International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2023	Issue 54	Volume 15	Number 1	Pages 309-317

MODELING AND DESIGNING CONCRETE WITH STEEL FIBERS TO IMPROVE MULTIPLE-RIBBED SLABS

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Abstract- This study examines and assesses the impact of adding steel fibers to concrete, which can increase its strength and performance. Through a comparison of seven case studies, this study seeks to determine the significance of adding steel fibers to concrete. In each of the seven cases, the waffle slab and other slabs were numerically modeled and simulated using the SAFE® software package. The reinforcement ratios in the slabs and beams, long-term deflection, and punching shear are some of the important factors considered when assessing the benefits of adding steel to concrete. Investigated are the effects of additional variables on waffle slab behavior. These factors include the incorporation of steel fiber into the concrete, the use of drop beams as a supporting structure, and solid sections at the columns. The maximum deflection of a waffle slab with beams along support lines, calculated by numerical analysis using the SAFE® program, is found to be 72% greater than that of a solid slab. A waffle slab system will deflect more than a solid slab system will. Additionally, it was found that concrete's self-weight increases with volume, leading to higher loads. Compared to the waffle slab with solid sections C4, the waffle slab with beams C1 has 49% more top reinforcement. The bottom and top reinforcement areas in case C2 are increased by 64% and 14%, respectively, in comparison to the waffle slab with beams. Furthermore, compared to the waffle concrete surface with solid structural steel C4, system C1 has 114% more top prestressing area.

Keywords: Reinforcement, Steel fibers, Deflection, Solid slab, Slabs waffle Concrete.

1. INTRODUCTION

Slabs are an exceptional case of fundamental structural elements. The horizontal nature of their surface is a distinguishing feature. They are essential because of their function as load bearers for the building. All three of these surfaces (roof, ceiling, and floor) are made of slabs. As a rule, beams, walls, and columns are used to support slabs. They typically fall into one of five broad categories:

1. Flat plate
2. Flat slab
3. Solid slab
4. Ribbed slab
5. Waffle slab

Table 1 provides additional information and characteristics. In this study, we'll examine just one variety of those five slabs the ribbed variety. The benefits of ribbed slabs, including reduced steel and concrete use [1], better thermal energy insulation, lighter weight, and enhanced acoustic insulation, are summarized in Table 1.

(a)

(b)

Figure 1. (a) A slab with ribs in only one direction, (b) A slab with ribs in both directions [2]

You can classify ribbed slabs as either "one-way" or "two-way," with the former referring to the direction in which the ribs run and the latter to the direction in which they cross. These two varieties of slabs are shown in Figure 1 [2]. There are many constructions uses for ribbed slabs. The ribs of this slab type are designed to hold a significant amount of steel and concrete, reducing the overall weight of the slab. In addition, concrete topping is used to connect a series of ribs in ribbed slabs. Alignment of a single set of ribs is accomplished through longitudinal arrangements, while alignment of a pair of sets of ribs is accomplished through orthogonal ones. The ribs inside the slab can take the place of beams to resist shear, bending, and compression [3].

Table 1. The primary types and features of slabs

Slab Category	Distance between Columns (m)	Live Loads (kN)	Critical Strengths and Properties.	Limitations
Flat Plate	6-8	3-5	increased adaptability to carry out mechanical work	Costs for steel and concrete go up as a result
Flat Slab	8-12	4-7	high likelihood of shifting the position of walls	No acoustic or thermal insulation
Solid Slab	< 9	3-7	Increase adaptability to complete mechanical work	Costs for steel and concrete go up as a result
Ribbed Slab	< 9	3-6	the ability to relocate the walls.	No acoustic or thermal insulation
Waffle Slab	5-17	3-7	The slab is relatively thin in thickness.	Costs for concrete and steel go up as a result

Because less steel and concrete are needed to construct two-way ribbed slabs (TWRSs) [4], they are widely used in a variety of construction projects. However, the TWRS presents some difficulties and important constraints for planners, civil engineers, and designers, resulting in the need for more elevated thickness and difficulties in completing the related mechanical works of these slabs. As a result, numerous studies and experiments have indeed been conducted over the past few decades to develop fresh approaches that can overcome these challenges and make TWRSs useful and effective for use in the majority of construction projects. SFSCC, or Steel Fiber Self-Compacting Concrete, is an illustration of these creative remedies [5]. Utilizing SFSCC for TWRSs helps to improve their mechanical qualities, including compressive strength, while reducing the heavier weight of these slabs. As shown in Table 2, SFSCC has a lower density compared to other conventional building materials.

