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College of Engineering

Civil Engineering Department

Enhancing Torsional Behavior of Reinforced Concrete Beams with Transverse Openings Using Ultra-High Performance Concrete

A research

Submitted to the College of Engineering/University of Babylon in Partial Fulfilment of the Requirements for the Degree of High Diploma in Civil Engineering/*(Structural Engineering).*

By

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Supervised By

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2021 AD   **1443** AH

بسم الله الرحمن الرحيم

﴿ قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ ﴾

صدق الله العظيم

سورة البقرة

الآية (٣٢)

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We *certify that we have read the research entitled* **(Enhancing Torsional Behavior of Reinforced Concrete Beams with Transverse Openings using Ultra-High Performance Concrete)** *presented by* **"Lina Hussein Ali**" and examined the student in its content and what related to it, and found it meets the standard of the research for the degree of high diploma in Civil Engineering *(**Structural Engineering**).*

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Supervisor Certification

I *certify that this research which is entitled* **(Enhancing Torsional Behavior of Reinforced Concrete Beams with Transverse Openings using Ultra-High Performance Concrete)** *has been prepared by* **(Lina Hussein Ali**) *under my supervision at College of Engineering, University of Babylon, in partial fulfilment of the requirements for the degree of High Diploma in Civil Engineering* **(Structural Engineering).**

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Name: **Asst. prof. Dr. Rafea F. Hassan**

Date: / / 2021

Acknowledgments

*In the name of **Allah**, the most compassionate, the most merciful. Praise be to **Allah**, and pray and peace be on his prophet Mohammed and his family.*

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Lina Hussein Ali

/ /2021

Dedication

The deepest words of gratitude and appreciation are the gratitude and dedication of a great person. If you are where I am today, then that is why it deserves a special mention that it is my father. I will not forget to devote the fruits of this effort to those who filled me with supplication, and what I am today God's response to her prayers for me. She is my mother.

I would like to apply My sincere appreciation to my sisters. I feel very lucky that they have been in my life.

Sincerity to my family and friends goes for their love, support, guidance, and endless patience in all my endeavours.

Lina Hussein Ali

/ /2021

Abstracts

This study aims to explore the torsional performance of reinforced concrete beams-containing transverse circular-openings and the techniques that can used to avoid the harmful effect of adding openings by using Ultra High Performance concrete (UHPC), diagonal reinforcement.

The study consists of experimental work which contains casting eight beams in dimensions (150 x 200 X 1200 mm) and testing under pure torsion. Two of these beams had no transverse opening one of them was casted with normal concrete NC and the other was casted with UHPC, while other specimens having transverse opening and divided into two groups (small and large). Each group contains three beams with circular opening at mid span(first one was casted with NC and reinforced with diagonal reinforcement , second one was casted with UHPC and reinforced with diagonal reinforcement and third one was casted with UHPC but without diagonal reinforcement

All tested beams containing opening and casted with UHPC showed an significant increase in the ultimate's torques concerning with the controlling NC solid beam. The ultimate torque capacity of normal concrete beam with small opening show slight decrease in ultimate load capacity (1.47%) but beams with large opening showed significant decrease in load capacity (17.65%). UHPC substituted the missing strength that caused by removing the diagonal reinforcement for both cases small and large opening.

The initial stiffness of NC beams showed drop for both small and large opening of 19.4% and 70.1% respectively while, the UHPC beams with opening showed enhancement in the initial stiffness rounded between 64% for small openings and 34% for large openings.

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Chapter One

Introduction

1.1. Background

As one of the four main structural actions -including axial loading, bending moment and shear forces- torsion was the subject of scientific research studies since long time. Several theories and analytical models were developed trying to describe the behavior of reinforced concrete beams under torsion both in the pre and post cracking regions.

Until today, torsion is still an active research area even on beam with traditional reinforced concrete materials (normal and high strength concretes). Nowadays there is a new innovative cementitious structural material known as Ultra High Performance Concretes (UHPC) which is categorized by great tensile and compressive strengths. This new material could have a compressive strength of reached to 200 MPa and a tensile strength of 8 -15 MPa according to its mix-proportions and steel fiber content. It has been proven that the material is brittle in compression and tension. Steel fibers were typically inserted to the UHPC mixture to increase ductility.

UHPC allows the construction of more complex architectural shapes than it has been used to be done using normal and high strength concretes. These complex shapes usually induce additional torsional loads to the supporting structural system, UHPC attracted a lot of researchers in the last two decades to investigate its performance under various load actions such as: tension (Leut,2008), shear (Feh, 2005), (Feh, 2011), punching shear (Harris,2008), bending moment (Feh, 2009), biaxial loading (Feh, 2007), (Feh, 2008), biaxial compression (Cur, 2008) and multi-axial and fatigue

(Grü, 2008). However, until recently, almost very little test data about the performance of UHPC under torsion are at hand.

As many UHPC structures - including bridges - have been already constructed worldwide, this urges research to be done on this important field so as to understand the behavior of this new structural material under torsion.

1.2. Worldwide Examples of Ultra High Performance Concretes (UHPC) Bridges

Many examples of innovative UHPC bridges exist around the world. They include:

1. The world's first UHPC pedestrian bridge , the Sherbrooke Footbridge in Quebec, Canada which was built in 1997. It is a post-tensioned structure composed of six 10 m length precast components with 60 m length, as shown in Fig. 1.1   . The cross-section is constructed up of a 3 cm thickness ribbed slab with monostrands for transverse prestressing. Fig. 1.1 shows the truss webs, which have been constructed of Reactive Powder Concrete encased in stainless steel tubes Resplendino (2004).
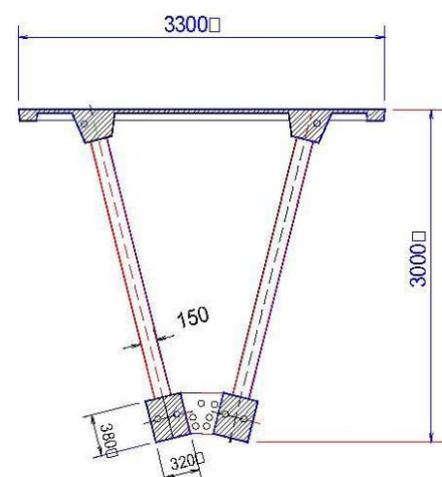
Fig.(1-1). Sherbrooke footbridge and the cross-sectional area of the bridge.

2. The first French UHPC bridge was built in Bourg - Les - Valence during the years 2000-2001, Fig. 1.2 a. The bridge contains two 2000 cm spans. By installing UHPC in situ between the two spans, the road deck has been manufactured continuous. As illustrated in Fig. 1.2 b, every deck supports a 900 cm wide road surface with 100 cm and 200 cm walkways. Five n-shaped prefabricated beams have been used to construct the decks Resplendino (2004).

