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Applications of Mixed Hollow Flat Slab System to Buildings of Irregular Roof Plans

Emad Mohamed Helal; ehelal@msa.edu.eg
Lecturer, October University for Modern Sciences and Arts (MSA), Egypt

الملخص العربى :

حيث أن البلاطات الخرسانية هى العنصر الرئيسى الحاكم فى كميات الخرسانة وحديد التسليح فى المنشئات. وهذا البحث يقدم تطبيقات على مقترح النظام المزدوج بين البلاطات المسطحة والبلاطات ذات الاعصاب المفرغة للأسقف الغير منتظمة المسقط. وذلك بهدف زيادة الوفر فى كميات الخرسانة وحديد التسليح المطلوبة. وقد تم اختبار هذا النظام على منشئات فعلية للمقارنة بين النظام المزدوج وبين نظام البلاطات المسطحة المصمتة، وذلك بتطبيق تحليل رياضى تحت تأثير الأحمال الاستاتيكية والديناميكية. وقد أظهرت النتائج وفرا بنسبة كبيرة فى كل من كميات الخرسانة والحديد وكذا أحمال الأعمدة والأساسات.

الكلمات الدالة: الأسقف المسطحة غير منتظمة المسقط، بلاطات الأعصاب، الأنظمة الانشائية، الأحمال الديناميكية

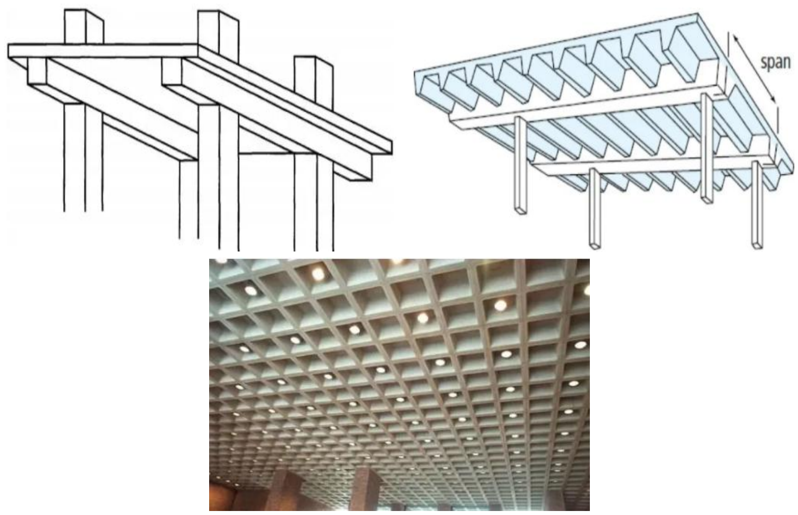
Abstract:

The slab is the fundamental structural element in building constructions that produces space and consumes more concrete quantities. The deflection of the slab increases as the service loads or the clear span between columns increased, resulting in an increase in slab thickness. Increased slab thickness makes the slabs heavier due to increased self-weight, which in turn increases the size of the columns and foundations. As a result, concrete and steel reinforcement quantities are increased that rises the cost of the construction. In comparison to standard flat slab systems, joist slabs, hollow-core slabs, and bubble deck slabs are different R.C. flooring solutions that were designed to deal with this problem. The effect of this problem growths for cases of irregular flat plate systems that is the common type for existent constructions. This paper aims to perform applications of this new trend for flooring slabs systems that combine between flat slab concept and two-way foamed blocks concept for irregular roof plans to achieve savings and other advantages compared to other systems. In this research, the validity of the proposed concept has been verified through a finite element analysis using Program SAP2000 that was applied to real constructed buildings with different configurations under static and dynamic loadings.

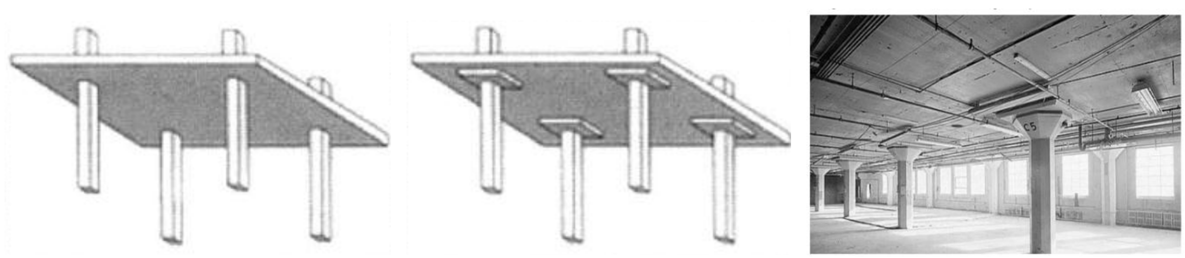
Keywords: Irregular Flat Slab, Ribbed Slab, Flooring Systems, Dynamic Load

Introduction

Many types of R. C. floor systems are used today to meet diverse architectural and functional building needs (Sergiu et al. 2010; Zekirija and Isak, 2017). Figure 1 represents several of these systems.



