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Assessing the Impact of Using (FRP) Material for Strengthening the Holes in (RC) Beams

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ABSTRACT

To provide convenient access to service ducts, beam and girder web openings are very prevalent in practice. The insertion of a reinforced concrete (RC) beam into the web, however, reduces the stiffness and strength of the beam because of the local cracking around the aperture. The employ of fiber-reinforced polymer (FRP) laminas in general and not a specific type of them for reinforcing the holes was showed in this paper including their dimension and some design parameters change, such as the number and placement of (FRP) sheets near the opening. The experimental work was presented by comprised the testing of ten reinforced concrete beams, four of them were tested without reinforcement, five of which had (FRP) sheets around the opening for reinforcement, and the remaining beam was solid. The (FE) program consists of ten beams were modelled by using Abaqus, one of them was control solid beam and other nine beams were with hollow. The load-deflection relationships were evaluated before failure, and crack patterns were obtained and compared with the experimental results available. The numerical and experimental results agreed well. Reinforced concrete beams are the cornerstone of modern infrastructure, carrying heavy loads and forming the basic structure of buildings and structures. However, these beams may be damaged or deteriorated over time due to multiple factors such as corrosion, overload, moisture, and fire. In addition, the need to make modifications or openings in these beams for maintenance or service installation purposes may negatively affect their load-bearing capacity. To overcome these challenges, modern techniques have emerged to strengthen concrete elements, the most important of which is the technique of strengthening concrete with fiber reinforced polymer (FRP). This technique is highly effective in increasing the load-bearing capacity of concrete beams, improving their performance under different loads, and extending their service life. A brief critique of the limitations of existing studies should be included to highlight the significance of the present work. Inadequate studies on the interaction between FRP and concrete: There are still gaps in our understanding of the interaction between FRP and concrete at the microscopic level, which affects the accuracy of computational models. The research focused on the behavior of FRP-reinforced concrete hollow core beams under different loads, filling a gap in previous research. The research combined computer simulations and laboratory tests to ensure the accuracy of the results and provide a comprehensive picture of the behavior of the beams. The research identified the best methods for applying FRP sheets to improve the load-bearing capacity of beams around openings, providing practical guidance for engineers.

1. INTRODUCTION

A hollow-core concrete beam is a beam with longitudinal hollows created by placing plastic tubes in the tension region. In certain circumstances, the structural engineer is often faced with the challenging task of designing safe and effective utility passageways; putting holes in these beams creates unnecessary stress that, if not tested and mounted properly, can be harmful. As demonstrated by technical and experimental experience, angled and vertical cracks are most commonly formed at the service load point at the opening corners. The beam's capacity to support loads will be greatly reduced by these cracks [1].

Abdalla et al. [1] and Abduljalil [2] strengthened the (RC) beam holes by applying (FRP) laminates. The application of (CFRP) laminates considerably lowers beam deflection, regulates hole cracking, and boosts the ultimate beam strength, according to the shearing arrangement presented in this study.

Chin et al. [3] and Al-Maliki [4] describe how to use (CFRP) laminate reinforcement to analyse the structural behaviour of (RC) beams with large circular and square holes in the flexicurity area. This analysis looks at the final load, load-deflection behaviour, crack patterns, and mode of failure. The study's outcomes demonstrate that the large flexure opening increases fracture and deflection while decreasing the strength and inflexibility of the beam. Using (CFRP) laminates in the intended strengthening configuration can also greatly lessen excessive cracking and deflection while raising the beam's ultimate capacity and stiffness.

El-Maaddawy and El-Ariss [5] and AL-Miliki [6] studied the test results for web-holed reinforced concrete (RC) beams demonstrated the advantages of using (CFRP) composite sheets with increased shear capacity. The depth and breadth of the opening were tested, as well as the (CFRP) sheets' shear strength. The test findings demonstrated that adding web openings significantly decreased the stiffness and capacity of the beam shear. The beam stiffness and shear capacity were significantly increased by reinforcing the aperture's exterior with (CFRP) sheets also increasing the width or depth of the opening lessened the enhanced shear capacity resulting from the (CFRP).

Diggikar et al.'s study [7] shows the behaviours of rectangular holes in (RC) beams reinforced with glass fibre reinforced polymer (GFRP) sheets and separate (CFRP) using various strengthening methods. Of all these methods, it was discovered that the strengthening with (CFRP) inside and around the opening improved the beam's ultimate load carrying capacity the most.

Chin et al. [8] reviews research done over the previous 40 years to examine how (RC) beams with various kinds of openings behave. It is imperative that more research be done on the use of (FRP) sheets to reinforce holes in (RC) beams.

Madkour [9] tries to use the rectangular opening of the web to explain the non-linear behaviour of improved (RC) beams using (CFRP). A state of the numerical implementation of damage-nonlinear elastic theory was introduced in order to study the non-linear behaviour. The numerical results have been presented and verified in comparison with the experimental results that are currently available in the literature. Additionally, each strengthening scheme's corresponding modes of failure have been introduced.

Osman et al. [10] presents an aramid fibre reinforcement polymers (AFRP) sheet repair technique that improves the opening functionality of pre-cracked (RC) beams while managing all failure modes and stress distribution through-beam chords. The findings demonstrate that, at failure load, the orientation of the (FRP) and the degree of pre-existing damage both have a significant influence on the efficiency and enhancement of the failure mode. The enhanced specimens both demonstrated higher capacities as the capacity increased in range and the crack width decreased in comparison to the control beam.