(a)

(b)
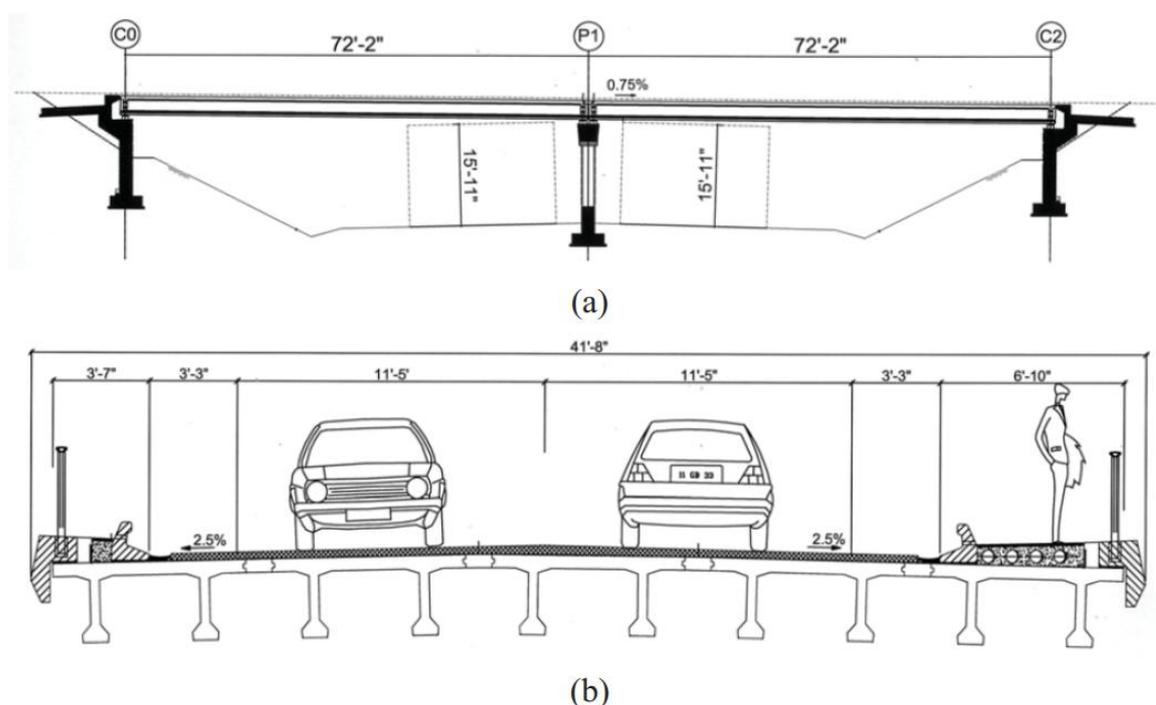
Fig.(1-2). Roury-Les-Valence bridge (a) Longitudinal cross section (b) typical cross section

3. The Sakata - Mirai Footbridge in Japan, built in 2003. The bridge is post-tensioned structure with span length of 49.35 m as shown in Fig. 1.3. The deck is a simple beam 2.4 m wide. It has no traditional steel bars as reinforcement, but only steel fibers, such that it reaches its maximal bearing capacity through the external prestressing. The bridge is extremely light and has a weight of about 56 tons only which

corresponds to about one-fifth the weight of a normal concrete alternative Tanaka et al (2002).

Fig.(1-3). SakataMira footbridge, and bridge deck

4. The Gartnerplatz Footbridge, which was built in 2007 in Kassel, Germany. Fig.(1-4) shows the bridge construction, which has six spans with such an overall length of 133.20 meters and a max. free span of 36 meters. The longest span is 36 meters long, and the

manufactured UHPC decks are 5 meters wide. The deck is 11 cm
thick at the sides and 8 cm thick in the center Tanaka et al (2002).

Fig. 1.4. Gartnerplatz footbridge, Kassel, Germany (Feh.2009).

1.3. Opening in concrete beams

As illustrated in Fig.(1-5), a networks of ducts and pipes are required in the
constructing of contemporary buildings to support vital services such as
water system, drainage, conditioning systems, electrical supply, telephone
wires, and internet connection. Typically, these pipelines and ductwork
were hidden under the beam soffit and wrapped by such a suspended ceiling
for aesthetic purposes, resulting in a dead zone. By routing these ducts via
transverse holes in the floor beams, less dead space is created, and the
design becomes more compact. The savings might not have been significant
for small buildings, however for multi - storied structures, any reduction in
building multiplied by the number of stories could indeed result in
significant reductions in total height, partition surfaces, plumbing risers,

walls, electrical and air-conditioning duct length, and overall foundation load.

The size of openings can be classifying either small or large. If the diameter (or depth) of the opening is lower than 40 % of the overall depth of beam, the openings can be considered as small. Opening corners are subjected to high stress concentration due to sudden changes in sectional arrangement, which may result in cracking that is undesirable from an aesthetic and durability standpoint. The serviceability and strengths of yet another beam might be severely harmed unless appropriate reinforcement is supplied in adequate amount and with suitable details. Mansur(1999)
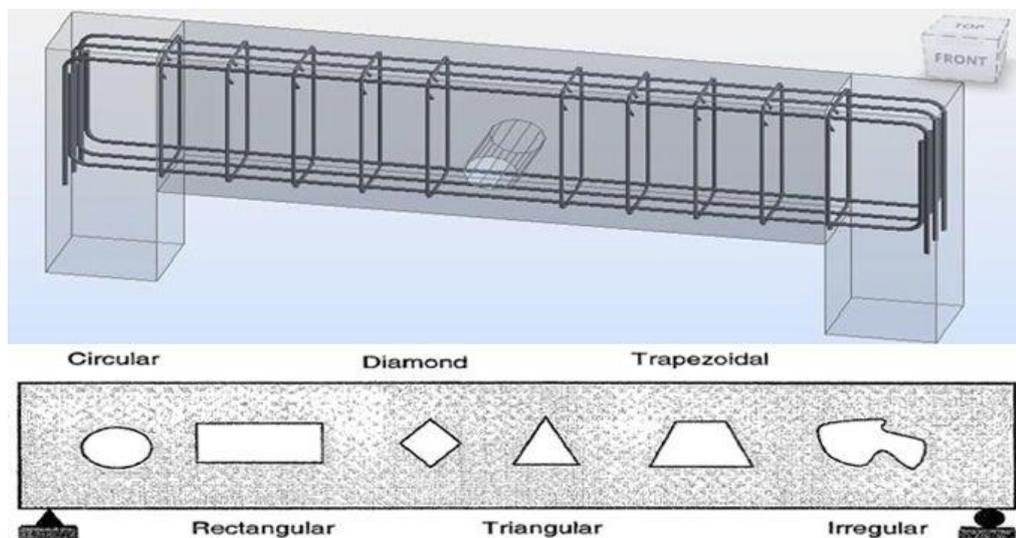
Fig. 1.5. concrete beam with opening

The hole in the solid beam reduces shear resistance, and it is necessary to increase the number of stirrups, particularly under cyclic shear. The behavior of hollow beams with holes in HSC and UHPC was not thoroughly investigated. As a result, the impact of an opening on a hollow beam was investigated using UHPC and HSC composites with half stirrups above and below the opening under cyclic, flexural, and torsional loading.