One-Way Slab on Beams One-Way Joist Floor System Two-Way Joist Slab (Waffle)



Typical Flat Slab System Flat Slab with Drop Panel Flat Slab with Column Head

Figure 1 Types of Traditional R. C. Flooring Systems

Hollow core flooring systems were recommended in the mid-twentieth century to reduce the significant self-weight of traditional R. C. flooring systems by eliminating concrete from the slab's center. Several types of this building flooring system are shown in Fig. 2 as demonstrated (Fangzhou, 2018; Ihsan et al. 2018).

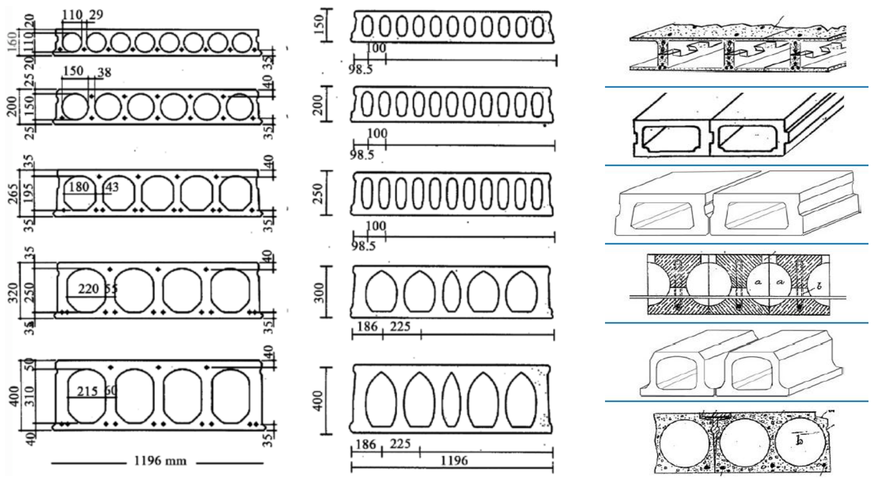
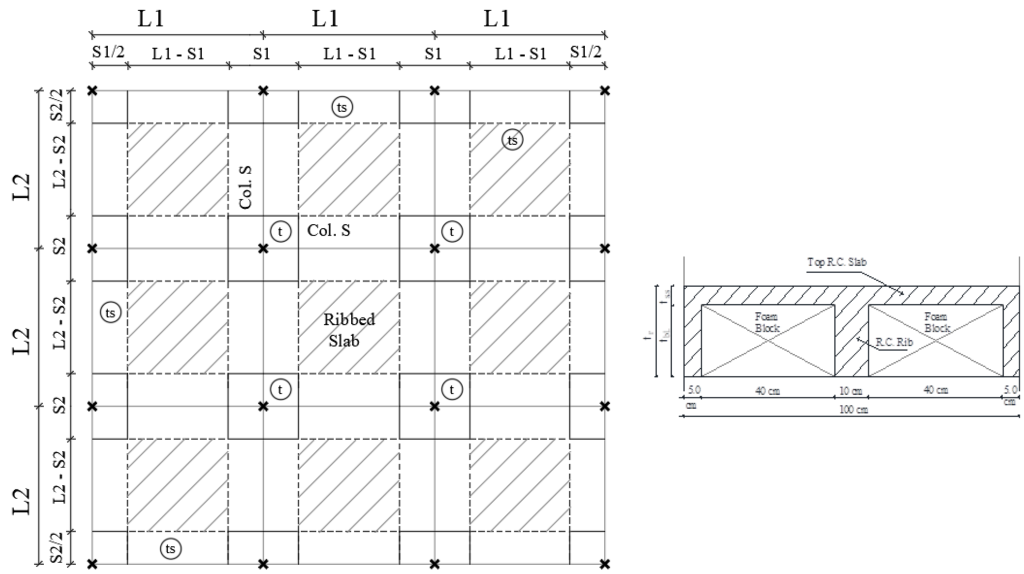


Figure 2 Types of Hollow-Core Flooring Systems

In the last decades, using two-way voided flat slabs, a new technology known as "Bubble Slab" has been developed. To reduce quantities of floor concrete, the core layer of the slab was replaced with plastic balls. Figure 3 depicts this developed bubble slab system (Bhagyashri and Barelikar, 2016; Churakov, 2014; Ihsan et al. 2018; Reshma and Binu, 2016; Surendar and Ranjitham, 2016; Tae-Young et al. 2010; Tina Lai, 2010).