Table 1. Density values of a group of structural elements [1]

Element	Density (kg/m^3)
Cement	465
Fly Ash	85
Coarse Aggregate	590
Fine Aggregate	910
Water	228
Steel Fiber Self-Compacting Concrete	40

The use of SFSCC can provide construction materials that are active and functional and are able to support greater flexural loading. Additionally, SFSCC can reduce micro-cracking, which can eventually grow into significant macro-cracks. As a result, concrete's ductility can be improved. Additionally, SFSCC is essential to significantly strengthen TWRSs, reduce stresses, and improve slabs' deflection resistance [6]. Additionally, using SFSCC can produce excellent mechanical and mixing properties for concrete without the use of compaction (Saba, et al., 2021; Majain, et al., 2019; Suparlan, et al., 2018). A study on the effects of adding steel fibers to concrete slabs on punching shear resistance was done by Nguyen-Minh, et al. in 2011. According to Nguyen-Minh, et al. (2011), adding steel fibers to concrete will lessen punching shear and increase the punching shear resistance of the slabs [7]. Nguyen-Minh, et al. (2011) also discovered that concrete slabs connected to steel fibers had higher integrity and homogeneity as well as significant improvements in their cracking behavior.

Researchers Zamri, et al. (2022), Saadoon, et al. (2022), Eren (2022), Alvarado, et al. (2022), Jahami, et al. (2022), and Nassif et al. (2022) investigated the crucial impact of steel fiber integration on the punching shear resistance of concrete slabs. Their experimental analysis supported the finding that adding steel fibers significantly increased the concrete slabs' punching shear resistance. Research was conducted in 2022 by Tekleab and Wondimu, Eren, Sahoo, and Singh to examine the integration of steel fibers into slabs [8]. They discovered that adding steel fibers to the slabs would lessen the amount of deflection and prevent cracking from spreading. The effects of incorporating steel fibers into concrete slabs were investigated by Xiang, et al. in 2022. Incorporating these fibers into concrete slabs would enhance the cyclic and flexural performance of the bridge deck slabs, as well as decrease deflection and increase stiffness, according to their analysis [9].

2. MATERIALS AND METHODS

2.1. Materials

This section demonstrates the analysis process carried out for TWRSs (Waffle slabs). The waffle slab systems with internal beams and the waffle slab system with solid sections at columns are both taken into consideration [10]. In terms of materials, it is investigated how adding SFSCC to concrete affects the structural behavior of waffle slabs. Maximum deflection, flexure reinforcement ratio, and shear reinforcement ratio are a few of the parameters that are extracted. To come to a final decision regarding the best TWRS system to be used in slab design, these variables are crucial. The floor system of three-by-three panels, each with a span of 12 meters by 10 meters to be used for residential purposes, was examined in this work, Table 3. Seven cases, representing two waffle slab support systems and a concrete additive, were examined in order to compare the performance of two optimal waffle slab systems [11].

Table 3. An illustration of the work's cases

Case ID	Number of Panels	Span Dimensions (m)	Presence of Beams along Support Lines	Presence of Solid Sections in Columns	Addition of Fibers to Concrete
C1	3×3	12×10	Pass	Fail	Fail
C2		12×10	Solid Slab		
C3		12×10	Pass	Fail	Pass
C4		12×10	Fail	Pass	Fail
C5		12×10	Flat plate		
C6		12×10	Fail	Pass	Pass
C7		12×10	Pass	Pass	Pass

2.1.1. Slab Sections

Typically, the thickness of the slab topping is 10 cm. The ribs are 15 cm wide, and they typically have solid metal reinforcements. The dimensions of the spaces between the ribs are (60×60×28) cm in length, width, and height, with top dimensions of 54×54 cm. In Figure 2 [12], the slab section is displayed. The initial slab thickness is taken into consideration in both cases to be 38 cm.

2.1.2. Columns and Beam Sections

All columns are assumed to have a cross-sectional size of 50×50 cm. The beams' cross-section is currently set to 30×70 cm. The floor height is taken to be 3 meters [13].

2.1.3. Strips Analysis

The two-way slab of beams all along support is divided into interior and exterior beam strips in the directions of *X* and *Y* as shown in Figure 3 [14].

