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Non-Linear Behavior of Concrete Deep Beams Subjected to Uniformly Distributed Load and Strengthen by CFRP

A Research

Submitted to the College of the Engineering \ University of Babylon in Partial Fulfilment of the Requirements for the degree higher diploma in Engineering/ Civil Engineering \Structural

By

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بسم الله الرحمن الرحيم

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ABSTRACT

Twenty-four deep concrete beams were modelled using ABAQUS Finite Element Analysis software, divided into two parts according to the type of concrete used (NSC & HSC). the parts were divided into three groups according to the presence, absence and shape of the opening which is in the middle of the deep beams in the bending region. Each group was divided into four models of deep concrete beams the first without strengthened CFRP, the second is CFRP strengthened with strips 100 mm wide U-shaped in the bending region with the addition of a single layer of CFRP on the bottom face of the deep concrete beam, the third is strengthened with single layer only of CFRP on the lower face, the fourth deep concrete beam is strengthened with double layers of CFRP on the bottom face.

All beams are same in section dimensions, the length of the deep concrete beams, the shear reinforcement.

The method for determining the non-linear behaviour in the ABAQUS program it is the method for the concrete damage plasticity (CDP). Where the deep concrete beams were tested according to the initial cracking load, the failure load, and the load-deflection curve.

The models that don't have openings showed a uniform cracking pattern by starting from the bottom of the bending area and continuing vertically towards the neutral axis. As for the cracks in the shear region start appearing near the supports and continue diagonally to the load application area before models fail after reach main reinforcement to ultimate stress.

As for models that contain openings (square or circular), the cracking pattern was to start cracks from the bottom of the opening and then from the up chord of the opening before appearing near the supports and continuing to the area of applying load, and the failure pattern was the arrival of the main reinforcement to the ultimate stress.

As for the use of CFRP strengthened, the main factor that increases the failure load is strengthening the bottom face of the models, where the failure load increases with the increase in the number of layers, And the rate of increase in the failure load ranges between (3% to 16%) depending on the method of strengthening and the number of layers and for the presence, absence and shape of openings.

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Chapter 1

INTRODUCTION

1.1. Background

Sometimes a structural designer may have to transfer a load of a column to a beam, such as transport dead loads, including the slab's weight, beams, columns, and finishings, as well as live loads, including the weight of people and furniture, Or the beams above doors and windows in the structural system that depends on the concrete walls. And this problem needs to use deep concrete beams to accommodate the loads and transfer them safely. Where because of the great depth for the beams, it is necessary to make openings for electrical installations, sewer pipes, water pipes, and cooling ducts to pass.

Providing openings in deep concrete beams causes stress concentration that appears as cracks and deformations according to the size and shape of openings, so the behaviour of the beam will differ and reduce their stiffness and endurance. So the designer must take the necessary precautions. As using CFRP treatment in several situations, such as when the building function changes, loads increase, or there is a need to add extensions to electrical, water and sewage pipes or cooling ducts. Use CFRP with concrete elements to repair and rehabilitation because of its good mechanical properties, high strength-to-weight ratio, low weight, corrosion resistance, cheap and easy maintenance, and fast execution compared to traditional materials such as steel sheets.

Many experimental studies have reported that externally bonded FRP laminates could significantly increase members' stiffness and load-carrying capacity, enhance flexural and shear abilities, provide confinement and ductility to structural compression members, and control cracks (Ferrier et al., 2003; Madkour, 2009).

Although FRP materials have plentiful applications in repair and retrofitting activities, the literature reviews show that very few studies are focused on FRP applications to strengthen the openings in concrete beams with uniformly distributed load.

(Mansur et al. 1999) investigated the employ of FRP plates to strengthen concrete T-beams with small circular openings.

(Abdalla et al. 2003) and (Allam 2005) studied the shear strengthening of concrete beams with rectangular openings using FRP sheets.

(El Maaddawy & Sherif, 2009) investigated FRP sheets for shear strengthening of deep concrete beams with square openings.

At the same time, (Pimanmas 2010) developed externally installed FRP bars to reinforce concrete girders with round and square openings.

Most of the available research investigating the impact of openings is experimentally based. And always, the experimental studies are very tedious and time-consuming. The literature review identifies that only two researchers (Madkour, 2009 & Pimanmas, 2010) used FE-based numerical analysis to estimate the strength of the beams incorporating the effects of openings. If such a methodology does validate through experimental studies, the results of the openings could be accurately determined and Verification.

Therefore, more research is needed to explore the effects of openings using simulation software such as ABAQUS or ANSYS to investigate the impact of openings for different sizes, shapes, locations, and treatment methods.

1.2. The problem

Since the sixties of the last century, the authority of many research on the problem of conflicting service pipes (water, sewage, electricity, cooling) with concrete beam, and the need to increase the story high for the passage of service pipes was one of the solutions. Still, it was not economical in cost and duration.

Where a lot of research dealt the subject of the openings, from where shape, size, positions, method of arming, and impact on bending, shear, and torsion, and also the beam stiffness, but many aspects of that problem need solutions, including

1. Problem of the effect of the openings (square or circular) in the bending areas for the deep concrete beams.
2. Problem of the effect of the size of the openings on the behaviour of deep concrete beams in the bending area in terms of the cracks, ultimate load, and deflection.
3. Problem of using simulations to study deep concrete beams that contain openings in the bending region (numerical analysis by Finite Elements method).
4. Problem of the effect of using carbon fiber laminates (CFRP) on the deep concrete beams through simulations using the ABAQUS program.
5. The problem of the effect of using normal-strength concrete NSC for deep concrete beams containing openings in bending areas and subject under uniformly distributed load by simulating the ABAQUS program.

6. The problem of the effect of using high-strength concrete HSC for deep concrete beams containing openings in bending areas and subject under uniformly distributed load by simulating the ABAQUS program.

1.3. The purpose of the study

This study's primary goal is to check the deep concrete beams' behaviour containing openings subject under uniformly distributed load and increase the external support system by finite elements Analysis Software (ABAQUS); the following objectives support this aim:

- The first goal of this research is to study the effects of openings on deep concrete beams' behaviour and employ finite element analysis, To achieve the following sub-aims defined.

i. To select the deep concrete beams' load-deflection behaviour and faulting patterns by placing openings in the bending area.

ii. To determine the impact of the shapes circular or square of the openings.

iii. The comparison by the method of finite elements between the presence and absence of openings, And the shape of openings.

- The second goal of this research is to determine the most effective method of strengthening deep concrete beams using CFRP strips by ABAQUS software simulation in three ways:

i. Strengthen the deep concrete beam with U-shaped CFRP laminates and a strip along the bottom face.

ii. Strengthen the deep concrete beam with a single layer strip of CFRP along the bottom face.

iii. Strengthen the deep concrete beam with a double layer strip of CFRP along the bottom face.

- The third goal of this research is to determine the effectiveness of using NSC or HSC on the behaviour of deep concrete beams.

1.4. Domain and Methodology

This research study deals with simulations using the ABAQUS program to model a deep concrete beam containing a circular or square opening in the bending region (the middle of the span).

And the behaviour of this deep concrete beam under the influence of uniform distribution load on the upper surface of the deep concrete beam reinforced with the minimum reinforcement of the bend and shear according to the ACI_318 -19 code according to strut & tie model and strengthening by CFRP in three ways

1. U shape CFRP for a distance of 100 mm and a strip along the bottom face of the deep beam, according to Figure (1-1).
2. A single layer of CFRP along the bottom face of the deep beam, according to figure (1-2).
3. In the form of a double layer of CFRP along the bottom face of the deep beam.

And compare the results of the three methods for normal-strength Concrete NSC and high strength concrete HSC.

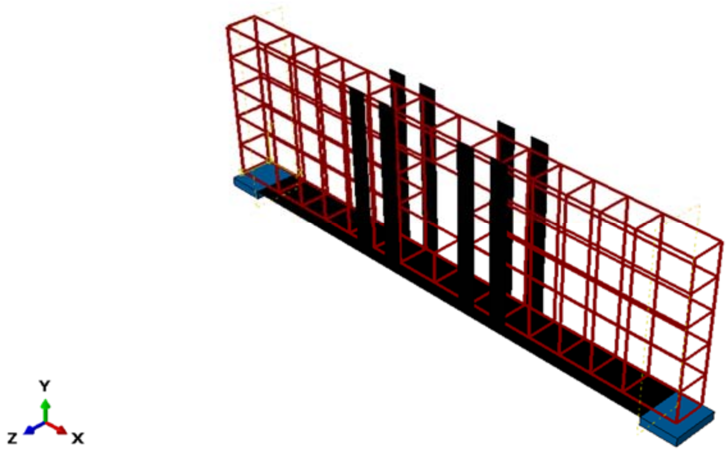


Figure (1-1) strengthen by U-shape CFRP and bottom face

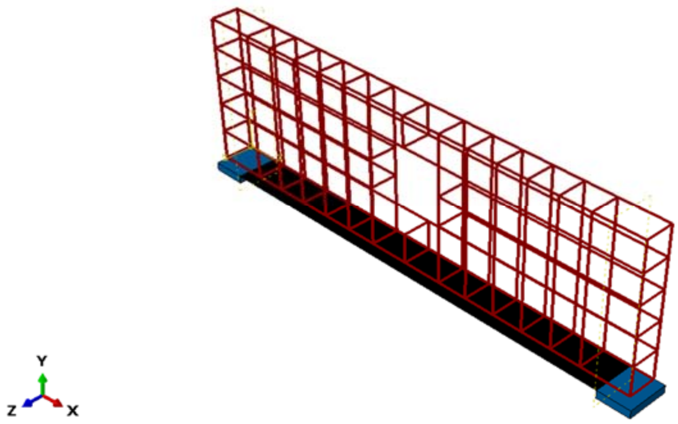


Figure (1-2) Strengthen CFRP in a bottom face

1.5. The Importance of this Study

This research study can contribute to understanding the behaviour of deep concrete beams that contain openings in the bending region by using the ABAQUS program to analyze the finite elements and the impact of strengthening to make the appropriate decision to save time and money.

The deep concrete beams can be strengthened in three ways and study the effect of each method in the ABAQUS program to determine which of the three methods is more effective by predicting the behaviour as a result of the deep concrete beams being influenced by the same load and for two forms of openings, Also increasing the stiffness of the deep concrete beams with increasing loads and reducing deformation and cracks.

Using the finite elements method to study the behaviour of various structural elements is very useful to a reduction of time, effort and expenses compared to the experimental work, which takes time and requires machines and equipment in addition to the action, which leads to a high cost with the difficulty of representing some loading solutions like a uniform distributed load.

Chapter 2

REVIEW OF THE LITERATURE

2.1. General

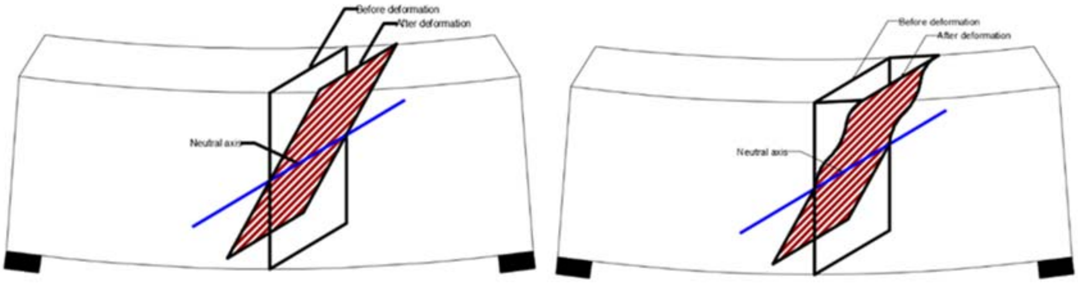
The literature review objective is to identify research that dealt with the strengthened deep concrete beams by (CFRP). To compare the installation method and the strength of each technique, knowing initial cracks and failure loads, for the latest studies. By using Normal Strength Concrete (NSC) and High Strength Concrete (HSC) with compressive strength equal to 25Mpa and 60Mpa respectively, And to further focus on the problem of openings in concrete beams in general and on deep concrete beams in particular, and to fill the research gaps regarding the use of (CFRP) for (NSC) and (HCS). And their effect on the openings and increasing the ductility under the influence of uniform distribution load.

2.2. Deep Beam

2.2.1. Introduction

Deep concrete beams are loaded members one of the faces and supported on the Opposite face, resulting in strut-like compression components between the loads and supports that meet the requirements. (1) or (2): (1) The apparent span of the member h does not reach four times its total depth. (2) Concentrated loads are placed twice the distance between the support face and the load. (ACI_318_19, pp. 151). it is preferred for tall construction, sea coast structures, and piles caps.

Deep concrete beams differ in terms of the distribution of internal stresses with regular beams, by the distribution of internal stresses in deep concrete beams are not linear. The prismatic section of deep concrete beams after deformation does not remain prismatic, and therefore does not depend on their analysis and design on the behaviour of materials (steel and concrete), and equilibrium The stresses and compatibility of internal strains that underlie standard package design and analysis (David at el,15Ed,2016) as Figure(1-2) .



(a)Linear deformation (b)nonlinear deformation

Figure (2-1) stress-strain deformation

The design or analysis of the deep concrete beams using elasticity theory and applying Bernoulli's hypothesis is inaccurate. Therefore, resort to a method called the strut & tie model, which is summarized in the work of a truss consisting of compression members called strut and tension members called a tie. More standards and codes recommend to use, strut & tie model an approach to design and analysis deep concrete beams.

2.2.2. Strut & Tie Model

Released strut & tie models at the beginning of the eighties in Europe (Darwin D. et al.,15Ed,2016), and in ACI_318_19 Chapter 23 deals with the design of areas of structural elements or concrete elements where the presence of openings or the location of the applied loads by making the longitudinal strain in cross-section non-linear (ACI_318_19: pp. 385).

Deep concrete beams are designed by representing the internal forces to truss, strut as compression members and tie as tension members connected by connecting joints. The strut & tie model is preferred as a logical approach to analyses deep concrete beams and will provide a coherent design standard that considers safety and service (Schlaich JS et al.,1987) and (Panjehpour M. et al.,2015).

2.3. Openings

2.3.1. Introduction

Openings affect the deep concrete beams and reduce their stiffness according to the openings shape, size, and location. The effect of the presence of openings reduces the moment of inertia. Thus, cracks begin at an early stage after applying loads when the tensile stresses exceed the limit for concrete. The cracks continue vertically towards the neutral axis compared to the appearance of cracks in the deep beams that do not contain openings, but their effect remains small on the width Cracks and deflection (Mansur & Tan, 1999) Figure.(2-2)

2.3.2. The Shape of Openings

The shape of the openings may be square, rectangular, circular, oval, diamond, trapezoidal, even triangular or irregular in shape, depending on Figure (2-2). The form depends on its function, but round and square openings remain preferred because they take the shape of the pipe and duct (Mansur & Tan, 1999) & (Choo,2013).

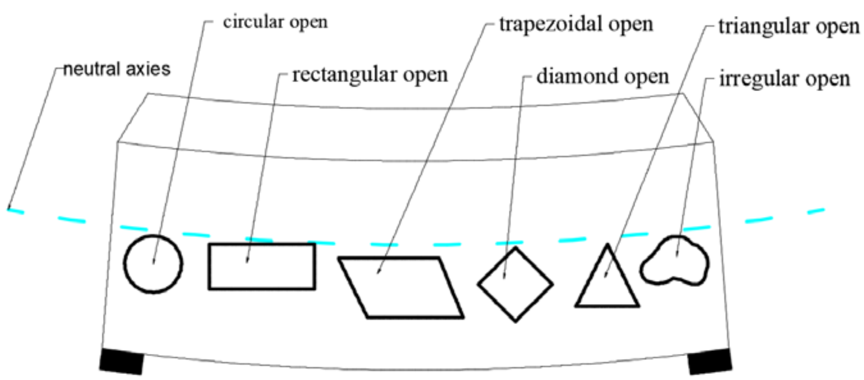


Figure (2-2) Openings shape

As an example of the effect of openings, which is also the subject of the research question, we will shed light on the square and circular openings widely used in building construction.

2.3.2.1. Square opening

A square or rectangular opening problem is that the stresses are concentrated at the four corners (Allam, 2005). causing early cracks to form around the sharp corners of the square or rectangle due to the concentration of stresses (Pimanmas, 2010). Concentrated pressures are three times higher than normal pressures (Choo, 2013), according to Figure (2-3). That leads to weaker material resistance and causes failure to reach the fatigue load (Huston & Josephs, 2008).

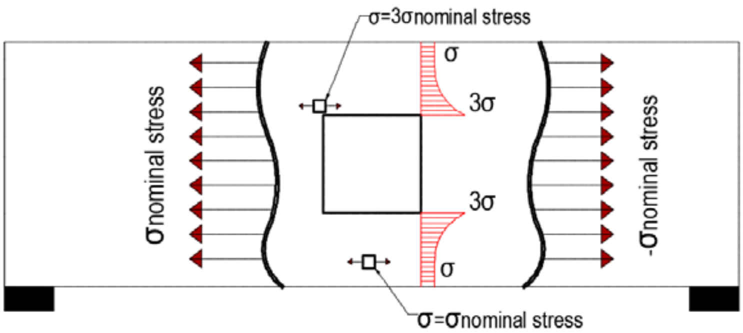


Figure (2-3) Distribution of stress around square openings

2.3.2.2. Circular Opening

The openings cause a cut in the transfer of loads, so the stress concentration increases. Still, the circular openings have less stress concentration because they wrap around the opening, which leads to its flow and lack of focus. (Moreno, 2011) according to Figure(4-2)

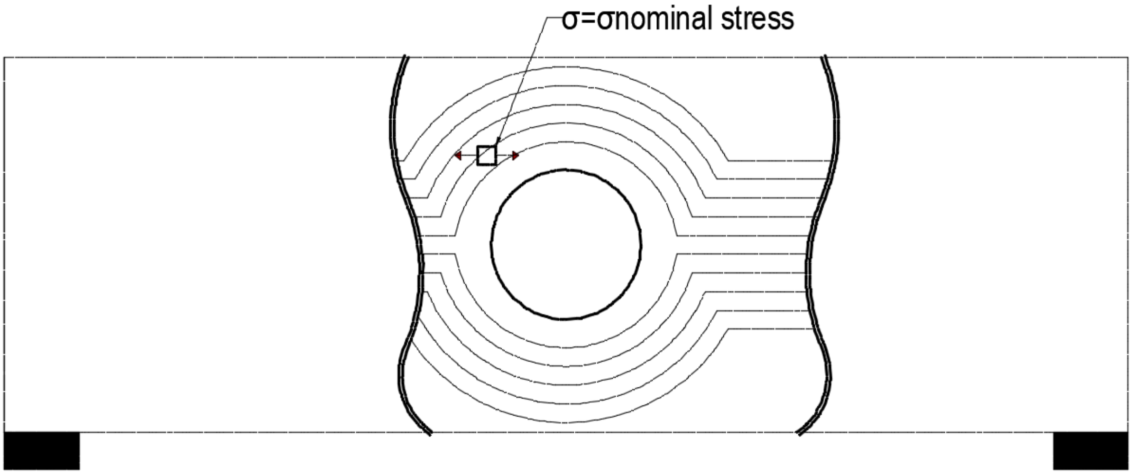


Figure (2-4) Distribution of stress around circular openings

2.3.3. The Size Of Opening

Classified openings as large or small according to the behaviour of the beam and the type of stresses Figure (2-5). One of the determinants of openings size is the type of stress to which the area of the openings is subjected. For example, if the openings are under the neutral axis, in the tensile stress region, the size of the openings has no effect because the area affected here is the reinforcing area, but if the opening or part of it is above the neutral axis, it reduces the size of concrete and thus reduces the compressive stresses needed to resist tensile stresses, and some previous studies have shown that the Diameter or dimensions of the opening if it is more significant than (0.25h), is considered a large opening (Somes & Corley, 1974) and (Mansur & Hasnat 1979)

(Mansur & Tan, 1999) consider openings dimensions or Diameter if they exceed 40% of the beam height as a large opening.

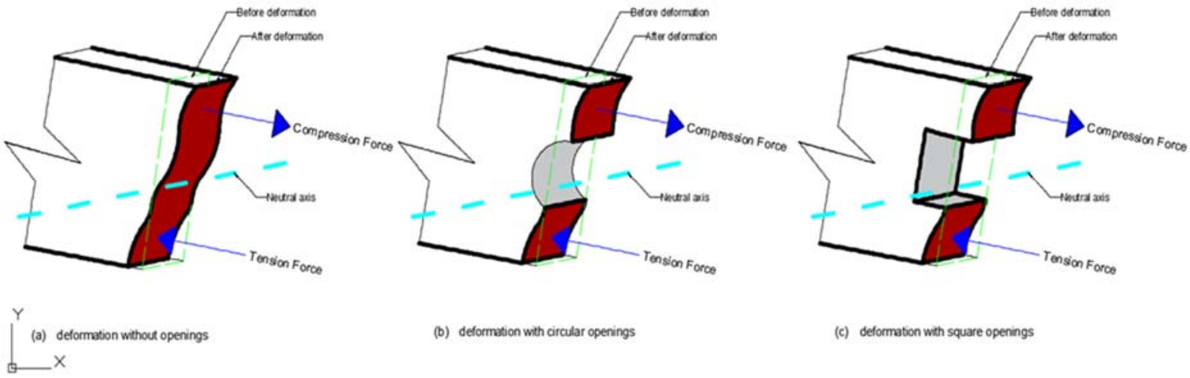


Figure (2-5) opening's effect of behaver deep concrete beams

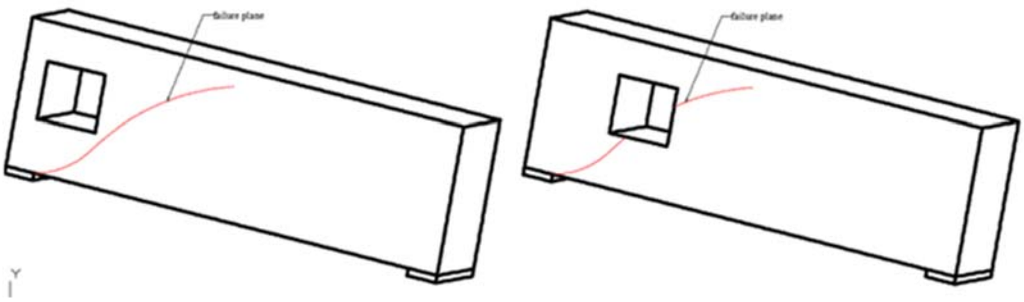
2.3.4. The Location of Openings

Openings location affects the behaviour of the beam according to the stress region and its type, Figure (2-5). Where are the openings located in the flexural area it has an effect if it is within the pressure region, as it leads to a reduction at the moment needed to resist external loads because the openings reduce the concrete area needed to resist compressive forces and thus decreases The stress that the section bears and affects the amount of bearing of the section (Mansour & Tan 1999). Still, if it is in the tensile region, its effect is only on the appearance of cracks faster. According to design theories, the impact of concrete on the tension region under the neutral axis does neglect. (Salam,1977) and (Tan, 1996).