Figure 3 Bubble Deck Slab

Hashad and Helal, 2021 proposed a combined flooring slab construction system that is a mix of two different systems. This system consists of flat slab system replacing its field strips by two-way hollow block slabs as shown in Figure 4, this proposed system aimed to achieve a dual system with more advantages. They studied the effect of applying this system on the required quantities of concrete and steel reinforcement under the effect of static and dynamic loadings.



a. General layout for ribbed/flat slab

b. Section in modified field strip

Figure 4 Proposed Mixed Hollow Flat Slab Systems for Regular Plans
(Hashad and Helal)

It was concluded that the required steel reinforcement's quantity of the flooring slabs was reduced with a valuable ratio reached to 16 % and the floor concrete quantity was reduced up to 14% consequently; the design loads for columns and foundations were reduced up to 10 %. The reduction ratios are minimal because the suggested concept is conservative by maintaining the same configurations of column strips and drop panels dimensions, whereas self-weight indicates the greater ratio of flooring loads.

The present paper aims to develop the previous concept proposed by Hashad and Helal for a mixed hollow flat slab that was applied to regular cases with typical dimensions to be expanded and generalized for applying to buildings of irregular roof plans. Additionally, the previous conservation keeping the column strips configuration and dimensions has been modified as detailed below.

Proposed Concept

The main concept for the proposed dual system has already been examined through application to regular cases by (Hashad and Helal). The proposed flooring slab was a dual system consists of a flat slab and a two-way hollow block slab. This system is achieved by keeping the solid flat slab in the column strips while using two-way foamed blocks in the interior field strips. The major goal is to minimize the self-weight of solid interior panels by employing light weight foam blocks, which reduces concrete amounts, reinforcing, and overall gravity loads, lowering column and foundation costs. When compared to other recent developed methods such as bubble deck slab, using the proposed mixed hollow flat slab concept is easier, cheaper, and more practical.

Therefore, it was proven that the proposed dual system achieves a valuable reduction values for both concrete and steel reinforcements quantities for the studied regular cases. The reduction ratios for the studied cases are shown in Table 1 for both concrete and reinforcement's quantities compared to traditional flat slab system. Additionally, the design loads for columns of the proposed system were reduced with a valuable ratios up to 10%.

Table 1 Reduction Ratios between both systems

Cases	Quantity Reduction % / Floor		
	Self-Weight	Concrete	Reinforcement
Case 1	14.5 %	15.5 %	15.7 %
Case 2	13.9 %	14.7 %	16.2 %
Case 3	13.9 %	14.5 %	16.4 %

The present research aims to extend and generalize application of the proposed dual system to any irregular flooring slab that is the common real construction pattern. That is achieved by keeping the solid flat slab only in the column's zones while using two-way foamed blocks in all other zones either column or field strips. Accordingly, this proposed application is not conservative as the proposed configuration in the previous research prepared by (Hashad, Helal) that keeps same column strips and drop panels dimensions for both typical and dual systems. Actually, this proposed application expects to provide more savings in the required quantities of concrete and steel reinforcements.

Evaluation Methodology

The suggested system was evaluated by comparing the results of designed floors using the typical flat slab system with the results of re-designing floors using the new system. The comparative study was performed through application on two real residential buildings in Cairo, Egypt. The advantages of the suggested system were clarified by comparing the results of the two design approaches. The proposed system's performance was examined under static and dynamic loads to evaluate how well it meet the design criteria for stress and serviceability.

The configuration of the studied buildings are shown in Figures 5, 6 for both conventional and proposed systems, and Table 2 presents the corresponding dimensions for both systems. The evaluation methodology steps for the studied cases were as follows: -

1- Collecting design data (dimensions and steel reinforcements) for the studied typical flat slab buildings from their structural working drawings (columns, column & field strips, slab & drop panel thickness).

2- Constructing numerical models for the conventional flat slab systems that has been analyzed using Program SAP2000 (Computers and Structures, Inc. 2002, ver.20), thus, the dimensions were checked under the effect of the service loads.

