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Reinforcing and Improving the Behavior of Reinforced Concrete Slabs Employing the Optimal Amount of Polymer Fibers and Examining the Effect of the Number of Fiber Layers

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Abstract
Reinforcing and increasing the bearing capacity of concrete slabs can increase the flexural and shear capacity of the structure, and it plays an important role in the behavior of structures because of using slabs in structures such as buildings and bridges. In this paper, reinforced concrete slabs' behavior has been reinforced and improved using the optimal amount of polymer fibers and examining the effect of the number of fiber layers. Modeling was performed in Abaqus software, and nonlinear static analysis was applied. The results showed that reinforced concrete slabs' reinforcement increases the amount of final displacement at the moment of rupture, and the reinforced slabs bear more displacement. Slabs reinforced with carbon fibers add about 9%, slabs reinforced with aramid fibers 6, and glass fibers about 4% to the final displacement rate. Carbon fibers have the greatest influence on this parameter, and aramid and glass fibers are in the next levels. Additionally, the rate of energy absorption in the concrete slab is increased after reinforcement. The energy absorption rate of carbon fiber and aramid-reinforced models is increased by approximately the same amount and about 7%. The glass-fiber-reinforced model also is improved in energy absorption by approximately 2%. The final displacement rate in models reinforced with a 2 mm thick plate presents an increase in the final displacement rate at the moment of rupture compared to the non-reinforced model. If carbon fiber is utilized, the final displacement rate will be increased by nearly 23%. The aramid and glass fibers are increased by 17 and 12%, respectively. The model with a carbon fiber reinforcement sheet in models with a 2 mm thick reinforcement sheet has the highest amount of energy absorption, which increases by 23%. In the model with aramid fiber reinforcement sheet, this amount is about 18, and it is increased by 8% with glass fibers.
Keywords: FRP fibers, concrete slab, glass fibers, aramid fibers, carbon fibers.

1. Introduction

Examining and studying the structures devastated by earthquakes that have happened in recent years has informed engineers of the role and significance of reinforcing concrete structures in increasing buildings' safety. The principle in the design of buildings against earthquakes is so that the structure should be designed and built in such a way that can resist moderate earthquakes without damage. It is assumed to resist the severe earthquakes that are predicted for its useful life without serious damage, and the structure will not be totally destroyed in the event of extraordinarily severe earthquakes. Damaged buildings because of earthquakes have shown that joints and concrete slabs are the most vulnerable structural elements under seismic load in concrete structures, and they should be considered significantly compared to other structural elements in design and construction. When earthquake-induced lateral forces influence a flexural ductile reinforced concrete frame, the beam-column joints should be able to transfer large shear forces, which, of course, are supplemented by many deformations.

Reinforced concrete slabs are one of the most frequent systems in structures. Slabs are proper for covering the floor of buildings with different openings. It is significant and needed to strengthen concrete slabs due to the extensive use of concrete slabs. Hence, many researchers have considered the flexural reinforcement of concrete slabs with fibers. Reinforcing and increasing the bearing capacity of concrete slabs can increase the structure's flexural and shear capacity. It plays an important role in the behavior of structures due to the use of slabs in structures such as buildings and bridges. This study's main problem is the reinforcement of reinforced concrete slabs using the optimal amount of polymer fibers and an examination of the effect of the number of fiber layers.

2. Literature review

Al-Rousan et al. conducted a laboratory study on the behavior of concrete slabs reinforced with FRP fibers. They compared the effect of FRP strip and plate fibers on the slab behavior. Their research aimed mainly to study the bearing capacity of concrete slabs studying the influence of FRP fibers. They concluded that FRP carbon fibers affect beneficially and directly reducing the flexural cracks generated in concrete slabs. They also determined that FRP fibers positively affect preventing the appearance of initial cracks in concrete slabs. They remarked that cracks appear in the slab not reinforced with FRP fibers under the same conditions, but no cracks appear in the slab in the slab reinforced with FRP fibers comparing the reinforced concrete slab with FRP fibers and not reinforced with FRP fibers. [1]

Lesmana et al. conducted research using distinctive methods for embedding FRP fibers in concrete. They compared the behavior of the concrete slab with different fiber arrangements. The same loading was performed for the studied samples. They concluded that the best result is achieved from plate FRP fibers among FRP fibers' different methods and arrangements [2].

Vasques et al. conducted a laboratory study on concrete slabs. They intended to study the effect of FRP fibers' effect on the reinforcement of concrete slabs. They concluded that fiber-reinforced slabs have fewer shear and flexural cracks compared to fiber-free slabs. Furthermore, the created crack due to loading for reinforced slabs is consistently distributed on the slab's cracked surface. It was also concluded that carbon FRP fibers significantly increase the bearing capacity of reinforced concrete slabs [3].

Mosallam et al. conducted a study on the behavior of concrete slabs by examining the flexural behavior of reinforced concrete slabs under point loading with the effect of adding FRP carbon fiber. Their results determined that adding fibers in the external part under the concrete slab brings about the best result in the concrete slab's behavior. Also, they concluded that adding fibers affects significantly increasing the bearing capacity of the concrete slab by comparing the shear crack width provided in a reinforced concrete slab with an unreinforced concrete slab [4].