Hollow structural parts are becoming more popular. These hollow portions are utilized to pass mechanical and electrical utilities while also lowering the height of the building and the cost of materials and building.

1.4. Aims and Objectives

The main aim of this dissertation is to study the behavior of UHPC as a new innovative structural material under the action of pure torsion. Under this main aim , the following objectives can be summarized:

- To study the behavior of concrete beams under pure torsion as well as explore the harmful effects of opening.
- To investigate the ability of UHPC to substitute the missing strength due to opening.
- To investigate the ability of UHPC to substitute the traditional reinforcement (diagonal reinforcement around the opening).

1.5. Thesis Outline

So as to obtain the outlined objectives, the dissertation was structured in 5 chapters:

- The first chapter, briefly describing the new UHPC material, and the main aim of the study is defined as well as the application of UHPC. In addition, the objectives of the study and finally the outline of the dissertation are described.
- In chapter 2, A review of the torsion researches was submitted.
- The own experimental program conducted on NC and UHPC beams with various opening size and traditional reinforcement is described in detail in chapter 3. The materials used, the production and treatment of the test beams, the test setup, and the instrumentation used are also reported in detail.

- In chapter 4, the test results both at the serviceability and the ultimate limit states are presented

- Finally In chapter 5 conclusions and recommendation are drawn.

Chapter Two

Literature Review

2.1. Ultra High Performance Concretes (UHPC)

2.2. Properties of the Fresh Mix

Ultra High Performance Concrete (UHPC) is considered amongst the latest improvements technology in concretes industry. The first development of this material was during the period between 1990 and 1995 in France and Canada and was first known as Reactive Powder Concrete (RPC) Cheyrezy et al (1995)

(UHPC) is a special dense concrete having compressive strengths of more than 120 MPa. It can be produced as either fine aggregates concrete with maximum aggregate size of only 0.5 mm or coarse aggregates concrete with maximum aggregate size of 16 mm, Schmidt et al(2008). According to the mix design and production method, the compressive strength may reach a value between 120 and 250 MPa.

The UHPC with steel fiber may reach a maximum tensile strength of about 15 MPa and a maximum flexural tensile strengths of about 25 MPa Fehling et al (2005). In addition to its high compressive strength, the UHPC exhibits - because of its dense structure - high resistance against all forms of physical and chemical attacks and thus shows a very high durability.

This high performance of the UHPC is due to several factors: a very little water/cement ratio which is normally between 0.20 and 0.3, a high solids content of the cement paste through addition of suitable chemical additives, a high packing density of the solids content Both in the cement paste and the coarse aggregates associated with a low water demand of fresh concrete

and a very low porosity of the hardened concretes and using of steel and other fibers to introduce sufficient ductility and controlling of the cracks widths under various kinds of structural actions. For the production of the UHPC, the following raw materials are primarily used Muller, (2005b)

- Fine or coarse rock aggregates (e.g. , quartz and basalt sands , basalt chippings , bauxite).
- Ground (fine) quartz.
- Portland cement free from or with little amount of C3A
- Silica fume, metakaolin and fine slag,
- High performance superplasticizer,and
- Water

UHPC is a high-tech material which allows the Construction of exceptionally light, delicate and highly corrosion - resistant structures. Raw materials and energy are saved and longer spans are possible the lower dead weight of the UHPC. Schmidt et al(2003).

2.3. Structural Performance of UHPC Elements

In the first and second funding periods of the German Research Foundation (DFG) priority programs (SPP1182), the tension and bending carrying capacity and deformation performance of UHPC were reinforced with both traditional reinforcement and steel fibers were investigated. Leutbecher et al (2008) experimental and theoretical studies on the performance of UHPC tension members with combined reinforcement. A mechanically consistent model for calculating the service load range, taking into account the shrinkage deformations has been developed.

In the second funding period, the carrying capacity at the serviceability and ultimate limit states of beams with combined reinforcement under the action

of bending moments were investigated. The main focus was on the interaction of structural components, the local and global deformation performance over all load ranges. The calculation approaches were experimentally supported with experiments on beams subject to bending moments under the variation of the reinforcement volumetric ratio, the position of the reinforcement and the steel

2.4. Previous Studies.

Because of the great strengths of UHPC and HSC components, these materials are used in hollowed structures. The hollow portions are strong against bending moments, but they are weak versus tensional stresses. Torsion of reinforcing concretes beams occurs in real-world building structures as a consequence of external loads outside the shearing center of the deflections or cross-section caused by beam continuation. For a while, torsion had been viewed as a secondary impact; it has not been expressly addressed in design, and its impact is also included in the total factor of safety that is not an inexpensive design (Namiq, 2008).

Yoo and Yoon investigated the structural performance of UHPC beams with various steel fibers in 2015. Steel fibers substantially increase cracking, post-cracking stiffness, and load bearing capacity responsiveness, but reduce ductility, according to their findings. With the adding of 2percent volumes of steel fibers, the load bearing capacity is increased by 27 percent–54 percent while the ductility is reduced by 13 percent–73 percent. Furthermore, increasing the smooth steel fibers length and utilizing twisted steel fibers improves post-peak responsiveness and ductility; nevertheless, the load post-cracking stiffness and bearing capacity are unaffected. The length and kind of fiber affect the cracking reaction (Yoo and Yoon, 2015).

According to Lopes and Bernardo (2009), under torsion, beams made of high-strength concrete have four distinct kinds of faults that depend on reinforcements. Brittle fracture produced by inadequate reinforcing, fragile fracturing induced by corners cracking, crisp failure resulting from a lack concrete strength, and ductile failure are examples of beam failures ranging from the lowest to the greatest reinforcement ratios. Once the concretes strengths of the beam have become raised, the failure gets more fulminatory.