Similar to this, Figure 4 shows how the interior and exterior column strips are divided into both directions of the two-way slab with such a durable concrete at the columns. Furthermore, exterior and interior middle strips are assessed in both short and long directions [15].

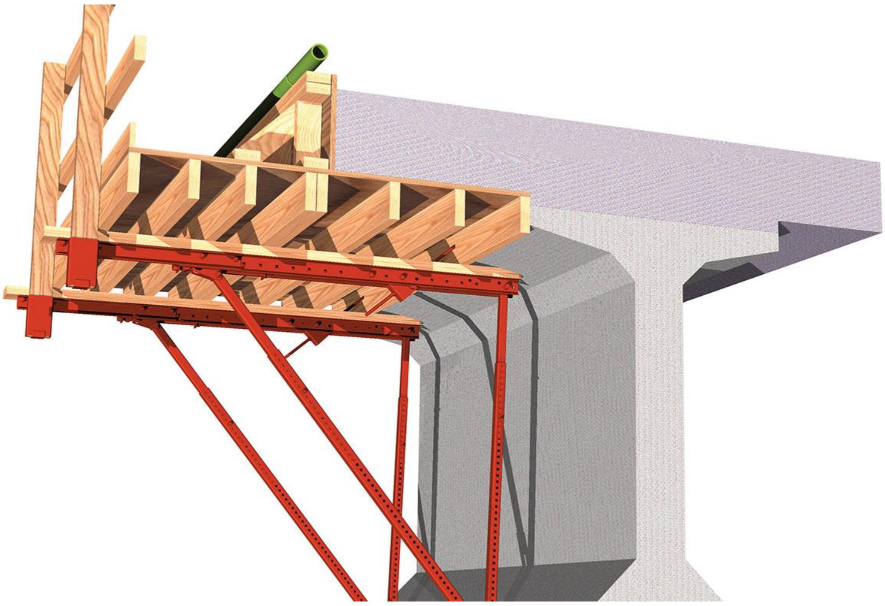

Figure 2. The cross-section of the slabs investigated in this work [12]

Figure 3. Analysis strips for waffle slab with beams [14]

Figure 4. Analysis strips of the waffle slab with solid sections at columns [15]

2.1.4. Material Properties

The value "f'_c=45" is chosen to represent the compressive strength of the concrete without fibers. According to the experimental study conducted by Velayutham and Cheah (2014), concrete with fibers had a compressive strength of "f'_c=70" [16]. The yield stress for flexural steel is chosen to be 400 MPa, and the yield stress for shear reinforcement is chosen to be 320 MPa. Tables 4 and 5, respectively, show the properties of concrete and steel.

Table 4. Concrete properties

Concrete mix	Compressive strength (MPa)	Flexural strength (MPa)	Elasticity modulus (MPa)
C45	45	5.5	37,900
C70	70	11.5	42,200

Table 5. Steel properties

Steel grade	Yield strength (MPa)	Ultimate strength (MPa)	Elasticity modulus (MPa)
T400	400	500	200,000
T320	320	400	200,000

2.2. Numerical Modeling

Based on finite element analysis and considering the seven cases, two waffle slab systems are examined (FEA) [17]. The slab's design is implemented as a shell component. A three- or four-node area object called a shell is used to simulate the behavior of plate bending. If not, columns and beams are intended to serve as frame components. To create a mesh in FEA, the slab is divided into various elements. To get more precise results, the mesh size must be small. Figures 5 and 6 display the slab specimen's meshing [18, 19]. The meshing parts that are used are 0.5 m long.

Figure 5. Meshing in waffle slab with beams [18]