Openings are produced in the slabs due to the passage of pipes and mechanical installations. These openings reduce the shear capacity. In the last decade, many studies have been conducted in the field of reinforcement and improvement of reinforced concrete members such as beams, columns in cutting, bending, and even twisting, applying reinforced polymer fibers as an external covering [5].

It is fundamental to be informed about the real strength of concrete is fundamental to guarantee the quality of new work performed, the influence of environmental factors, and using existing concrete structures to repair and reinforce structures. Accordingly, the conditions and strength of substrate concrete should be examined and calculated to define the FRP's reinforcing capacity. The twist-in-place method is one of the latest innovative methods to specify surface strength [6].

Some researchers have concluded by comparing the rupture of CFRP-reinforced beam examples that the lack of internal reinforcement causes the crack to open immediately. The main diameter crack to continue diagonally from the bottom to the top of the beam. This provides high stresses at the FRP joint with the concrete, causing the FRP plate to be separated from the beam surface and the cross-section edges. They believe that limited and low shear reinforcement regularly provides this type of separation [7].

Studies conducted by several researchers indicate that concrete beams that have been reinforced to bear bending may be destroyed because of various factors, including steel rupture, composite plate rupture, concrete damage in the compression zone, flexural and shear cracks in concrete, or separate the plate from under the concrete beam. Accordingly, achieving the correct modeling of a concrete beam's rupture behavior reinforced with composite fibers requires considering several factors [8].

We can consider the nonlinear finite element method to simulate the overall behavior of reinforced concrete beams using several researchers performed by sheet FRP among the different numerical methods applied so far. It is possible to predict reinforced members' behavior with any pre-reinforced loading history using this method. The bonding behavior of concrete, rebar, and FRP sheet with 6-point surface components has been modeled in this method. [9].

Ardouni et al. used ABAQUS finite element software to analyze 8 beams reinforced with FRP sheets. This analysis is restricted to beams with a uniform loading history and no damage preceding the reinforcement. In this analysis, concrete is modeled by a continuous cracking method and assuming complete adhesion between concrete and FRP. [10].

3. Research methodology

In this paper, a reinforced concrete slab reinforced with FRP carbon fiber has been applied for analysis. Modeling has been done based on laboratory conditions. The sample has been performed by simulating the loading of a hydraulic jack device. The sections and design of the structure are based on a single laboratory sample. Next, the reinforced concrete slab reinforced with carbon fiber FRP has been analyzed structurally according to the reference model sections in ABAQUS software. Volume elements have been used for concrete slab, truss element for round bar, shell element for FRP carbon fiber. Nonlinear static analysis has been used due to the compressive load of the force and the problem's independence at the time. Sample modeling has been thoroughly explained in the following parts. The dimensions of the models have been provided based on the laboratory samples. Figure (7) shows a laboratory sample.

Figure (1) Experimental sample of reinforced concrete slab model [8]

The shell element has been used to provide FRP fibers. Figure (2) determines the final drawing model based on Figure (3) of the Experimental sample after registering the FRP fibers' specifications.

Figure (2) The fibers used in the laboratory sample

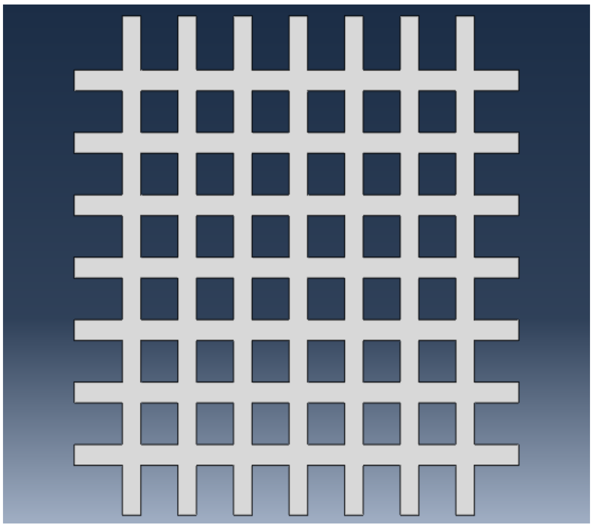
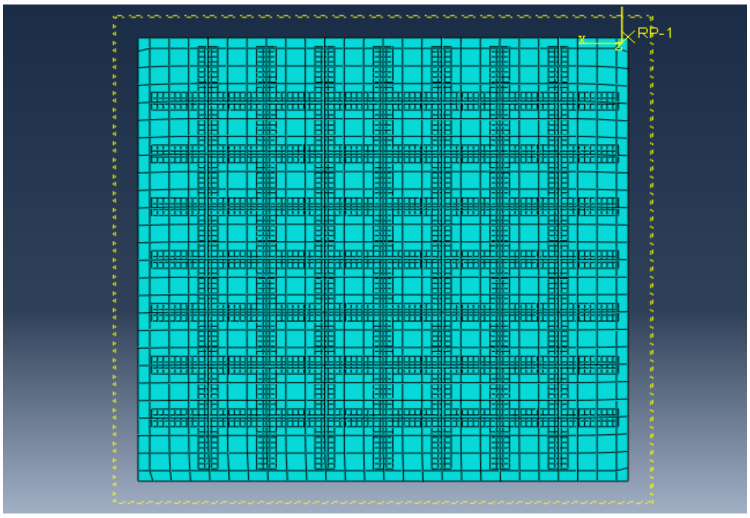


Figure (3) shows the fibers made in ABAQUS software.



software Figure (4) meshing the model studied in this study.

