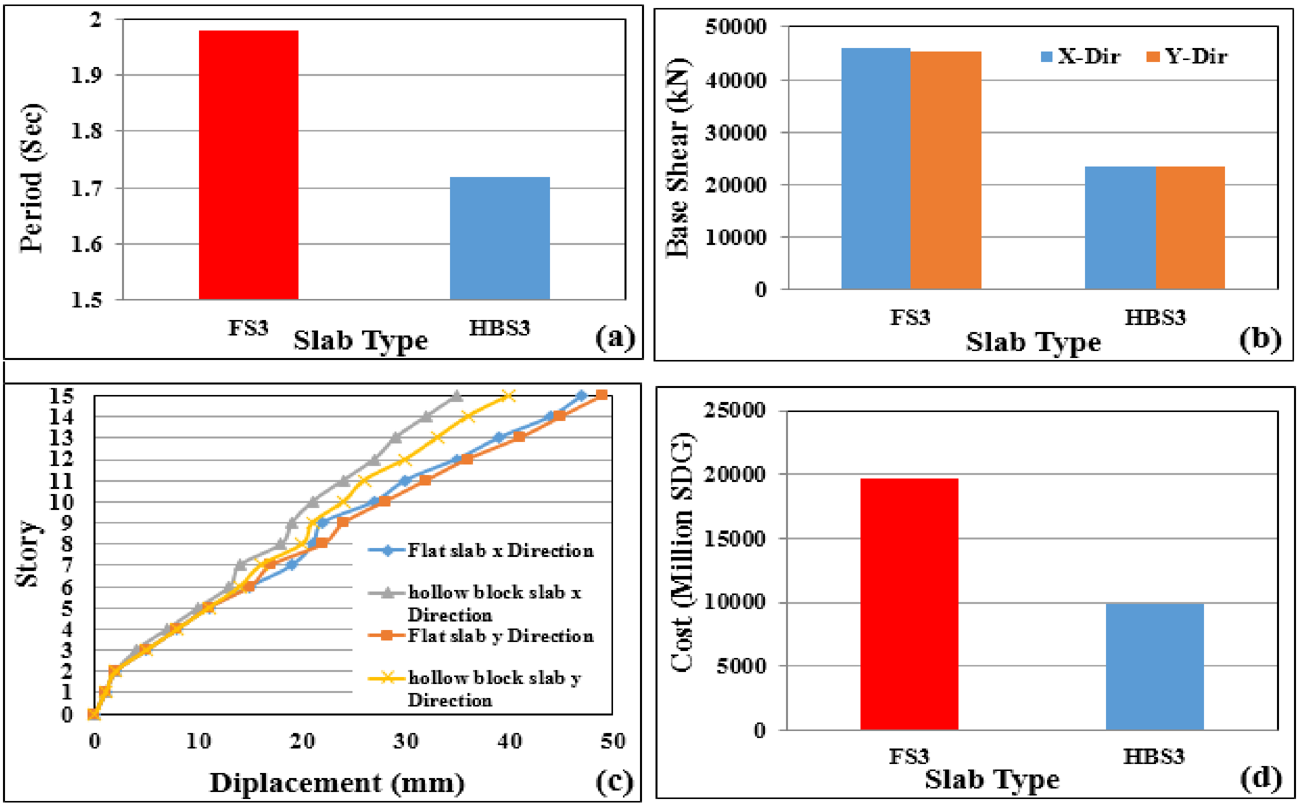


Figure 8. 15 story buildings with 9 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) overall cost