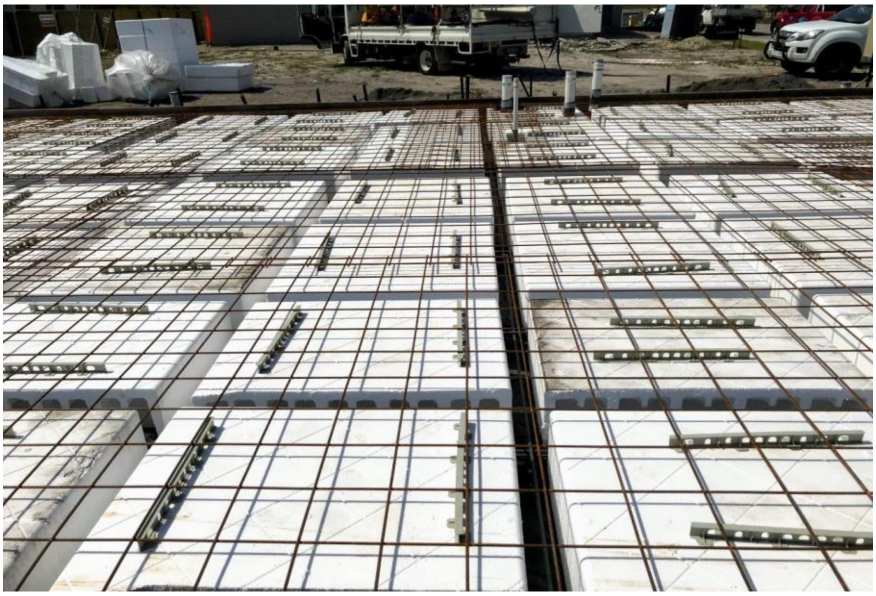

Figure 6. Meshing in waffle slab with solid sections [19]

2.3. Loads Definition and Mathematical Model

2.3.1. Dead Loads

The term "Dead Load" refers to loads that are primarily brought on by the self-weight of a building's enduring structural components, such as slabs, walls, beams, and columns. The calculations are done automatically by Safe. The member sections' estimated material densities are used to calculate the dead loads using some formulas.

2.3.2. Super-Imposed Dead Loads

Super-Imposed Dead Loads (SDLs) are the additional loads that are placed on a structure by adding the weight of the building's structural elements to that of its finishing, fault ceiling, plastering, and nonstructural elements. SDLs are considered to be 5 kN/m^2.

2.3.3. Live Loads

Live loads (LLs) are any transient forces acting on a structure or structural component. They typically consist of individuals, pieces of furniture, and nearly everything else that may be taken out of a building. ASCE 7-16-table 4-1 is used to determine the live loads (LLs). The estimated live loads value for residential buildings is 3 kN/m^2.

2.4. Deflection Control Combinations

When a slab deflects over time, it means that temperature and shrinkage have caused it to do so. ACI 318-14 states that the sum of the instantaneous deflection for 75% of the live load and the long-term effect of 25% LL is what is meant by long-term deflection. This definition is shown in Figure 7 [20].

Figure 7. waffle-slab-construction-reinforcement [20]

For the deflection study, we take into account three scenarios.

1. In ACase (1) represents (DL + SDL + 0.25 LL), taking creep and shrinkage into account.
2. In ACase (2), the short-term deflection is represented by (DL + SDL + LL),
3. In ACase (3) offers a deflection for the short term of (DL + SDL + 0.25 LL).

The long-term deflection can be determined using these three cases by:

Long Term deflection = Acase (1) + Acase (2) – Acase (3)

3. RESULTS

3.1. Maximum Deflection Findings

In order to evaluate the effectiveness of the waffle slab system, four distinct scenarios are evaluated side by side. Figure 8 depicts the maximum deflection seen in Cases C1, C2, C4, and C5 respectively. The two-way waffle slab C1 that is supported by a beam can deflect up to 47 millimeters at its most. The conventional solid slab case, designated C2, had a maximum deflection of 27.3 millimeters. The scenario C4 of the waffle slab with solid sections exhibits the greatest amount of deflection, which is displayed as 38.1 millimeters by the graph. The chart reveals a maximum deflection of 29.8 millimeters for the scenario C5, which involves the flat slab.