The plasticity behavior is considered with the criterion of concrete damage plasticity for concrete. Specific modeling behavior is considered for fibers for steel-plastic behavior rebar. Figure (4) shows the meshing of the studied model in this study.

4. Research results

This session examines the results of numerical analysis achieved by examining the behavior of concrete slabs reinforced with FRP fibers. Different types of fibers have been utilized. The effect of fiber arrangement on the strength of the concrete slab has been then studied. The past section stated the way of analyzing fully. The analysis was performed on different modes of concrete slabs with and without fibers. This chapter examines and analyzes the outputs in the form of diagrams and figures. The application of FRP materials in the tensile zone of concrete, if it is in the direction of the fibers and in the longitudinal direction of a flexural member, will increase that member's flexural strength. In the design, the behavior of concrete and elements of concrete structures such as reinforced concrete slabs should be examined considering the significant reduction of rotation and curvature in the reinforced parts. Additionally, the effect of compressive loads on FRP materials should be examined in this situation. The flexural strength of a reinforced section depends on its rupture mode. The following flexural fracture modes are studied for a presented section.

4.1. Evaluating the numerical basis model

The outputs are examined after modeling the base model. Displacement load diagrams have been investigated for different analyzes and compared with each other. Figure (5) indicates the displacement force diagram in kN for force and millimeters for slab displacement. The diagram in Figure (6) shows the deformation and displacement of the concrete slab for the fiber-free state. Figure (7) shows the von Mises tension distribution in a fiber-free concrete slab from the top representation. Figure (8) shows the amount of energy waste in a fiber-free concrete slab.

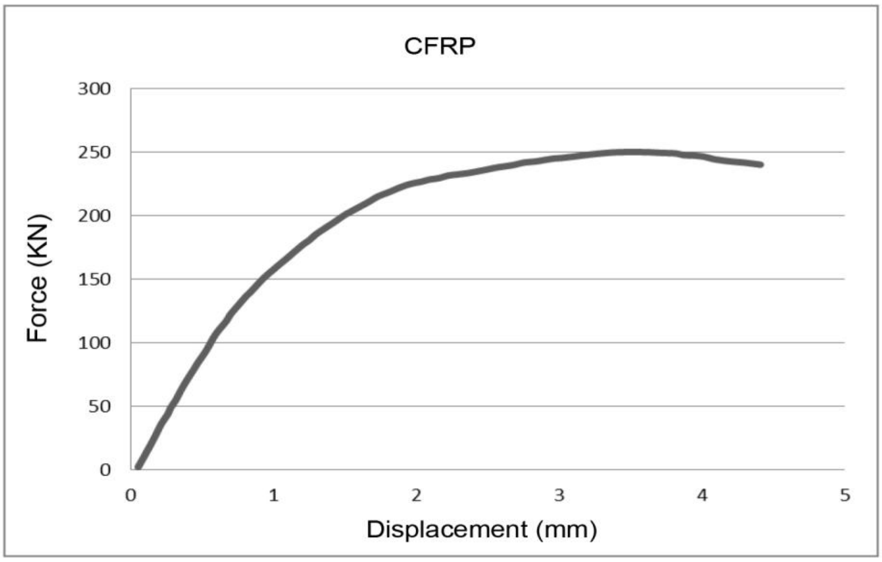


Figure (5) Displacement force diagram for a fiber-free concrete slab

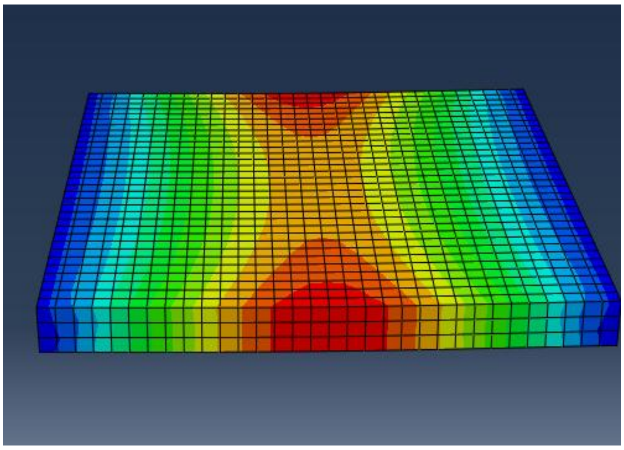


Figure (6) Deformation and displacement of concrete slab for fiber-free mode

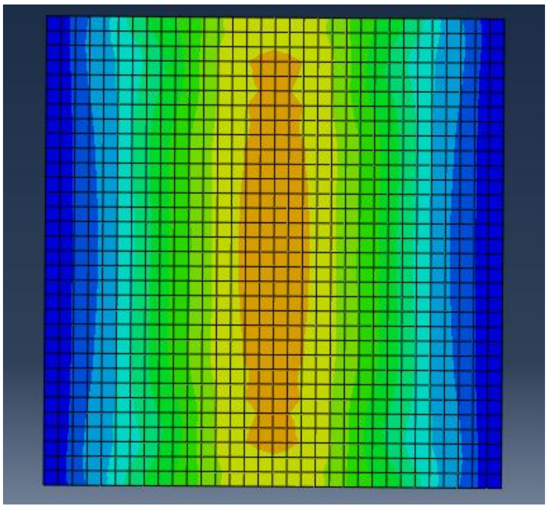


Figure (7) Von Mises tension distribution in a fiber-free slab from the top representation

Figure (8) reveals a diagram of the amount of energy waste in a fiber-free concrete slab.