They performed a plastic study and assessed the twisting capacity of high-strengths concretes hollow beams in single torsion in 2013. They discovered that increasing the concrete's compressive strengths causes a slight reduction in plastic twist capacity (Bernardo and Lopes, 2013). They used HSC in 2013 to study defeat patterns and cracking in hollow beams exposed to torsion. When comparison with NSC, the usage of HSC results in less ductile and fractured beams, as well as cracks that are more brittle and louder (Lopes and Bernardo, 2013).

Hii and Al-Mahaidi (2006) examined the torsional reinforcement of hollow and solid RC beams external joined with carbon fiber-reinforced polymers, which increased both ultimate strengths and cracking by up to 78 percent and 40 percent, respectively.

The impacts of holes on the reinforcement concretes beams performance without specific reinforcing in the opening location were studied by Hafiz et al. (2014). The ultimate load capacity of reinforcement concretes rectangular beams with circular holes less than 44 percent of the beam's depth (D) was unaffected; nevertheless, circular openings larger than 44 percent of D decreased the ultimate load capacity by at least 34.29 percent. With a 9.58 percent difference in ultimate load, their team discovered that the circular aperture is stronger than the corresponding square opening.

The majority of beams in modern buildings are intended to withstand a variety of loads, including dynamic loads produced by earthquakes, car and rail vibration, rotating machinery, and other sources of vibration. Because the failure mechanism of a beam exposed to dynamic loads is more complicated than that of a beam exposed to static loads, assessing the failure patterns of a beam exposed to dynamic loads under ultimate loading circumstances is critical. Numerical techniques are used to address the majority of structural dynamics analysis issues Torii and Machado(2012).

Under cyclic stress, Inoue and Egawa (1996) investigated the shear performances and flexural one of hollow beams. Their findings showed that the hollow beam's final deformation and energy dissipation capacity are lower even than the solid beam, and that the hollow beam's ultimate failure is more brittle. Furthermore, the diagonal fracture may form early on, resulting in a significant increase in the pressure on the stirrups.

The seismic response of hollow and solid reinforcement concretes beams in framed structures was addressed by Guleria (2014). Their findings revealed that hollow members may assist decrease pressures without causing failure, resulting in a more cost-effective structure design. The overturn moment and concretes consumption are also reduced when hollow sections are used.

Alnuaimi et al(2008). looked at the outcomes of 14 reinforcement concretes beams that were split into fourteen samples half of them was hollow and the other half was solid beams. The 14 beams (as hollow portions) have been intended to withstand a combination load of torsion, bending, and shear. The cross-section of the beam seemed to be (30x30) cm, and its length seems to be 380 cm. The inner hollow core dimensions for the hollow beams were (20x 20) cm, resulting in a peripheral wall thickness of 5 cm. The findings revealed that the concrete core affects the strengths of the beam and cannot be overlooked when a collective loading of torsion,

bending, and shear is present. At lower stresses, all hollow beams split and failed than their solid equivalents. The large disparities in failure loading between hollow and solid beams were due to the lower proportion of torsion to bending. The longitudinal steel produced lower strain magnitudes than the transverse steel.

Bernardo and Lopes (2013).   investigated the ultimate torsion performance of hollow beams made from high-strengths concretes based on their ductility and strengths. Sixteen beams with a square cross-section and symmetrically distributed reinforcing have been tested. The compressive strengths of concretes (from 46.2 to 96.7 MPa) and the quantity of torsional reinforcement were among the study's characteristics (from 0.30 to 2.68 percent). According to the findings, torsional ductility has been low in the small reinforcement proportion in which ductility had been found in a very limited ranging. Different codes of practice have been compared based on the experimental findings, including ACI, European, New Zealand, Canadian, and Norwegian codes. As a result, they discovered that the ACI Code performed largely accurate in forecasting torsional strength as well as preventative torsion reinforcing, resulting in acceptable ductile performance.

Abdul-Hussein (2010) studied at the torsional strength of reinforcement concretes beams as a function of several factors including the number of fibers (with and without holes) and the reinforcement proportion in each direction. Steel fibers vary from zero to one percent in each of the fifteen tested beams. When compared to the findings of the laboratory testing, the finite element method "FEA" using finite element software ANSYS produced excellent finding. The findings indicated that adding 1% steel fiber to the mix improved ultimate torque and significantly decreased cracking. When the transverse and longitudinal reinforcement proportions

have been maintained constant, a forty-three percent increase in cracking torque and a fifty-eight percent increase in ultimate torque for hollow and solid sections, respectively, was obtained.

The torsion capacity of the ultimate point on rectangular beams with spiral reinforcement in the torsion directions and its anti-directions was studied by Barghlame at el. ANSYS software was used to quantitatively evaluate the beam models under various loads. The spirally strengthened prismatic beam, as well as beams with spiral links, were shown to have lower torsional capacity than beams with tied links.

Under pure torsion, Al-Tahan (2019) explorer the torsional performance of reinforced concrete-beams-containing transverse horizontal-opening strengthened with fiber wire mesh. Also, study the effect of using different shapes and locations of transverse openings. the experimental work contains casting and testing nine beams in dimensions (150 x 150 X 1200mm). All tested beams containing opening showed a decrease the ultimate torque with respect to the reference beam. While strengthens beams increase in ultimate torque when compared with unstrengthened beams in a range between (8.85% to 14.8%). Also, the ultimate twisting moment of beams containing circular and square opening at mid-span is more than that beams containing circular and square opining in a quarter of span with a range between (1.23% to 5.8%). the circular opening at mid and quarter span show increase in ultimate torque by about (4.72 %, 5.19%, 2.31% and 8.67%) when compared with square opening in mid and quarter span.

Chapter Three

Experimental Work

3.1 General

In the current chapter, it has been described the characteristics of the materials used in this experiment, as well as all information on casting, equipment, and devices. Initially , several mixes design were testing before starting the experimental work to determine the type and quantities of materials that affected on the performance of UHPC. Below some important point to be noted that the sand that used in UHPC was the normal sand sift on sieve of 600 µ size but the sand that already soft should not be used ..

3.2 Materials

3.2.1 Cement

All of the samples were cast using sulfate resistant cement (Type V) throughout this study. Tables 3.1 and 3.2 show the chemical analysis and physical characteristics of the utilized cement, respectively. They were made in accordance with Iraqi Requirement **(IQS) No.5/1984.** The test is conducted at Babylon University's College of Engineering's construction laboratory.

Table (3.1): Chemical analysis for cement.