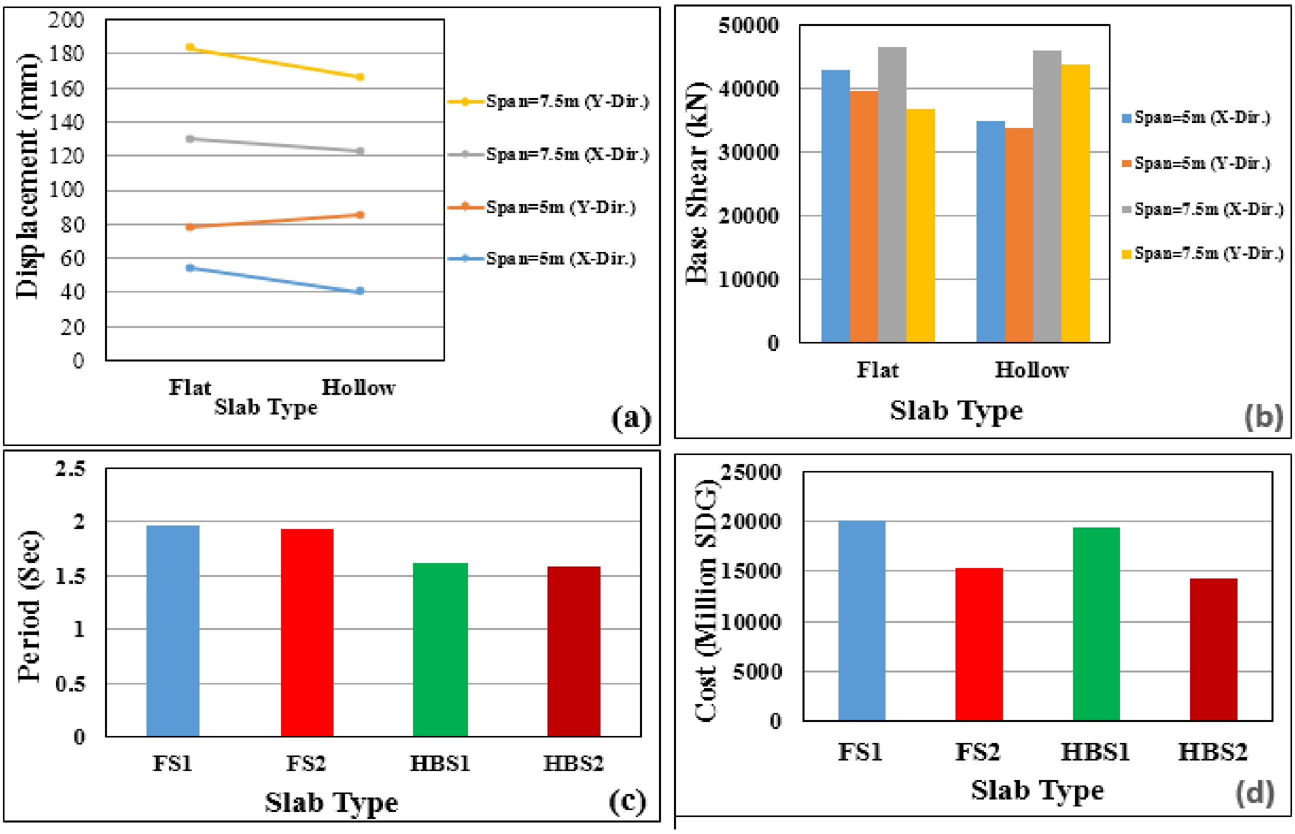


Figure 9. 15 story buildings with 5 to 7.5 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) overall cost