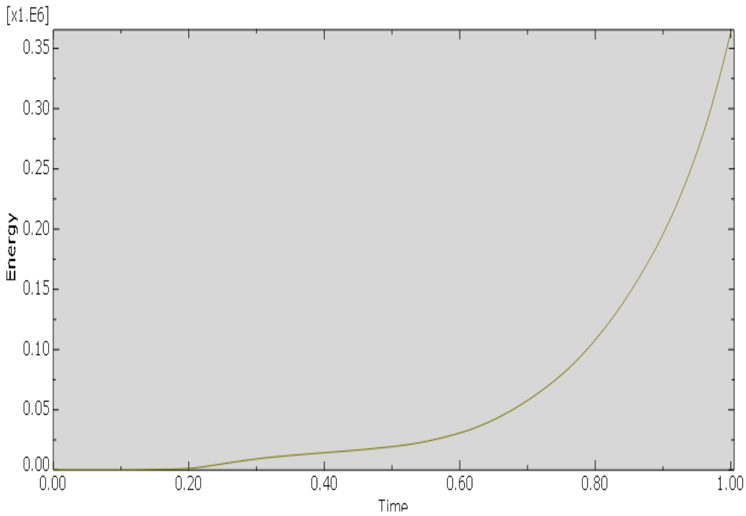


Figure (8) The amount of energy waste in a fiber-free concrete slab

4.2. Evaluating a concrete slab model with rebar

This section shows the deformation and tension distribution in the fiber-free and rebar slab. Figure (9) shows the concrete slab's deformation and displacement for the fiber-free mode with the rebar. Figure (10) reveals the Von Mises tension distribution in a fiber-free concrete slab from the above representation in a fiber-free reinforced concrete slab with rebar. Figure (11) shows the amount of energy waste in a fiber-free concrete slab and with rebar

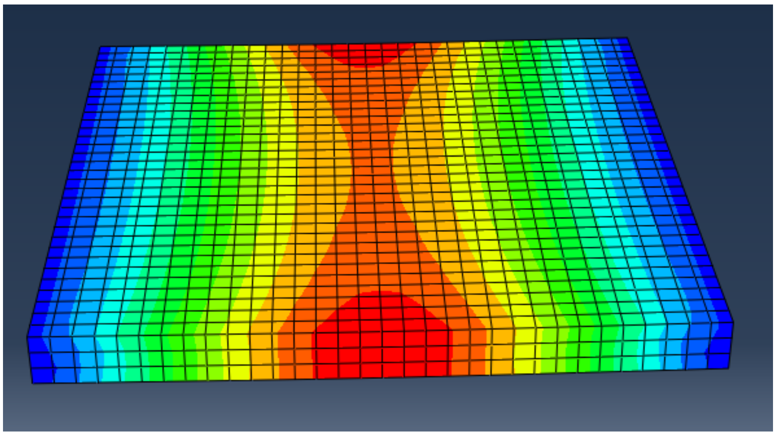


Figure (9) Deformation and displacement of concrete slab for a fiber-free mode with rebar

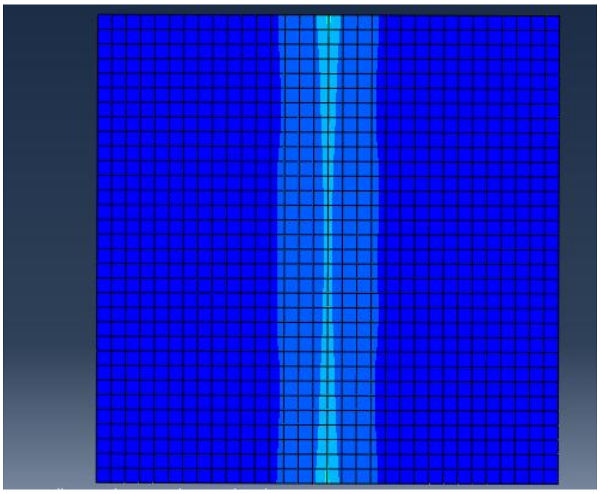


Figure (10) Von Mises tension distribution in the fiber-free concrete slab from the above representation in a fiber-free concrete slab with rebar