As for the effect of the presence of openings in the shear areas, it is the appearance of inclined cracks because the shear stresses change the direction of tensile stress in concrete from the horizontal direction to the inclined direction on the beam axis and lead to the failure of the inclined tension. And loss can occur even with shear zone strengthening causing the concrete to fracture in the inclined direction in bevel stress failure (Mansour & Tan, 1999).

The openings effect in the shear area depends on the distance of openings near or far from the supports. When the opening s close to the support, their impact is less than their presence in the shear area due to passage of the failure plan through opening s Figure (2-6) (Mansour & tan 1999).

In summary, the size of the openings has a more significant impact than its location and shape, as the resistance decreases linearly with the increase in size, and the opening does not consider small if it is within (20-30) % of the height of the beam (Mansour & tan 1999).



(a)The failure plane does not pass through the openings (b) The failure plane pass through the openings

Figure (2-6) opening in the shear zone

2.4. Carbon Fiber-Reinforced Polymer (CFRP)

(CFRP) is defined as a polymer matrix composite material with carbon fibre fabric, mat, or strands (ACI440_2R_08).

All strengthened fibres have a modulus of elasticity, which is the highest. Carbon fibres have incredibly high tensile strength-to-weight and tensile-modulus-to-weight ratios, one of their benefits. Carbon fibres are also highly fatigue resistant. And a very low linear thermal expansion coefficient, or even negative thermal expansion in rare cases. This feature gives dimensional stability, allowing the composite to increase near-zero structure.

2.4.1. CFRP properties

When exposed to tensile forces, the behaviour of CFRP materials is linear, where the stress-strain relationship is a linear elastic relationship, meaning it fails fragile and suddenly before passing through the stage of plasticity.

Table (2-1) displays the CFRP properties used in this study based on Table (A1.1) ACI COMMITTEE REPORT 440.2R-72, which shows the Elastic modulus, Ultimate Strength and Rupture strain.

Table (2-1) properties of CFRP.

Carbon Fiber type	Elastic modulus (Mpa)	Ultimate strength (Mpa)	Rupture strain,minimum, %
General-purpose	220 to 240	2050 to 3790	1.2
High-strength	220 to 240	3790 to 4820	1.4
Ultra-high-strength	220 to 240	4820 to 6200	1.5

2.4.2. Benefits of using fibre-reinforced polymers in strengthening concrete structures:

1. Not subject to rust
2. lighter in weight compared to iron
3. The possibility of using it more efficiently in a confined field.
4. reduces the cost of the hand working.
5. High tensile Strength (for both static and long-term loading).
6. hardness controlled according to design requirements.
7. large deformation energy.
8. It is available in an infinite variety of dimensions in terms of size and thickness.

2.4.3. Fiber Optic Polymer Applications

Reinforced Concrete covered with fabric or slats. As a result, it increases necessary resistance (for tensile, bending, shearing, torsion, and confined columns) while also improving ductility without increasing CFRP reinforced concrete hardness treatments. As a result, the use of polymers is fast growing.

2.5. Finite Element ABAQUS

With the increasing use of computers, computer simulation has become an essential structure design and analysis tool. The simulation model is also known as 'FEA' (FE Analysis), (Computer Simulation models), or computer analysis. Since the expansion of FEM in the 1960s, It's been a helpful tool for analysis. (Zienkiewicz et al., 2005). In some ways, computer simulation has replaced experimental research, and it helps to lessen the experimental workload (Graybeal & Pooch, 1980).

Traditional testing typically entails fabricating expensive models, testing the specimens with costly load frames, refining the design based on the test findings, and repeating the procedure until satisfactory results are obtained. Experimental testing is also difficult to use when researching structures that are susceptible to the effects of severe events such as blast, penetration, collapse impact, or typhoon. The findings of an experimental test recorded in the system can be assessed on the computer using a correct parameter and numerical model using computer simulation. Additionally, the computer visual simulation allows for a clear presentation of the data. The use of computer simulation to replace experimental effort has several benefits. (safe, efficiency and cheap) (Choo,2013).

2.6. Previous researches on CFRP-strengthened deep concrete beams

2.6.1.(Hana' Al-Ghanim et al.,2017). The study investigates the flexural and shear behavior of externally strengthened deep concrete beams with carbon fiber-polymers (CFRP). Different schemes were investigated experimentally using two Deep concrete beams using CFRP composites, sheets, and laminates for shear and flexural reinforcement.

Twenty deep concrete beam specimens were cast and tested to failure, having a cross-sectional width of 19cm, a depth of 40cm, and a total length of 190cm.

Compared to the control beams in fracture formation, failure mechanism, overall stiffness strengthened beams' effectiveness, ultimate strength. The success of the CFRP technique in improving the shear and flexural capacity of deep concrete beams demonstrate by the test results; however, the efficiency varies depending on the strengthening planner and the material. In terms of shear strengthening, adopting a continuous wrap of two sheets results in a value of more than 86 percent, compared to only 36 percent with inclined laminates. This is the most increase in ultimate strength. On the contrary, bending strengthening with double layers of sheets achieves a 51% improvement and 26% when laminates utilize; both are followed by a shift in the failure mechanism from bending to shear .

2.6.2 (Sara Saad Faraj,2018) Seven deep concrete beams are modelled by uniform the reinforcement and dimensions (80 x 320 x 800) mm, where six strengthened deep concrete beams with (CFRP) according to the beam's longitudinal axis, and it was (B 1) as a deep reference beam, (B 2) reinforced at an angle of 90degrees, (B 3) supported at an angle (0-90) degrees, (B 4) was reinforced at an angle of 45degrees (B 5) Reinforced at an angle (0-45)degrees, (B 6) Reinforced at an angle of (90-0) degrees, (B 7) Reinforced at an angle of (45-0) degrees according to the Figure (2-7) and compared with the seventh (reference beam) through shear resistance and deflection, the results were as follows

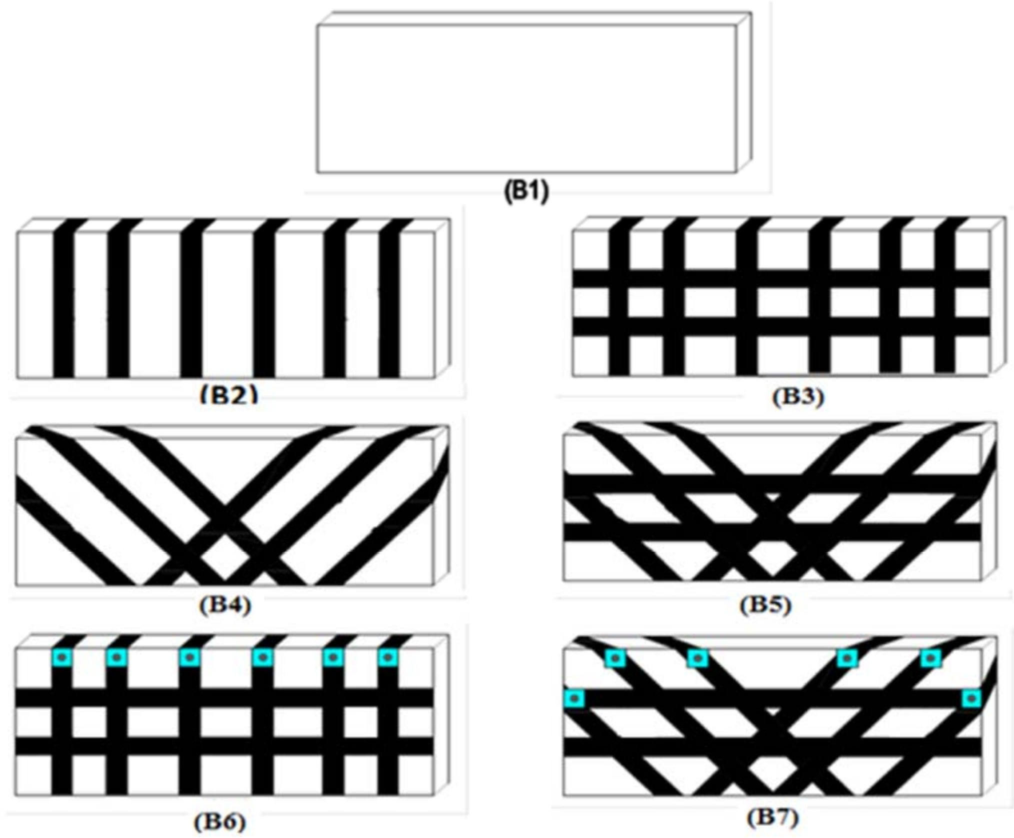


Figure (2-7) the method of installation CFRP

The load of beam type B4 was 209KN, strengthened with 45o CFRP strips, delivered a larger ultimate load than beam-type B2 (176.5KN), strengthened with 90o CFRP strips. Because The deep concrete beam's inclined web reinforcing effectively inhibited diagonal crack propagation, preventing the typical diagonal–cracking failure.

Used Longitudinal CFRP strips and 90º CFRP strips to strengthen beam-type B3. the load of B3 is 220KN. Model B3 increases the maximum load by (24.60%) compared to beam B2. In comparison to beam-type B2, beam-type B3 has an In the post-cracking stage; stiffness is higher of the reaction. Strengthen longitudinal CFRP strips and 45° CFRP strips for the beam-type B5. Its strength (291.5KN) compared to the B4 beam of (209KN), the B5 beam increased the final load by (39.5%). And in the post-fracture response stage, beam B5 has a higher hardness than beam B4. According to the results, stiffening with longitudinally oriented CFRP strips and transverse CFRP strips (90° or 45° strips) wrapped around it improves the absolute strength and post-fracturing deflection significantly.

The effect of steady CFRP strips on the deep beam was demonstrated using models B6 and B7. Placing anchors in beam B6 enhanced the CFRP added to the beam's ultimate shear resistance by 24.50% beam B6 versus beam B3. However, the increase was 10.10% beam B7 vs beam B5.

Compared with the deep concrete beam B3 and beam B5 without anchors, anchors' inclusion enhances post–cracking deflection.

2.7. Previous Research on Deep Beams with Openings Strengthen with CFRP

2.7.1. (NG KIN MUN,2015). The purpose of this experimental study is to know how CFRP wrap affects the strength of deep concrete beams with large squares open in the shear area. The first technique determines concentrated load transfer in a typical deep concrete beam without openings. The second is to use large square openings in a deep concrete beam without CFRP stiffening, and the third and fourth are to use large square openings in a deep concrete beam CFRP connected around the openings in a different approach. A total of four deep concrete beams dose examined to break down under four-point loading to determine relative structural behaviour such as crack patterns, ultimate load, load-deflection behaviour, and failure mode. All of the deep concrete beams had dimensions of (12 x 60) cm and a length of 240cm. The width and height of the enormous square opening were (27 x 27) cm, and they were 30cm from the deep beam's edge.

The loading point and support were 80cm and 30cm from the deep beam's edge, respectively. Compared to the solid control beam, the deep concrete beam with big square openings has lowered the beam capacity by (61.76 %). Compared to an Un-strengthened deep concrete beam with square openings, the deep concrete beam with a big square opening strengthened by CFRP strips wrapped in U-shaped has enhanced beam capacity (62.77%). According to the findings, the most successful CFRP strengthening method for deep beams with big square openings was U-shaped, which recovered up to (62.24%) of the beam capacity compared to the solid control beam.

2.7.2. (Nurul Izzati Rahim et al.,2020) The structural behaviour of deep concrete beams that strengthen openings with externally connected CFRP composite in the shear zone has been in this experimental investigation the failure mode, cracking pattern, load-deflection reactions, stress concentration, and reinforcement factor were all evaluated as structural behaviour. A total of nine reinforced deep concrete beams with CFRP-enhanced openings and one control beam without an opening were cast and tested until they failed under a static four-point bending load. Found that increasing the aperture size caused a 30% loss in shear strength. As a result, the larger the openings, the lower the load-carrying ability, even though the load capacity could be improved by increasing the number of CFRP layers. As a result of using the CFRP layer wrapping approach, the shear behaviour of the reinforced deep concrete beams was improved by roughly 10% to 40%. Two or three layers are shown to be the most effective for openings diameters of 150 mm and 200 mm, respectively.

2.7.3 (Mohammed Riyadh Khalaf et al.,2021) Three continuous deep concrete beams, one without openings, the second had an opening without strengthening. The third had openings and strengthened with CFRP. See Figure (2-8) with dimensions (160x400x1190) mm. were experimental and numerically tested under five-point bending to investigate the losses in strength and stiffness after supplying two 40% openings of the overall beam depth.

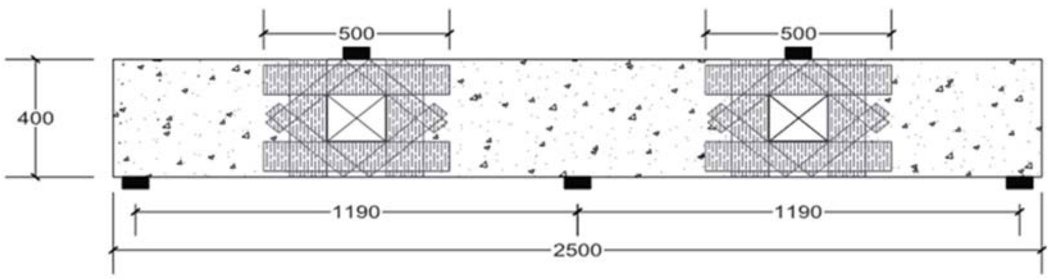


Figure (2-8) Diagram showing how to install (CFRP) what taken from the original research

The outcome of the experiment

Compared to the reference specimen, the initial loading crack has reduced by 30%. The mode of failure for the model with openings and un-strengthening with CFRP was bearing failure at the upper chords of openings. On the other hand, the inclusion of CFRP shifted the stresses away from the openings. The diagonal CFRP strips were employed to withstand the stresses concentration at the corners of these openings, preventing shear cracks. Compared to the un-strengthened specimen, the initial fracture load has raised by 50% for the model with openings and un-strengthening with CFRP. When the load rose, the CFRP strips were debonding.

The load-deflection relationship at the centres of the spans of the tested specimens is shown. Compared to models of a solid deep beam, large openings resulted in lower stiffness, ultimate capacity, and ultimate deflection. The presence of a large opening resulted in a 35 % reduction in stiffness for specimens of the deep concrete beam with openings and un-strengthen with CFRP. However, placing CFRP strips around these openings restricted the decline to only 20%, indicating a 15% improvement over the un-strengthened version. Furthermore, for specimens of deep beams with openings and without CFRP and deep beams with opening and (CFRP), these openings reduced ultimate capacities by 21% and 7%, respectively. When comparing the specimen's deep beams with opening s without CFRP and deep beams with opening and CFRP, the ultimate capacity increased by 17%. The CFRP strips alleviated stress concentrations at the corners of the holes, improving the behaviour of the strengthened beam.

The outcome of the FE analysis

The findings of the experiments were used to validate the correctness of a finite element model capable of reproducing the static response of a deep concrete beam with an opening. In terms of deformations of the examined specimens, The specimen's reactions from the two techniques were similar during the elastic stage. The FE values became slightly stiffer as the applied load approached the yielding load. To assumed complete contact between concrete and the strengthening strips and reinforcement was blamed for the discrepancy in reaction. However, because there was good agreement in general, the validated FE model was employed to conduct a parametric investigation.

2.8. Previous Research on Deep Beams of High-Strength Concrete with Openings.

2.8.1 (.Tan-Min Yoo et al.,2013) The research focuses on an experimental investigation of HSC deep beams with varying openings dimensions and placements. Forty-three deep concrete beams were cast and tested to failure. All deep concrete beam specimens had overall dimensions of 240cm x 60cm x 11cm thick. The shear span was 900mm for samples subjected to single-point stress, The clear span to depth (l/d) ratio is three, while the shear span to depth (a/d) ratio is 1.5. The l/d for those beams subjected to two-point loading was 60cm, and the a/d was 1.0. The openings ranged in size from 6cmx6cm to 21cmx21cm. The compressive strengths for all models were primarily high, ranging from (63Mpa to 91 MPa). With a lower compressive strength of four deep concrete beam specimens with 34 MPa. The beams were divided into three groups. The variables included concrete strengths, opening sizes, forms, placements, and shear span-to-depth ratios.

The beams' crack shapes and failure mechanisms were expected for supported deep beams with openings. Overall, it appears that openings significantly influenced cracking behaviour, with more substantial evidence of shear-type cracking in the panels with openings. In contrast, the panels without openings show more typical shear-flexure cracking behaviour. The final strength of the deep concrete beam was be reduced by the relationship of change in place of opening in the horizontal direction. The beam with an opening cross with load route has the lowest ultimate strength. The decrease in the effective compressive area of the concrete can be related to the drop in ultimate strength. The shear resistance decreases as the opening approaches the critical path of the load because it will reduce the concrete section area .The final resistance of the deep beams decreases in the case of ordinary concrete by 17%. Still, in the case of highly resistant concrete, the final resistance reduces by 34% when a single-centre load is applied and up to 70% when two central loads are applied when the opening size is from 150mm to 210mm.

2.8.2. (Alaa Alsaad et al.,2015) The results of an experimental examination into the usage of (CFRP) to strengthen a high-strength deep concrete beam with a circular opening. The structural behaviour of five group samples was evaluated in shear strength capacity and deflection. The samples were 1200mm long and had a 100x500mm rectangular cross-section. At the midpoint of each shear span, two symmetric circulars of 150mm diameter do construct. CFRP strips were added in three forms distinct around the openings. The diagonal layout of CFRP strips was the best, with an ultimate shear strength ratio of 0.97 compared to a solid control beam and 0.86 when compared to a control beam with cutouts. The deflection of the beams that improved with CFRP strips showed a substantial favourable effect. In addition, the CFRP sheet positioned diagonally around the openings was the best for reducing deflection.

CHAPTER 3

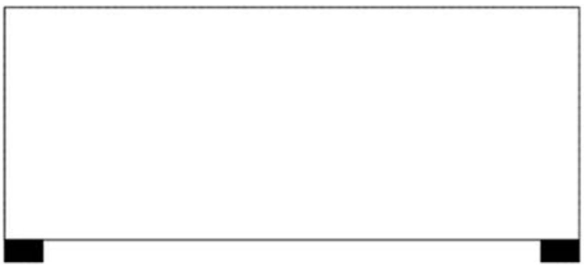
FINITE ELEMENT ANALYSIS APPLICATION

3.1. General

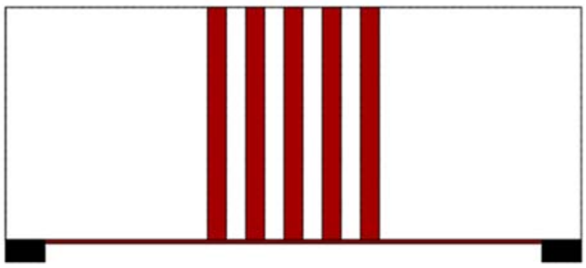
This chapter dealt with properties of materials, distribution details of rebar, and modelling stages briefly according to the finite element analysis method in the ABAQUS program. In addition, modelling a deep concrete beam from previous research and comparing the results to ensure the efficiency of the ABAQUS Finite Element release 2019.

3.2. Study models

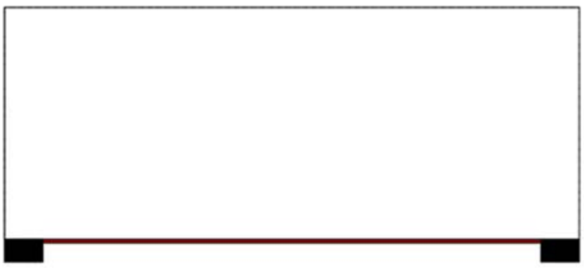
Twenty-four models modelled, similar in dimensions (250X1000X3000) mm with dimension of square openings (400x400) mm and diameter of circular openings 400mm, Divided into two parts according to the compressive strength of concrete (25Mpa and 60Mpa), and each part contains three groups according to the presence or absence of the opening as well as the shape of the open as shown in Figure (3-1).