3- Constructing and re-design another numerical models for proposed mixed systems that has been analyzed using Program SAP2000 replacing flat slabs with two-way foam ribbed slabs except for the columns' zones for each model.

4- Finally, comparing the overall performance in terms of resulting straining actions with corresponding deformations for both systems was performed.

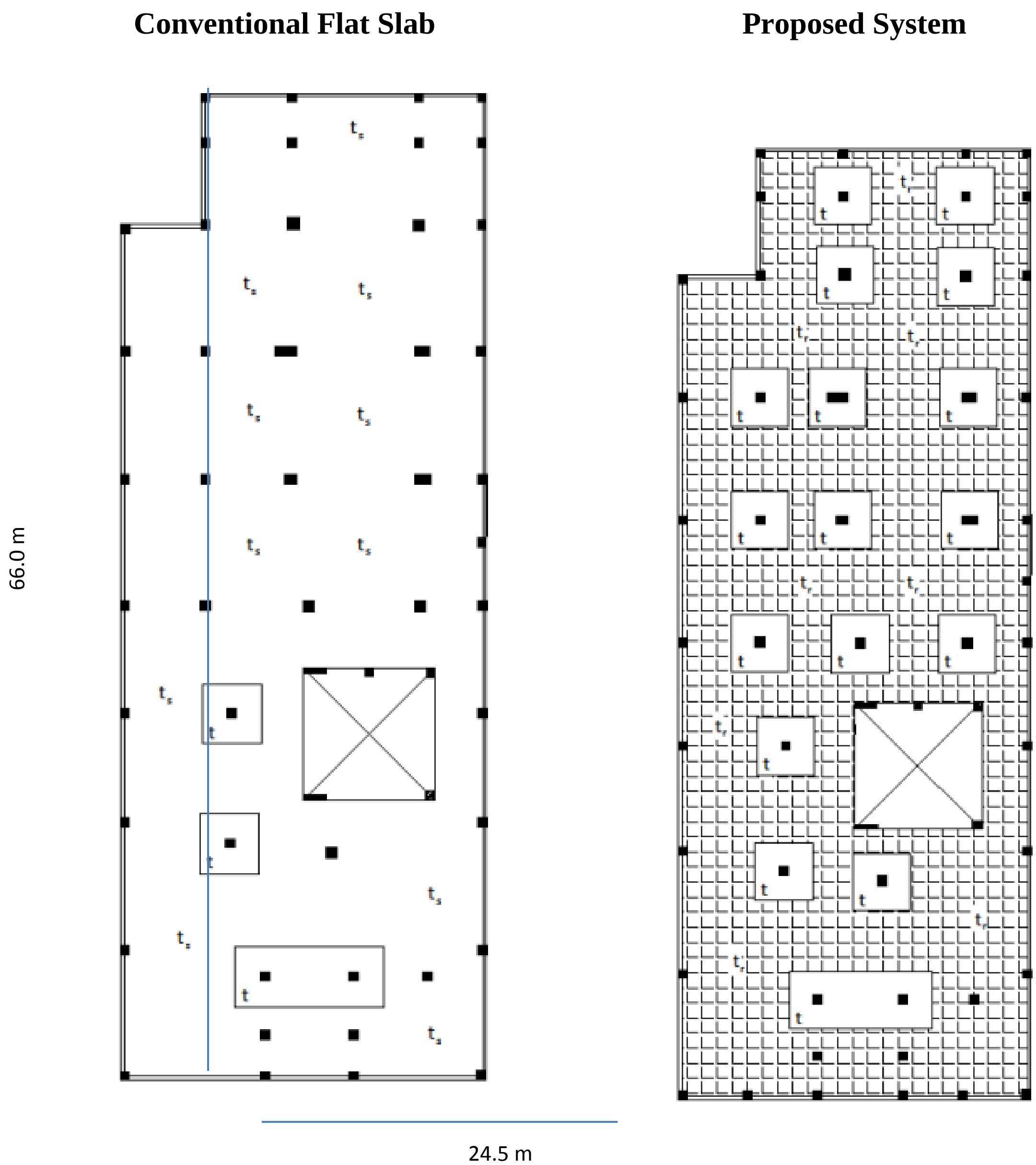


Figure 5 Configuration for Building 1

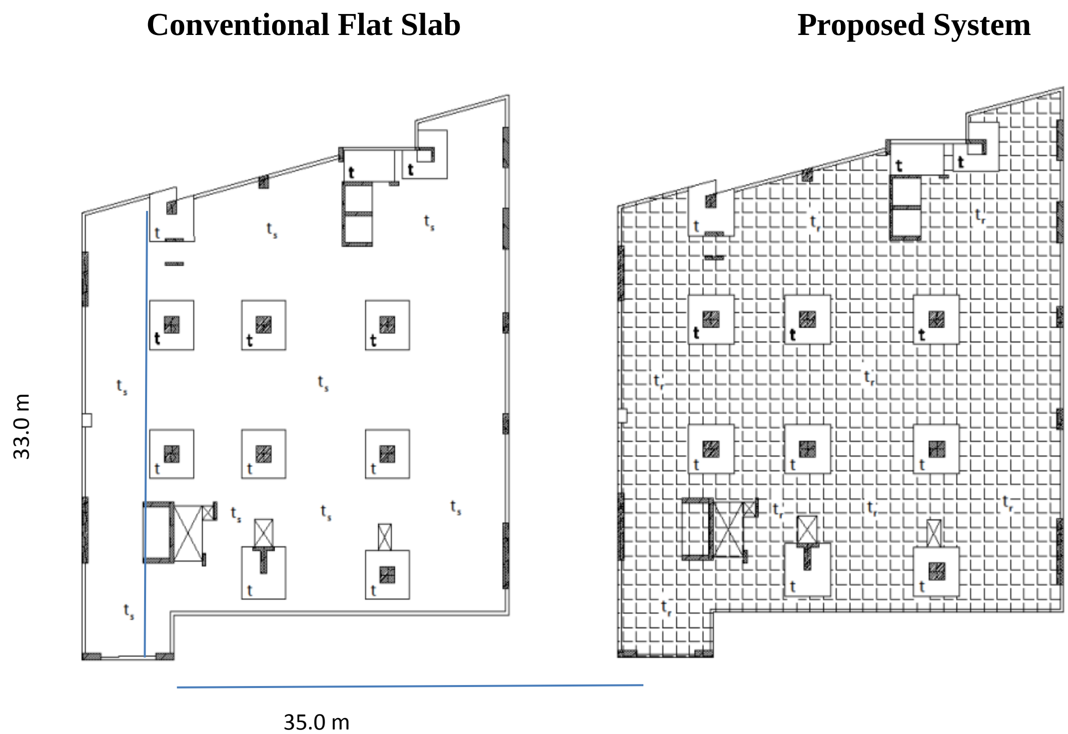


Figure 6 Configuration for Building 2

Table 2 Dimensions for the Studied Buildings

Cases	**Conventional Flat slab**			**Proposed System**		
	t_s	t_d (drop panel)	$t = t_s + t_d$	t_s solid slab	t_r rib thick.	t col. zone
Build. 1	29	16	45	9	29	45
Build. 2	26	19	45	9	29	45

Numerical Modeling

Two-dimensional linear static and dynamic analysis using finite element program SAP2000 was used to study the structural behavior of the proposed system and comparing to the conventional flat slab. The FEM for each case was