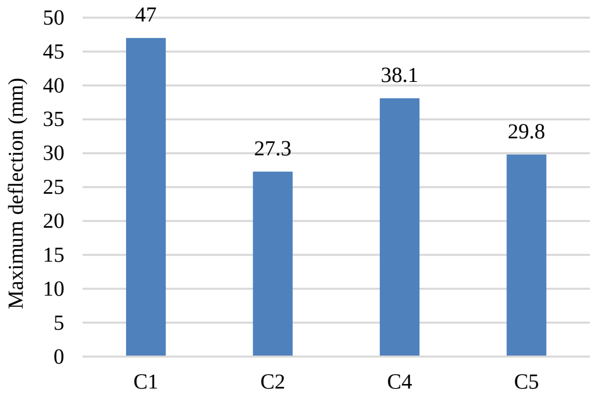

Figure 8. The maximum deflection of cases C1, C2, C4, and C5

When it came to maximum deflection, a waffle slab with drop beams C1 and a solid slab C2 were put up against one another. According to the findings, the maximum deflection of a waffle slab that has beams along the support lines is 72% higher than that of a solid slab. In practice, the deflections of waffle slab systems are greater than those of solid slab systems. This feature demonstrates how much more adaptable waffle slab systems are in comparison to systems that use solid slabs. The maximum slab deflections experience a discernible reduction in response to an increase in the volume of concrete. Furthermore, in comparison to the solid slab system, the waffle slab system is capable of a maximum deflection that is 28% greater. The circumstances that led up to Cases C1 and C2 continue to be relevant today. Because it contains a greater volume of concrete, the solid slab is considerably more rigid than the waffle slab. In conclusion, the research indicates that a two-way waffle slab that is supported by beams on support lines has a maximum deflection that is 23% greater than a waffle slab that has a solid section. The solid section at the columns with a depth of sixty centimeters makes the waffle slab C4 more rigid and reduces the maximum amount of deflection by twenty-three percent when compared to the waffle slab that has drop beams.

3.2. Slab Reinforcement Outputs

3.2.1. Interior Middle Strip in *X* Direction

The second crucial output is the reinforcement area per strip for the four scenarios C1, C2, C4, and C5. Figure 9 depicts the reinforcement area per interior middle strip-x for the four different slab systems.

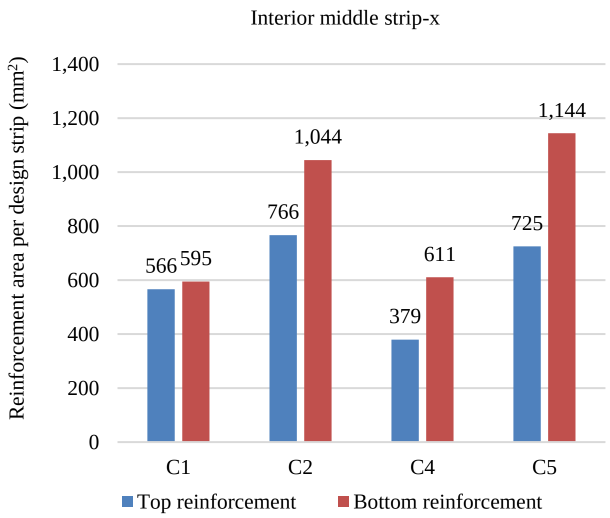

Figure 9. Interior middle strip-x reinforcement case C1, C2, C4, and C5

Case C1 has a top reinforcement area measuring 566 mm^2 and a bottom reinforcement area measuring 594 mm^2 respectively. A bottom reinforcement area of 1,044 mm^2 and a top reinforcement area of 766 mm^2 are required if the Case C2 flat slab is to be used. The top reinforcement area of Case C4 is 379 mm^2, while the bottom reinforcement area is 611 mm^2. The internal middle strip of the case C5 flat slab has reinforcement areas of 725 mm^2 and 1,144 mm^2 per strip. These areas are designated for top reinforcement and bottom reinforcement, respectively. Several graphs are generated in order to provide a visual comparison of the reinforcement results across all of the different types of slabs.

When compared to the waffle slab that was reinforced with beams, case C2 features an increase in the top and bottom reinforcement areas of 75% and 35%, respectively. In addition, when compared to the waffle slab with solid sections at columns, the reinforcement area per middle strip for Case C5's solid slab increased by 87 and 91 percent, respectively, when compared to the waffle slab. The recent findings make it abundantly clear that an increase in the volume of concrete results in an equivalent increase in its self-weight, which in turn results in an increase in the loads [21]. When comparing the two waffle systems, the waffle slab with beams C1 has 49% more top reinforcement than the waffle slab with solid sections C4.

3.2.2. Exterior Middle Strip in X Direction

For the exterior middle strip-x, Figure 10 displays a graph illustrative of the four slab systems.