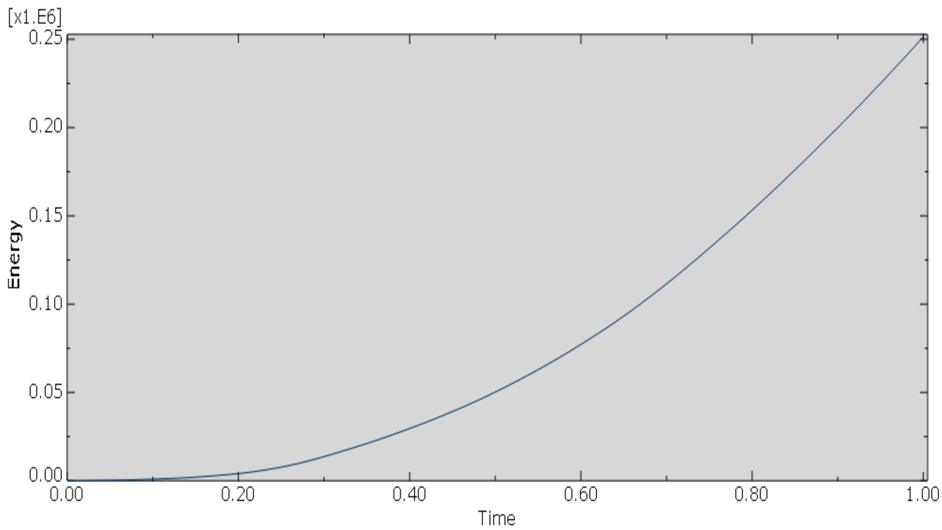


Figure (11) The amount of energy waste in a fiber-free concrete slab with rebar

4.3. Evaluating the fiber-reinforced model

This section studies and compares displacement load diagrams for a carbon fiber-reinforced concrete slab with a checkered model. Figure (12) shows the deformation of FRP carbon fibers for the fiber-reinforced slab. Figure (13) shows the deformation and displacement of a reinforced concrete slab with checkered carbon fibers. Figure (14) shows the Von Mises tension distribution of concrete slab reinforced with checkered carbon fibers from the top representation. Figure (15) shows the von Mises tension distribution of concrete slab reinforced with checkered carbon fibers from the front representation. Figure (16) shows the amount of energy waste in a concrete slab reinforced with checkered carbon fibers.

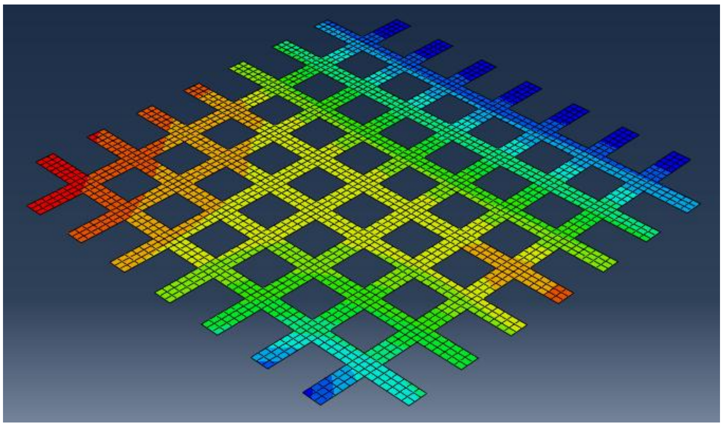


Figure (12) FRP carbon fiber deformation for fiber-reinforced slab mode

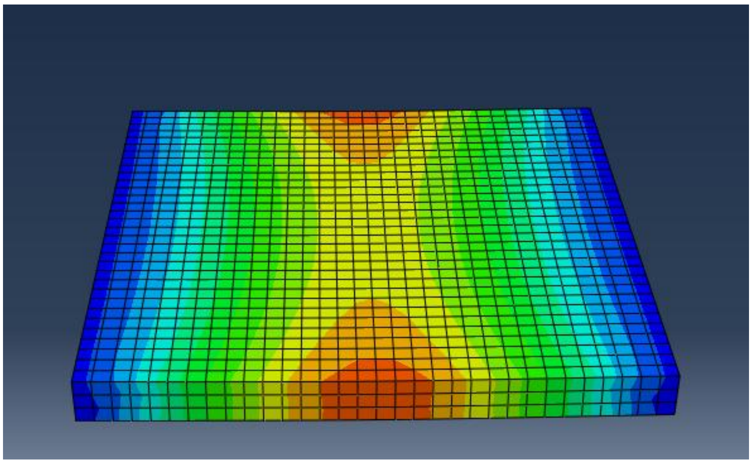


Figure (13) Deformation and displacement of concrete slab reinforced with checkered carbon fibers

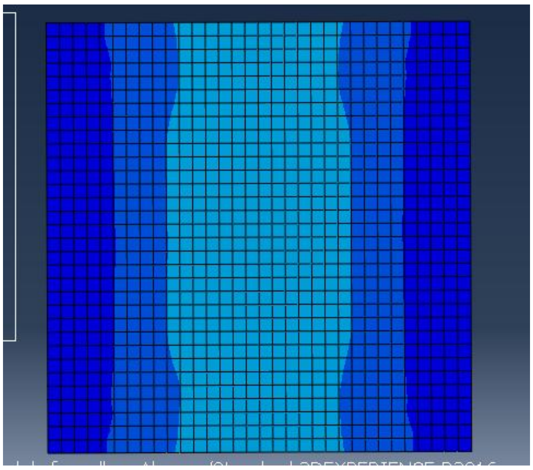


Figure (14) Von Mises tension distribution of concrete slab reinforced with checkered carbon fibers from top representation