consisted of Shell elements representing the solid flat slabs, and Frame elements representing the ribs and drop beams. The flooring models were loaded with uniformly distributed dead and live loads and then analyzed for static and dynamic responses. The properties of the materials and the applied service loads are shown below.

Concrete properties: Density = 2.5 t/m^3, Poison's ratio = 0.3, Ultimate strength = 250 kg/cm^2

Steel Reinforcements: Yield strength = 3600 kg/cm2

The applied loads:

Floor Covering = 150 kg/m^2 Intensity of Walls = 150 kg/m^2

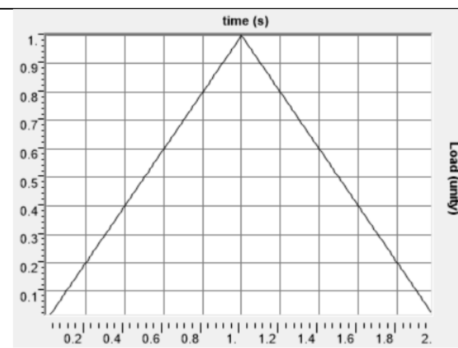
Live Loads = 300 kg/m^2 Density of Foam Blocks = 20 kg/m^3

Dynamic Analysis

Both the typical and proposed systems were subjected to a modal analysis. Table 3 compares the proposed and traditional flat slab systems in their first three modes. In addition, using the shown load function, an impulsive gravity load of = 200 kg/m2 is applied to the studied buildings for both traditional and proposed flooring systems.