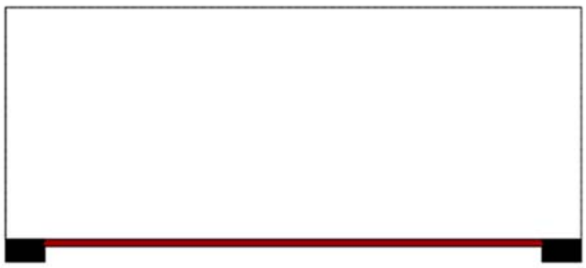
(a) Deep beams without opening and without strengthen by CFRP (DB_GB)



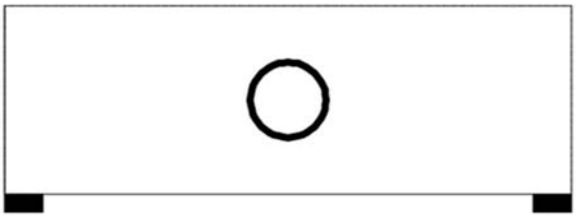
(d) Deep beams without opening ,with strengthen by u-shape and in the lower face between the supports of CFRP (DB_S_CFRP)



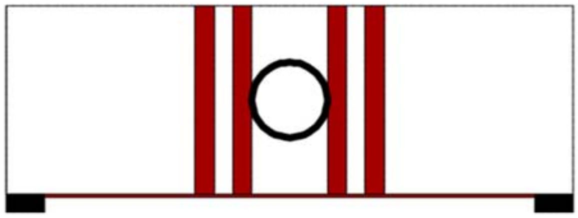
(c) Deep beams without opening ,with strengthen by single layer CFRP in the lower face between the supports (DB_B_CFRP)



(d) Deep beams without opening ,with strengthen by double layer CFRP in the lower face between the supports (DB2_B_CFRP)

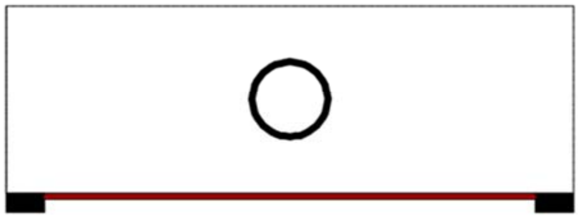


(h) Deep beams with circular opening and without strengthen by CFRP (DB_CO)

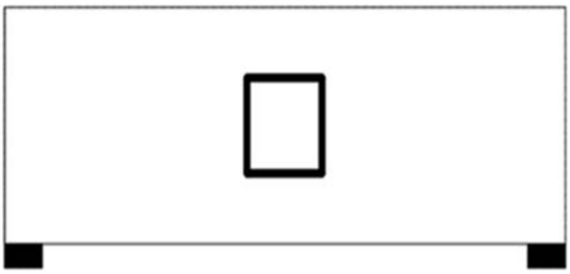


(i) Deep beams with circular opening ,with strengthen by u-shape and in the lower face between the supports of CFRP (DB_CO_S_CFRP)

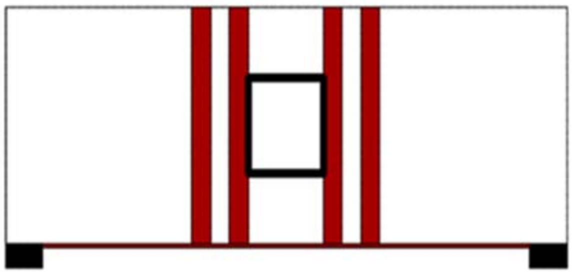
(j) Deep beams with circular opening ,with strengthen by single layer CFRP in the lower face between the supports (DB_CO_B_CFRP)



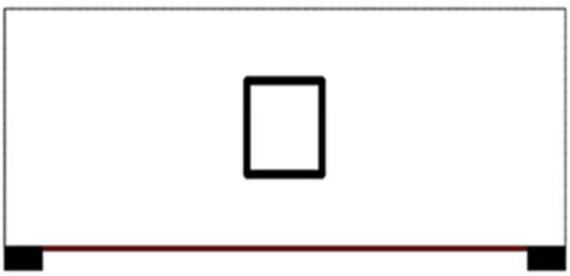
(k) Deep beams with circular opening ,with strengthen by double layer CFRP in the lower face between the supports (DB_CO2_B_CFRP)



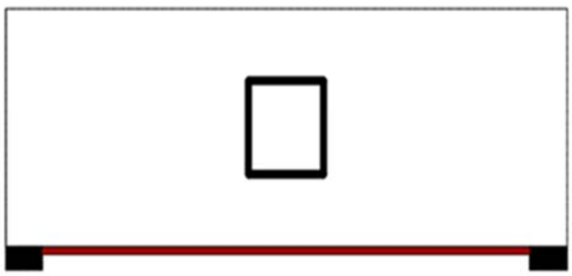
(e) Deep beams with square opening and without strengthen by CFRP (DB_RO)



(f) Deep beams with square opening ,with strengthen by u-shape and in the lower face between the supports of CFRP (DB_RO_S_CFRP)



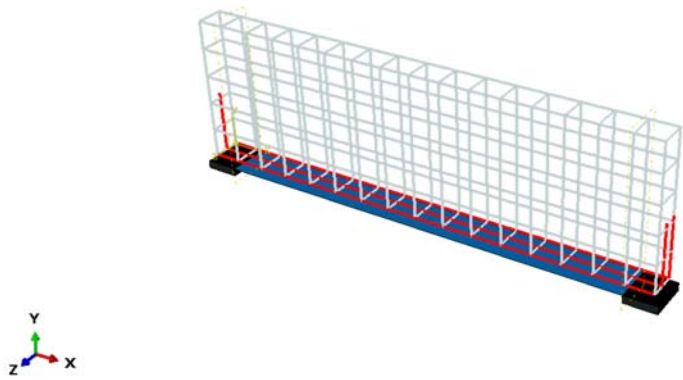
(g) Deep beams with square opening ,with strengthen by single layer CFRP in the lower face between the supports (DB_RO_B_CFRP)



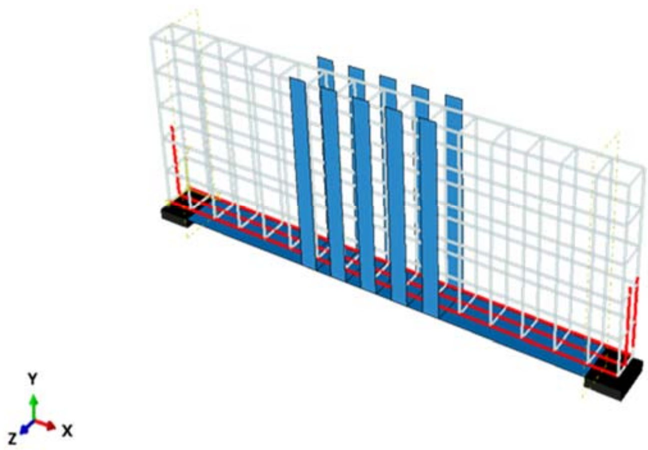
(h) Deep beams with square opening ,with strengthen by double layer CFRP in the lower face between the supports (DB_RO_2B_CFRP)

Figure (3-1) Models types for deep concrete beams

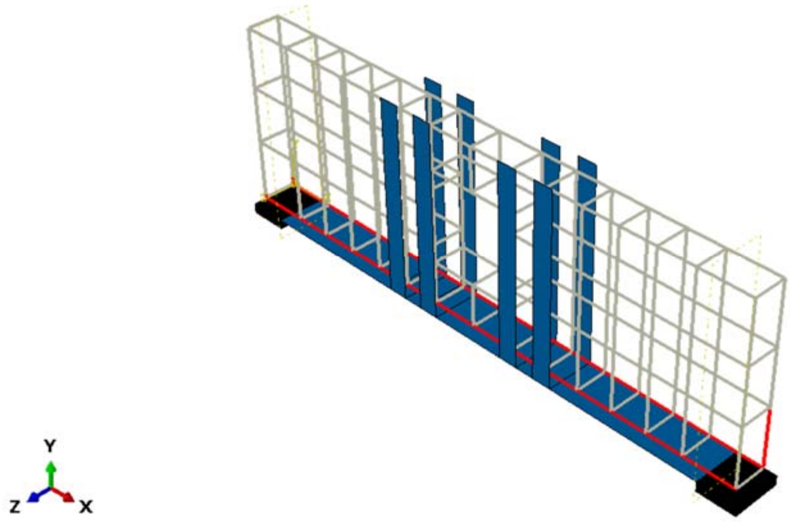
Each group contains four models according to the CFRP method of strengthening. CFRP strengthen method for conventional and high-strength concrete, consisting of one or two 250 mm wide and 0.337 mm thick strips laid along the bottom face of the net space between the supports (2600 mm length). As shown in Figure (3-2(a)). or, in addition to a 100 mm wide U-shaped strip around the sides and bottom, bottom face every 100 mm in the flexural zone for one strip, installed along the bottom face of the spacing between the supports figure [3- 2 (b & c)] Note L/h =3000mm/1000mm=3>4 and agree with condition of ACI 318-19 code.



(a) Deep beam, strengthened with one or two layers of CFRP



(b) Deep beam, strengthened with bottom and U-shape layers of CFRP



(c) Deep beam, strengthened with bottom layers and U-shape CFRP in the presence of opening

Figure (3-2) Method of strengthened deep concrete beams

Designations and details of deep concrete beam models for traditional concrete as per table (3-1) and high strength concrete (3-2).

Table (3-1) Definition symbols of traditional deep concrete beams part A

symbols	Details
GROUP 1	
DB_GB	Deep beams without opening and without strengthening by CFRP
DB_GB_S_CFRP	Deep beams without opening, with strengthening by u-shape and in the bottom face between the supports of CFRP
DB_GB_B_CFRP	Deep beams without opening, with strengthened by a single layer CFRP in the bottom face between the supports
DB_GB_2B_CFRP	Deep beams without opening, with strengthened by double-layer CFRP in the bottom face between the supports
GROUP 2	
DB_SO	Deep beams with square opening and without strengthening by CFRP

DB_SO_S_CFRP	Deep beams with a square opening, with strengthened by u-shape and in the bottom face between the supports of CFRP
DB_SO_B_CFRP	Deep beams with a square opening with strengthened by a single layer CFRP in the bottom face between the supports
DB_SO_2B_CFRP	Deep beams with a square opening with strengthened by double-layer CFRP in the bottom face between the supports
GROUP 3	
DB_CO	Deep beams with circular opening and without strengthening by CFRP
DB_CO_S_CFRP	Deep beams with a circular opening, with strengthened by u-shape and in the bottom face between the supports of CFRP
DB_CO_B_CFRP	Deep beams with a circular opening with strengthened by a single layer CFRP in the bottom face between the supports
DB_CO_2B_CFRP	Deep beams with a circular opening with strengthened by double-layer CFRP in the bottom face between the supports

Table (3-2) Definition symbols of high strength deep concrete beams part B

Symbols	details
GROUP 4	
DB_HSC_GB	Deep beams of high strength concrete without opening and without strengthening by CFRP
DB_HSC_S_CFRP	Deep beams of high strength concrete without opening, with strengthening by u-shape and in the bottom face between the supports of CFRP
DB_HSC_B_CFRP	Deep beams of high strength concrete without opening, with strengthened by a single layer CFRP in the bottom face between the supports
DB_HSC_2B_CFRP	Deep beams of high strength concrete without opening, with strengthened by double-layer CFRP in the bottom face between the supports
GROUP 5	
DB_HSC_SO	Deep beams of high strength concrete with square opening and without strengthening by CFRP
DB_HSC_SO_S_CFRP	Deep beams of high strength concrete with a square opening, with strengthened by u-shape and in the bottom face between the supports of CFRP

DB_HSC_SO_B_CFRP	Deep beams of high strength concrete with a square opening, strengthened by a single layer CFRP in the bottom face between the supports
DB_HSC_SO_2B_CFRP	Deep beams of high strength concrete with a square opening, strengthened by double-layer CFRP in the bottom face between the supports
GROUP 6	
DB_HSC_CO	Deep beams of high strength concrete with circular opening and without strengthening by CFRP
DB_HSC_CO_S_CFRP	Deep beams of high strength concrete with a circular opening, with strengthened by U-shape and in the bottom face between the supports of CFRP
DB_HSC_CO_B_CFRP	Deep beams of high strength concrete with a circular opening, strengthened by a single layer CFRP in the bottom face between the supports
DB_HSC_CO_2B_CFRP	Deep beams of high strength concrete with a circular opening, strengthened by double-layer CFRP in the bottom face between the supports

3.3. Calculation of Reinforcement to deep beam

The reinforcement for bending and shear strength dose inferred according to the minimum requirements of ACI318_19, paragraph 9.9 for traditional and high strength concrete.

3.3.1. Reinforcement for traditional concrete deep beam

3.3.1.1. Flexural Reinforcement: in agreement with ACI318_19 paragraph 9.6.1, the smallest area of flexural tension reinforcement (A_s, min) must establish. it must be (As, min) of (1) and (2)

$$As, min = \frac{0.25 * \sqrt{f'c}}{fy} * bw * d \quad \text{-------- (1)}$$

OR

$$As, min = \frac{1.4}{fy} * bw * d \quad \text{-------- (2)}$$

Taken $f'c = 25Mpa \ \& \ fy = 400Mpa$

And $d = h - cover\ of\ concrete - diametar\ of\ stirrap - \frac{1}{2}\ main\ bar$

$d = 1000 - 40 - 10 - \frac{1}{2}(25) \quad d = 937.5mm$

From equation (1) $As, min = 0.25 * \frac{\sqrt[2]{25}}{400} * 250 * 937.5 = 732.42mm^2$

From equation (2) $As, min = \frac{1.4}{400} * 250 * 937.5 = 820mm^2$

Use $As, min = 820mm^2$ then use 2ϕ25mm

2ϕ25=982mm^2 > 820mm^2 ok

3.3.1.2. **Shear Reinforcement:** distributed reinforcement along the two inverse sides of deep beams must meet requirements (1) and (2), according to paragraph 9.9.3.1(ACI318 19): (1) Av, the distributed reinforcement area perpendicular to the beam's primary reinforcement, must be at least (0.0025bwS1), where S1 is the distributed transverse reinforcement spacing. (2) Parallel to the main reinforcement of the beam, the distributed longitudinal reinforcement area, A_{vh}, must be at least (0.0025bwS_2), where S2 is the distributed reinforcing bars spacing.

S_1 & S_2 As for d/5=937.5/5=187.5mm

OR 300mm

Use S_1 & S_2 =185mm

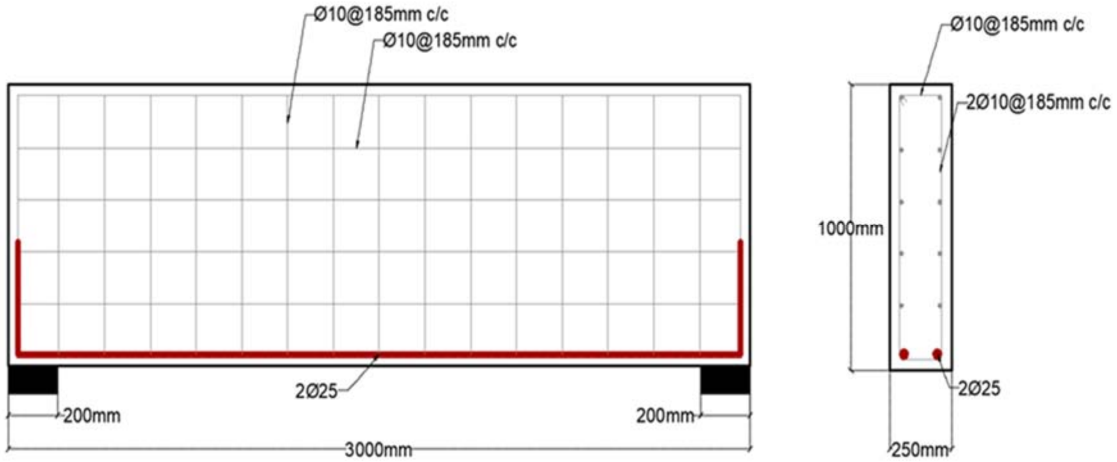
So $Av, min = 0.0025 * bw * S1 = 0.0025 * 250 * 185 = 113.75mm2$

Use ϕ10@185mm c/c for vertical straps

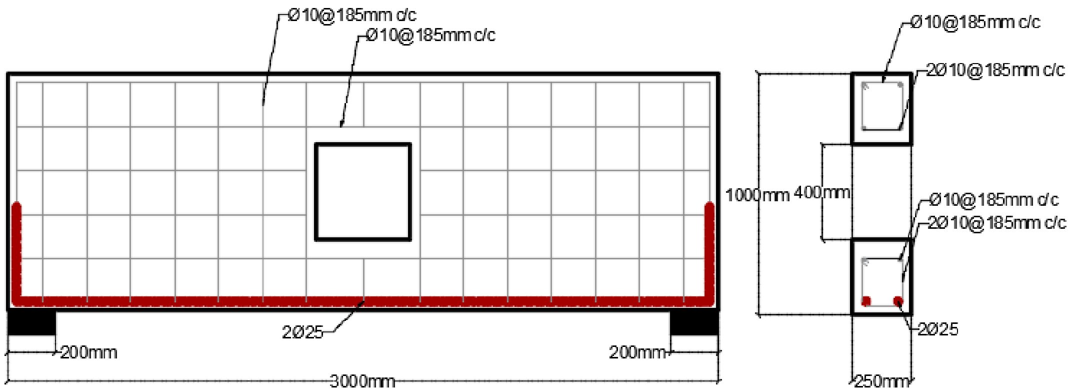
So $Avh, min = 0.0025 * bw * S2 = 0.0025 * 250 * 185 = 113.75mm2$

Use ϕ10@185mm c/c for horizontal straps

As shown in Figure (3-3)



(a)



(b)

Figure (3-3) Detail reinforcement for traditional deep concrete beams

3.3.2. Reinforcement for high strength concrete deep concrete beam

3.3.2.1. **Flexural Reinforcement:** The bending design of the deep concrete beam for high strength concrete is similar was mentioned in paragraph (3.3.1.1.) above

$$As, min = \frac{0.25*\sqrt{f'c}}{fy} * bw * d \quad \text{--------} \ (1)$$

OR

$As, min = \frac{1.4}{fy} * bw * d$ -------- (2)

Taken f^' c=60Mpa & fy=400Mpa

And d=h-cover of concrete-diameter of stirrap-1/2 main bar

$d = 1000 - 40 - 10 - 1/2\,(25) \quad d = 937.5mm$

From equation (1) A_s, min=0.25*√ (60)/400*250*937.5=1134.66mm^2

From equation (2) A_s, min=1.4/400*250*937.5=820mm^2

Use A_s, min=1134.66mm^2 then use 2ϕ25mm +1ϕ16mm

2ϕ25 + 1ϕ16=1183mm^2 > 1134.66mm^2 ok

3.3.2.2. Shear Reinforcement: The shear design of the deep concrete beam for high strength concrete

S_1 & S_2 As for d/5=937.5/5=187.5mm

OR 300mm

Use S_1 & S_2 =185mm

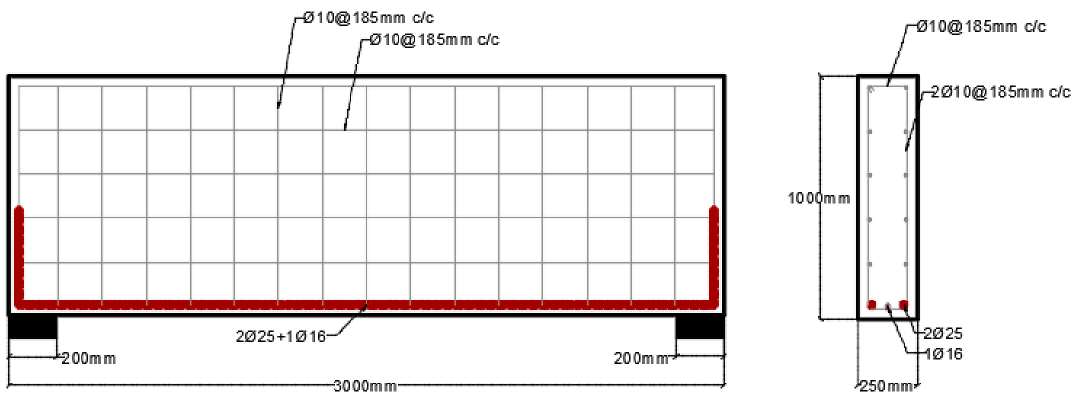
So, A_v, min=0.0025*b_w*S1=0.0025*250*185=113.75mm^2

Use ϕ10@185mm c/c for vertical straps

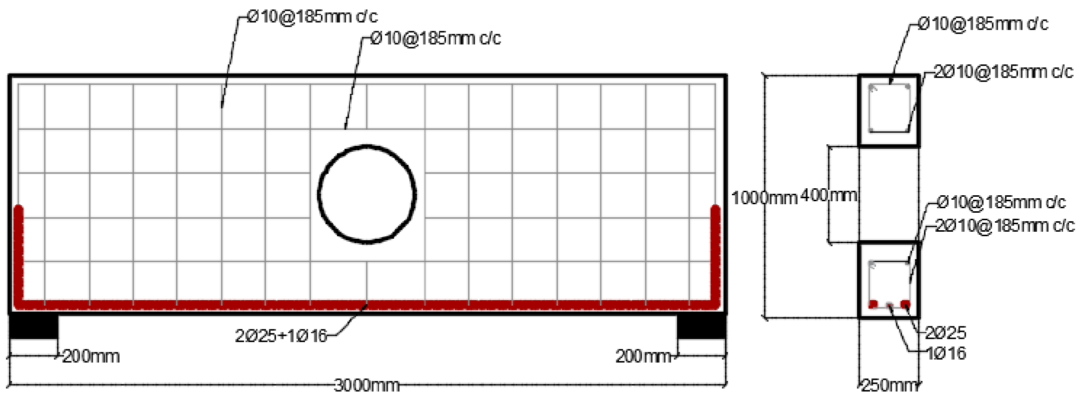
So A_{vh}, min=0.0025*bw*S_2=0.0025*250*185=113.75mm^2

Use ϕ10@185mm c/c for horizontal straps

As shown in Figure (3-4)



(a)



(b)

Figure (3-4) Detail reinforcement for high strength deep concrete beams

3.4. Computer Simulation models

A non-linear finite element model in three dimensions employing "Abaqus-19" was used to forecast the whole response reinforced concrete deep beams. Such as initial crack patterns, load-displacements, and failure modes, in circumstances when a clear force path in the strut and tie is not visible. Non-linear concrete constitutive models with concrete damage plasticity parameter (CDP) and reinforcement it explores in this model. SOLID65, a three-dimensional reinforced concrete element capable of cracking in tension and crushing in compression, is used to model concrete. The concrete SOLID65 modelled the primary and web reinforcements using the LINK8-3D bar element.

The model is represented through several stages, starting from the drawing stage to the analysis stage and reading the results, as shown in the subsequent paragraphs.

I) Parts modelling

At this stage, modelling parts are drawn, such as the drawing of the deep concrete beam with or without openings, reinforcing bars, supports, and CFRP, as follows:

1) Create deep concrete beam from, create part use modelling space 3D, type is Deformable, the base feature is Solid, and type is extrusion.
2) Create reinforcing bar, create part use modelling space 3D, type is Deformable base feature is Wire and type is Planar.
3) Create support from, create part use modelling space 3D, type is Deformable, the base feature is Solid, and types is extrusion.
4) Create CFRP form, create part use modelling space 3D, type is Deformable, the base feature is Shell, and type is extrusion.