Compound composition	Chemical compositions	Percentage by weight	Limits (IQS NO.5/1984)
Lime	CaO	63.66	----
Silica	SiO2	21.86	----
Alumina	Al2O3	3.96	----
Iron oxide	Fe2O3	4.72	----
Magnesia	MgO	2.24	<5.00
Sulfate	SO_3	2.21	<2.50
Loss on ignition	L.O.I	1.20	<4.00
Insoluble residue	I.R	1.46	<1.5
Lime saturation factor	L.S.F	0.89	0.66-1.02
Main compounds (Bogue's equs.)	Percent by weight of cement		
Tricalcium silicate (C_3S)	51.00		
Dicalcium silicate (C_2S)	23.28		
Tricalcium aluminate (C_3A)	2.51		
Tetracalcium aluminoferrite (C_4AF)	14.36		

Table (3.2): Cement's Physical characteristics.

Physical characteristics	Test results	Iraqi specifications limits (I.O.S.5/1984)
Setting time (Vicat's technique) Initial setting, hr: min Final setting, hr: min	4:24 5:32	$\geq$00:45 $\leq$10:00
Fineness (Blaine Method), m^2/Kg	314	$\geq$250
Compressive strength, MPa 3days 7days	25.7 29.68	$\geq$15:00 $\geq$23:00
Soundness (Autoclave) method %	0.15	$\leq$0.8

3.2.2 Coarse Aggregate (Gravel)

This study used crushed gravel from the Al–Nabai region in Salah Al–Din. The gravel gradient is shown in Table 3.3, which shows the findings of laboratory experiments. The findings of the tests have been compared to Iraqi requirement **(IQS) No.45/1984.**

Table (3.3): Coarse aggregates Grading.

Sieve size (mm)	Passing %	
	Coarse aggregate	Limits of Iraqi Requirement No. 45/1984
14	100	100
10	100	85-100
4.75	5	0-30
2.36	0	0-10

3.2.3 Fine Aggregate (Sand)

The concrete's mixture included ordinary sand. The findings of the sand gradient are shown in Table (3.4). The findings of the tests are compared to Iraqi requirement **(IQS) No.45/1984**.Natural sand was used for UHPC mix in this investigation. Before being ready to use, sift on sieve of 600 μ size.

Table (3.4): Fine aggregates Grading.

Sieve size (mm)	Passing (%)	
	Fine aggregates	Limits of IQS No. 45/1984 for Zone 3
10	100	100
4.75	96	90-100
2.36	91	85-100
1.18	86	75-100
600	73	60-79
300	31	12-40
150	9	0-10

3.2.5 Mixing Water

In this study, tap water was used to cast and cure samples.

3.2.6 Steel Reinforcing Bars

Utilizing (Ø 10) mm diameter bars for longitudinal reinforcing in both compression and tension faces, and (Ø 6) mm diameter bars as a closed stirrup. Table (3-6) shows the degree of ultimate and yielding strengths for every bar size, and depending on (ASTM A615-86)**.**

Table (3.5): Reinforcing steel properties.

Bar size	Actual diameter (mm)	Yield stress (MPa)	Ultimate strength (MPa)
10	9.8	460	623
6	5.9	430	614

3.2.7 Micro Silica Fume (MSF)

Silica fume is defined by the American Concrete Institute (ACI) as "extremely fine non-crystalline silica generated in electrical arc kilns as a waste materials of the manufacture of pure silicone or alloys of silicon " (ACI 116R/2005). There are particles ranging in size from 0.1 to 1μm. The silica fumes utilized in the study is shown in Fig. 3-1.

The advantages of using silica fume come from variations in the micro-structures of the concretes. These alterations are the consequence of two key processes.

One being the physically contributing of silica fumes, which fills in gaps between cement particles as micro-filling or particle distribution, and the second is its chemicals contributing , which involves reacting with the Ca(OH)2 product of hydration of portland cement to create extra binder's materials (hydrated calcium silicates) (C-S-H). Micro-silica fumes was utilized in this research, and the specifications of **(ASTMC1240/2005)** were compared.**.**

3.2.8 Super-Plasticizers

The super-plasticizers utilized in this research seems to have been an available commercially 3rd generation superplasticizers of mortar and concrete called (Hyperplastic PC200). It differs from traditional Super-Plasticizer in that it is built on polycarboxylic polymers having long-chains, devoid of chlorides, and conforms to **(ASTM C494/2001)**, that is specifically intended to allow the concrete's moisture amount to function more efficiently. Fig. 3-2 depicts the Hyperplast PC200 utilized in the study.   https://www.magnaprime.com.ph/buildrite-admixture/ritemix-pc-200-gallon

Fig. (3-1) Micro-Silica fumes   Fig. (3-2) Super-plasticizers

3.2.9 Steel Fiber

Steel fiber, as can be seen in Fig. (3-3), were used to strengthened beams in this study. The fibers' density is about 7800 Kg.m-3, and the characteristics of micro-fibers of steel are demonstrated in Table (3.6).
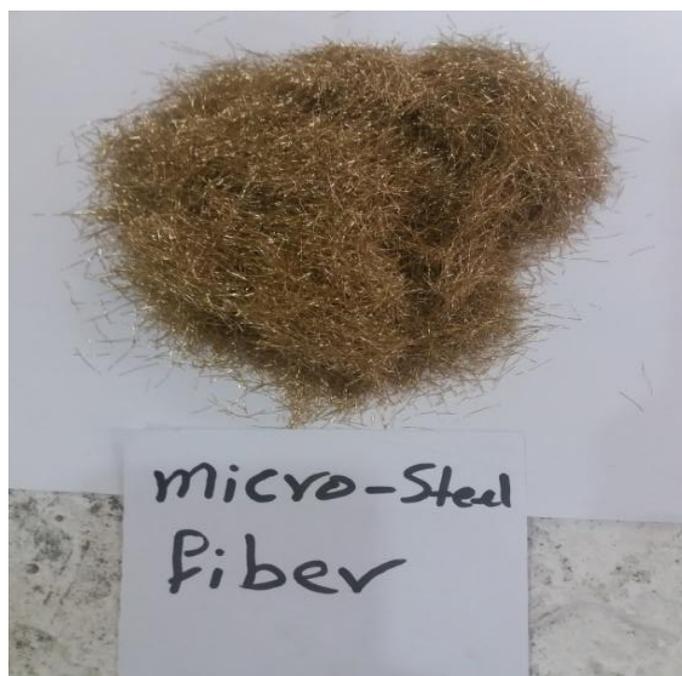
Fig. (3.3) Steel Fibers

Table (3.6): Micro-fibers of steel Characteristics.