Table 3 Dynamic parameters for the two systems

Cases/ Modes		Conventional F. S. System	Proposed Mixed System	Reduction Ratio (%)
		Frequency (Hz)	Frequency (Hz)	
Build. 1	Mode 1	7.38	5.84	22.9 %
	Mode 2	7.78	6.25	19.7 %
	Mode 3	8.44	6.70	20.6 %
Build. 2	Mode 1	12.51	8.92	28.8 %
	Mode 2	14.63	10.31	29.4 %
	Mode 3	14.94	10.77	27.7 %



Impulsive Load Function

Results

ECP was used to check the straining actions for both the traditional flat slabs system and the proposed mixed system, and the critical sections were found to be completely safe, as well as the required steel reinforcements for both the conventional and proposed systems were calculated.

Figures 7 to 9 illustrate examples of the resulting straining actions.

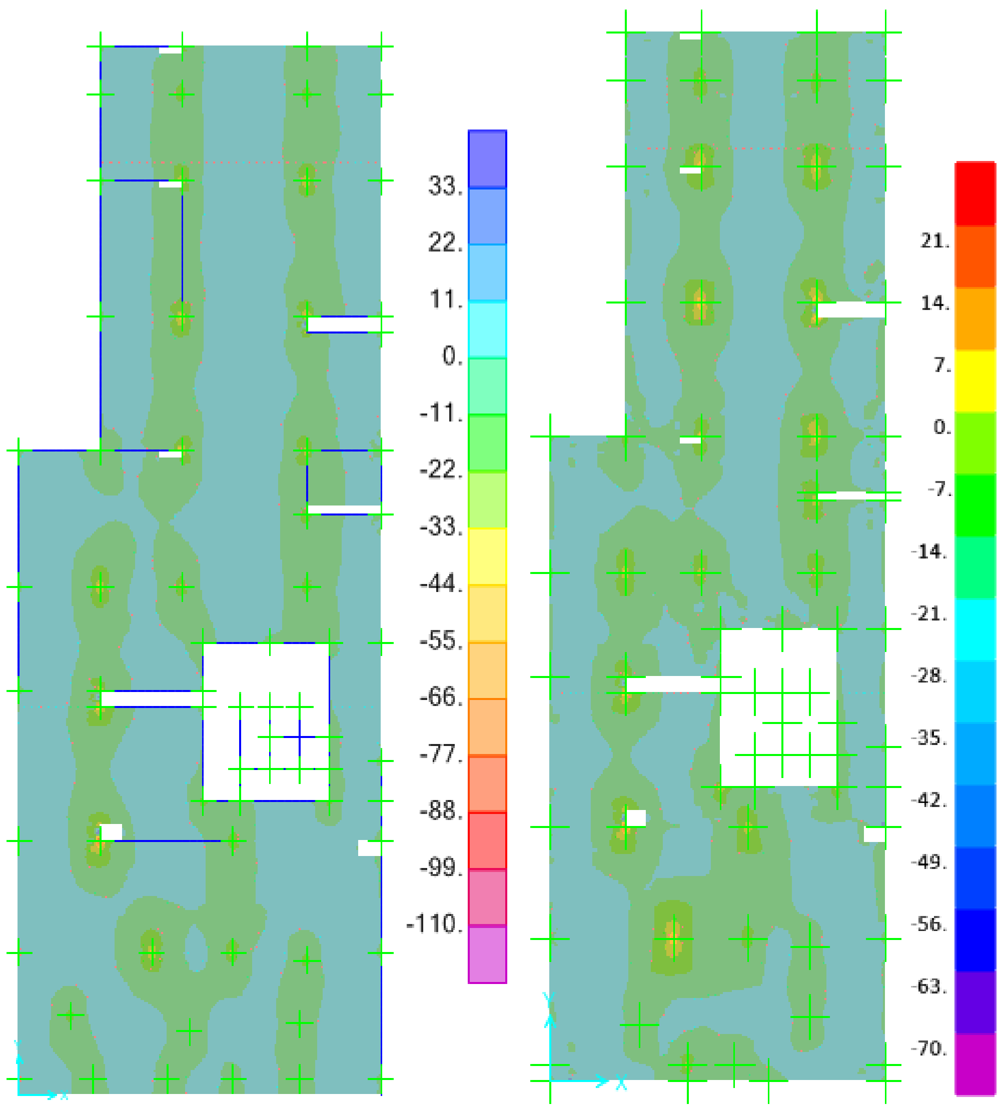


Figure 7 Moment Results Building 1 (M_{11})

The results indicates that a significant reduction of the moment values for the proposed system than the conventional system, this result is expected due to the valuable reduction of self-weight of the replaced hollow block slabs compared to the typical solid flat slab system. For instance the reduction ratio of M11 for building 1 is about 30%.