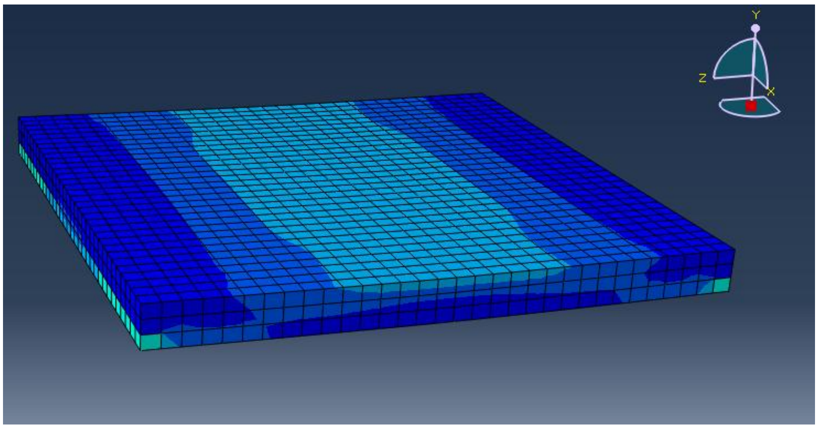


Figure (15) Von Mises tension distribution of concrete slab reinforced with checkered carbon fibers from the front representation

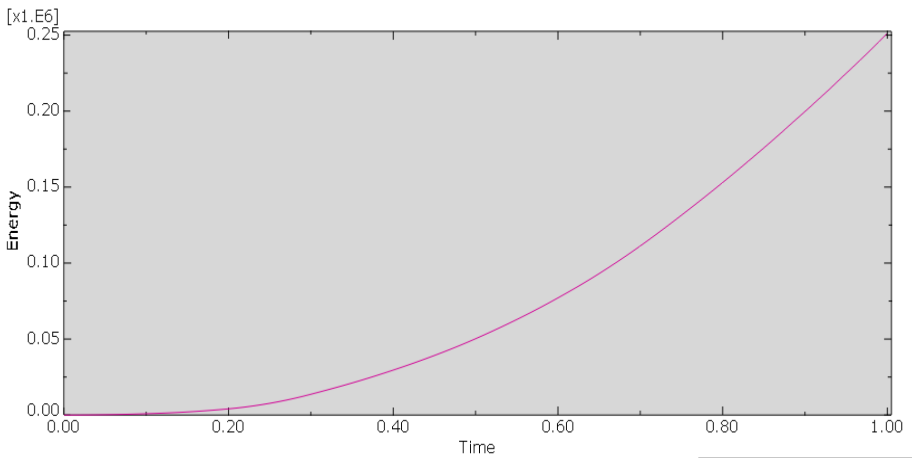


Figure (16) the amount of energy waste in a concrete slab reinforced with checkered carbon fibers

In the following, displacement load diagrams for carbon fiber reinforced concrete slab with rectangular carbon fiber arrangement have been studied. Figure (17) shows the deformation of FRP carbon fibers for the slab-reinforced rectangular fiber mode. Figure (18) shows the deformation and displacement of a reinforced concrete slab with rectangular carbon fiber.
Figure (19) shows the Von Mises tension distribution of concrete slab reinforced with a rectangular carbon fiber reinforced from a front representation. Figure (20) shows the amount of energy waste in a rectangular reinforced concrete slab.

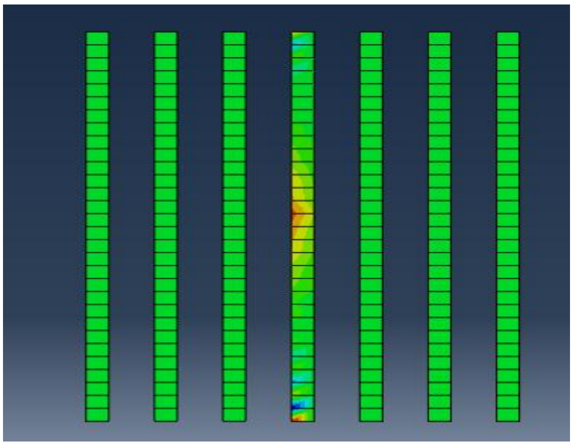


Figure (17) FRP carbon fiber deformation for slab mode reinforced with rectangular fibers

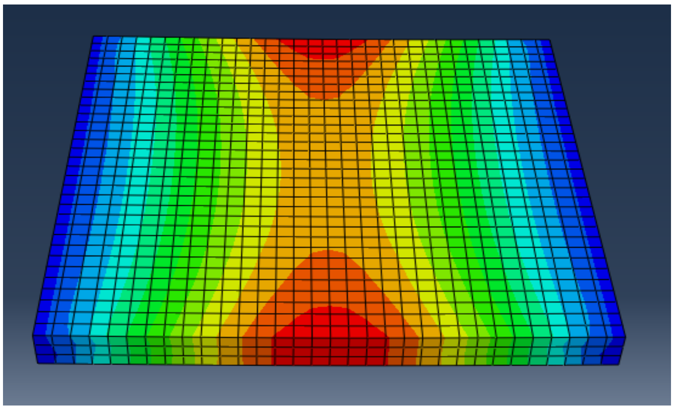


Figure (18) Deformation and displacement of a reinforced concrete slab with a rectangular carbon fiber