Pimanmas [11] talks about using (FRP) rods to strengthen the opening in (RC) beams. We look into two different patterns of (FRP) rod strengthening: one where the rods are positioned around the opening, and the other where the rods are positioned diagonally along the whole depth of the beam. It is discovered that the opening cannot be completely sealed with (FRP) rods alone. A nonlinear finite element analysis based on the smeared crack approach is conducted for numerical verification and to explore the effects of the length, position, and inclination of (FRP) rods. Two strut mechanisms connected to (FRP) rod are depicted in the plot of analytical principal compressive stress. More effectiveness is found with inclined rods than with vertical ones.

Naqe and Al-zuhairi [12] presented the study of the beam response of simply supported rectangle beams made of reinforced concrete with square web openings. The study included several web openings and their use for strengthening the member at the openings (internal deformation steel bar is used when the beam is planned before casting, and (CFRP) fabric is used when the opening is already present in the beam). According to the test results, the opening Because there are openings in the shear zone, strengthening the beams may be necessary to make up for the reduction in beam load capacity. The chosen strengthening strategy determines how the beam capacity is compensated. The reduction in shear crack loads of the (CFRP) specimens that were strengthened externally ranged from 15.38 to 38.46 percent of their failure loads, whereas the internally reinforced strengthened specimens had shear crack loads that ranged from 15.38 to 30.76 percent.

Abdulkareem and Izzat [13] examine how various sized and shaped openings affect the behaviour of non-prism-reinforced concrete beams following fire exposure. Provide a unified computational method to assess beam cracks and deflection. Additionally, contrast the outcomes of the experiment and analysis. The numerical results demonstrated good agreement with the experimental findings in terms of displacement and ultimate load failure. The size and form of the aperture had a major impact on the behaviour of the beams, according to the study.

Naqi and Al-zuhairi [14] presents the non-linear finite element method to study the behavior of four reinforced rectangular concrete (MD) beams with web circular openings tested under two-point load. Much more practically, the numerical finite elements methods have been applied to obtain approximations of solutions for increasingly complicated problems. To investigate the behaviour of (MD) beams, ABAQUS / CAE is utilised. This paper also examines the impact of the circular apertures' size and shape on MD beams. The external strengthening method around the (MD) beam opening that is employed in this paper is (CFRP) strengthening. Regarding displacement and ultimate load failure, the numerical and experimental results were compared. There was a strong correlation between the experimental and (FE) results.

The purpose of this study is to investigate the effects of using (FRP) to strengthen the openings of (RC) beams by simulating the (FE) results with experimental work using numerical analysis.

2. MATERIAL AND METHODOLOGY

2.1 Methodology

Previous work data presented by Abdalla et al. [1] used as experimental data. 10 (RC) beams were tested; 5 of the specimens had a shear zone opening that was reinforced with (FRP); the other 4 specimens had unreinforced holes; while the control specimen had no holes at all and was solid. The 10 (RC) beams which had a dimensions of 100 × 250 mm and a 2000 mm clear span , were subjected to two concentrated static loads. Table 1 presents the parameters of the tested beams; the symbols SB, RO, and UO denote solid beam, FRP-reinforced beam, and unreinforced beam, respectively. The third character corresponds to the beam's serial number in the experimental programme. Testing was conducted under load control, increasing the load by 5 kN gradually until the beam failed. The variables adopted in our research are the shape of the opening, its size, and the arrangement of the FRB sheets around the opening within the reinforced concrete beams. Figure 1 depicts the test's schematic view.

Table 1. Details of the tested beams

Specimen	Dimensions of Opening	
	H (mm)	W (mm)
SB1		
RO2	100	100
RO3	200	100
RO4	300	100
RO5	300	150
RO6	300	150
UO7	100	100
UO8	200	100
UO9	300	100
UO10	300	150

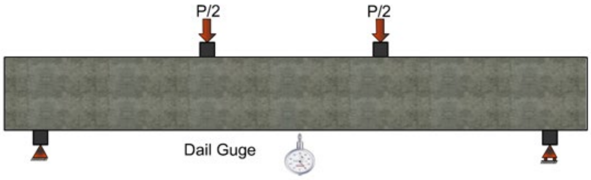


Figure 1. The test configuration's schematic view

2.2 Materials

2.2.1 Steel reinforcing bar

For the steel bar with an elastic, entirely plastic material, equivalent stress and compression behavior was used [15]. The bar of steel was viewed as a portion of the uniaxial content of an element in the entire steel bar, the rebars can be defined as one-dimensional strain components that can be single or embedded in concrete, this action is the same as that of the elastic-plastic material presented by Hu and Liang [16], were treated separately as concrete cracking operation by changing the load across the boundary by adding some tension stiffening to the concrete fracturing model concrete cracks in the rebars can be identified. Hu et al. [17] thought that in the reinforced concrete beam, the steel bars used we have the yielding stress:

$$\sigma_y=400 \text{ MPa}$$

Although it was believed that its elastic modulus was:

$$Es=200 \text{ GPa}$$

The reinforced concrete was allocated to the 0.3 Touch Poisson ratio between steel and concrete reinforcement, and complete bond contact was assumed to be included. The choice of an embedded element to link the reinforcement unit with the concrete component was used to choose an embedded component.

The embedded component used was steel reinforcement, and concrete was designated as the host component.