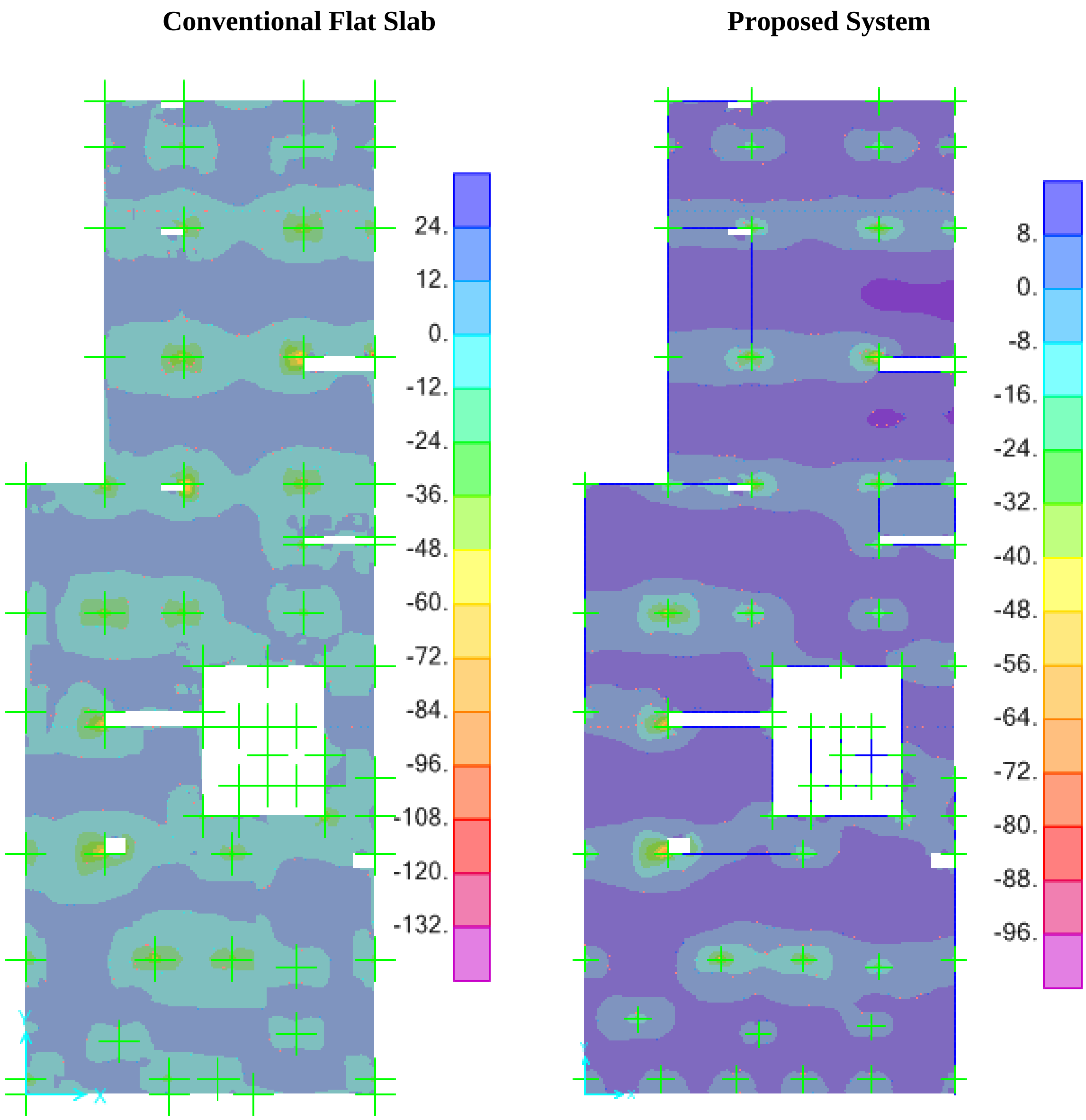


Figure 8 Moment Results Building 1 (M22)

As shown in Figure 8 for building 1, the reduction ratio for M22 is about 27% that achieves adequate safety margins compared to the traditional flat slab system.