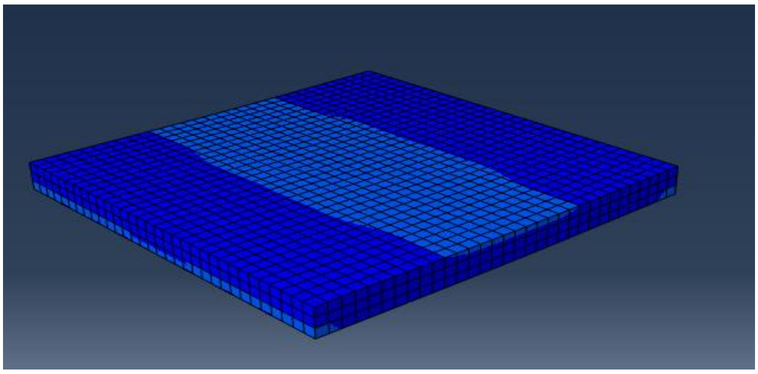


Figure (19) Von Mises tension distribution of concrete slabs reinforced with rectangular carbon fibers from the front representation

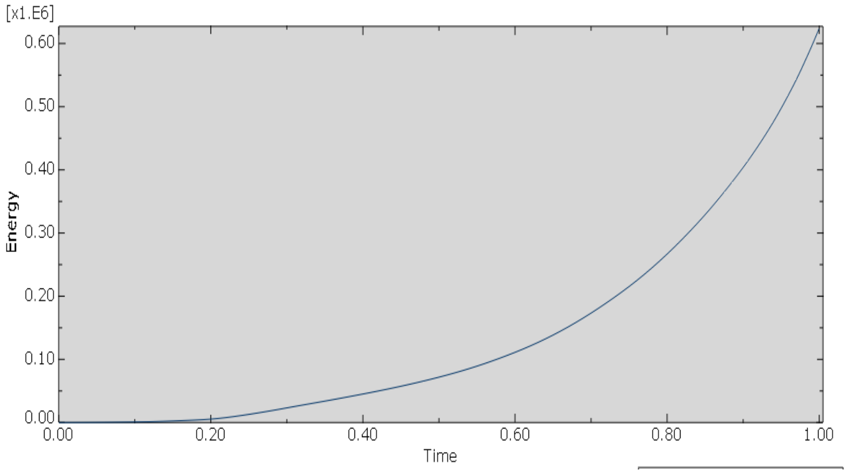


Figure (20) The amount of energy waste in a concrete slab reinforced with rectangular carbon fibers

4.4. Examining fiber-reinforced slab

This section presents the results of the slab reinforced with FRP fibers. In this section, we will first examine the models reinforced with CFRP, GFRP, and AFRP fibers by drawing displacement force diagrams for each sample, and we will then investigate the effect of fiber thickness. 1 mm thick and then 2 mm thick models have been examined. Figure (21) determines the displacement load diagram for a sample reinforced with CFRP fibers. Figure (22) presents the displacement load diagram for a sample reinforced with GFRP fibers. Figure (23) presents the displacement load diagram for a sample reinforced with AFRP fibers.