II) Properties modelling

In this stage, materials define and assigned to the parts that were drawn in the previous stage, as follows:

1) Define concrete material from, create material

- Density, as in the table (3–3)
- Elastic properties, as in the table (3–3)

Table (3–3) The elastic properties

Property	**(NSC)**	**(HSC)**
density (Ton/mm^3)	2.40E-09	2.40E-09
Young's modulus (Mpa)	23500	32616.61
Poisson's ratio	0.17	0.2

- use of concrete damage plasticity to simulate the non-linear behaviour of concrete in the plasticity phase by parameters in the table (3-4)

table (3-4) plasticity parameter

Dilation Angle	**Eccentricity**	**fb0/fc0**	**K**	**Viscosity Parameter**
36	0.1	1.16	0.667	0.01

Where:

- Dilation Angle is the angle of frictional resistance of concrete, ranging from 36° to 40°, with 36° recommended by the Abaqus program.
- Eccentricity is the deviation of concrete behaviour from the standard of Drucker-Prager, and Figure (3-5) shows this deviation, where the dotted line is considered standard of Drucker-Prager, and the hard-line represents the behaviour of concrete and can be considered (0.1)
- fb0/fc0 is the ratio between the behaviour of concrete when applied biaxial pressure to its behaviour when applied to its uniaxial pressure, as shown in Figure (3-6)
- K is an adjustment ratio for Standard of Drucker-Prager and making it suitable for the concrete material, and this ratio is 0.667 as recommended.
- Viscosity Parameter

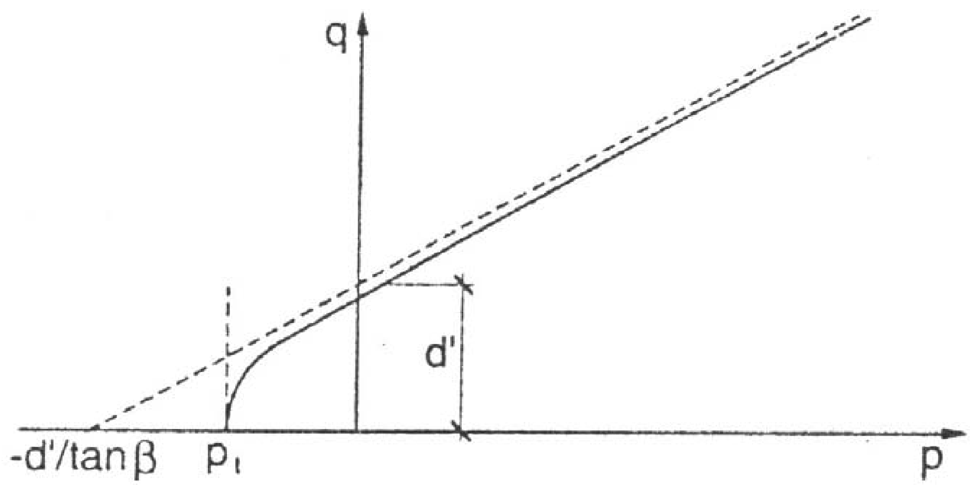


Figure (3-5) The deviation between the behaviour of concrete and the Drucker-Prager criterion

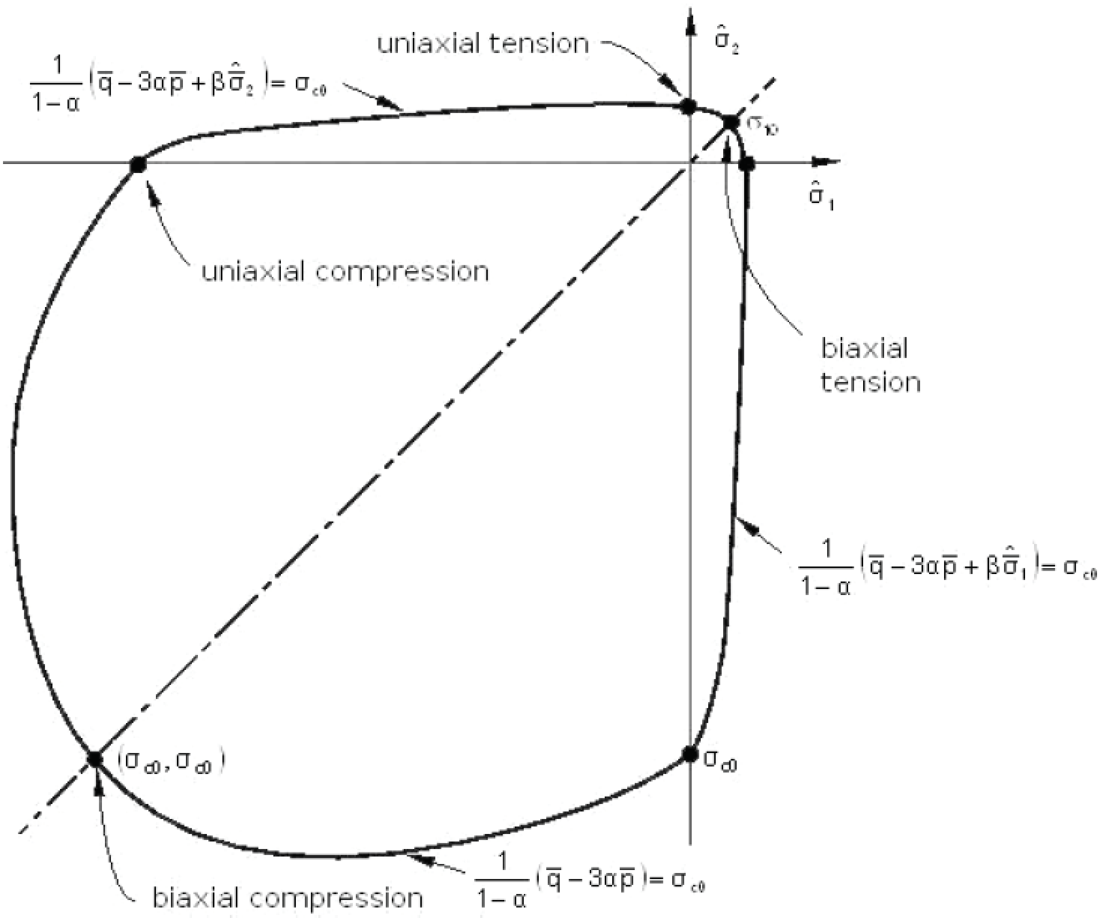


Figure (3-6) A sample of concrete subjected to tension or compression from uniaxial and another subjected to tension or compression from biaxial.

Like most materials during loading, concrete passes through the state of elasticity and plasticity, where the boundary between the two forms of elasticity and plasticity ($0.4f'_c$). The mechanics of collapse occur due to cracks in the tension Figure (3-7) and cracking in the compression Figure (3-9). Several equations infer this behaviour based on the compressive strength obtained by examining the cylindrical sample of concrete.

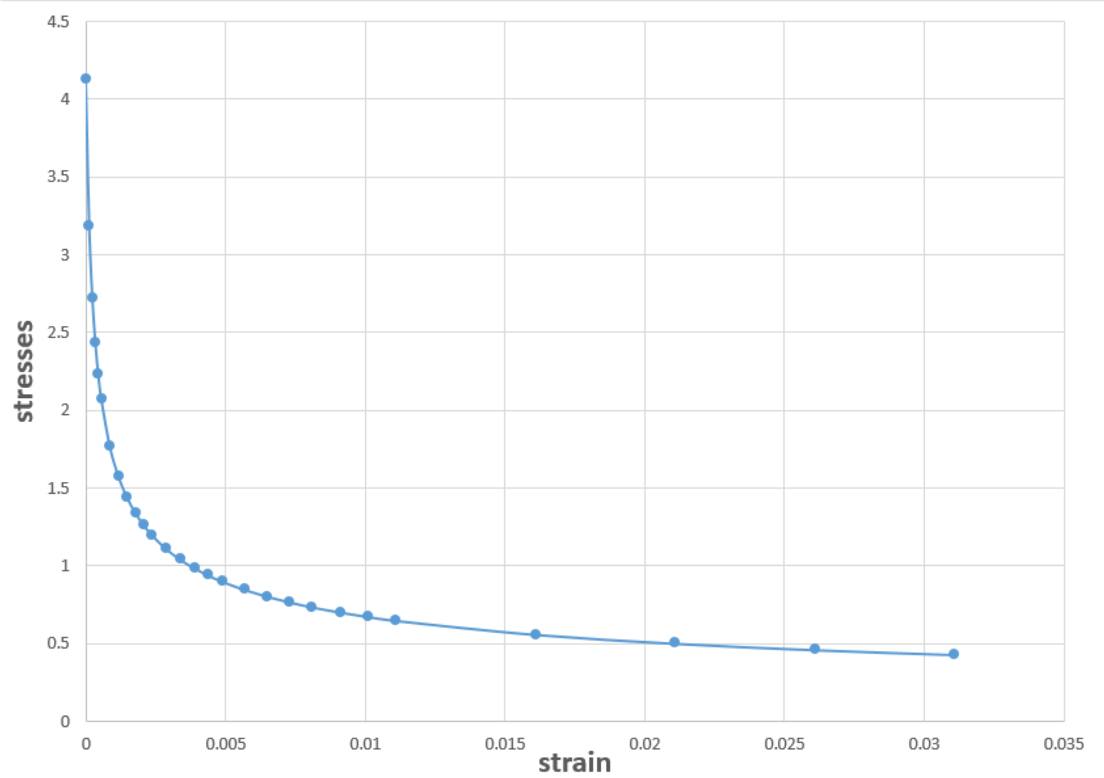


Figure (3-7) tension behaviour in a plastic state

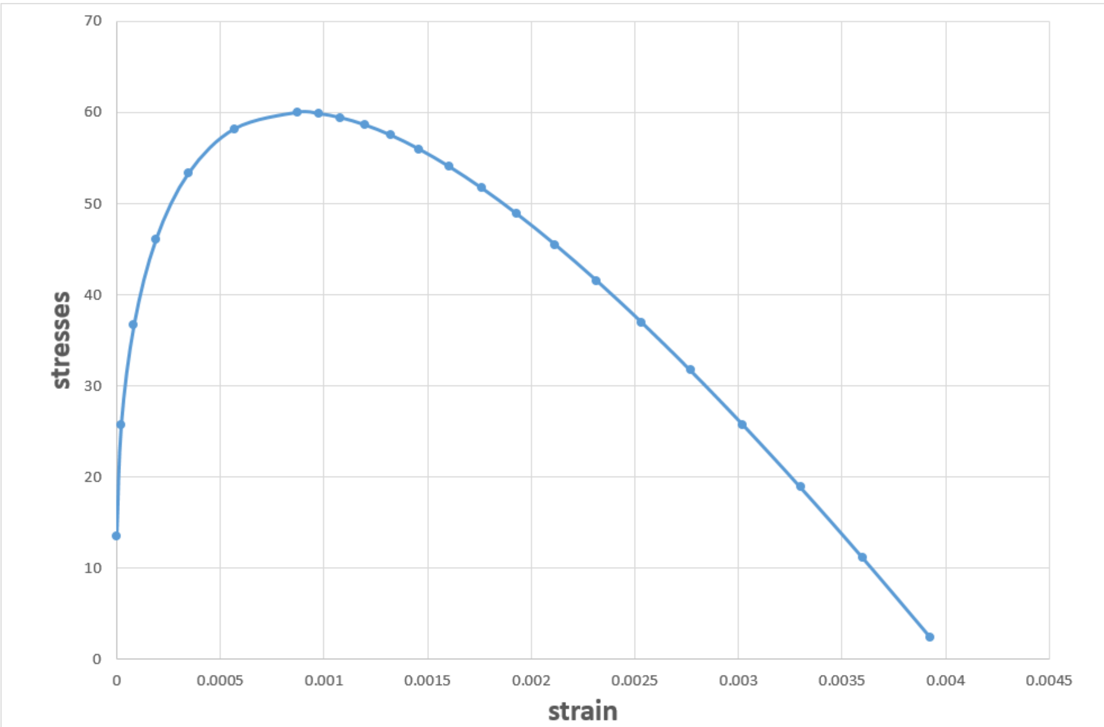


Figure (3-8) compression behaviour in a plastic state

Table (3-5) shows the equations by which it is possible to predict the stress of concrete in the case of plasticity in compression.

Table (3-5) Experimental models of stress-strain relationships for NCS and HSC

NO.	Researchers	Equations	Type of concrete
1	Hognestad (1951)	$\sigma_c = f_c[2(\varepsilon_c/\varepsilon_{co}) - (\varepsilon_c/\varepsilon_{co})^2]$	HSC
2	(Saenz, LP 1964) & (Hu and Schnobrich (1989))	$\sigma_c = \left[\frac{E_c\varepsilon_c}{1+(R+R_E-2)\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)-(2R-1)\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^2+R\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^3}\right]$ $R=\frac{R_E(R_\sigma-1)}{(R_\varepsilon-1)^2}-\frac{1}{R_\varepsilon},\ R_E=\frac{Ec}{Eo},\ Eo=\frac{fc}{\varepsilon_{co}}$ $R_\varepsilon=4,\ R_\sigma=4,\ and\ \varepsilon_{co}=0.0025$	HSC & NC
3	CEB-FIP MODEL CODE 1990 Thomas Telford	$\sigma_c = f_c\left[\frac{\frac{E_{ci}}{E_{co}}\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)-\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^2}{1+\left(\frac{E_{ci}}{E_{co}}-2\right)\frac{\varepsilon_c}{\varepsilon_{co}}}\right],\ E_{co}=f_c/\varepsilon_{co}$ $E_{ci}=2.15\times10^4(f_c/10)^{1/3}$	HSC & NC
4	Collins and Mitchell 1997	$\sigma_c = f_c\left[\frac{n\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)}{n-1+\left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^{nk}}\right],$ $n=0.8+\frac{fc}{17}$ $\varepsilon_{co}=\frac{fc}{Ec}\times\frac{n}{n-1}$ $k=0.67+\frac{fc}{62}>1$ $E_c=(3300\sqrt{fc}+6900)\times\frac{\gamma c}{2300},$ $use\ 1500\le\gamma c\le2500\ kg/m^3$	HSC & NC
5	Ertekin Oztekin, S. Pul, M. Husem (2003)[66]	$\sigma_c = f_c[k(\varepsilon_c/\varepsilon_{co})-(k-1)(\varepsilon_c/\varepsilon_{co})^2]$ $k=2-[(f_c-40)/70],\ \ (60MPa\le f_c\le90MPa)$	HSC
6	BS EN 1992-1-1 2004	$\sigma_c = f_c\left[\frac{kn-n^2}{1+(k-2)n}\right],$ $n=\varepsilon_c/\varepsilon_{co}$ $\varepsilon_{co}=0.0007\times f_c^{0.31}<0.0028$ $k=[1.05\times Ecm\times\lvert\varepsilon_{co}\rvert/f_c],\ \ Ecm=22\times10^3(0.1f_c)^{0.3}$	HSC & NC

Compute the compressive behavior by equation of BS EN 1992-1-1 2004(equations NO.6) in table (3-5) above.

Where:

σ_c: The compressive stress of concrete

f_c: The compressive strength of concrete

As for the tensile behaviour of concrete in the plastic state, it determined by the equation.

ε_c: The strain at any point

$\varepsilon_{co} = 2f_c/E_c$:is the strain at peak stress

And find the plastic strain from the equation

$$\varepsilon_{pl} = \varepsilon_c - \frac{\sigma_c}{E_c}$$

In the Abaqus program, the relationship of stress depended on plastic, not elastic, tension, so this relationship was made in the Excel program and the compression behaviour of concrete as defined in a table.

$$\sigma_t = f_t\left[f(w) - \frac{w}{w_c}f(w_c)\right]$$

$$\varepsilon = \frac{w}{L}$$

$$f(w) = \left[1 + \left(\frac{c_1 w}{w_c}\right)^3\right] exp\left(-\frac{c_2 w}{w_c}\right)$$

$$wc = 5.14 * \frac{Gf}{ft}$$

where:

L: length of element

w: is the crack opening displacement.

w_c: is the crack opening displacement at which stress can no longer be transferred.

c_1 is a material constant and $c_1 = 3.0$ for normal density concrete.

c_2 is a material constant and $c_2 = 6.93$ for normal density concrete

G_f, is the area under the softening curve, according to Beton (1993) estimated as:

$$G_f = G_{fo}\left(\frac{f\grave{c}}{10}\right)^{0.7}$$

2) Define Rebar material from, create material
- The density of steel is 7.85E-9 Tone/mm3
- The elastic behaviour of Young's module is 200000Mpa, and Poisson's ratio is 0.3.
- The plastic behaviour yield stress is 400Mpa, and zero plastic strain.

3) Define support material from, create material
- The elastic Young's module is 200000Mpa, and Poisson's ratio is 0.3.

4) Define CFRP material from, create material
- The density of CFRP is 1.81E-9 tonne/mm3
- The elastic Young's module is 230000Mpa, and Poisson's ratio is 0.25.
- the thickness of CFRP =0.337mm

III) Assembly modelling

The model parts have assembled this stage by calling the parts and putting them in their places, placing reinforcing bars inside the deep concrete beam and the support at the ends, also CFRP in form (U shape, and in the bottom face between supports or a single layer of CFRP in the bottom face Inter-strut or double layer of CFRP in the bottom face between the struts Figure (3-9) shows the assembly of the model.

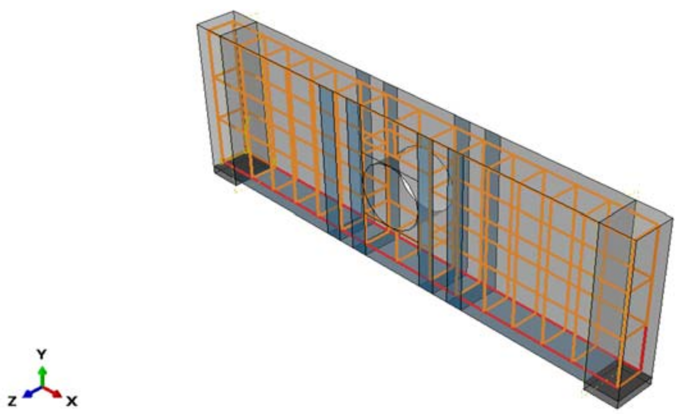


Figure (3-9) parts after assembly

IV) Step Modelling

The process develops a sequence that the ABAQUS program allows, like determining the type of analysis (Direct Cyclic, Dynamic Implicit, Geostatic, Soil, Static General and al etc.) and determining the period for the increases, determining the lowest pregnancy in which the analysis begins, as well as the lowest increase in pregnancy.

V) Interaction Modelling

Use This property if more than one part binds them together and makes them act as one material.

- Concrete to support, create an interaction (surface-to-surface contact) to link the concrete to the support.
- Rebar to concrete, create constraint (Embedded region) to link the rebar to the concrete.
- Concrete to CFRP, create constraint (Tie) to link the concrete to the CFRP.

VI) Load Modelling

- Pressure, create load to select the type of load (pressure).
- Boundary condition, create a boundary condition to select the type of reaction (hinge and roller). As shown in Figure (3-10)

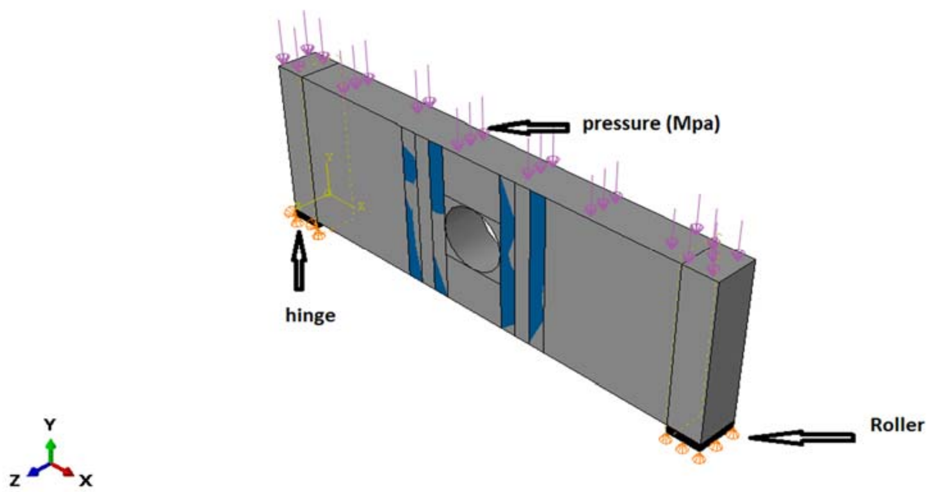


Figure (3-10) Load & boundary condition

VI) Mesh Modelling

The term meshing refers to dividing geometry into smaller parts, And the ABAQUS program will divide all parts into minor regular or irregular elements considering the finite element method program. All finite elements are dependent on a discrete component into the member and nodes. In this search taken the size of mesh was 50mm.

VII) Job Step

This step is critical since the modelling moves from the preprocess stage to the process stage. Furthermore, this stage serves as a checkpoint for all preceding steps, beginning with creating pieces and ending with the meshing. In this step, any missing or incorrect data will be identified—the result of this stage's importance in terms of double-checking and re-checking prior processes.

VIII) Visualization of Step Result

The visualization step is the simulation moves from entering analysis information (dimensions, material specifications, assembly, interaction, applied load, boundary conditions, and mesh) to showing results (Load deflection, Stresses and Failure mode). And will discuss the results obtained in the next chapter.

3.5. Check the results of the ABAQUS program for finite element analysis.

Using ABAQUS 2019 software in the research to verify the accuracy of the results, a deep concrete beam from previous research was re-modelled and analyzed. The results were measured and verified for accuracy.

Where the paper entitled "Behavior of reinforced concrete deep concrete beam with web openings strengthened with (CFRP) sheet*" for the year 2021, it selected by researchers (W. A. Jasim, Y. B. Abu Tahnat, A.s. M. Halahla). And enter all the parameters used for re-modelling the deep concrete beam bearing the symbol B1 (DP-S1). As shown in Figure (3-11) and Figure (3-12).

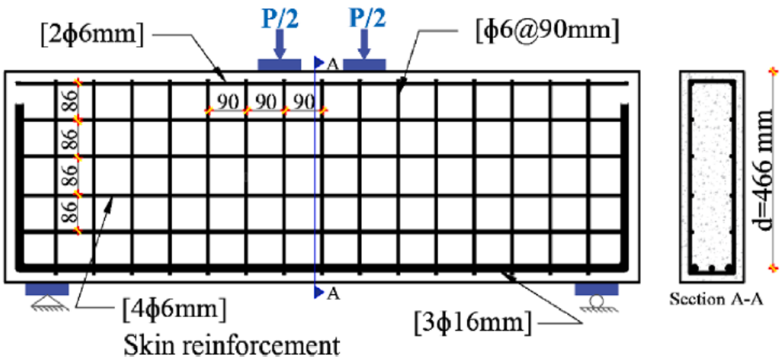


Figure (3-11) Reinforcement deep concrete beam B1 (DP-S1) (from original research)

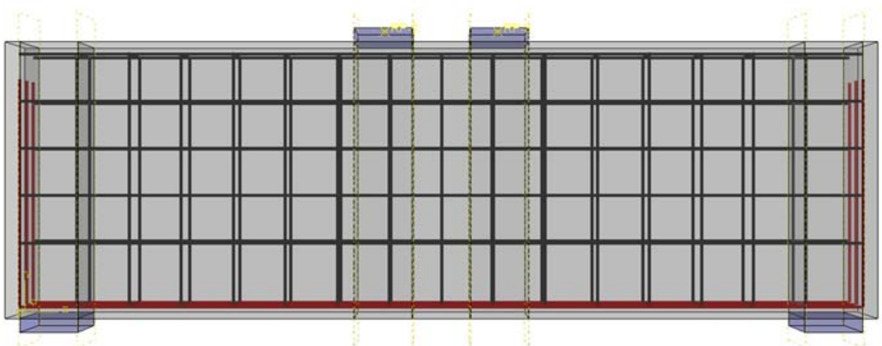


Figure (3-12) Re-modelling deep concrete beam B1 (DP-S1)

In the beginning, they are drawing the parts of the deep concrete beam, whose dimensions (150 x 500 x 1500) mm, and the reinforcement details are shown in Figure (3-12) according to the characteristics and parameters in the tables below.