2.2.2 Concrete

Concrete fc' is uniaxial compressive strength and they were selected as:

$$fc'=50 \text{ MPa}$$

The concrete strain ε_0 corresponding to fc' would be between 0.002 and 0.003 respectively, the value of ε_0=0.003 suggested and employed is in analyzing, the Poisson concrete ratio υ_C is taken as:

$$\upsilon_C=0.2$$

In this paper, the tensile strength of concrete ft was calculated from:

$$ft=0.61\sqrt{(fc')}$$

The modulus of elasticity E_c and the intensity of compression of the concrete depends on each other and it is possible to consider E_c to the importance is as follows:

$$E_c=4700\sqrt{(fc')}$$

Under multi-axial, the concrete failure intensity differs from combinations and uniaxial-status combinations.

The load direction, the maximum power, does not seem to be successful multiaxial loading below concrete. At ABAQUS, using a compression surface form of the Mohr-Coulomb type along with crack detection surface. Using the theory of elastic-plastic, in which the key stress elements of the elastic-plastic theory were modeled, the inability of the concrete surface was modeled, concrete is primarily compressive and the concrete has been designed with a law of isotropic hardening and a corresponding flow as illustrated in Figure 2.

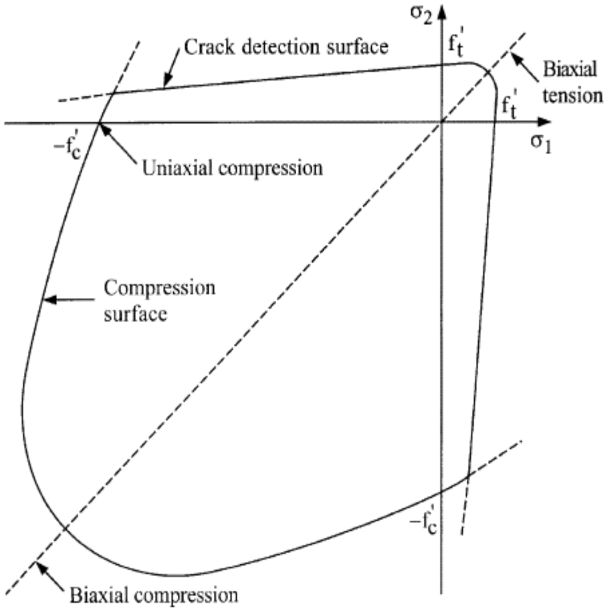


Figure 2. Concrete surface failure during plane tension [18]

The position of the crack is stored as the crack before the crack is formed. Stress takes place when there is plastic deformation, a certain parameter is necessary to direct the surface expansion of the yield. Efficient strain and efficient in such a way that can all be compared to the equivalent uniaxial stress-strain curve, the findings were obtained by following distinct directions for loading. The approach for using the effective tension solution is a suitable one.

Desayi and Krishnan [19] suggested a stress-strain relationship that can be used as the concrete uniaxial stress-strain curve, as shown in Eq. (1):

$$\sigma_c=\frac{E_c\varepsilon_c}{1+(R+R_E-2)\left(\frac{\varepsilon_c}{\varepsilon_o}\right)-(2R-1)\left(\frac{\varepsilon_c}{\varepsilon_o}\right)^2+R\left(\frac{\varepsilon_c}{\varepsilon_o}\right)^3} \qquad (1)$$

where, $R = \frac{R_E(R_\sigma - 1)}{(R_\sigma - 1)^2} - \frac{1}{R_\varepsilon}$, $R_E = \frac{E_c}{E_o}$, $E_o = \frac{f_c'}{\varepsilon_o}$, R_E=4 and R_σ=4.

It's possible to use.

The uniaxial stress-strain curve can be estimated and then using the above comparison and finding many points for concrete, as shown in Figure 3, multiple linear segments. Concrete while there is cracking, the motion of the crack is identified and used to identify an affected stability test. After breaking, concrete in the usual direction of the break which is called strain stress stiffening, still has some tensile strength.

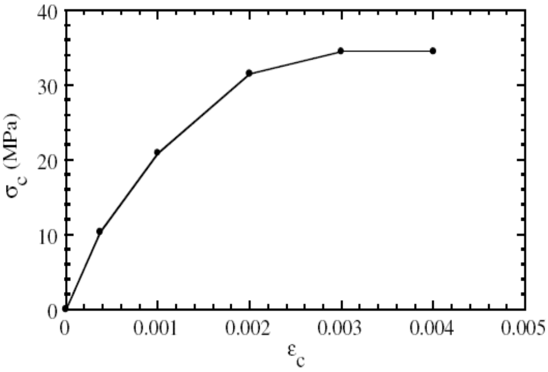


Figure 3. Equivalent uniaxial stress-strain curve of concrete

The linear mechanism of stiffening tension stress has been modeled in this paper as shown in Figure 4. To describe the concrete, the damaged plasticity model (CDP) was used in the inelastic material conduct continuum. The model developed by Lee and Han [20] was tensile and compressive cracking. The principal failure mechanisms of the concrete in the crushing are the weakened concrete plasticity model. Based on the feedback of inelastic strain versus stress, the software calculates the compression curve of the concrete stress-strain, the strain stress of the concrete inside an axial structure is assumed to be linear before the initial formation is formed, cracking is known as stress from peak stress failure, interms of stress the stress in the program after failure is known as cracking strain, this activity facilitates the effect of concrete and reinforcement rebar interaction by adding stress stiffening to the curve's softening side.