Twenty Story Buildings

Layouts with 5-meter spans

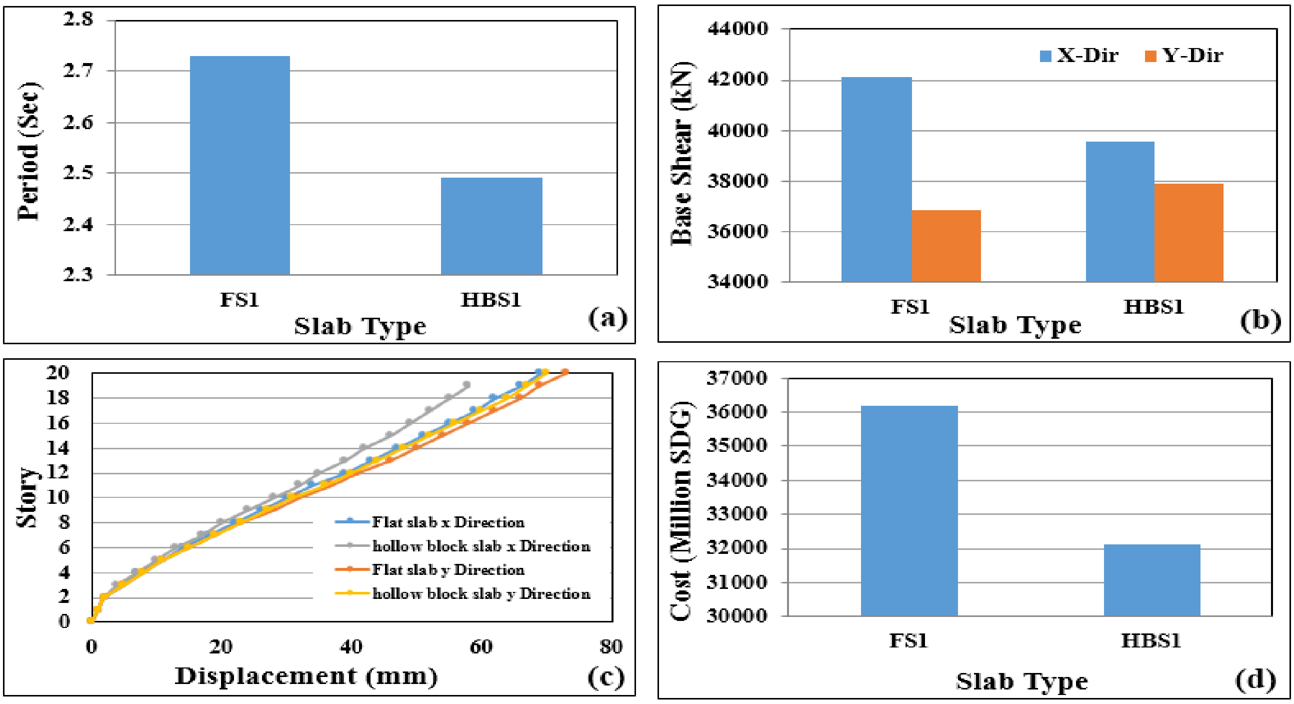


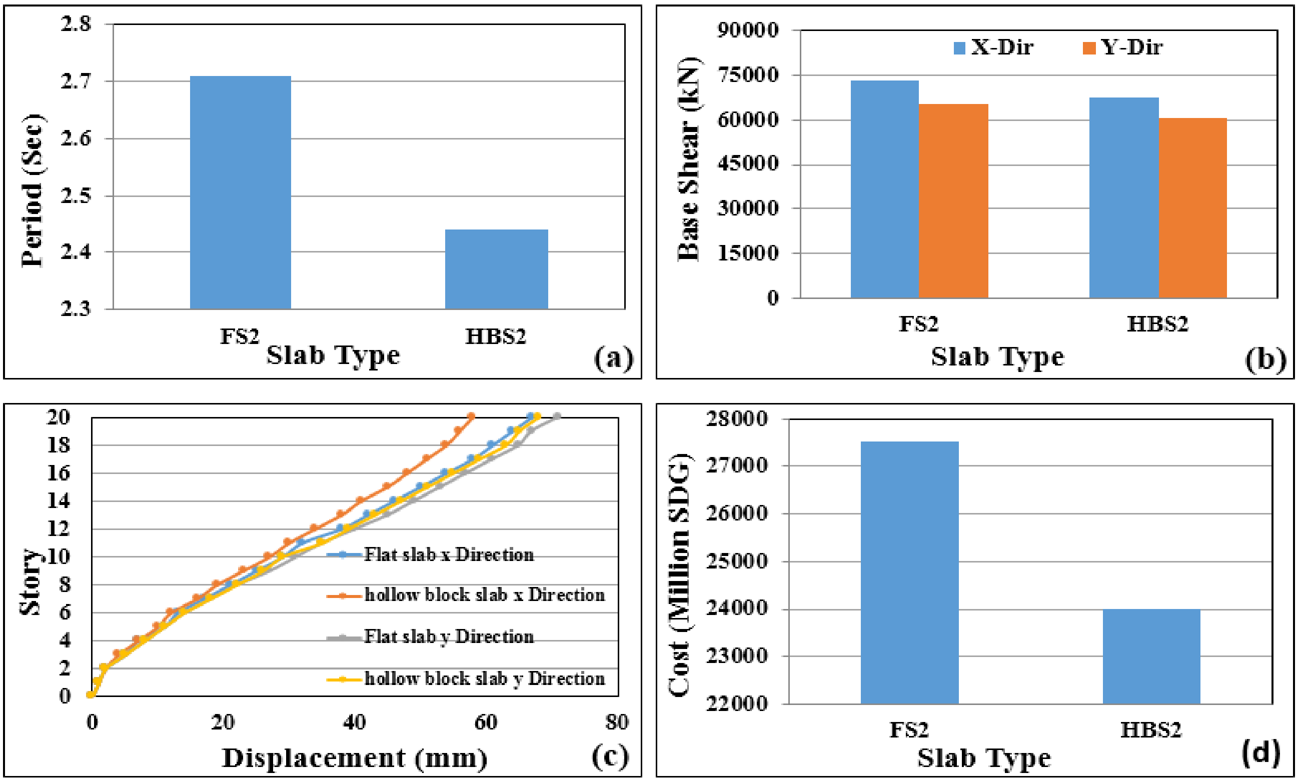
Figure 10. 20 story buildings with 5 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) Total cost