Table (3-6) Properties of Reinforcement

Nominal Diameter mm	Measured Diameter mm	Area mm^2	Yield stress f_y MPa	Ultimate stress fu MPa	Elongation %
6	5.5	23.75	623.960	685.50	8.50
16	16	201	569.670	668.790	12.0

Table (3-7) Properties of Concrete

Item	f'_c (MPa)	ft Mpa	fr Mpa	Ec Mpa	Y
Value	27	3.50	3.10	24,667	0.20

Table (3-8) Parameters of damage-plasticity

Parameter name	Value
Dilation angle (ψ)	36°
Eccentricity (e)	0.1
fb0 /fc0 (initial uniaxial compressive yield stress divided by initial equiaxial compressive yield stress)	1.16
K (on the tensile meridian, the ratio of the second stress invariant)	0.667

After completing the property of material definition process and assembling the model, defining the boundary conditions, and meshing the appropriate, it was analyzed to get the results

Table (3-9) Comparison of the ultimate load outcome (experimental, ABAQUS and ABAQUS /Re-modeling)

Result	Value
Pu(experimental) [KN]	500.00
Pu (ABAQUS) [kN]	570.00
Pu (ABAQUS /Re-modelling) [kN]	560.00
Pu(experimental)/Pu (ABAQUS)	0.88
Pu(experimental)/ Pu (ABAQUS /Re-modelling)	0.89
Pu (ABAQUS)/Pu (ABAQUS /Re-modelling)	1.02
Δu (experimental) [mm]	9.00
Δu (ABAQUS) [mm]	7.90
Δu (ABAQUS /Re-modelling) [mm]	8.20
Δu (experimental)/ Δu (ABAQUS / Re-modelling)	1.09
Δu (experimental)/Δu (ABAQUS)	1.14
Δu (ABAQUS)/Δu (ABAQUS / Re-modelling)	0.96

CHAPTER 4

OUTPUTS

4.1. Introduction

The results are calculated depending on the initial cracks load and how they start, the ultimate load and deflection, the type of failure and the load-deflection relationship. Where strengthen deep beams use three methods (single laminate CFRP at the lower face or several laminates (CFRP) U-shaped in the flexural area and laminate CFRP at the lower front or two laminates CFRP at lower face), the results are as follows.

4.2. Part A

The specified part is normal strength concrete (NSC) with compressive strength (25 Mpa), where Three groups each have four models; this is modelled based on creation with the ABAQUS Finite Elements program.

4.2.1. Group 1

Table (4-1) shows the results obtained from studying models of deep concrete beams that without openings, as shown in Figure (4-1), strengthened three with (CFRP). The fourth is an un-strengthened beam considered a reference beam for the group.

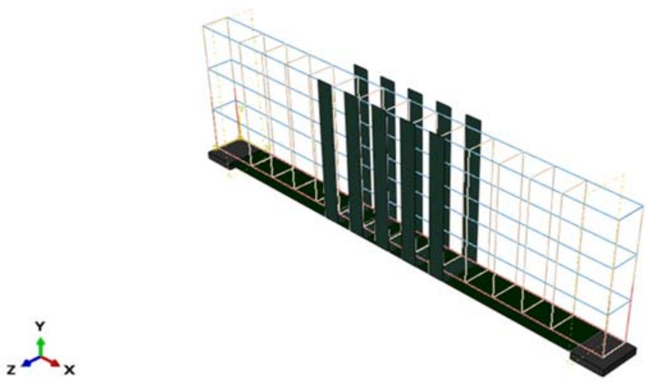


Figure (4-1) Deep concrete beam (NSC) type DB_GB_S_CFRP

Table (4-1) Result of group 1

Model	Cracking Load KN/M	Deflection mm	Failure Load KN/M	Deflection mm
DB_GB	131.75	0.3	568.5	5.19
DB_GB_S_CFRP	131.75	0.29	628.5	5.68
DB_GB_B_CFRP	144.75	0.32	620.25	5.08
DB_GB_2B_CFRP	144.75	0.32	643	5.05

☒ Shape and value of first crack load

All the deep beams in this group had their first cracks appear simultaneously in the bending and shearing regions, where the cracks developed in the bending area upwards till the neutral axis. In contrast, the shear cracks developed diagonally upwards to the upper face figure (4-2).

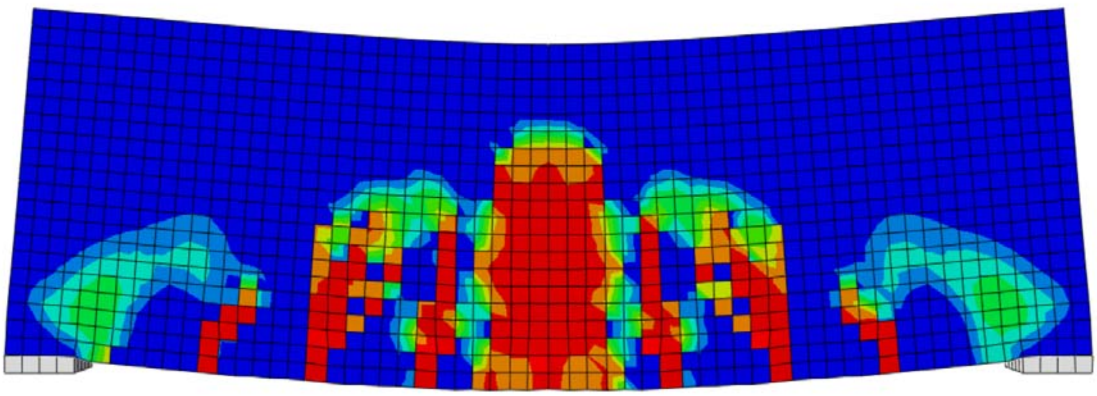


Figure (4-2) model of cracking in DB_GB

The initial crack load increases with the presence of CFRP compared to the reference beam. Except for model (DB_GB_S_CFRP), it has a U-shaped CFRP and a single layer at the lower face, with the same initial cracking load for reference beam (131.75KN/m) due to the stress concentration between U-shaped CFRP strips.

☒ The failure load and load-deflection mode

All models of this group failed when the steel reached the ultimate stress (fy) imposed at 400 MPa, where the highest value of the failure load was for DB_GB_2B_CFRP, followed by DB_GB_B_CFRP, then DB_GB_S_CFRP. 13%,9% and 10% respectively Increasing the CFRP layers on the underside of a deep concrete beam as expected increases the ultimate load

As for the beam DB_GB_2B_CFRP, which has double layers of CFRP, it had the lowest deflection compared to the rest of the beam, followed by the beam DB_GB_S_CFRP. Due to the presence of additional U-shaped CFRP strips that increased stiffness.

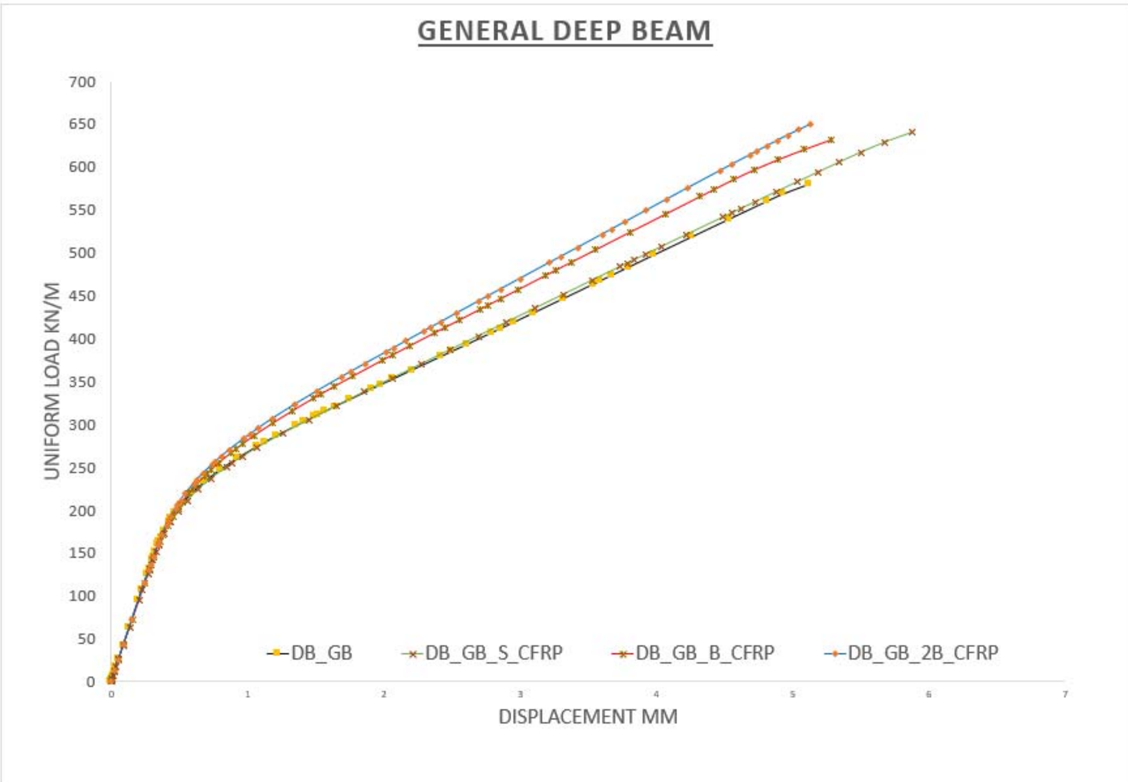


Figure (4-3) Load-deflection relationship for group 1

4.2.2. Group 2

Table (4-2) shows the results obtained from the second group of deep concrete beams with square openings in the bending region. As shown in Figures (4-4), three of which are reinforced with CFRP, and the fourth is an unreinforced package that is the reference beam for this group.

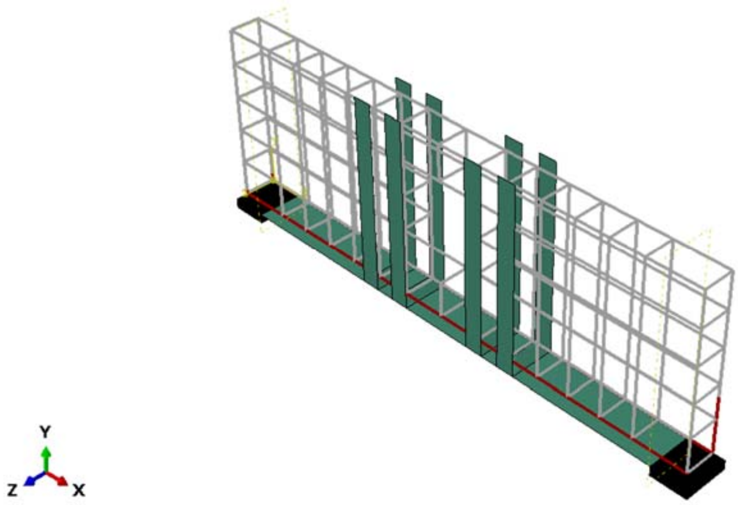


Figure (4-4) deep concrete beam (NSC) type DB_SO_S_CFRP

Table (4-2) Result of group 2

Model	**Cracking Load KN/m**	**Deflection mm**	**Failure Load KN/m**	**Deflection mm**
DB_SO	125	0.29	519.5	4.98
DB_SO_S_CFRP	141.75	0.33	567	5.11
DB_SO_B_CFRP	141.75	0.33	570.25	5.27
DB_SO_2B_CFRP	141.75	0.32	600.5	5.3

- Shape and value of first crack load

The reference beam for this group (DB_SO) started cracking with a load of 125KN/m due to stress concentration, and thus cracks arise around the square opening, especially in the lower chord. At the same time, the rest of the models increased the load at which the crack started and was equal for all beams containing CFRP. It doses noted that the deflection of the model (DB_SO_S_CFRP) and model (DB_SO_B_CFRP), which includes a single layer of CFRP on the bottom face, is equal (0.33mm), As shown in Figure (4-5).

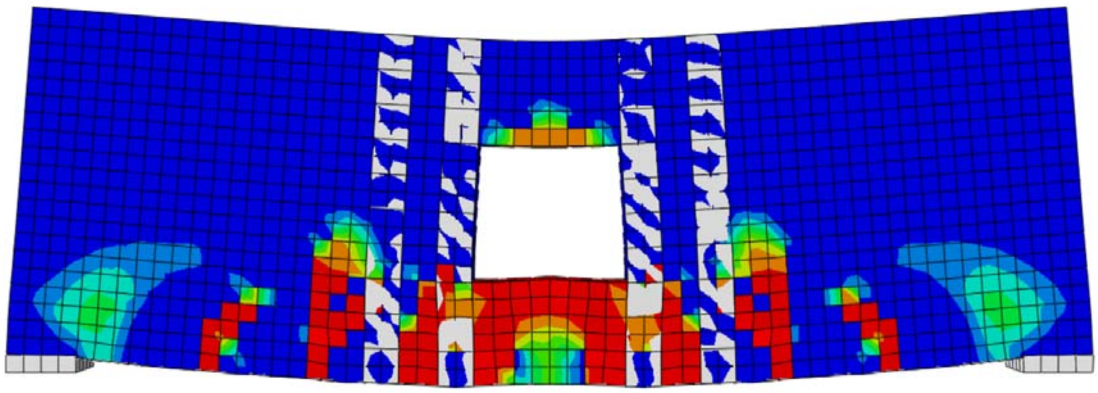


Figure (4-5) model of cracking in DB_SO_S_CFRP

- load-deflection model and failure load

Compared with the reference beam (DB_SO), DB_SO_2B_CFRP deep concrete beam has the highest improvement of 16%, followed by DB_SO_B_CFRP with a gain of 10%, and finally DB_SO_S_CFRP with an improvement of 9%. As for the deflection, DB_SO_S_CFRP has the lowest and highest. DB_SO_2B_CFRP give a high ductility by increasing the deflection and strength. Figure (4-6) shows the relationship between the stages of growing the distributed force on the models with the corresponding deflection.

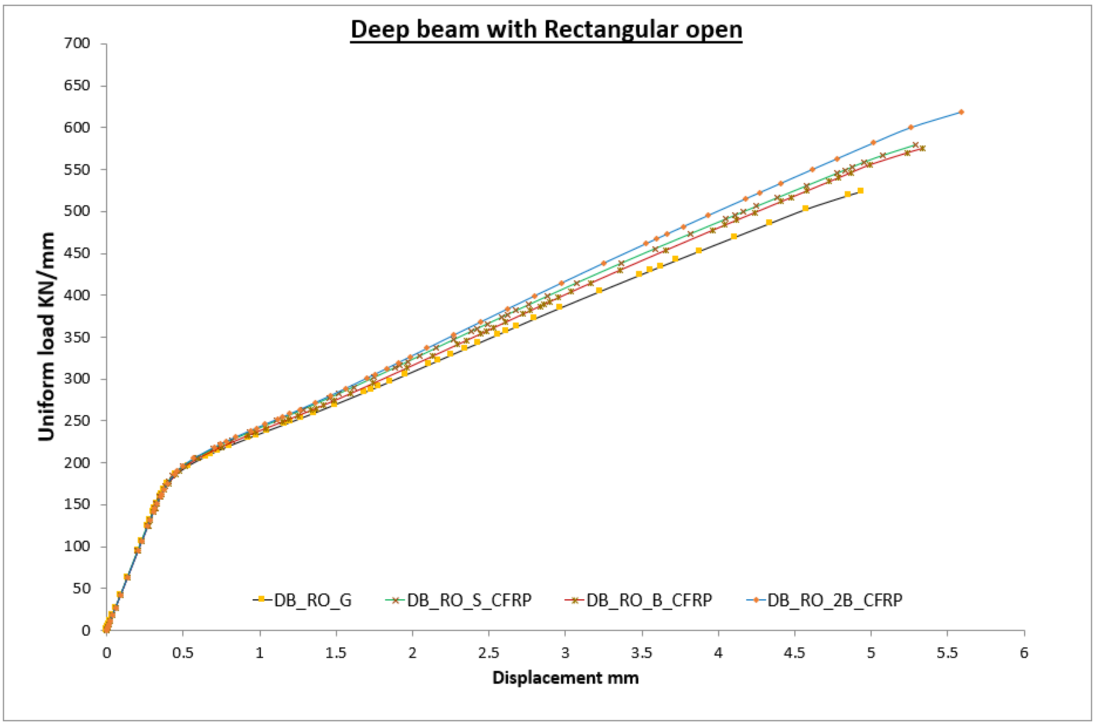


Figure (4-6) load-deflection relationship for group 2

4.2.3. Group 3

Table (4-3) shows the results obtained from the study of the third group of samples of deep concrete beams with a circular opening in the bending area as shown in Figure (4-7), three of which reinforced with (CFRP) and the fourth is for an unreinforced package that is the reference package for this group.

Table (4-3) Result of group 3

Model	Cracking Load KN/M	Deflection mm	Failure Load KN/M	Deflection mm
DB_CO	131.75	0.3	525.25	5.03
DB_CO_S_CFRP	141.75	0.32	569.75	5.08
DB_CO_B_CFRP	141.75	0.32	567.75	5.2
DB_CO_2B_CFRP	141.75	0.33	599	5.23

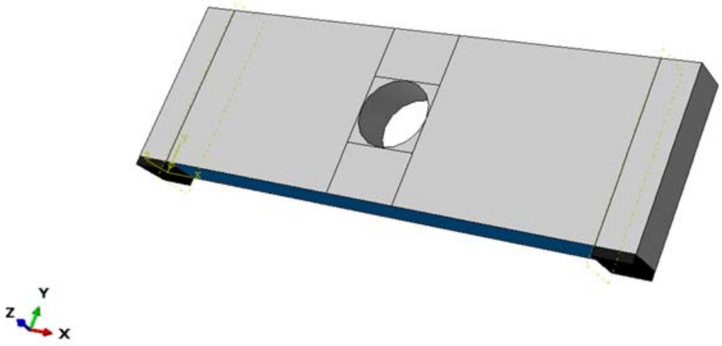


Figure (4-7) deep concrete beam (NSC) type DB_CO_B_CFRP

☒ Shape and value of first crack load

The cracks initially start in the bending area and then propagate upwards until they intersect the cracks below the circular opening, which appeared earlier before. Diagonal cracks begin near the supports and continue towards the upper face.

The presence of the circular opening reduced the crack load by comparing the (DB_CO) model with the model without aperture, and the initial crack load was (131.75 kN/m) with a deflection of 0.3 mm, and that the presence of CFRP on the bottom face improving the initial crack load,

☒ load-deflection model and failure load

As the load increases, the stress of steel under the opening increase until it reaches ultimate stress, according to Figure (4-8), which shows the state when the stress of the steel comes ultimate stress (fy = 400 MPa). In (DB_CO_2B_CFRP), which corresponds to a distributed load (599 kN/m) that represents a 14% improvement from the reference beam for this group compared to an equal improvement percentage for the other two models (DB_CO_S_CFRP & DB_CO_B_CFRP) each of 8%, it also gives a higher ductility see Figure (4-9).

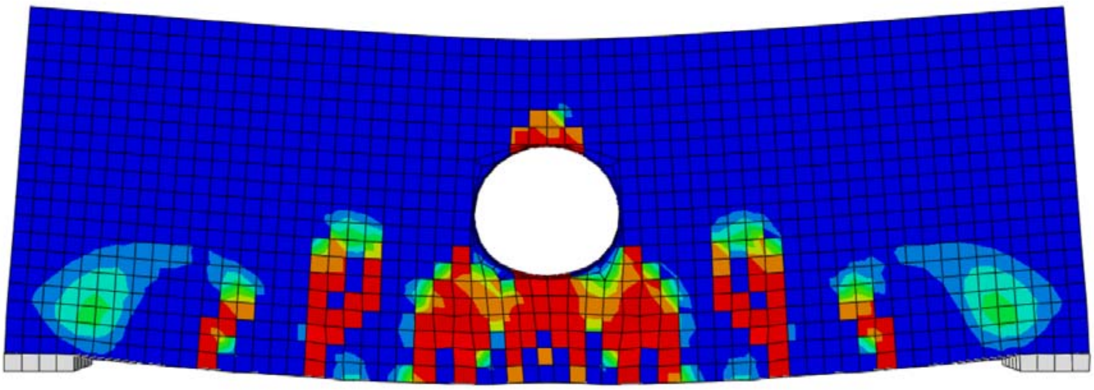


Figure (4-8) model of cracking in DB_CO_B_CFRP

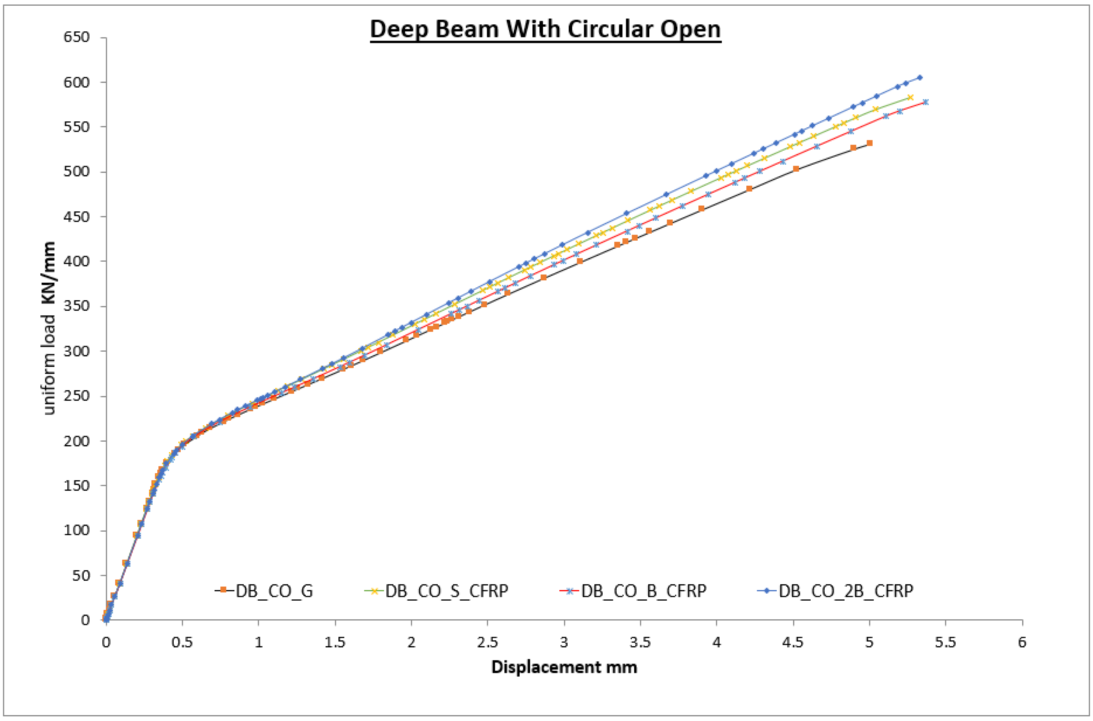


Figure (4-9) load-deflection relationship for group 3

4.3. Part B

Specified the part is to high strength concrete (HSC) with compressive strength (60 Mpa), where Three groups each group have four models; this is modelled based on creation with the Abaqus Finite Elements program.