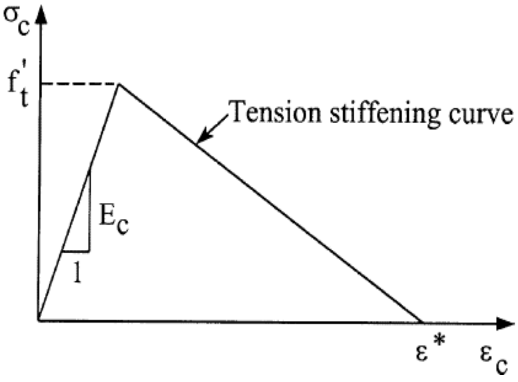


Figure 4. The model for tensile stiffening

2.3 Modelling of FRP strips

In general, FRP is known as a transverse isotropic substance this is a subset of material that is orthotropic. The behavior of Lamina in ABAQUS describes isotropic material transversely, requiring five Constitutive constants to describe the relationship of stress-strain, unlike nine orthotropic substance constants. (FRP) (S4R) is modeled using the 3-dimensional shell part.

2.4 The mesh for finite elements

To purchase specific outcomes from the (FE) model, all of the same mesh was intentionally allocated to elements in the model size to ensure that the same size is shared between two different materials. The mesh style chosen in the model is standardized. The 3D solid mesh feature for concrete is called (C3D8R) [21] and the 2D truss for the rebar that is called (T3D2) as illustrated in Figure 5. Comparing the results obtained from the theoretical application using the FEA method with realistic experimental data is to ensure that the models describe the real behavior of the approved samples.

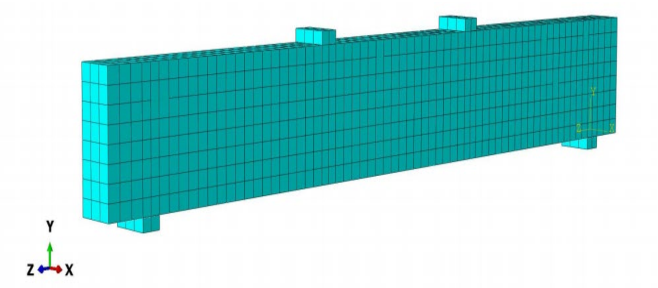
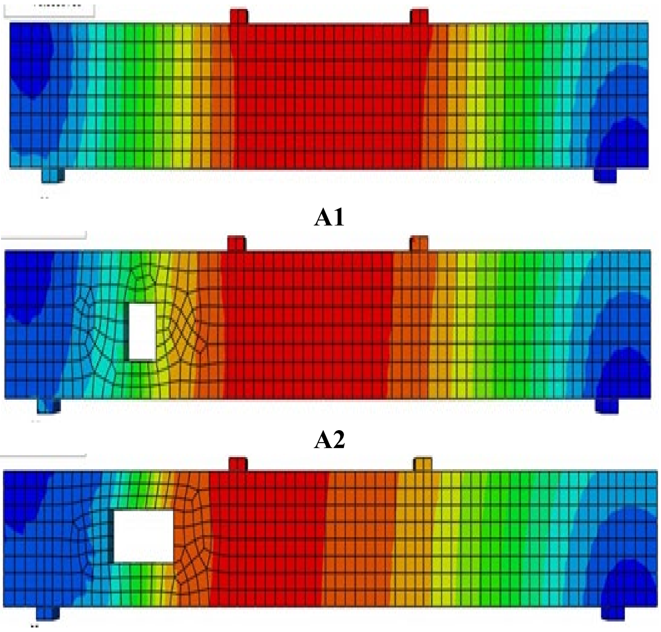


Figure 5. Concrete meshed model in ABAQUS

2.5 Abaqus models

The experimental research was performed in Abaqus to simulate the model, we modeled the beams as volumes. The model has a cross-sectional area of 100×250 mm and measures 2000 mm in length., there are three classes, the first group which comprises five samples of the same dimensions and the same rebar without openings for the first model and the other versions contain different dimensions openings respectively {(A2(100×100) mm, A3(100×200) mm, A4(100×300) mm, A5(150×300) mm)} and non-reinforcing by (FRP) as shown in Figure 6.



A1

A2

A3

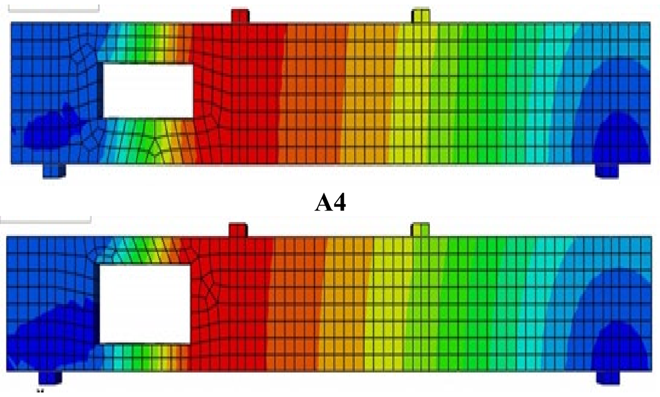


Figure 6. Group 1: Abaqus model for non reinforcing by (FRP)

Five models form part of the second category comprising five samples of the same size and the same bar, all models with apertures {(B2(100×100) mm, B3(100×200) mm, B4(100×300) mm, B5(150×300) mm, BB5(150×300) mm)} and (FRP) stiffening as shown in Figure 7.