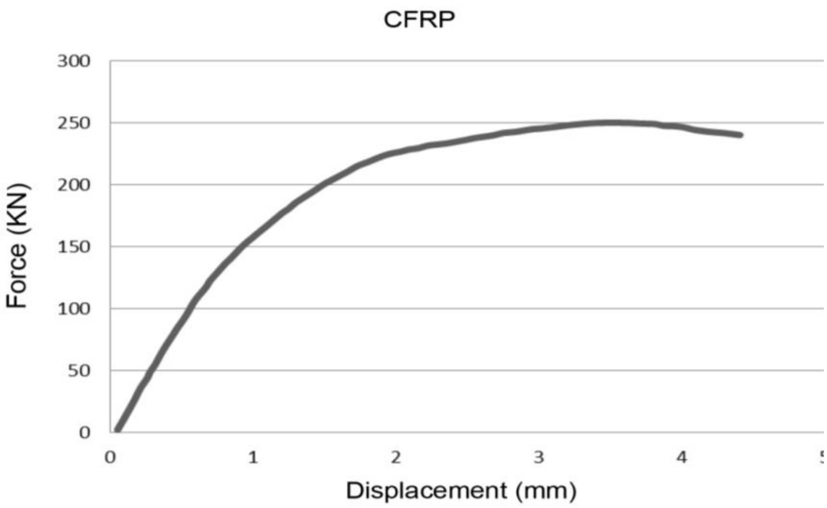


Figure (21) Load diagram of displacement of a sample reinforced with CFRP fibers

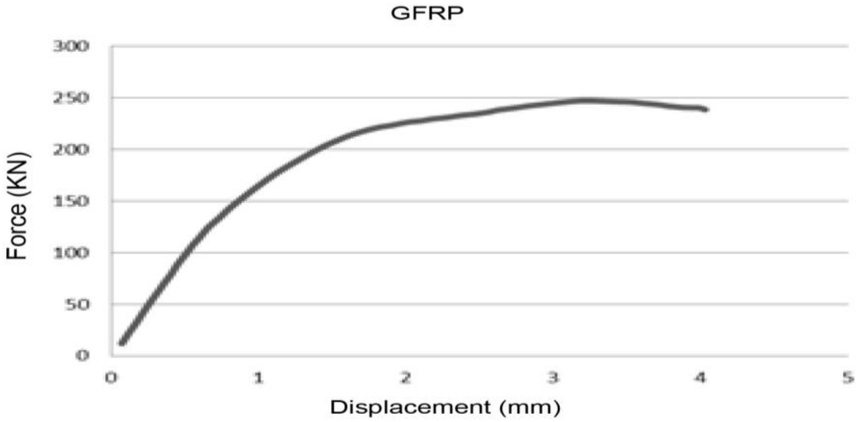


Figure (22) Load diagram of the displacement of a sample reinforced with GFRP fibers

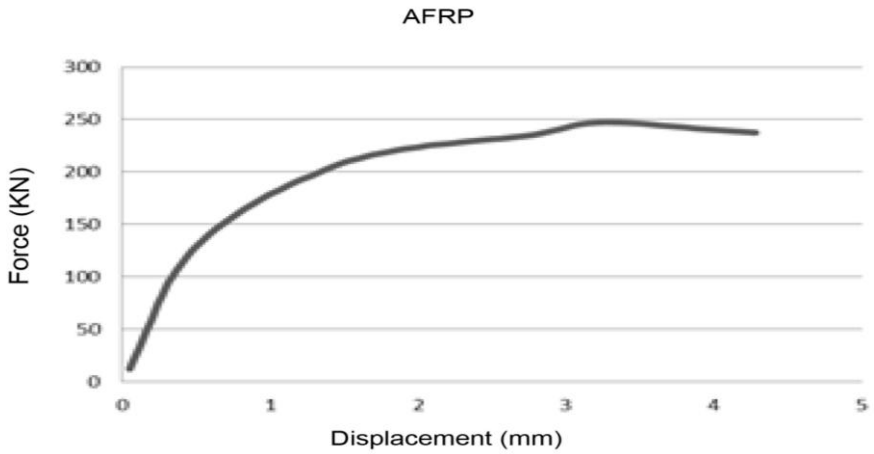


Figure (23) Load diagram of the displacement of a sample reinforced with AFRP fibers

As exhibited in the above figures, reinforced concrete slabs' reinforcement increases the rate of final displacement at the moment of rupture, and the concrete slab bears more displacement. Carbon fiber reinforced concrete slab increases the final displacement by about 3.4% and reinforced with aramid fiber 2.6% and glass fiber reinforced by about 3.7%. It can be concluded that carbon fibers have the greatest influence on this parameter, and aramid and glass fibers are in the next levels. Table (1) shows the distinctive models utilized in the analysis with different fibers. Table (1) shows the specifications of the fibers used in modeling

Table (1) Different models utilized in analysis with different fibers

Model	Reinforcement sheet type	Model Name
1	No reinforcement sheet	Base model
2	Carbon fiber	CFRP
3	Glass fiber	GFRP
4	Aramid fiber	AFRP

5. Discussion and conclusion

This paper examined the influence of improving the behavior of reinforced concrete slabs employing the optimal amount of polymer fibers and the effect of the number of layers. Models were analyzed to examine the analytical results by considering static analysis and nonlinear properties of materials utilizing ABAQUS software. The results explained that FRP fiber reinforcement increases the flexural strength and bearing capacity of one-way and two-way slabs and increases the shear strength. Adding fibers causes to increase energy absorption and corrosion resistance. Fibers reduce ductility due to increasing hardness and brittleness. Adding fibers causes to save the overall cost of the project and reduce its duration. Reinforcement of reinforced concrete slabs increases the amount of final displacement at the moment of rupture, and reinforced slabs bear more displacement. Slabs reinforced with carbon fibers add about 9.3% and slabs reinforced with aramid fibers 6.2 and glass fibers about 3.7% to the final displacement; consequently, carbon fibers have the greatest influence on this parameter, and aramid and glass fibers are in the next levels. The elastic hardness rate of the concrete slab depends on the type of reinforcement so that aramid fibers increase the hardness by 28%, and reinforcing the concrete slab with carbon and glass fibers reduces by 14.7 and 7.5%, which indicates the more ductile behavior of the concrete slab against lateral and gravitational forces. The rate of energy absorption in the concrete slab increases after reinforcement. The energy absorption rate of carbon and aramid fiber reinforced models is increased by approximately the same amount and about 6.6%, and the glass fiber reinforced model is also improved in energy absorption by approximately 1.7%.It is suggested reinforcement using carbon fibers in concrete slabs where increasing the displacement at the moment of rupture is considered. If increasing the system's hardness is regarded, reinforcement with aramid fibers will be the best option. The outcomes determined that the checkered model of FRP fibers performs better than the rectangular model in terms of reducing displacement and reducing tension in the concrete slab.

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