Conventional Flat Slab **Proposed System**

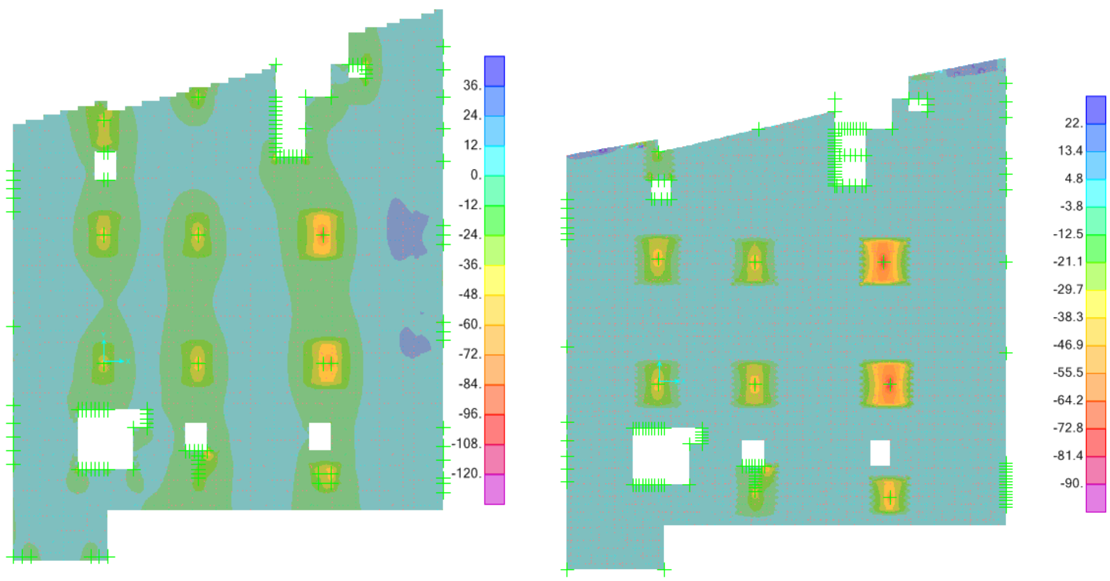


Figure 9 Comparison of Moment Results Building 2 (M11)

Similarly, a comparison of resulting moments between the two concepts for building 2 indicates also a reduction ratio about 25%.

Table 4 summarizes the total quantities of concrete and steel reinforcements for both systems of the studied buildings. Whereas, savings in self-weight of floors, concrete quantities, and needed steel reinforcement for studied buildings ratios are indicated in Table 3.

Finally, as indicated, the findings reveal a significant reduction in concrete and steel reinforcing quantities for the studied buildings.

Table 4 Comparisons of Quantities between Proposed System & Conventional Flat Slab

Cases	Concrete Quantity / floor (m^3)		Reinforcement Quantity/ floor (ton)	
	Conventional Flat Slab	Proposed Mixed System	Conventional Flat Slab	Proposed Mixed System
Building 1	477	342	53.3	36.0
Building 2	334	232	39.9	28.3

Table 5 Reduction Ratios between Proposed System & Conventional Flat Slab

Cases	Quantity Reduction % / Floor		
	Self-Weight	Concrete	Reinforcement
Building 1	24.5 %	28.3 %	32.5 %
Building 2	26.4 %	30.5 %	29.1 %

As indicated in Table 5, the flooring self-weight for the proposed system decreases than the typical flat slab system about 25 % that represents the greater ratio of flooring loads. Consequently, the design loads for columns and foundations were reduced between 25 % and 30 %, this saving is for the roof of a single floor, which achieves significant savings in the cost of columns and foundations especially for multistory buildings.

Concerning the dynamic analysis, Table 3 shows the modal responses for the first three modes of the proposed system that indicates a reduction ratio of frequencies ranges between 20 % and 30 %, that is expected due to the reduction of stiffness between both systems. Additionally, the results indicate an increase of the maximum deflection and velocity values for the proposed system than the conventional system although the results are within the allowable vibration limits according to the international vibration codes (BS 7385, 1993; DIN 4150, 1999; SN 640 312, 1992).

Conclusions

The applications of the present research is an extension to the previously proposed system for a dual flat hollow slabs, to be generalized to irregular plan cases. This proposed application reduces the required quantities of concrete and steel reinforcements of the flooring slabs with a considerable ratio about 30 %. Accordingly, up to 25 % of the design loads for columns and foundations were lowered, this saving is for the roof of a single floor, which achieves significant savings in the cost of columns and foundations especially for multistory buildings.

The findings show that the suggested system has higher deflection values than the conventional method, although they are still within acceptable ranges.

The results of the dynamic analysis reveal that the suggested system is efficient within the vibration velocity limitations set out by the relevant standards.

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