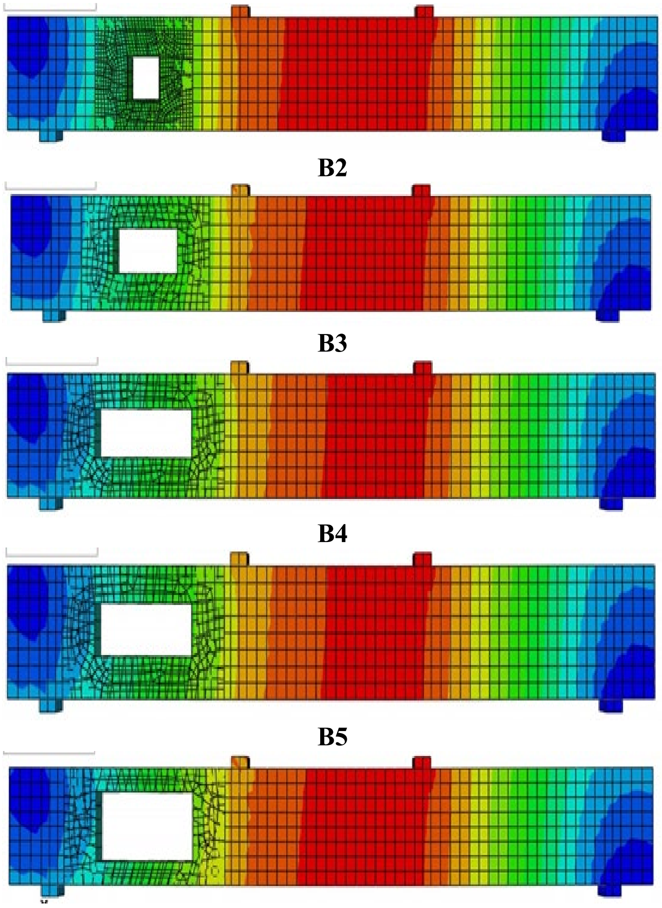


Figure 7. Group 2: Abaqus model for reinforcing apertures by (FRP)

The third group consists of four models tow of which are strengthening by (FRP) and the others without (FRP) of the same size as the previous models but the opening of the square and rectangular shapes has been transformed into circular holes with the same area (C1, C2, D1, D2) as shown in Figure 8.

A comprehensive numerical simulation was performed using Abaqus software to study the behavior of reinforced concrete beams with openings and the effect of fiber reinforced polymer (FRP) reinforcement on their load-bearing capacity. The beams were modeled as three-dimensional objects with a rectangular cross-section of 100 × 250 mm and a total length of 2000 mm.

The beams were divided into three main categories:

Category 1: This category included five models without FRP reinforcement, where the opening size differed in each model. The first model was free of openings, while the second model contained a square opening of 100 × 100 mm, and so on until the fifth model, which had the largest opening of 150 × 300 mm.

Category 2: This category also included five models, but this time all of them had openings of different sizes and were reinforced with FRP. The same opening sizes were used in the first category, in addition to an additional model (BB5) that contained the same opening as model B5 but with a different arrangement of FRP sheets.

Category 3: This category included four specimens, two of which were reinforced with FRP and the other two were without reinforcement. The shape of the openings in this category was changed from square and rectangular to circular while maintaining the same total area of the opening. This research aims to evaluate the effect of opening size and shape, in addition to FRP reinforcement, on the behavior of reinforced concrete beams under loads. The results are expected to provide valuable information for engineers and designers to evaluate the performance of FRP reinforced beams and make appropriate decisions in design and construction. The use of advanced microscopic and spectroscopic techniques represents a quantum leap in our understanding of the complex interactions that occur between FRP and concrete. This knowledge will contribute significantly to the development of more durable and safe materials and structures.