Product	Lengths, L (mm)	Diameters, D (mm)	Aspect proportion, L/D	Tensile strengths (MPa)
Micro steel fiber (WSF0213)	13	0.2	65	2200

3.3 Specimens Description

Eight reinforcement concretes beams with a cross-sectional area of 15x20 cm and a length of 120 cm were prepared . The torsion behavior of reinforcement concretes beams for solid and beams with openings was investigated using all samples. The opening represented both large and small size with (75mm) transverse small opening (D/H= 37%) and with transverse large opening (D/H= 50%). In the long direction of beam, four Ø10 mm bars have been used for all of the reinforced specimens beams. In the short directions, bars of (Ø 6 mm) have been used as closed secondary reinforcement bars.

The distance between stirrups was decreased to prevent local failure towards the conclusion of the sample (33 mm). The distance between stirrups is (5 cm). As well as, four diagonal reinforcement (6mm diameter) applying on the each face of beam around the opening (Mansur, 1999). Fig. (3.4) illustrates the geometric and steel reinforcing features of the controlling beam and beams that have transverse hole.
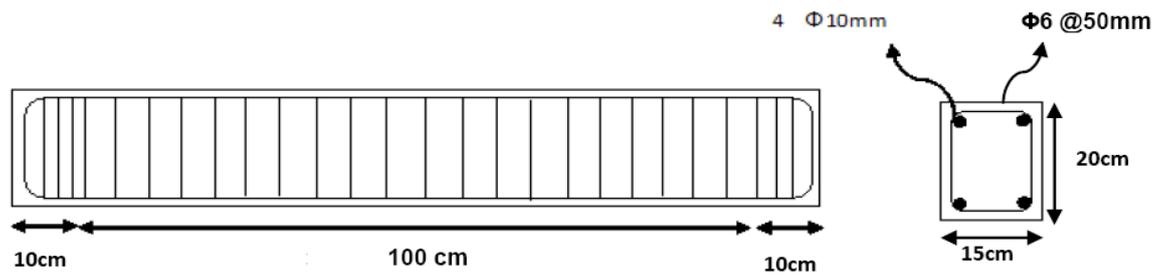
(a)
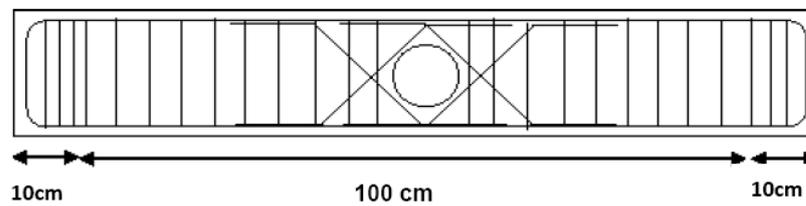
(b)
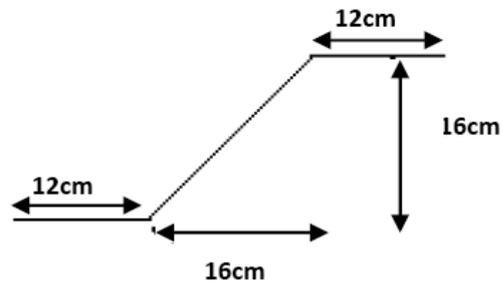
(c)
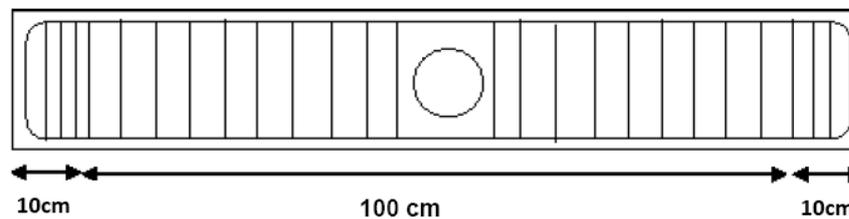
(d)

Fig. (3-4): Steel reinforcement a- solid beam. b- beam with opening and diagonal reinforcement. c- diagonal reinforcement bar. d- beam with opening and without diagonal reinforcement**.**

3.4 Specimens Identification

One of the eight beams has been used as a control that did not have any openings as controlling sample and casting with normal concrete, while other solid beam casting with UHPC. The remaining six beams included openings. Table (3.7) demonstrated the samples identification details.

Table (3.7) The utilized beams' details for testing**.**

Sample identification	Depiction
NS	Solid concretes beam with normal concretes
US	Solid concrete beam with UHPC
ND-75	Normal concrete beam with (75mm) circular opening reinforced diagonal reinforcement
ND-100	Normal concrete beam with (100mm) circular opening reinforced diagonal reinforcement
UD-75	UHPC beam with (75mm) circular opening reinforced diagonal reinforcement
UD-100	UHPC beam with (100mm) circular opening reinforced diagonal reinforcement
UW-75	UHPC beam with (75mm) circular opening without diagonal reinforcement
UW-100	UHPC beam with (100mm) circular opening without diagonal reinforcement

3.5 Concrete Mix Design

Many experimental mixes were tested to see whether they could reach the standard compressive strengths (ACI 211.1-95). The weight mixing ratios obtained for the compressive strength (35 MPa) for normal concrete beams and (130 MPa) for UHPC after the 28-day treatment period. Table (3.2) demonstrates the mixture's details for normal concrete and Table (3.3) demonstrates the mixture's details for UHPC.

Table (3.8): Normal concrete mixture's Details**.**

Material	Quantity
Cements (kg.m^{-3})	500
Fine agg. (kg.m^{-3})	775
Coarse agg. (kg.m^{-3})	825
Water (kg.m^{-3})	190
Super plasticizer (1/100 kg cement)	5

Table (3.9): Details of UHPC mix**.**

Material	Quantity
Cements (kg.m^{-3})	950
Fine agg. (kg.m^{-3})	1050
Silica fumes % cement	20%
Fiber dosage %	2%
Water / cement	16%
Super plasticizer % cement	3.5

3.6 Mixing and Casting Procedure

Eight wooden molds with dimensions (150x200x1200) mm and six cubes to determine compressive strength (three of 150*150*150mm for normal concrete and the other of 50*50*50mm for UHPC), cylinders and prism with dimensions (100x200) mm and (100x100x400mm for normal concrete and 50*50*300mm for UHPC) mm to determine splitting strength and flexural strength respectively .

The Fig.(3.5) shows the mixing and pouring method as in the following steps:

1.   All molds used have been lubricated before reinforcing steel frame is installed.
2.   After weighing all of the dry substances, beginning with the heaviest living ones, sand, and cement, a mixer has been turned on, and the substances within have been mixed thoroughly. Following that, water has been adding onto the concrete's mixture.
3.   A polyethylene layer has been laid down on the floor, then concrete from a mixer has been poured on top of it. The concrete had been distributed to the molds and physically pushed on three layers with an electric vibrator, after which the surface of concrete has been smoothed.
4.   The molds have been removed and put in the curing basin at the Faculty of Engineering's construction laboratory once the concrete had hardened.
   5. After twenty-eight days, all specimens have been taken out from the curing basin.