4.3.1. Group 4

Table (4-4) shows the results obtained from studying models of deep concrete beams without openings as shown in Figure (4-10), three of which strengthened with (CFRP). The fourth is an un-strengthened deep concrete beam considered a reference beam for the group.

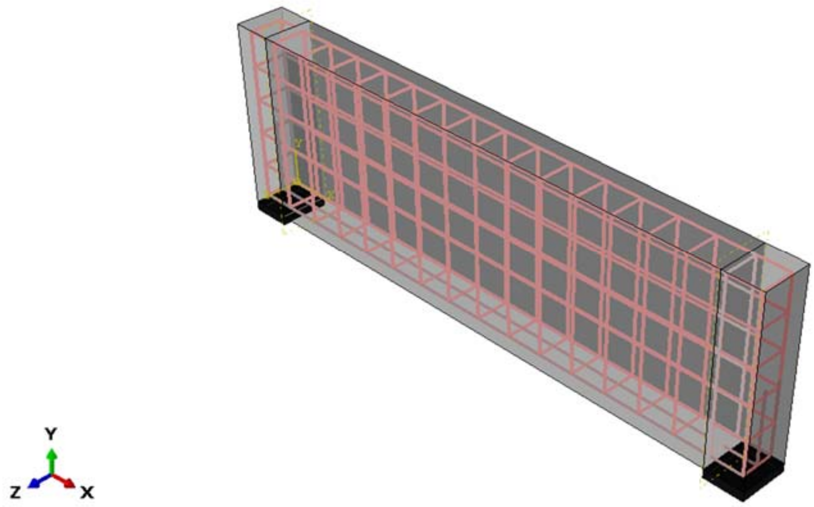


Figure (4-10) deep concrete beam (HSC) type DB_HSC_GB

Table (4-4) Result of group 4

Model	Cracking Load KN/M	Deflection mm	Failure Load KN/M	Deflection mm
DB_HSC_GB	320.5	0.53	756	4.28
DB_HSC_GB_S_CFRP	324.75	0.53	807.25	4.52
DB_HSC_GB_B_CFRP	323	0.53	794.5	4.4
DB_HSC_GB_2B_CFRP	324.75	0.527	828.75	4.54

☒ Shape and value of first cracks load all

The deep beams in this group had their first cracks appear simultaneously in the bending and shearing regions, where the cracks developed in the bending area upwards till the neutral axis. In contrast, the shear cracks developed diagonally upwards to the upper face figure (4-11).

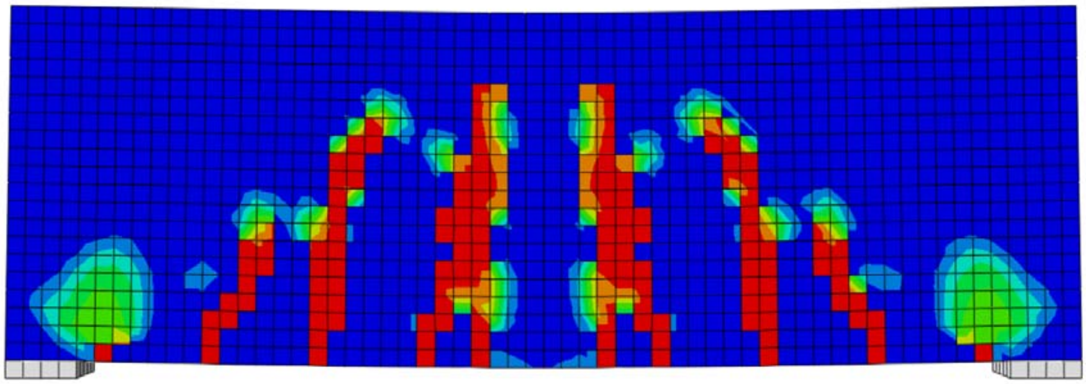


Figure (4-11) model of cracking in DB_HSC_GB

The initial cracks load rises with the presence of CFRP in the bottom face of the deep concrete beam compared to the reference beam. It also increases when the number of layers increases (DB_HSC_2B_CFRP). And the U-shape CFRP does not impact on initial cracks load because it starts from the bottom face of the deep beam. After that, upward between U-shape CFRP, as shown in Figure (4-12).

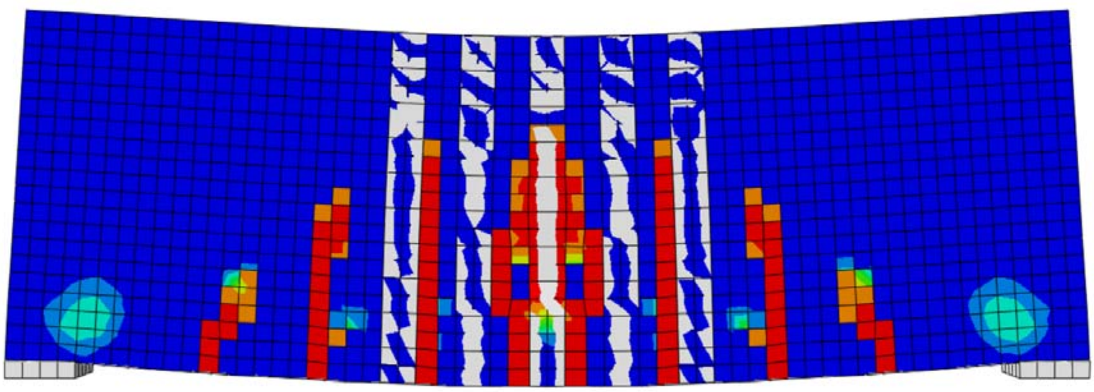


Figure (4-12) model of cracking in DB_HSC_S_CFRP

- The failure load and load-deflection mode

All models in this group collapsed when the shear reinforcement reached the ultimate stress (fy) imposed at 400 MPa, with the highest failure load value for DB_HSC_GB_2B_CFRP, followed by DB_HSC_GB_S_CFRP, and then DB_HSC_GB_B_CFRP. With an improvement of 10%, 7%, and 5%, respectively, the reason is due to the increase of the CFRP layers under the deep concrete beam face as expected increases the final load

Figure (4-13) shows that the difference in improvement between the two models (DB_HSC_S_CFRP & DB_HSC_B_CFRP) is imperceptible compared to the deep concrete beam without CFRP for this group and that there is a slight discrepancy between the deflection. Hence, it considered that the presence of CFRP increases the failure load, but the deviation remains close.

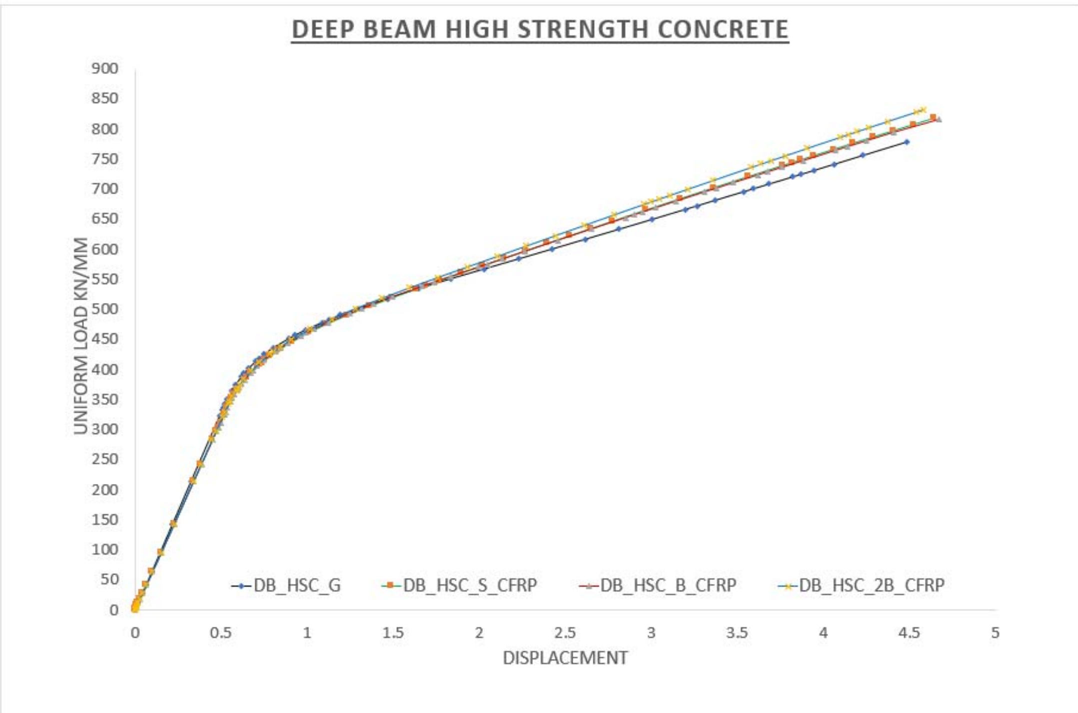


Figure (4-13) load-deflection relationship for group 4

4.3.2. Group 5

Table (4-5) shows the results obtained from studying models of deep concrete beams with square openings as shown in Figure (4-14), three of which strengthened with (CFRP). The fourth is an un-strengthened deep concrete beam considered a reference beam for the group.

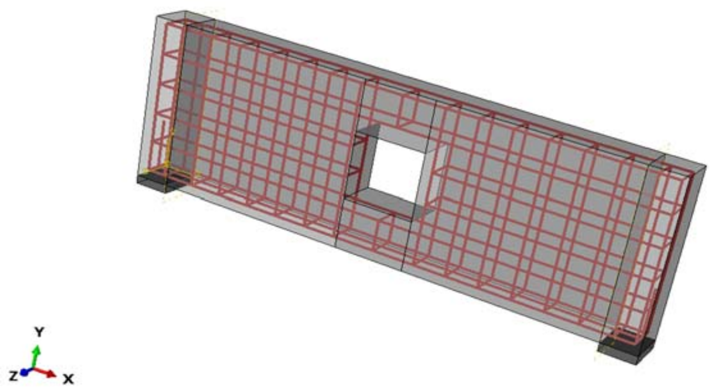


Figure (4-14) deep concrete beam (HSC) type DB_HSC_SO

Table (4-5) Result of group 5

Model	Cracking Load KN/M	Deflection mm	Failure Load KN/M	Deflection mm
DB_HSC_SC	303.5	0.52	667	4.1
DB_HSC_SC_S_CFRP	324.75	0.55	730.75	4.38
DB_HSC_SC_B_CFRP	320.5	0.55	708	4.21
DB_HSC_SC_2B_CFRP	329.25	0.56	759.75	4.41

- Shape and value of the first cracks load

The cracks started with a load of 303.5 kN/m for the deep reference beam (DB_HSC_SO) from the bottom. Then cracked arise in the lower chord after that crack created in the upper chord of the square open. Finally, cracks begin near the supports, and the behaviour of the rest of the models containing CFRP in the group with convergence by the initial cracks load with equal deflection of (0.55 mm) as shown in Figure (4-15).

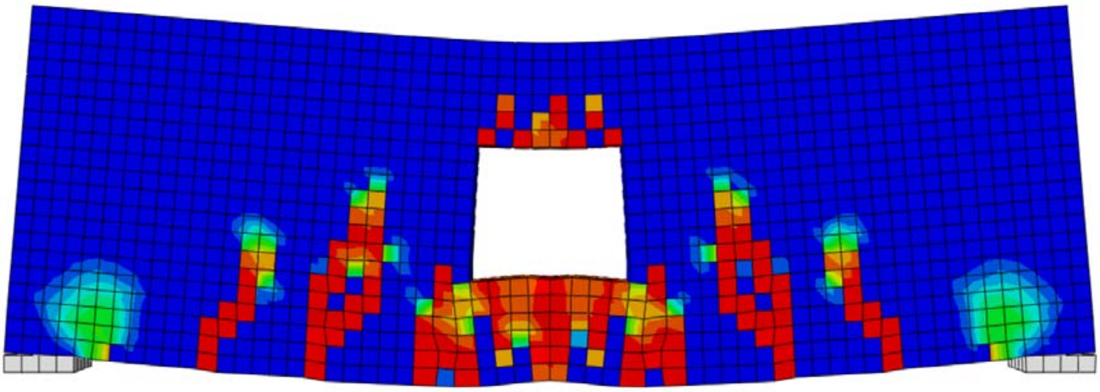


Figure (4-15) model of cracking in DB_HSC_SO

The initial cracks load rises with the presence of CFRP in the bottom face of the deep concrete beam compared to the reference beam, and it also increases when the number of layers increases, as is the case of (DB_HSC_SO_2B_CFRP). As for the U-shape of CFRP impact prevents stress concentration in the corners of the square opening and increases the load of the initial cracks see deep concrete beam model (DB_HSC_SO_S_CFRP) Figure (4-16). Still, the number of CFRP layers is more effective on the bottom face.

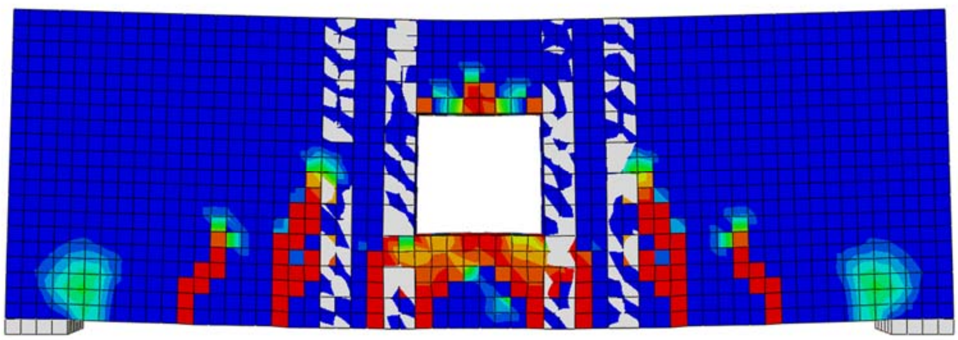


Figure (4-16) model of cracking in DB_HSC_SO_S_CFRP

☒ The failure load and load-deflection mode

All models in this group collapsed when the bending reinforcement reached the ultimate stress (fy) imposed at 400MPa, with the highest failure load value for DB_GB_2B_CFRP, followed by DB_GB_S_CFRP, and then DB_GB_B_CFRP. With an improvement of 14%, 10%, and 6%, respectively, the reason is due to the increase of the CFRP layers under the deep concrete beam face as expected increases the final load

Figure (4-17) shows that the difference in improvement between the two models (DB_HSC_S_CFRP & DB_HSC_B_CFRP) is imperceptible compared to the deep concrete beam without CFRP for this group and that there is a slight discrepancy between the deflection. Hence, it considered that the presence of CFRP increases the failure load, but the deflection remains close.

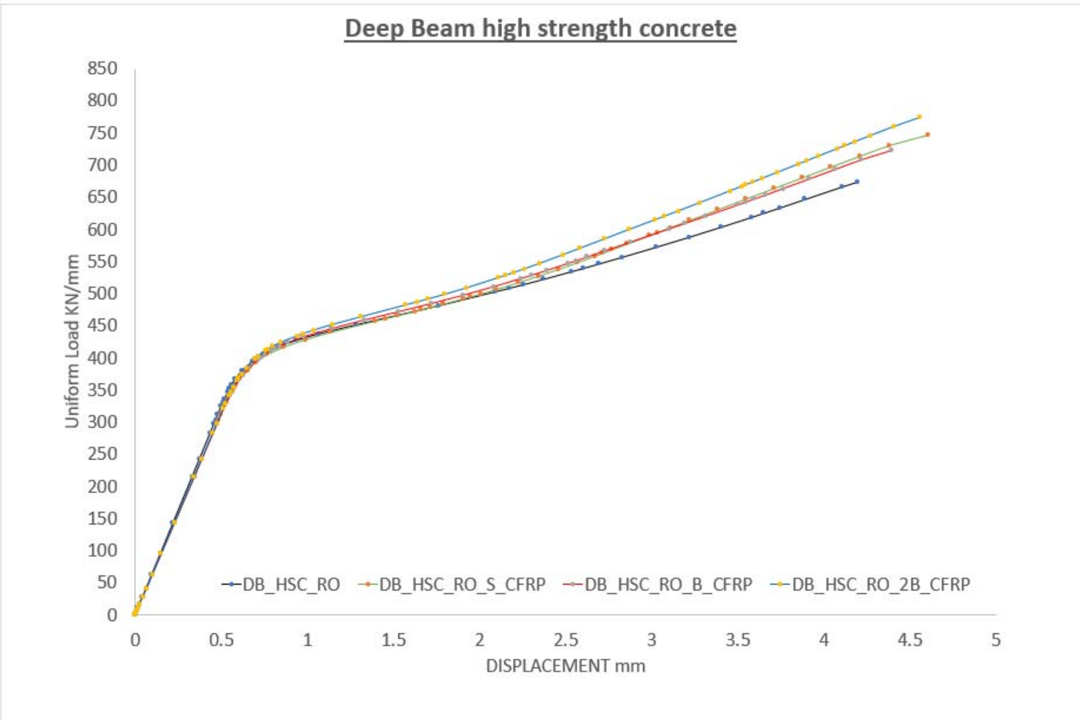


Figure (4-17) load-deflection relationship for group 5

4.3.3. Group 6

Table (4-6) shows the results obtained from studying models of deep concrete beams with circular openings as shown in Figure (4-18), three of which strengthened with (CFRP). The fourth is an un-strengthened deep concrete beam considered a reference beam for the group.

Table (4-6) Result of group 6

Model	Cracking Load KN/M	Deflection mm	Failure Load KN/M	Deflection mm
DB_HSC_CO	312	0.53	684.75	4.19
DB_HSC_CO_S_CFRP	324.75	0.54	722.75	4.34
DB_HSC_CO_B_CFRP	320.5	0.54	705.5	4.16
DB_HSC_CO_2B_CFRP	329.25	0.55	745.25	4.29

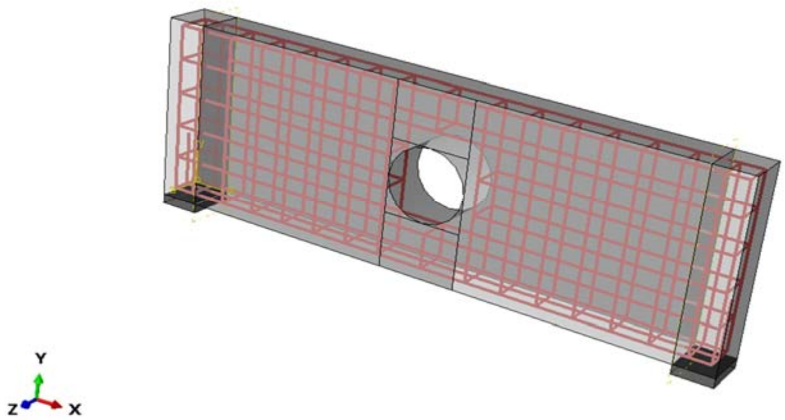


Figure (4-18) deep concrete beam (HSC) type DB_HSC_CO

☒ Shape and value of the first cracks load

The cracks started with a load of 312kN/m for the bottom's deep reference beam (DB_HSC_CO). Then cracked arise in lower chord after that crack created in the upper chord of the circular opening. finally, cracks begin near the supports, as well as the behaviour of the rest of the models including CFRP in the group with convergence by the initial cracks load with equal deflection of (0.54mm) see Figure (4-19).

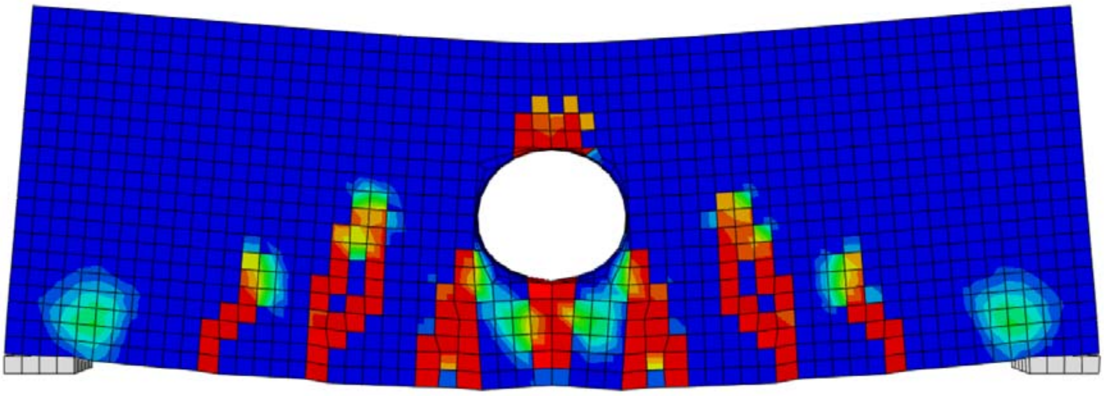


Figure (4-19) model of cracking in DB_HSC_CO

The initial cracks load rises with the presence of CFRP in the bottom face of the deep concrete beam compared to the reference beam, and it also increases when the number of layers increases, as is the case of (DB_HSC_CO_2B_CFRP). As for the U-shape of CFRP impact prevents stress concentration around the circular opening and increases the load of the initial cracks see deep concrete beam model (DB_HSC_CO_S_CFRP) Figure (4-20). Still, the number of CFRP layers on the bottom face is more effective.