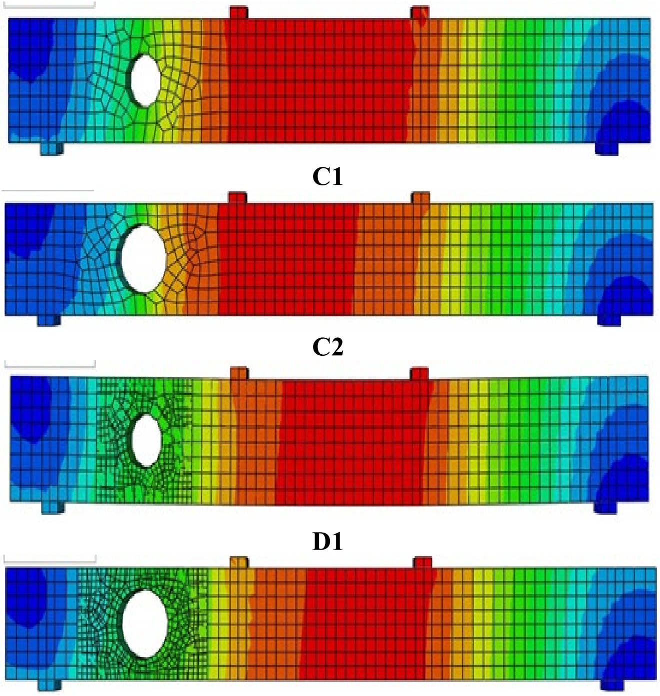


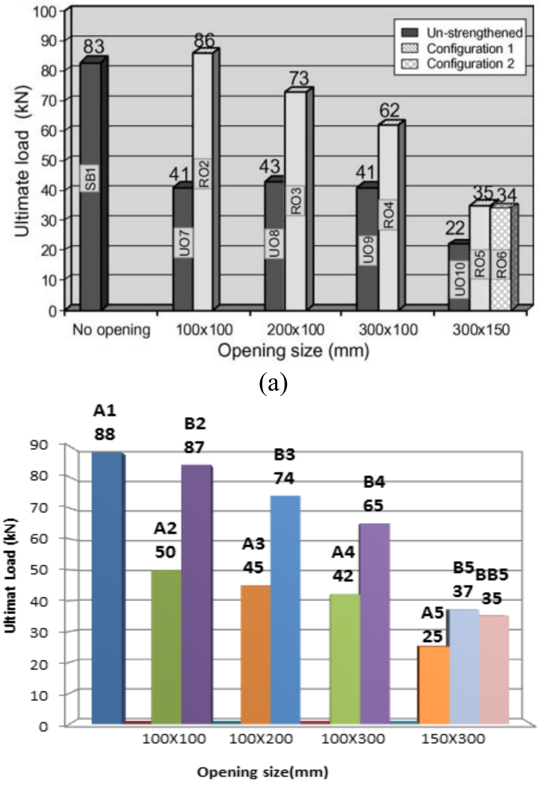
Figure 8. Group 3: Abaqus model for circular apertures reinforcing and nonreinforcing by (FRP)

3. RESULTS AND DISCUSSION

For every loading increment until failure, strains, deflections, the pattern of cracks, and their width were noted. A few parameters were estimated to have an impact on the tested beams' structural performance. These parameters cover the width and height of the opening in addition to the amount and arrangement of the (FRP) laminas. Comparison is made between the performance of the control solid beam and beams with and without strengthened openings. Table 2 compares the beams with and without (FRP), displaying percentages of the increase in the ultimate load of numerical and experimental beams. Figure 9 displays all of the tested beams' ultimate capacities by comparing the outcomes. It is evident that the ultimate load capacity is greatly increased when the concrete surface is laminated with (FRP). Moreover, we found that if the concrete surface was locally wrapped around a small opening, the capacity loss caused by the opening's existence could be fully restored. This suggests that the beam's ultimate load capacity was unaffected by the reinforcement of its top and bottom surfaces. In addition to the flexural cracks that extended across the beam's midspan, all beams with non-strengthened apertures developed severe cracks in the opening region. These beams typically failed as a result of shearing in the area of opening. The tested beams' load-deflection behaviour with the openings non-strengthened is shown in Figure 10. The same figure displays the control solid beam's deflection response. Based on the findings, the ultimate capacity of the beam is considerably reduced when the shear zone has an opening. The control solid beam's maximum load support was greater than the maximum load supported by the beams with 100 mm height openings. The maximum load was reduced to that of the solid beam when the opening height was increased to 150 mm. Moreover, Figure 10 demonstrates that the beam's deflection is unaffected by raising the opening height while maintaining the opening width. By comparing the outcomes, it is evident that the primary factor influencing how load-deflection behaves in beams with unstrengthen openings is the opening height.

Table 2. Comparison of ultimate loads

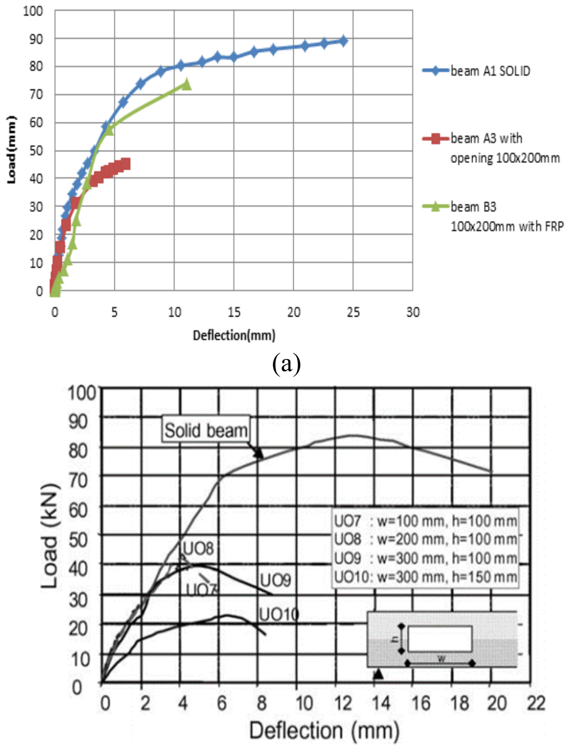
Beam From Exp. Work	Beam From Abaqus	Ultimate Loads in kN		Percentage Increase in Ultimate Load	
		Exp. Work	Abaqus	Exp. Work	Abaqus
SB1	A1	83	88	-	-
UO7	A2	41	50	50.6	43.18
UO8	A3	43	45	48.19	48.86
UO9	A4	41	42	50.6	52.27
UO10	A5	22	25	73.49	71.79
RO2	B2	86	87	3.48	1.13
RO3	B3	73	74	12.04	15.90
RO4	B4	62	65	25.30	26.13
RO5	B5	35	37	55.42	57.95
RO6	BB5	34	35	57.83	60.22



(a)

(b)

Figure 9. Ultimate load of the tested beams: (a) beam from experimental work, (b) beams from Abaqus



(a)

(b)

Figure 10. The tested beams' load-deflection behaviour with non-strengthened openings: (a) formed by Abaqus, (b) experimental beams