Fig.(3.5): Mixing and casting steps

3.8. Test Procedure

All beams are tested at the material laboratory of the University of Babylon's Civil Engineering Department. A panoramic view for testing and

loading setup is shown in Fig. 3-6. Fig. (3-7) shows a testing equipment with a capacity of (480 kN). The following stages describe the testing process:

1. Fig. (3-8) demonstrated that, the beam's end is fixed by a support containing an arm of torque, and all bolts were tightened.
2. In the machine, the beam is situated on a flat span of (100 cm)
3. After applying a concentrically load to ensure complete contact between the beam and the loading system, the imposed force is withdrawn.
4. The beams were loaded at a steady pace and evaluated under simple torque.
5. From every load period, the angle of twisting is read and recorded, as well as the first cracking loads and the collapse load, as demonstrated in Fig. (3-9).
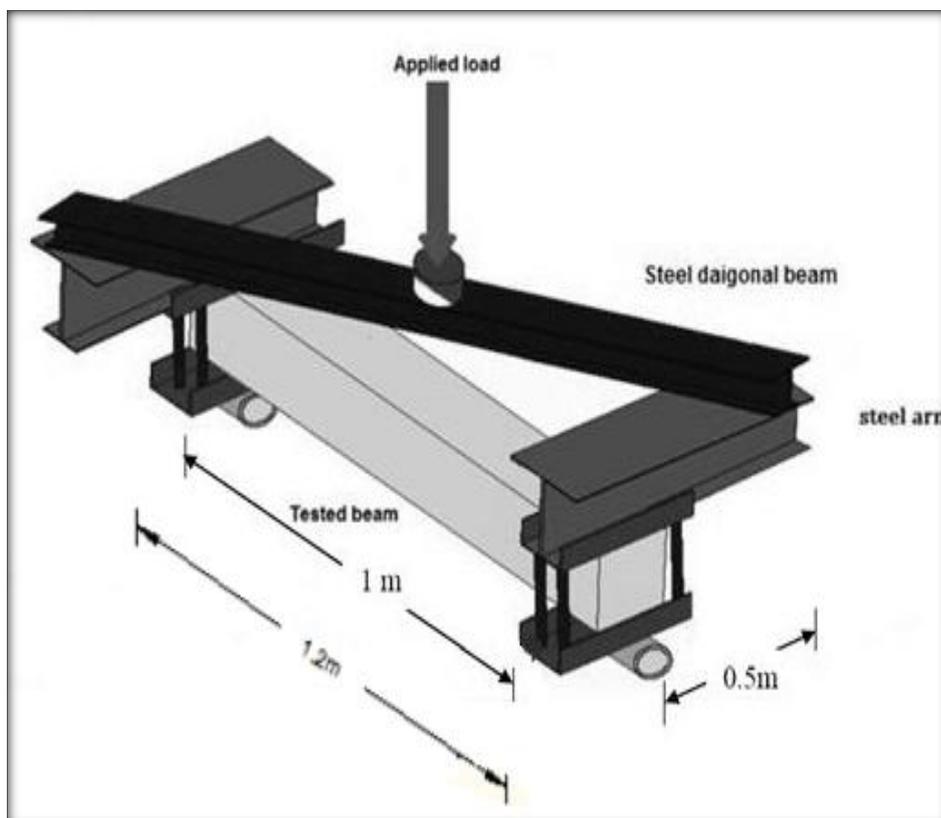
Fig.(3-6): Graph demonstrates torsional test.

Fig. (3-7) The utilized Machine for applying Loads during tests.

Fig. (3-8): Beam's end Supports

Fig. (3-9): loads Recording

.

3.9 Measurements of Twisting Angle

To calculate the twisting angle, two 0.001 cm dial gages have been placed at the end cross section of the beam at a position (7.5 cm) from the center of the beam's width, as illustrated in Fig. (3-6). One dial gage was adjusted on the right to recording uplift magnitudes and the other dial gage was adjusted on the left to recording down magnitudes to calculate the twisting angle in radians by adding the readings of the first dial gage (D1) and the readings of the second dial gage (D2) and dividing by the distance between them (15 cm) as shown in Fig. (3-7)**.**

Fig. (3-10): Measurement of Twisting Angle
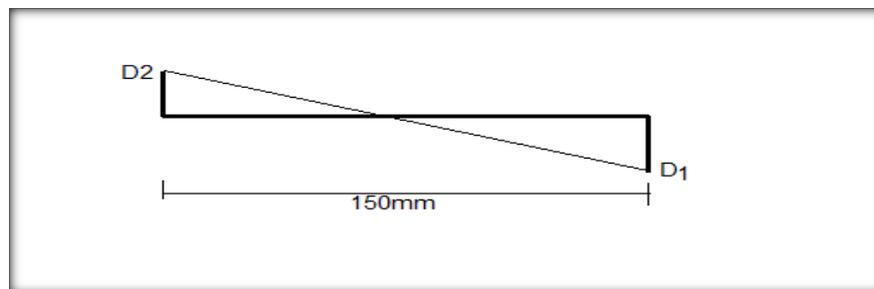
Fig. (3-11): A sketching to degree the twisting angle

Chapter Four

Test Results And Discussions

4.1 General

As previously reported, the key aim of current research work is to examine the rectangular reinforced concrete beams torsional behavior with opening that is improved by using UHPC. An experimental program has been undertaken to achieve this aim, as defined in chapter three. Eight rectangular beam were examined under pure torsion, to research the impact of various considered variables. In this chapter, the test results are explored in terms of torque - twist action, ultimate torque, and failure modes.

4.2 Hardened Concrete's Mechanical Properties

Understanding the behavior of concrete beam specimens requires a thorough understanding of its mechanical features. The strengths of splitting tensile and Compressive one; and rupture modulus are among the mechanical properties of hardened concrete investigated in this research.

.2.1 Testing of Compressive Strength (f_{cu})

The compressive strength of normal concrete has been determined by the compressive testing of cubes samples that have dimensions of 150mm while the UHPC compressive strength was determined by the compressive testing of cubes samples that have dimensions of 50mm. According to (**BS.1881:Part 116:1989**) three concrete cubic have been tested so as to identify the strengths of the compressive by utilizing hydraulically compressive machine with capacity (1,600,000 N) in construction lab /

Babylon University. The average compressive strengths of concrete were 38.2 MPa for normal concrete and 134.5MPa for UHPC. see Fig(4-1a).