Figure 10a illustrates that the buildings with flat slabs had the longest periods, while the building with hollow block slab had the shortest period. Figure 10b shows that the base shear force was highest in the building with flat slabs, while the building with hollow block slabs exhibited the lower shear force. Figure 10c displays that the building with flat slabs experienced the larger displacement in terms of rooftop displacement, whereas the building with hollow block slabs encountered smaller displacement. Based on the information provided in Figure 10d, it was concluded that the flat slab alternative proved to be the priciest selection resulted in a 23%, increase in construction cost, whereas the hollow block slab was recognized as the more economical option.

Layouts with 7.5-meter spans

Among the different types of slabs used, the buildings with flat slabs had longer periods of vibration (Figure 11a), while, the building with a hollow block slab had shorter period. The

Figure 11. 20 story buildings with 7.5 m. spans: (a) periods, (b) base shear, (c) max. rooftop



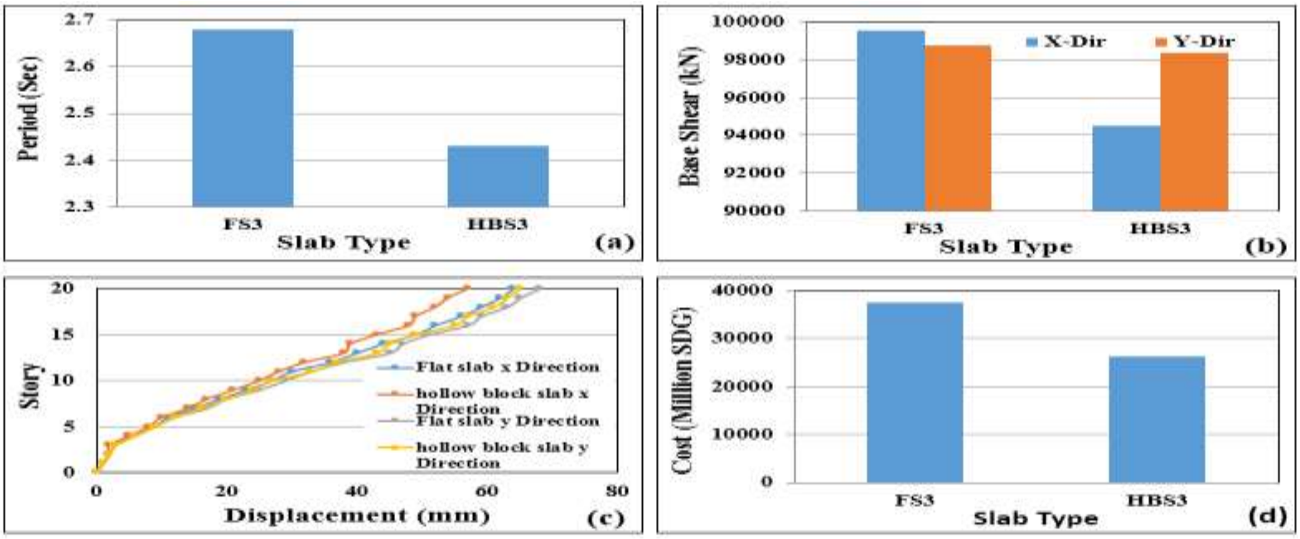
displacement, (d) Total cost

buildings with flat slabs experienced higher magnitudes of the base shear forces (Figure 11b). The building with flat slabs had greater displacement at the rooftop, whereas the building with hollow block slabs exhibited smaller displacement (Figure 11c). In contrast tobuildings with 5-meters spans, the hollowblock slab was found to be the cost-effective solution in this case, while the flat slab was the expensiveoption (Figure 11d).