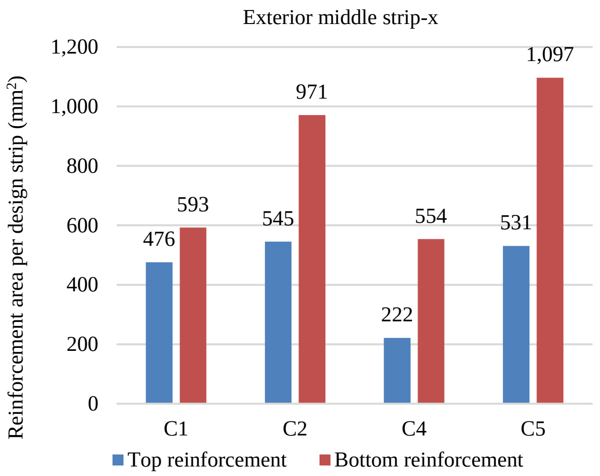

Figure 10. Exterior middle strip -x cases C1, C2, C4 and C5

Case C1 features a top and bottom reinforcement area that are each 476 millimeters square in size. The flat slab in case C2 has a bottom reinforcement area of 971 mm^2 and a top reinforcement area of 545 mm^2. In scenario C4, the reinforcement area for the bottom is 554 mm^2, while the reinforcement area for the top is 222 mm^2. The bottom reinforcement of the outside middle strip of the C5 flat slab has an area of 1097 millimeters squared per strip, and the top reinforcement has an area of 531 millimeters squared [22]. When compared to the waffle slab with beams, the bottom and top reinforcement areas in case C2 are expanded by 64 and 14 percent, respectively, more than the waffle slab with beams. In addition, when compared to the waffle slab with solid sections at columns, the reinforcement area per middle strip for the case C5 solid slab increases by 98 and 139 percent, respectively, for bottom and top reinforcement. The findings demonstrate that the waffle system C1 has a top reinforcement area that is 114% larger than that of the waffle slab with solid panels C4. The reinforcement area for the four different cases C1, C2, C3, and C4 is depicted in Figures 11 and 12, which show the interior and exterior middle strips, respectively. The graphs follow the same general trend as the strips do in the *x* direction [23].

StaSTEEL uses a single-story industrial structure model and three-story, ten-story and fifteen-story steel structures with symmetrical and L-shaped asymmetrical floor shapes. For building analysis, the 2019 Turkish Building Earthquake Regulation was used. By looking at program interfaces, it has been found out how well data entry, result analysis, and outputs meet user needs [22].
The importance and application of planning and cost management in construction projects is discussed. Different planning techniques are mentioned in different situations. It has been emphasized that project management is not adequately implemented in many construction companies. As a result of the study, there are suggestions for the correct use of cost management and programming [24].