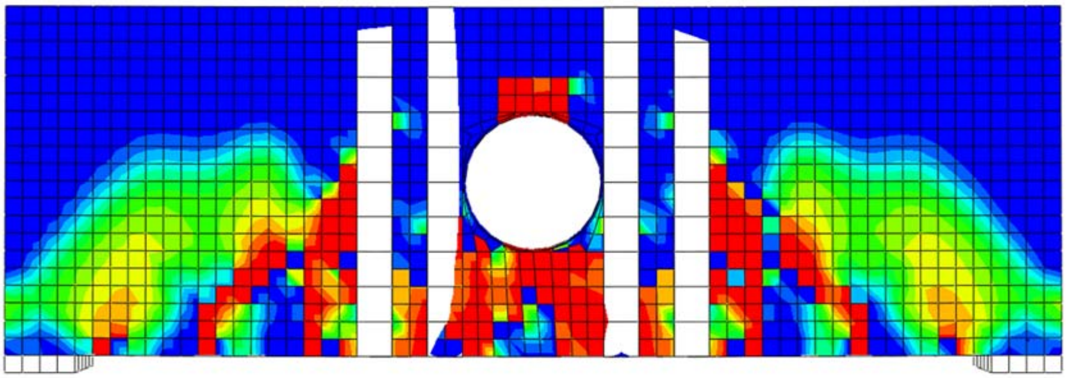


Figure (4-20) model of cracking in DB_HSC_CO_S_CFRP

☒ The failure load and load-deflection mode

All models in this group collapsed when the bending reinforcement reached the ultimate stress (fy) imposed at 400 MPa, with the highest failure load value for DB_HSC_CO_2B_CFRP, followed by DB_HSC_CO_S_CFRP, and then DB_HSC_CO_B_CFRP. The improvement of 9%, 6%, and 3%, respectively, increased the CFRP layers under the deep concrete beam face as expected, increasing the final load.

Figure (4-21) shows that the difference in improvement between the two models (DB_HSC_S_CFRP & DB_HSC_B_CFRP) is imperceptible compared to the deep concrete beam without CFRP for this group and that there is a slight discrepancy between the deflection. Hence, it considered that the presence of CFRP increases the failure load, but the deviation remains close.

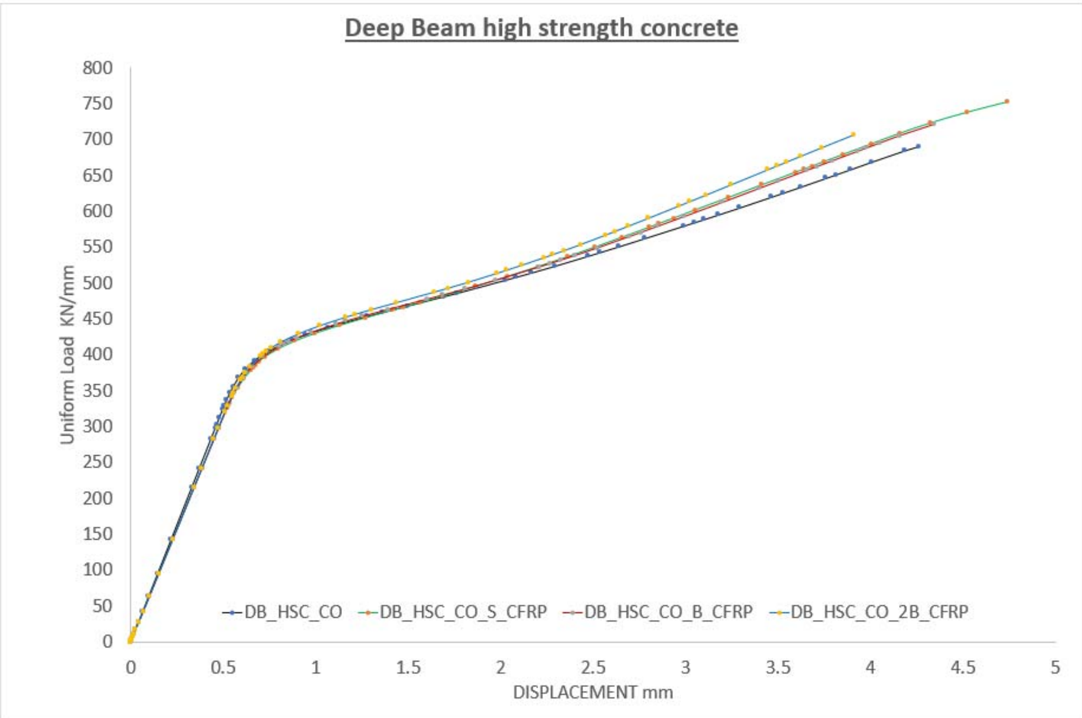


Figure (4-21) load-deflection relationship for group 6

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1. General

This chapter summarizes the results of applying the 3-D non-linear finite element analysis using ABAQUS on deep concrete beams with or without openings and CFRP. for normal or high strength concrete .

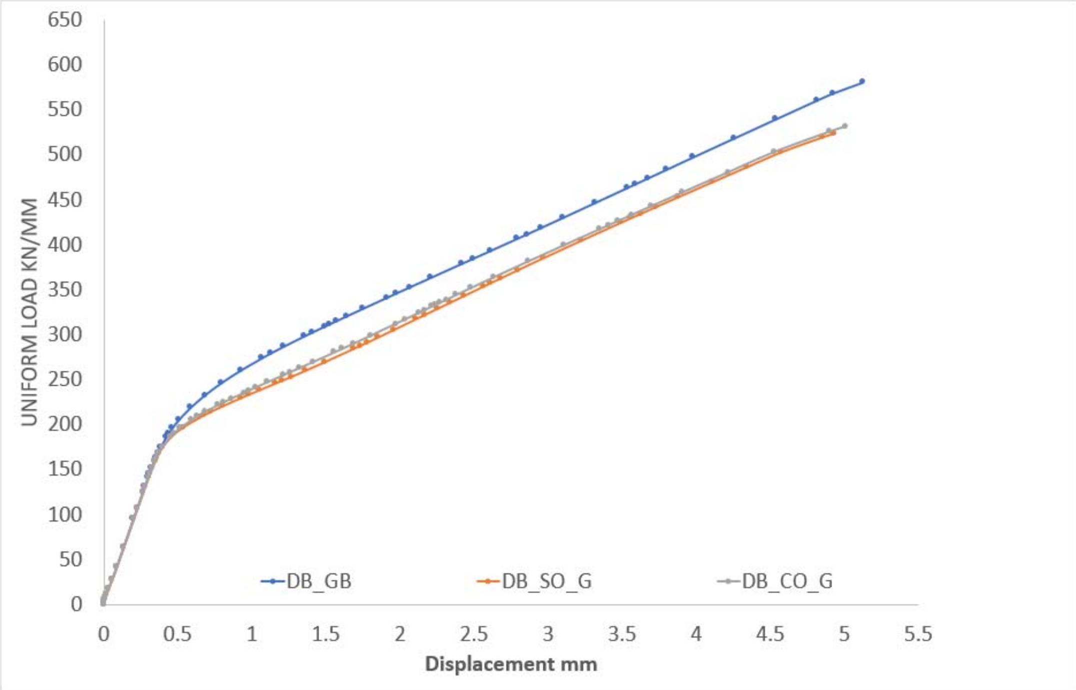
Use ABAQUS finite element program to examine three types of CFRP strengthening and two compressive strength values for Verification 24 models deep concrete beams.

5.2. Summary of the Output of Part A

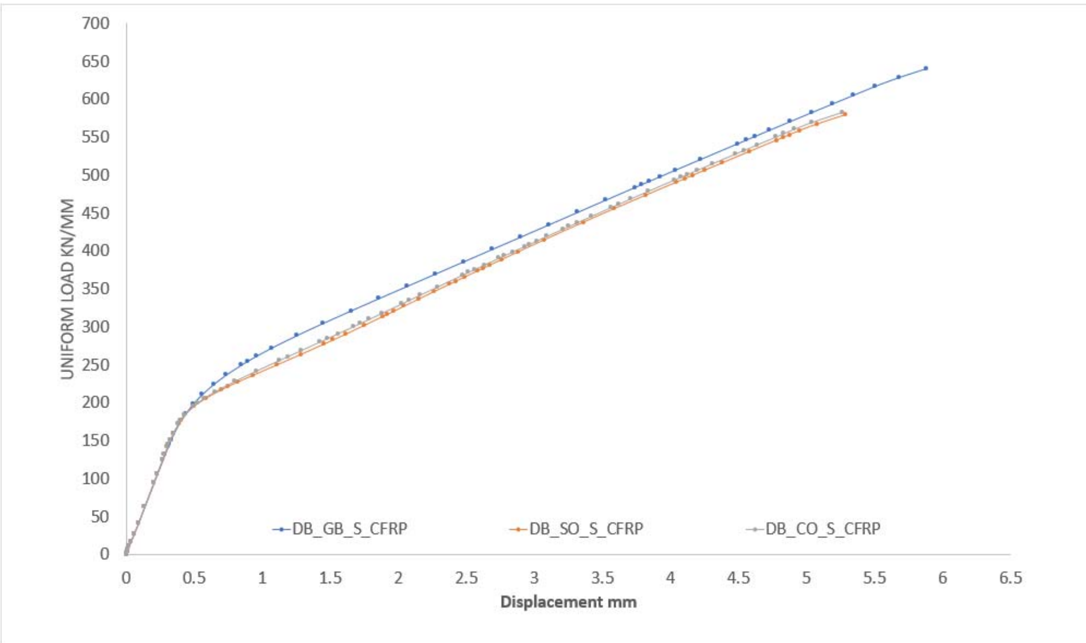
The opening in the flexural region directly affects the failure load simultaneously, a small impact to the shape of the opening about 8.5% and 7.5% for the square and circular openings, respectively. Compared to deep concrete beam without opening (difference in opening shape about 1%) .

The CFRP does not cause much difference in the failure load for the different opening shape and stay little than the failure load for the same type of strengthening for the deep concrete beam without opening .

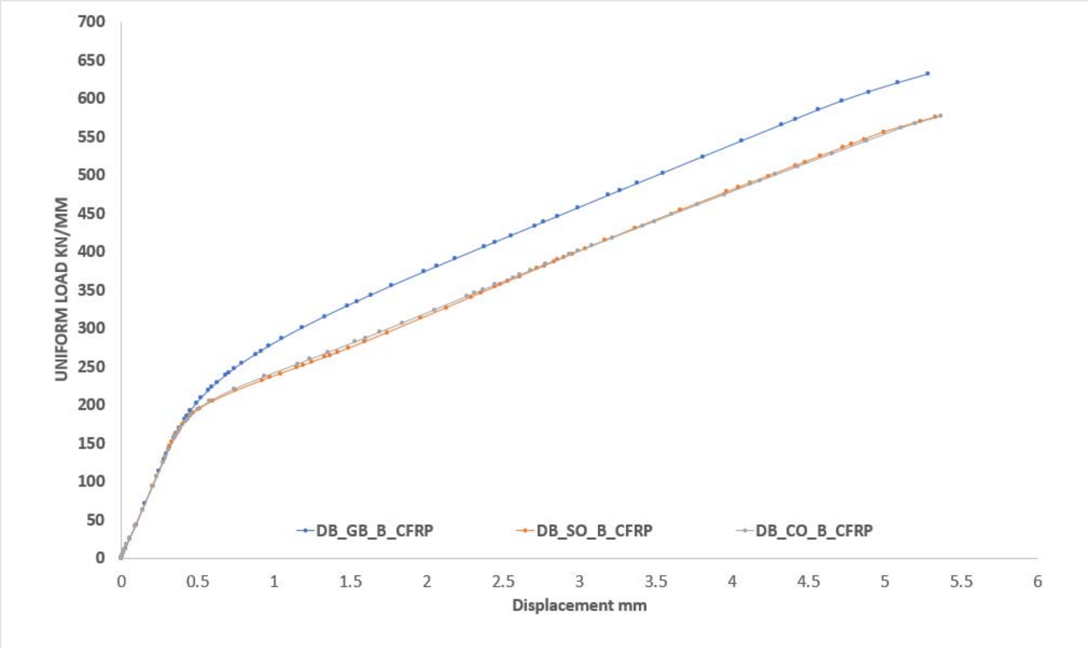
The deep concrete beam strengthened with a double layer of CFRP is superior to the rest of the deep concrete beams with a single layer of CFRP in the bottom face. And Figure (5-1) shows the difference in the shape of the openings with different methods of strengthening.



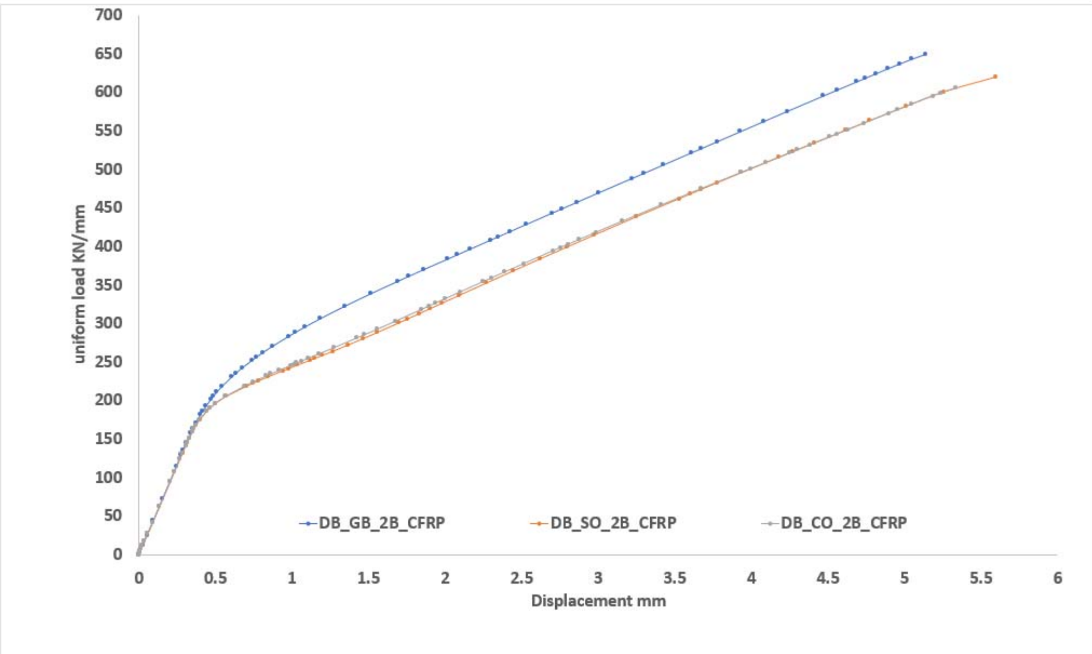
(a) Load-deflection plan for a deep concrete beam that does not contain CFRP



(b) Load-deflection scheme for a deep concrete beam strengthened with a layer of CFRP on the bottom face and U shape stripe in a flexural zone



(c) Load-deflection plans for a deep concrete beam supplemented with a single layer of CFRP on the bottom face.

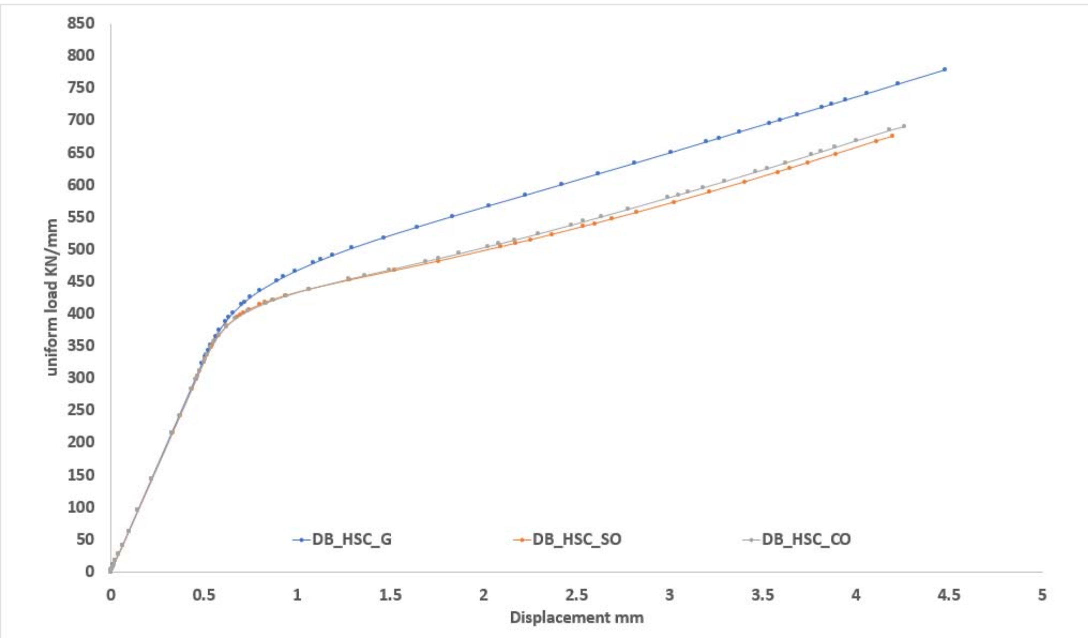


(d) Load-deflection plans for a deep concrete beam supplemented with a double layer of CFRP on the bottom face.

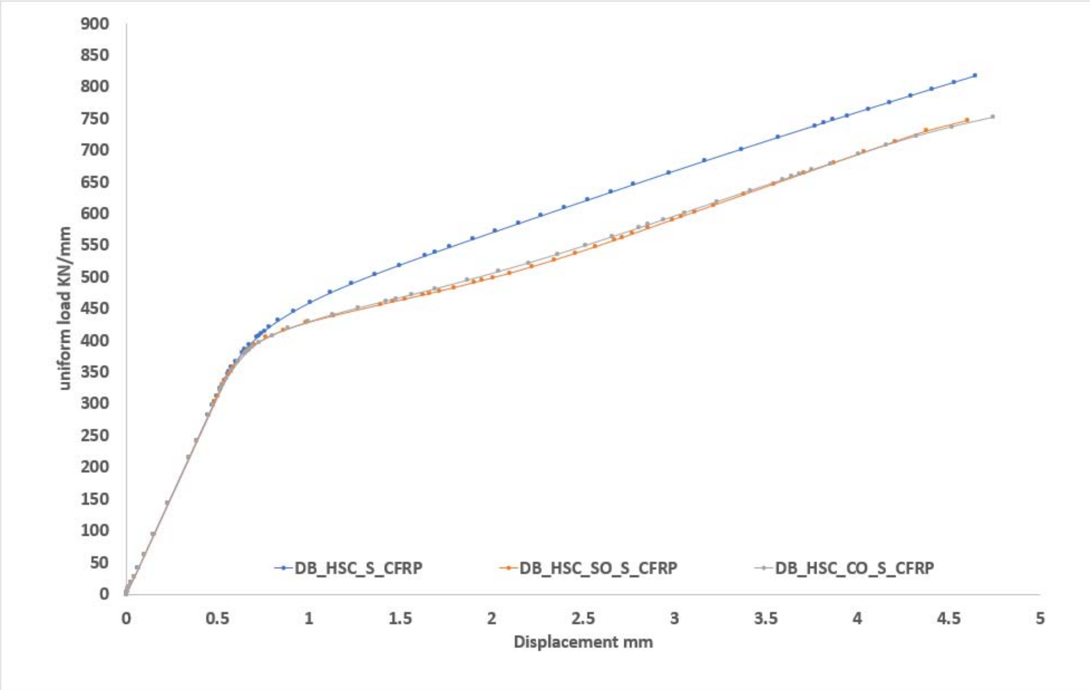
Figure (5-1) Difference in the shape of the openings with different methods of strengthening for NSC he opening in the flexural region directly affects the failure load simultaneously, a small impact to the shape of the opening about 11.7% and 9.4% for the square and circular openings, respectively. Compared to deep concrete beam without opening (difference in opening shape about 2.3%).

The CFRP does not cause much difference in the failure load for the different opening shape and stay little than the failure load for the same type of strengthening for the deep concrete beam without opening.

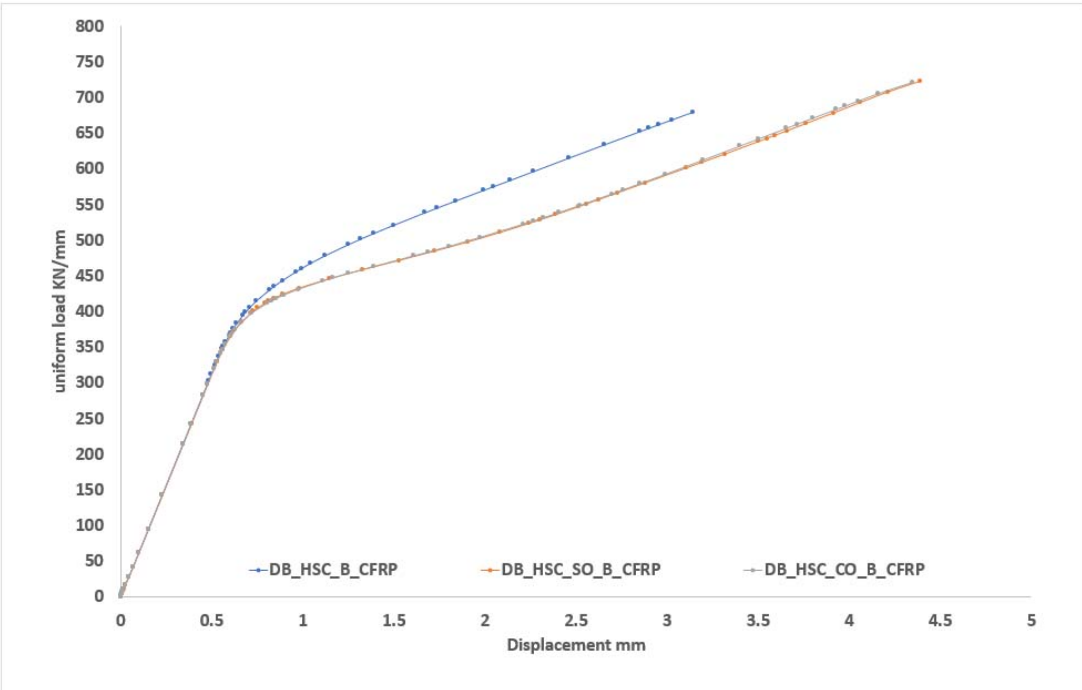
The deep concrete beam strengthened with a double layer of CFRP is superior to the rest of the deep concrete beams with a single layer of CFRP in the bottom face. And Figure (5-2) shows the difference in the shape of the openings with different methods of strengthening.