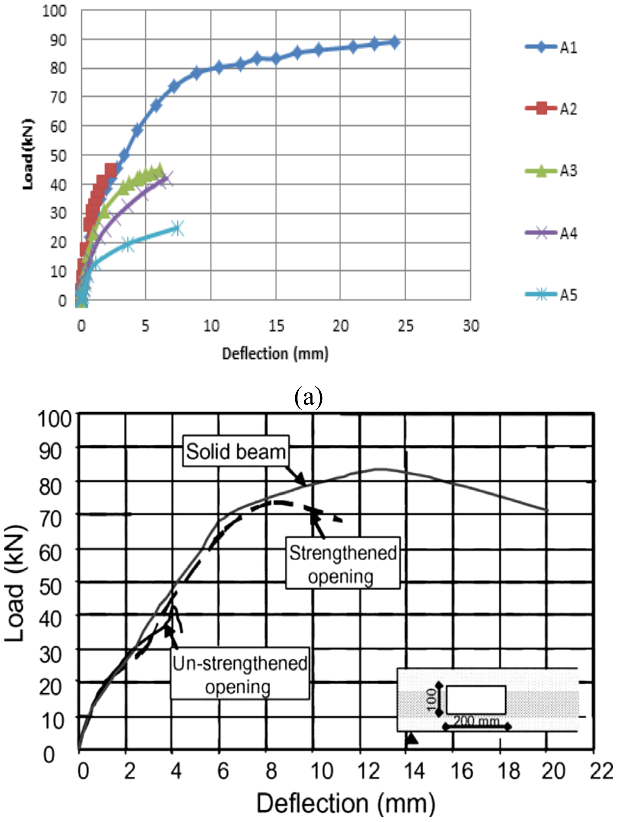
Computer simulation plays a vital role in evaluating the effect of using FRP to strengthen holes in reinforced concrete beams. It allows:

Studying the behavior of the beam: Simulating an FRP-coated beam before and after repair can provide detailed information about the distribution of stresses and strains within the beam, helping to understand the mechanisms that contribute to its increased load-bearing capacity.

Identifying critical areas: Simulation can identify areas that are subject to the highest stress levels, helping to optimize the design of FRP reinforcement and determine the best locations for its application.

Evaluating the efficiency of different strengthening techniques: The performance of different strengthening techniques using FRP can be compared by running multiple simulations for each technique, helping to select the best technique for a given situation.

Reducing costs: Simulation allows for conducting multiple virtual experiments at a much lower cost than laboratory or field experiments.



(a)

(b)

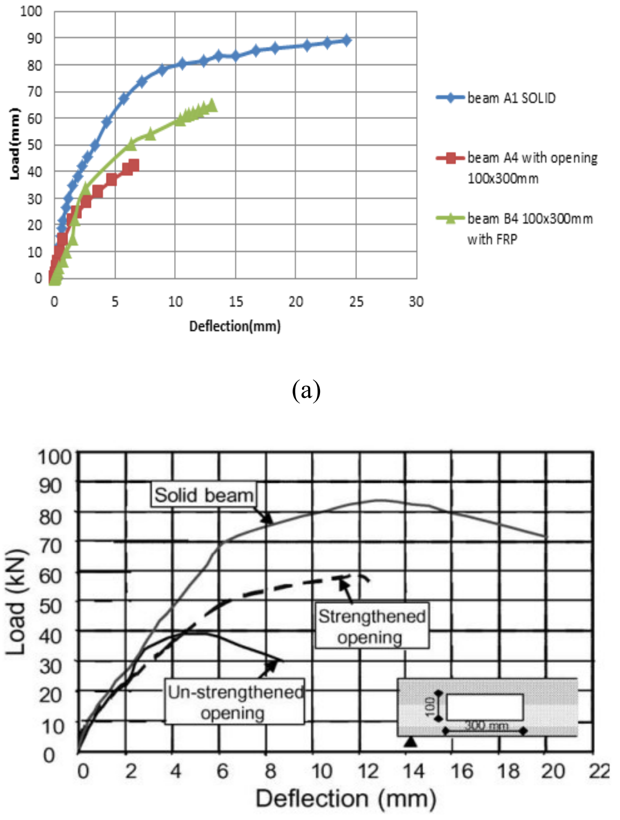
Figure 11. The relation between load and deflection of beams with opening dimensions of 200 × 100 mm: (a) formed by Abaqus, (b) beams from experimental work

Figure 11 displays the load-deflection results for beams with identical 200×100 mm opening dimensions. Figure 12 shows the load-deflection response of the beams with an opening size of 300×100 mm. The figures demonstrate that the beam's ultimate capacity increased with opening, leading to a decrease in the maximum deflection. From the above results we have a good simulation between numerical and experimental work. • Effect of FRP volume ratio:

- Increase in load-bearing capacity: The results showed that increasing the FRP volume ratio leads to a significant increase in the load-bearing capacity of the beams, especially in the areas surrounding the openings. This is due to the ability of the fibers to improve the tensile strength of the concrete and enhance the adhesion between the fibers and the concrete.
- Improved deflection behavior: An improvement in the deflection behavior of the FRP-reinforced beams was observed, as the maximum deflections decreased compared to the non-reinforced beams.
- Effect of opening shape: The results showed that the opening shape has an effect on the performance of the beam, as the beams with circular openings showed slightly better performance than the beams with square and rectangular openings.

During the period in which we noticed that the ultimate load decreases by increasing the size openings and increases with the use of (FRP) around the openings. The results were also converging between the experimental and numerical beams and through achieving this we made models to change the shape of the openings from square and rectangular to circular shapes with the same area and the results were as in Table 3 and Figure 13 shows the comparison between beams with rectangular and square holes and circular holes. And the results proved that the circular-shaped openings are stronger effected. The changes we observed here in the data are not just a coincidence, but are real and important changes. Through comparisons with previous studies.