Layouts with 9-meter spans

The buildings with flat slabs had longer periods, while those with hollow block slabs had shorter periods (Figure 12a).The maximum base shear force was observed in the building with a flat slab, while the building with a hollow block slab had the minimum value (Figure12b).The building with a flat slab exhibited the highest rooftop displacement, whereas the building with a hollow block slab showed the lowest displacement (Figure12c).Similar to the buildings with 7.5-meter spans, the hollow block slab was determined to be the more cost-effective solution, while the flat slab was the more expensive type of slab (Figure12d).

Comparison of layouts with 5 and 7.5 meter spans



According to Figure 15a, buildings with 5-meters spans experienced longer periods than those

Figure 12. 20 story buildings with 9 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) Total cost

With 7.5-meters spans. The buildings with 7.5-meters spans recorded higher base shear forces (Figure 15b). Increasing the span length from 5 to 7.5 meters resulted in a 43% increase in base shear forces for buildings with flat slab. For buildings with a hollow block slab, the base shear forces increased by 41.5%. Figure 15c illustrates that buildings with 5-meter spans experienced larger rooftop displacements compared to buildings with 7.5-meters spans. Buildings with 7.5-meters spans resulted in increased expenses, as indicated in Figure 15d. The cost difference between layouts with 5-meters spans and layouts with 7.5-meters spans with hollow block and flat slabs was 28.24% and 23.47%, respectively.

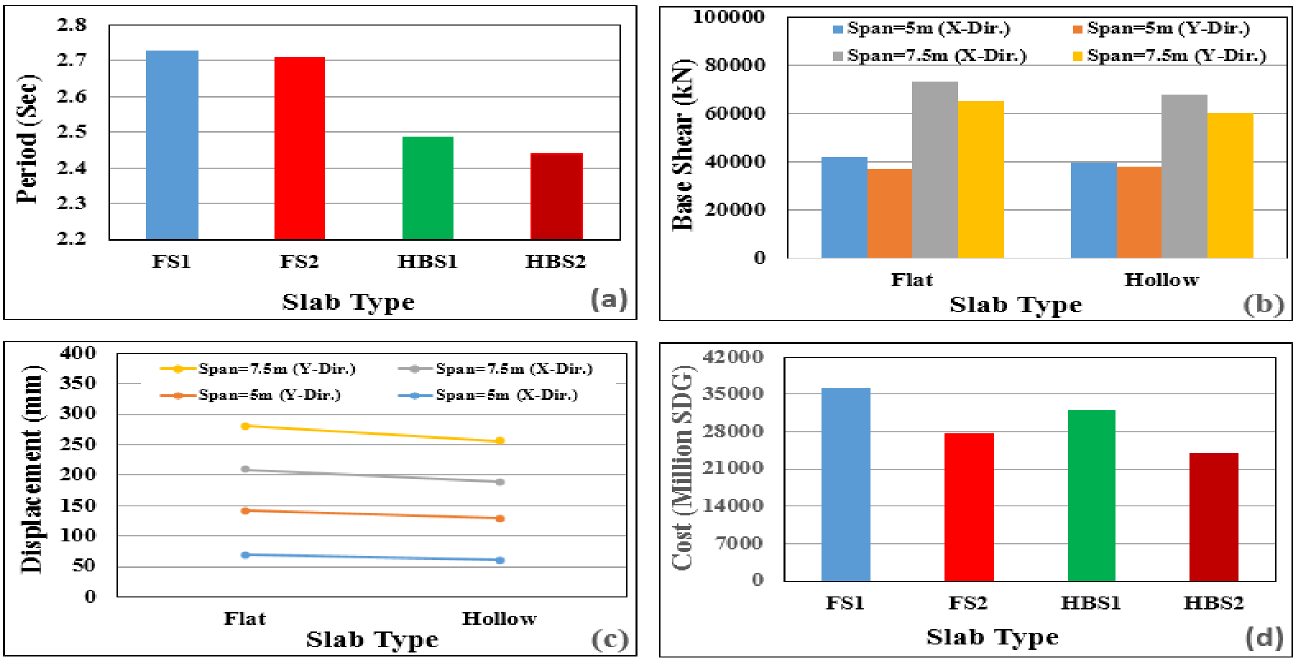


Figure 13. 20 story buildings with 5 to 7.5 m. spans: (a) periods, (b) base shear, (c) max. rooftop displacement, (d) overall cost

CONCLUSIONS

The list provided below presents the results of the parametric studies carried out on the 18 structures, along with recommendations for further analysis.