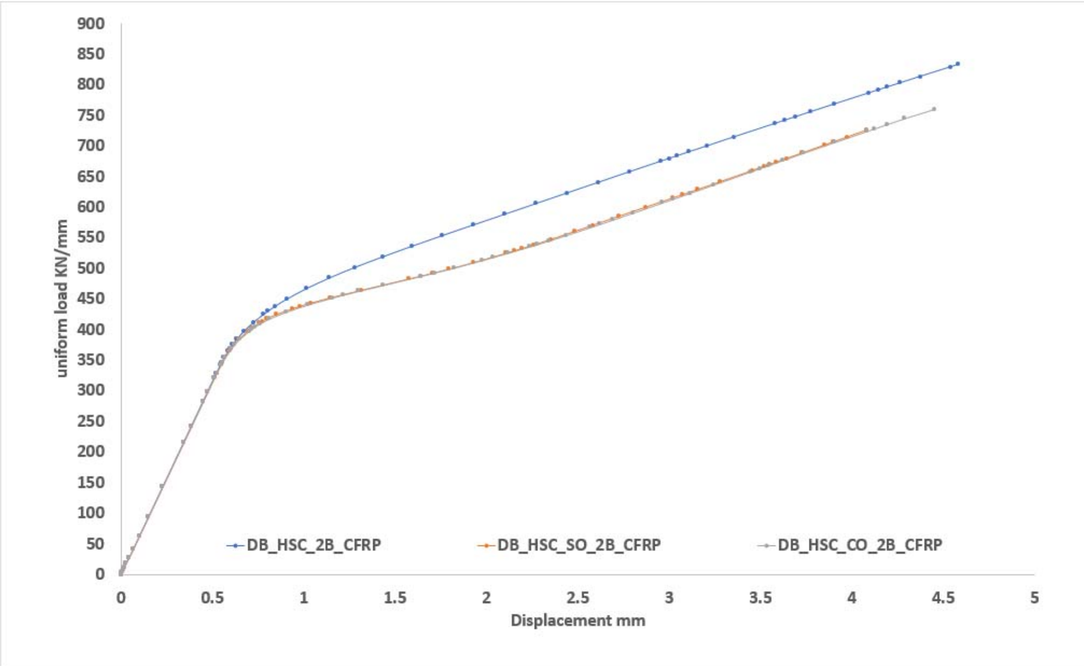
(a) Load-deflection plan for a deep concrete beam that does not contain CFRP



(b) Load-deflection scheme for a deep concrete beam strengthened with a CFRP layer on the bottom face and U shape stripe in a flexural zone.



(C) Load-deflection plans for a deep concrete beam supplemented with a single layer of CFRP on the bottom face.



(d) Load-deflection plans for a deep concrete beam supplemented with a double layer of CFRP on the bottom face.

Figure (5-2) Difference in the shape of the openings with different methods of strengthening for HSC

5.3. The difference between the results according to the type of concrete

The results show that as the compressive strength of the concrete grows from 25 MPa to 60 MPa and the deflection increases, the initial cracking load of the deep beams increases, showing that the concrete is becoming more ductile.

The results indicate that the failure load rises with the increase in compressive strength from 25Mpa to 60Mpa, which suggests an increase in stiffness. Still, a decrease in deflection indicates that the concrete has become more brittle.

The Figures below show the improvement in the initial cracking load Figure (5-3) and the failure load Figure (5-4) for the two types of concrete (NSC & HSC) used in this research: 25Mpa and 60Mpa, respectively.

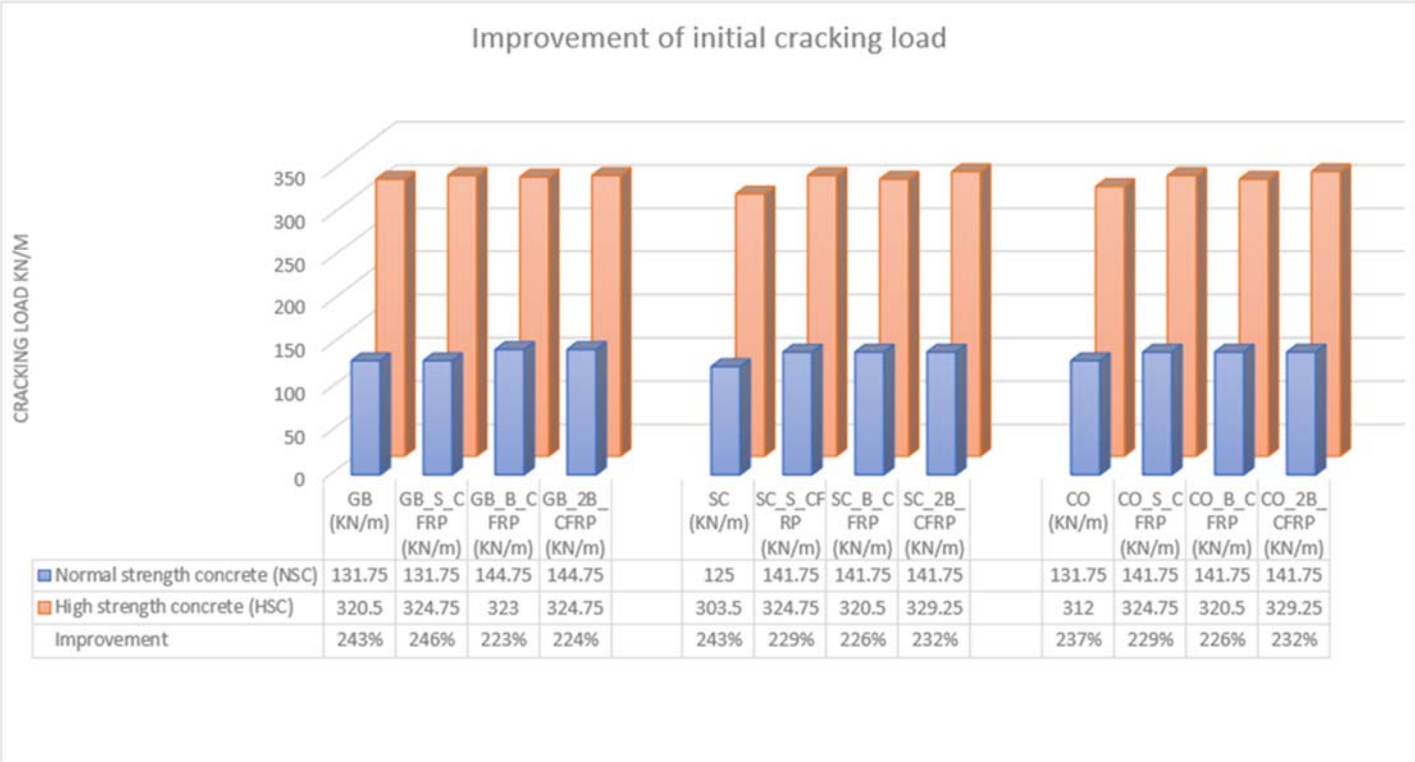


Figure (5-3) Improvement of initial cracking load

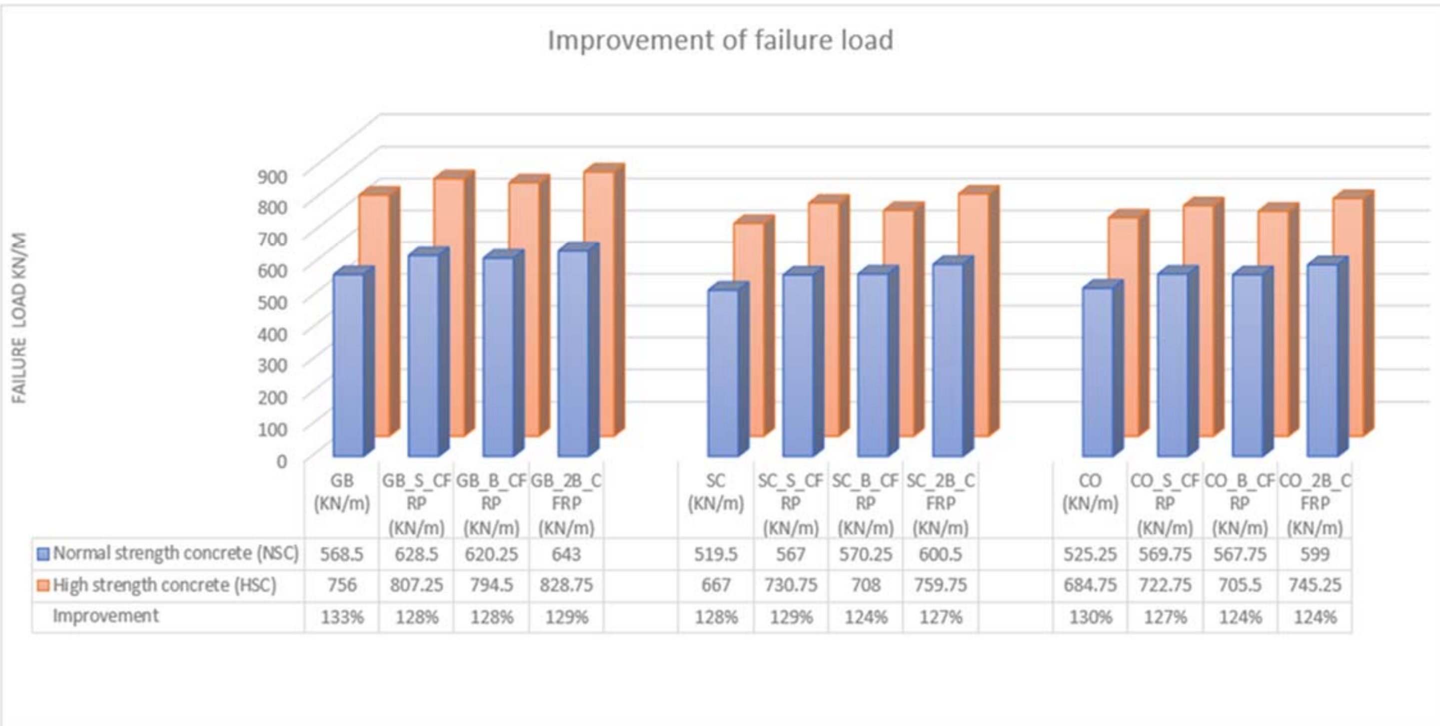


Figure (5-4) Improvement of failure load

5.5. Conclusions

- ✓ The cracking pattern in strengthened and un-strengthened deep concrete beams by CFEP is similar.
- ✓ The collect and propagate of cracks deep concrete beams strengthened with CFRP, between U-shaped strips CFRP in bending zone.
- ✓ The square openings at the bending zone for deep NSC beams leads to reduced strength of 9% due to the loss of part of the section stiffness.
- ✓ The circular openings at the bending zone for deep NSC beams leads to reduced strength of 8% due to the loss of part of the section stiffness.
- ✓ The square openings at the bending zone for deep HSC beams leads to reduced strength of 12% due to the loss of part of the section stiffness.
- ✓ The circular openings at the bending zone for deep HSC beams leads to reduced strength of 9% due to the loss of part of the section stiffness.
- ✓ The increase in the rate of strength using a single layer of CFRP strips on the bottom face for deep concrete beams between the supports in addition to U-shaped strips in a bending zone are 8%.
- ✓ The increase in the rate of strength using a single layer of CFRP strips on the bottom face for deep concrete beams between the supports are 7%.
- ✓ The increase in the rate of strength using a double layer of CFRP strips on the bottom face of the deep concrete beams between the supports are 13%.
- ✓ Increasing the number of layers CFRP strips on the bottom face of the deep concrete beam between the supports is the best way to increase failure load.

5.6. Recommendations for Future Work

investigated the effects of square and circular openings in deep concrete beams subjected to bending by the uniformly distributed load. With study, CFRP laminates were used around the openings and on the bottom face of the deep concrete beam to create an effective strengthening system. Where the study was limited to 3D FE analysis and static loading conditions.

The following are the study's recommendations for future work:

1. To investigate the impact of apertures of various shapes and sizes subjected to critical shear, bending, and torsion on the dynamic behavior of deep beams.
2. To look into the influence of CFRP laminates on the dynamic behaviour of beams.
3. Study the failure modes of CFRP laminates around openings of varied shapes, sizes, and positions.
4. To study the behaviour of uniformly distributed loads on deep beams with effects of openings to various shapes and sizes subjected to critical torsion.

References

1	ACI Committee 318, 2019. Building Code Requirements for Reinforced Concrete (ACI 318-19) and Commentary (ACI 318R-19). American Concrete Institute, pp.151.	2019
2	ACI Committee 318, 2019. Building Code Requirements for Reinforced Concrete (ACI 318-19) and Commentary (ACI 318R-19). American Concrete Institute, pp.385.	2019
3	ACI Committee 440.2R, 2008. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (ACI 440.2R-08). American Concrete Institute,	2008
4	Darwin D., D.W.C., N.H.A.,2016:DESIGN OF CONCRETE STRUCTURES. Fifteenth Edition. McGraw-Hill Education, 2 Penn Plaza, New York.	2016
5	Zienkiewicz, O.C, Taylor, R.L. & Zhu, J.Z., 2005. The Finite Element Method: Its Basis and Fundamentals 6th ed., Elsevier Ltd.	2005
6	Eurocode2. EN 1992–2:2005, Design of concrete structures—Part 2: Concrete bridges—Design and detailing rules2005	2005
7	Huston, R. & Josephs, H., 2008. Stress Concentration (Practical Stress Analysis in Engineering Design) Third Ed., CRC Press.	2008
8	Mansur M. A. & TAN K.H., 1999: Concrete Beams with Openings Analysis and Design, CRC Press LLC, 2000 Corporate Blvd., N.W., Boca Raton, Florida 33431.	1999
9	CHOO C.S.,2013: STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH OPENINGS USING CFRP LAMINATES, A Thesis Submitted to the Postgraduate Studies Programmer as a Requirement for the Degree of DOCTOR OF PHILOSOPHY CIVIL ENGINEERING DEPARTMENT UNIVERSITI TEKNOLOGI PETRONAS BANDAR SERI ISKANDAR, PERAK	2013
10	El-Sawi W, D, D,.2013:DESIGN OF REINFORCED CONCRETE BEAMS WITH OPENINGS, A thesis Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science IN STRUCTURAL ENGINEERING IN Mansoura University.	2013

11	MUN N.K.,2015: STRENGTHENING OF REINFORCED CONCRETE DEEP BEAMS HAVING LARGE SQUARE OPENINGS IN SHEAR ZONE WITH CARBON FIBER REINFORCED POLYMER (CFRP),Thesis submitted in fulfilment of the requirements for the award of the degree of B. Eng. (Hons.) Civil Engineering, Faculty of Civil Engineering and Earth Resources UNIVERSITI MALAYSIA PAHANG.	2015
12	Al-Ghanim H., Al-Asi A., Abdel-Jaber M.,Alqam M.,2017:Shear and Flexural Behavior of Reinforced Concrete Deep Beams Strengthened with CFRP Composites, Civil Engineering Department, School of Engineering the University of Jordan, Amman, Jordan,doi:10.5539/mas.v11n10p110.	2017
13	Allam, S.M., 2005. Strengthening of RC Beams with Large Openings in the Shear Zone. Alexandria Engineering Journal, 44(1), pp.59-78.	2005
14	Alsaad A., Sulaiman.Mohammed J.A.2015: Using CFRP for Enhancing of Circular Cutout in High Strength RC Deep Beam GSTF Journal of Engineering Technology (JET), DOI 10.7603/s40707-014-0020-4	2015
15	El Maaddawy, T. & Sherif, S., 2009: FRP Composites for Shear Strengthening of Reinforced Concrete Deep Beams with Openings. Composite Structures, 89(2009), pp.60-69.	2009
16	Faraj S.S., Hamad N.T., Hammoodi A.H., Abduljalel B.S.,2018: Analysis of reinforced concrete deep beam strengthened by CFRP strips using ANSYS program, doi: 10.14419/ijet.v7i4.13833	2018
17	Ferrier, E., Avril, S., Hamelin, P. & Vautrin, A., 2003: Mechanical Behavior of RCBeams Reinforced by Externally Bonded CFRP Sheets. Materials and Structures, 36(8), pp.522-529.	2003
18	Graybeal, W. & Pooch, U.W., 1980. Simulation: Principles and Methods, Winthrop Publishers, Cambridge, MA.	1980
19	Khalaf M.R., Al-Ahmed A.H.A., Allawi A.A., El-Zohairy A.,2021: Strengthening of Continuous Reinforced Concrete Deep Beams with Large Openings Using CFRP Strips, www.mdpi.com/journal/materials, doi.org/10.3390/ma14113119	2021

20	Madkour, H., 2009: Non-linear Analysis of Strengthened RC Beams with Web Openings. Proceedings OfThe Institution Of Civil Engineers, Structures and Buildings, 162(2), pp.115-128.	2009
21	Mansur M. A., 1999: Design of Reinforced Concrete Beams with Small Openings under Combined Loading. ACI Structural Journal, 96(5), pp.675-682.	1999
22	Mansur, M.A. & Hasnat, A., 1979. Concrete Beams with Small Openings under Torsion. Journal ofthe Structural Division, ASCE, 106(ST11 Nov), pp.2433-2447.	1979
23	Moreno, A., 2011. Knovel Solutions in Aerospace Engineering. Available at: librarians. lmovelblogs. conV2011/ll/04/lmovel-solutions-in-aerospace-engineering.	2011
24	Panjehpour M.,Chai H.K.,Voo Y.L. 2015:Refinement of Strut-and-Tie Model for Reinforced Concrete Deep Beams, DOI:10.1371/journal.pone.0130734	2015
25	Pimanmas, A., 2010: Strengthening R/C Beams with Opening by Externally Installed FRP Rods: Behavior and Analysis. Composite Structures, 92(8), pp.1957-1976.	2010
26	Rahim N.I.,Mohammed B.S.,Al-Fakih A.,Wahab M.M.A.,2020:Strengthening the Structural Behavior ofWeb Openings in RC Deep Beam Using CFRP, doi.org/10.3390/ma13122804	2020
27	Salam, S.A., 1977. Beams with Openings under Different Stress Conditions. In Proceedings of 3rd Conference on Our World in Concrete and Structures, Cl- Primier, 25- 26Aug. Singapore, pp. 259-267.	1977
28	Schlaich JS, Schafer K. Towards a consistent.,1987: design of reinforced concrete structures. Journal of the prestressed concrete institute. ; 32(3).	1987
29	Somes, N.F. & Corley, W.G., 1974. Circular Openings in Webs of Continuous Beams. Shear in Reinforced Concrete. American Concrete Institute, Farmington Hills, Mich, SP-42(l),pp.359-398.	1974

30	Tan, K. H., Mansur, M.A. & Huang, L.M., 1996. Reinforced Concrete T-Beams with Large Web Openings in Positive and Negative Moment Regions. ACI Structural Journal, 93(3), pp.277-289.	1996
31	Yoo, Tae-Min, Doh, Jeung-Hwan, Guan, Hong, Fragomeni, Sam,2013: Experimental behaviour of high-strength concrete deep beams with web openings. The Structural Design of Tall and Special Buildings, doi.org/10.1002/tal.718	2013

جمهورية العراق

وزارة التعليم العالي وبحث علمي

جامعة بابل كلية الهندسة

قسم الهندسة المدنية

السلوك غير الخطي للعوارض العميقة الخرسانية التي تخضع للحمل الموزع بشكل منتظم وتقويتها بواسطة CFRP

بحث

مقدم لكلية الهندسة / جامعة بابل كجزء من

متطلبات نيل درجة الدبلوم العالي في الهندسة المدنية /هندسة الإنشاءات

بواسطة

صباح أنور صاحب وهاب

بأشراف

الأستاذ المساعد الدكتور حيدر محمد جواد الخفاجي

2021

الخلاصه

تم نمذجة أربعة وعشرين عتب خرساني عميق باستخدام برنامج تحليل العناصر المحدده ABAQUS ، مقسمة إلى جزأين حسب نوع الخرسانة المستخدمة .(NSC & HSC) وتم تقسيم كل جزء إلى ثلاث مجموعات وفقًا لوجود وغياب وشكل الفتحة التي تكون في منتصف الاعتاب العميقة في منطقة الانحناء.

المجموعات قسمت إلى أربعة نماذج. الأولى هي عوارض خرسانية عميقة غير مقواة بـ CFRP، والثاني مقواة بـ CFRP بشكل شرائط بعرض 100 مم على شكل حرف U في منطقة الانحناء مع إضافة طبقة مفرده من CFRP على الوجه السفلي، والثالث مقوى بطبقة مفرده من CFRP على الوجه السفلي فقط، اما النموذج الرابع فتم تقويته بطبقه مزدوجة من CFRP في الوجه الأسفل.

وكانت المعلمات الثابتة هي أبعاد المقطع ،طول النموذج وتسليح القص.

طريقة تحديد السلوك الغير خطي في برنامج ABAQUS ،من خلال طريقة اللدونة التالفه للخرسانة (CDP) حيث تم اختبار النماذج وفقًا لحمل التشقق الأولي وحمل الفشل ومنحنى Load-Deflection.

أظهرت النماذج التي لاتحتوي على فتحات نمط تشقق موحد من خلال البدء من أسفل منطقة الانحناء والاستمرار عموديًا نحو محورالحيود وفي مرحلة متقدمة تبدأ الشقوق في الظهور بالقرب من الدعامات وتستمر قطريًا إلى منطقة تطبيق الحمل قبل ان تفشل النماذج بعد وصول حديد التسليح الرئيسي إلى الحمل الاقصى.

أما بالنسبة للنماذج التي تحتوي على فتحات (مربعة أو دائرية) ، فقد كان نمط التشقق هو أن تبدأ الشقوق من أسفل الفتحة ثم من الوتر العلوي للفتحة قبل الظهور بالقرب من الدعامات والاستمرار بشكل قطري الى منطقة تطبيق الحمل ، وكان نمط الفشل هو وصول التسليح الرئيسي إلى الإجهاد الأقصى

.أما بالنسبة لاستخدامCFRP فإن العامل الرئيسي الذي يزيد من حمل الفشل هو تقوية الوجه السفلي للنماذج حيث يزداد حمل الفشل مع زيادة عدد الطبقات ، ويكون معدل الزيادة في حمل الفشل يتراوح بين (3٪ إلى 16٪) اعتمادًا على طريقة التقوية وعدد الطبقات ووفقًا لوجود وغياب وشكل الفتحات.