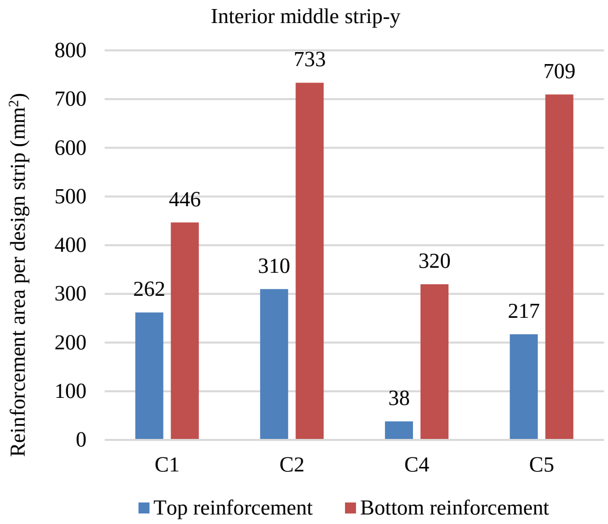

Figure 11. Interior middle strip-y cases C1, C2, C4, and C5

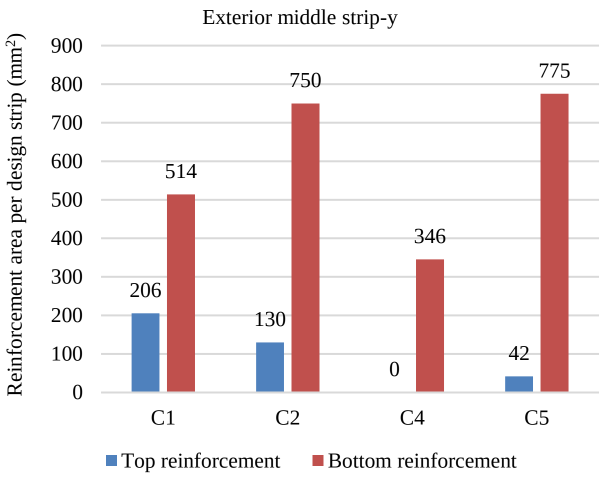

Figure 12. Exterior middle strip-y cases C1, C2, C4, and C5

4. DISCUSSIONS

According to the findings of this research, including steel fibers in a waffle slab would result in a reduction in the maximum amount of deflection that the waffle slab is capable of. In addition, the findings showed that the deflections in the waffle slabs are significantly higher than those in the solid slab. In addition, the findings of the research demonstrated that the punching shear values in concrete Case C6 decreased after steel fibers were added to the mixture. These findings are in line with the findings of Nguyen-Minh, et al. (2011), who carried out an investigation into the effect that incorporating steel fibers into concrete would have on the punching shear resistance of slabs of concrete. They discovered that incorporating steel fibers into concrete would reduce the punching shear and increase the slabs' punching shear resistance. These findings are consistent with the findings of Nguyen-Minh, et al. (2011).

In addition, Nguyen-Minh and colleagues (2011) discovered that the concrete slab containing steel fibers exhibited significant improvements in the cracking behavior, as well as higher integrity and homogeneity of slabs that were connected to steel fibers. The findings of this study are also in line with the findings of Zamri, et al. (2022), Saadoon, et al. (2022), Eren (2022), Alvarado et al. (2022), Jahami, et al. (2022), and Nassif, et al. (2022), who conducted research investigating the critical role that steel fibers integration into concrete slabs plays in their punching shear resistance. The results of their experiments demonstrated that the addition of steel fibers resulted in a significant increase in the punching shear resistance of the concrete slabs. Also, the results of this work are consistent with the findings of Eren (2022), Sahoo and Singh (2022), and Tekleab and Wondimu (2022).

These researchers carried out research analyzing the integration of steel fibers into slabs and discovered that adding steel fibers to the slabs would reduce the amount of deflection and minimize the growth of cracking. Tekleab and Wondimu (2022) found that adding steel fibers to the slabs would reduce the amount of deflection in addition, the results of this work are consistent with the findings of Xiang, et al. (2022), who investigated the effect of incorporating steel fibers into concrete slabs and discovered that integrating these fibers into concrete slabs would improve the cyclic and flexural performance related to bridge deck slabs, as well as reduce deflection and increase its stiffness. Xiang and his colleagues studied the impact of incorporating steel fibers into concrete slabs.

5. CONCLUSIONS

The purpose of this research is to investigate and assess the potential benefits of incorporating steel fibers into concrete in order to boost both the material's strength and its overall performance. In order to accomplish the purpose of the study, a comparative analysis is carried out. As part of this process, seven case studies are taken into consideration in order to determine the applicability and essential advantages of incorporating steel fibers into concrete. In each of the seven tests, a numerical model and simulation of the waffle slab and other slabs were carried out with the help of the SAFE software package. When determining whether or not adding steel to concrete has a positive impact, it is necessary to take into account a number of important parameters, such as the reinforcement ratios in the slabs and beams, the long-term deflection, and the punching shear. In addition, research is done to investigate how the behavior of waffle slabs is affected by a number of different factors. These elements include the influence of solid sections at columns, the effect of steel fiber integration into concrete, and the effect of drop beams as a supporting system. On the basis of the numerical analysis that was carried out by means of the SAFE® program, the findings of the research can be broken down into the following paragraphs:

1. When compared to a solid slab, the maximum deflection that can be achieved by a waffle slab that has beams running along the support lines is 72 percent greater. The waffle slab system has deflections that are significantly greater than those of the solid slab system.
2. Due to the fact that the self-weight of concrete increases in proportion to its volume, there are a greater number of loads. When comparing the two waffle systems, the waffle slab with beams C1 has 49% more top reinforcement than the waffle slab with solid sections C4, which can be seen by looking at the comparison table below.
3. When compared to the waffle slab with beams, the bottom and top reinforcement areas in case C2 are expanded by 64 and 14 percent, respectively, more than the waffle slab with beams.
4. The top reinforcement area of the waffle slab that is reinforced with solid panels, designated as C4, is 114% smaller than that of the waffle system designated as C1.

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