- The study highlights that for a ten-story building with a 5-meter span, a flat slab building has a longer fundamental period and higher base shear value compared to a building with a hollow block slab. Additionally, the flat slab building exhibits higher rooftop displacement.
- The study reveals that a hollow block slab building is the more cost-effective option where the cost of FS1for (10,15, and 20) exceeds the cost of HBS1 for (10,15, and 20) by 11%,7.8% and 23% respectively.
- For a building with a 7.5-meters span, flat slab buildings have longer fundamental periods and higher base shear forces, while the building with a hollow block slab experiences the lower shear force and displacement. The hollow block slab is found to be more cost-effective option where the cost of FS2 for (10,15, and 20) exceeds the cost of HBS2 for (10,15, and 20) by 13%,12.8% and 17.4% respectively.
- For a building with a 9-meters span, the flat slab structure has the longer period value and higher base shear force and rooftop displacement, while the hollow block slab with beams has the shorter period value and lower base shear force and rooftop displacement. The hollow block slab remains the cost-effective option where the cost of FS3 for (10,15, and 20) exceeds the cost of HBS3 for (10,15, and 20) by 22.67 %,24% and 28.34%, respectively.
- The investigation found that for 10 story buildings with a 5-meter span had longer periods, while buildings with a 7.5-meter span had higher base shear forces and lower rooftop displacements. Additionally, buildings with a 5-meter span had higher construction costs compared to buildings with a 7.5-meter span with 15% ,16% difference in flat slab and hollow block slab respectively compared to 5m spans.
- The study found that for a fifteen-story building with a 5-meter span, flat slabs had longer periods and higher base shear force, while hollow block slabs had the shortest periods.
- For a 7.5-meter span, the flat slab had the higher period value and lower base shear force, while the hollow block slab was the more cost-effective.
- For a 9-meter span, flat slabs had longer periods and higher base shear force, while hollow block slabs had the shorter periods. The hollow block slab option was the costly-effective for a 9-meter span.
- This study revealed that buildings with 5-meter spans have longer periods and greater rooftop displacements compared to those with 7.5-meter spans. Additionally, increasing the span length from 5 to 7.5 meters results in higher base shear forces and lower costs for buildings with hollow block slabs and flat slabs.
- The comparison between two types of slabs used in twenty-story buildings with varying spans, concludes that buildings with flat slabs have longer periods of vibration, higher magnitudes of shear forces at the base, and greater displacement at the rooftop compared to buildings with hollow block slabs.
- The hollow block slab is recognized as the costly-effective option compared to the costly flat slab.

- The analysis findings from the study indicate that buildings with 5-meter spans have longer periods, larger rooftop displacements, and lower base shear forces compared to buildings with 9-meter spans.
- Additionally, increasing the span length from 5 to 9 meters resulted in higher base shear forces and increased expenses for both flat slab and hollow block slab buildings.
- The main findings of the study indicate that for different spans and number of stories, buildings with flat slabs generally has longer periods, higher base shear forces, and greater rooftop displacements compared to buildings with hollow block slabs. The hollow block slab is consistently identified as the cost-effective option, while the flat slab is the least economical choice.
- For buildings with 5-meter spans flat slabs had longer periods and higher base shear force, but experienced larger displacement, making them an expensive option. On the other hand, buildings with hollow block slabs had the shortest period, lowest shear force, and smallest displacement, making them an economical choice.
- In conclusion, the investigation found that buildings with 5-meter spans had longer periods, while buildings with 7.5-meter spans had higher base shear forces and higher construction costs. Additionally, layouts with 5-meter spans experienced higher rooftop displacements compared to layouts with 7.5-meter spans.
- Increasing the span length while maintaining the overall dimensions of a layout led to shorter periods of vibration as a result of the larger sizes of beams, columns, and slabs.

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