By introducing new variables into the research, more accurate and useful results were obtained for using sheets (FRB) within reinforced concrete thresholds, and compared with previous know-how, the results obtained reinforced what researchers found before us.



(a)

(b)

Figure 12. The relation between load and deflection of beams with opening dimensions of 300 × 100 mm: (a) beams form Abaqus (b) beams from experimental work

Table 3. Comparison of ultimate load for beams containing different shaped holes

Beam From Abaqus		Ultimate Loads in kN		Percentage Increase in Ultimate Load	
Non Circular Holes	Circular Holes	Non Circular Holes	Circular Holes	Non Circular Holes	Circular Holes
A1	-	89	-	-	-
A2	C1	50	66	43.82	25.84
A3	C2	45	57	49.43	35.95
B2	D1	84	85	5.61	4.49
B3	D2	74	76	16.85	14.6

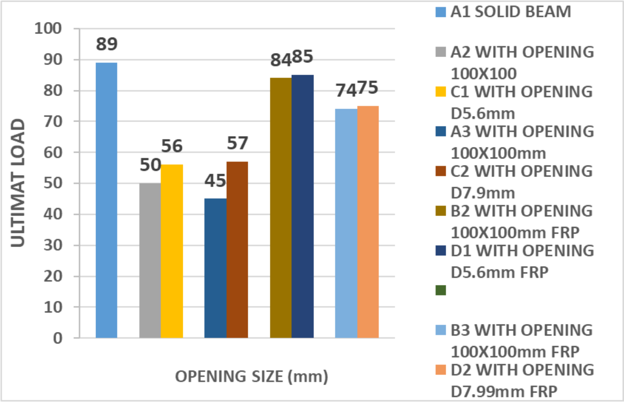


Figure 13. Comparison of ultimate loads

4. EVALUATING THE PROS AND CONS OF USING REINFORCED POLYMER FIBRES TO ENHANCE THE DURABILITY OF CONCRETE

Evaluating the pros and cons Pros:

- Increased strength of concrete elements: FRP contributes to increasing the ability of concrete elements to bear loads, especially in weak areas such as holes and cracks.
- Ease of application: FRP is easy to install and operate, which reduces the time and effort required to repair concrete elements.
- Light weight: FRP is characterized by its light weight, which facilitates the process of transportation and installation.
- Corrosion resistance: FRP has a high resistance to corrosion and various environmental factors.
- Design flexibility: FRP can be designed and shaped to fit different shapes and sizes.

Cons and concerns:

- Cost: The cost of FRP may be higher than traditional materials used in repair, which limits its use in some projects.
- Bonding with concrete: It is necessary to ensure that there is a strong bond between FRP and concrete to ensure effective strengthening, and this requires the use of appropriate adhesives and good preparation of the concrete surface.
- Impact on concrete durability: The use of FRP may affect the durability of concrete in the long term, especially under changes in temperature and humidity.
- Technical expertise: FRP implementation requires high technical expertise to ensure quality work, which may be a challenge in some areas.
- Expansion of the application: Expansion of the FRP application may face some difficulties in obtaining the necessary approvals from official authorities, in addition to challenges in training workers.

5. CONCLUSIONS

The behaviour and strength of the shear openings in the (RC) beams were investigated numerically. Ten tested beams' results were used to assess how well (FRP) sheets work to manage local cracks around openings. The following conclusions may be drawn based on the results of this study.

1. A (RC) beam's ultimate capacity is greatly reduced when there is an unstrengthened opening in the shear zone.
2. When (FRP) sheets are applied in accordance with the methodology described in this study, beam deflection is significantly reduced, cracks around openings are managed, and the beam's ultimate capacity is increased.
3. For comparatively small openings, the beam's full capacity may be restored by using (FRP) to reinforce the region surrounding the holes.
4. The study presents a numerical approach focused on models of shear reinforcement. This technique can be used to calculate a reinforced concrete beam's shear capacity if its openings are strengthened with (FRP).
5. When compared the numerical and experimental results there was a strong correlation between the experimental and (FE) results.
6. The life of the FRB depends on several interrelated factors, including (type of FRB, installation method, environmental conditions, type of loads used, and quality of design and implementation). Studies indicate that its life span reaches several decades if it is designed and implemented correctly and in an appropriate environment.
7. Potential practical applications:
   - Strengthening reinforced concrete elements: FRP can be used to reinforce columns, beams, and foundations of concrete buildings, increasing their ability to bear loads and increasing their lifespan.
   - Restoration of damaged concrete structures: FRP can be used to repair cracks and damaged reinforcement in concrete structures, extending their life and reducing maintenance costs.
   - Creating new structures: FRP can be used to create new structures, such as bridges, tanks, and columns, as it provides less weight and greater strength compared to traditional materials.
   - Protecting structures from corrosion: FRP can be used to protect concrete structures from corrosion caused by environmental factors, such as water and salts.
8. Economic challenges and impacts:
   - Material and installation cost: The initial material and installation cost of FRP may be higher than traditional materials, but in the long run, it can offset this cost by saving maintenance costs and increasing the life of the structure.
   - Installation Skills: FRP installation requires special skills and experience, necessitating workforce training.
   - Codes and Standards: National and regional codes and standards must be developed to regulate the use of FRP in construction, and specify quality and performance requirements.
   - Environmental Impact: The full environmental impact of the FRP life cycle, from production to disposal, must be assessed to ensure its sustainability.

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