4.2.2 Strengths of Splitting Tensile (f_t)

Three cylindrical concretes samples (10x20) cm have been tested to gain the strengths of splitting tensile for both normal concrete and UHPC test according to **(ASTM C496-2004).** The average splitting strengths of concrete were 3.4MPa for normal concrete and 13.8MPa for UHPC. see Fig(4-1b).

4.2.3 Rupture's modulus (f_r)

The rupture's modulus of normal concrete has been identify by the flexural testing of prism specimens with dimension of (100*100*400mm) while the UHPC rupture's modulus has been identify by the flexural testing of prism specimens with dimension of (50*50*300)mm. The average flexural strengths of concrete were 4.2 MPa for normal concrete and 24.3MPa for UHPC. see Fig(4-1c).

a.

Fig.(4-1). Tested specimen and results of UHPC. (a-compressive testing, b-splitting testing and c-flexural testing).

b.

c.
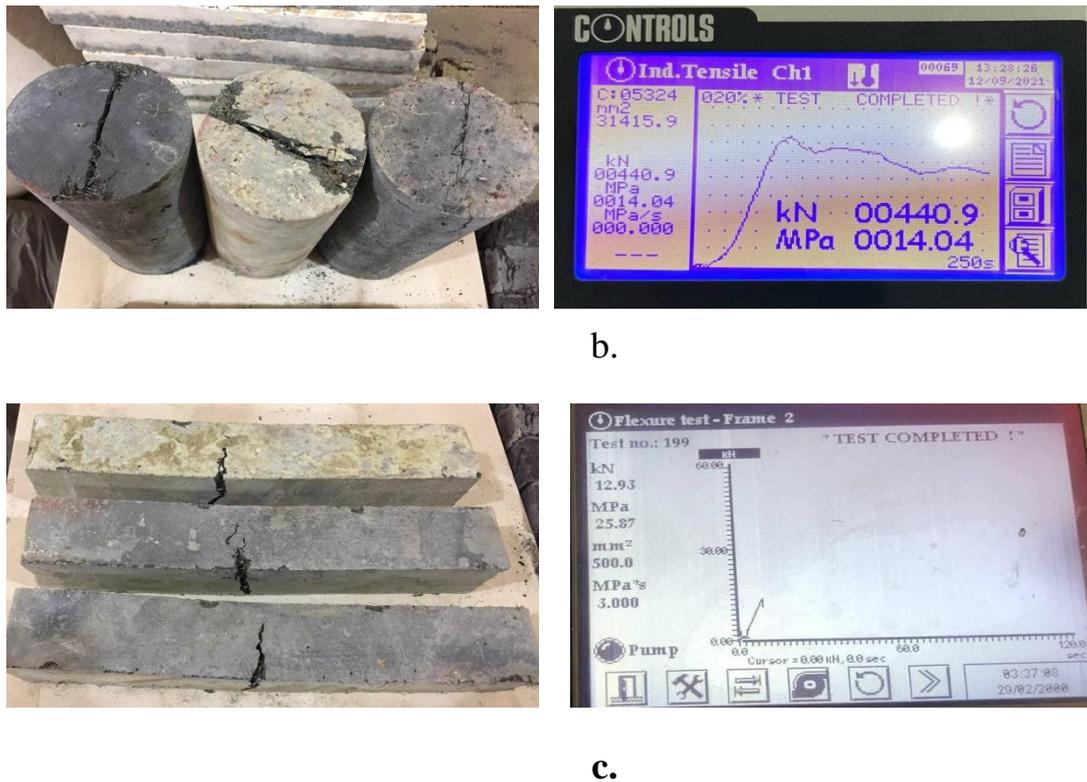
Fig.(4-1). continued

4.3 Test Results of Tested Beams

4.3.1 Torsional Strength and Crack Pattern

The most important characteristics of beam are first cracking torque and ultimate torque capacity. The results were listed in Table (4.1) The results showed that the influence of small opening on ultimate loading capacities of normal concrete beams was limited because of the additional strength provided by diagonal reinforcement and shear flow remain constant approximately but the first crack load was affected by small opening because of the fact of depending first cracking load on section cross area. Also, the UHPC beams show a significant enhancing in both ultimate torque and cracking torque.

The crack pattern of tested beams affected by adding opening , type of concrete and the diagonal reinforcement as shown in Figs. (4-2) to (4-9) .

Where, the inclined cracks of NS beam appeared and distributed along the beams while the US beam has two main inclined cracks appeared at mid-span because of the high strength of UHPC beam which prevent additional cracks occur. The cracks propagation of ND-75 beam were similar to NS beam but the ND-100 has only three main inclined cracks at mid span with cover spilling. For beam UD-75, the crack pattern consist of two inclined cracks appear above and down the opening while the UD-100 cracks with one inclined crack through the opening. The absence of diagonal reinforcement. Where , the UW-75 and UW-100 failed with two cracks above and down the opening one of them (above the opening) changed its direction from inclined to semi vertical

Table (4.1) First crack torque and ultimate capacity of tested beams

Specimen code	First cracking torque kN.m	% of change w.t.r to control beam	Ultimate torque kN.m	% of change w.t.r to control beam
NS	4.5	0	6.8	0
US	8.5	88.889	22.9	236.76
ND-75	3.5	-22.22	6.7	-1.471
ND-100	3	-33.33	5.6	-17.65
UD-75	7.25	61.111	20.6	202.94
UD-100	5.7	26.667	15.7	130.88
UW-75	6.25	38.889	18.9	177.94
UW-100	4.25	-5.556	14.8	117.65

Fig. (4-2): The cracks patterns of tested specimen (NS)

Fig. (4-3): The cracks patterns of tested specimen (US)

Fig. (4-4): The cracks patterns of tested specimen (ND-75)

Fig. (4-5): The cracks patterns of tested specimen (ND-100)

Fig. (4-6): The cracks patterns of tested specimen (UD-75)

Fig. (4-7): The cracks patterns of tested specimen (UD-100)

Fig. (4-8): The cracks patterns of tested specimen (UW-75)

Fig. (4-9): The cracks patterns of tested specimen (UW-100)

4.4 Torque Moment- Angle of Twist of Tested Beams

The twisting torque-angle's curves for the beams of all tested beams as given in the Fig. (4-10) to (4-13).

The influence of opening size is shown in Fig.(4-10) .The influence of opening size is more pronounced. It can be noticed that small opening without any substantial impact on ultimate load capacity as a result of the contribution of diagonal reinforcement offset the amount of concrete opening but on the other side the small opening has obvious effect on torsional stiffness of beam. Also, it can be noticed that large opening has more significant effect on both ultimate load capacity and torsional stiffness of beam as a result of the dramatic change in mechanism of shear flow.
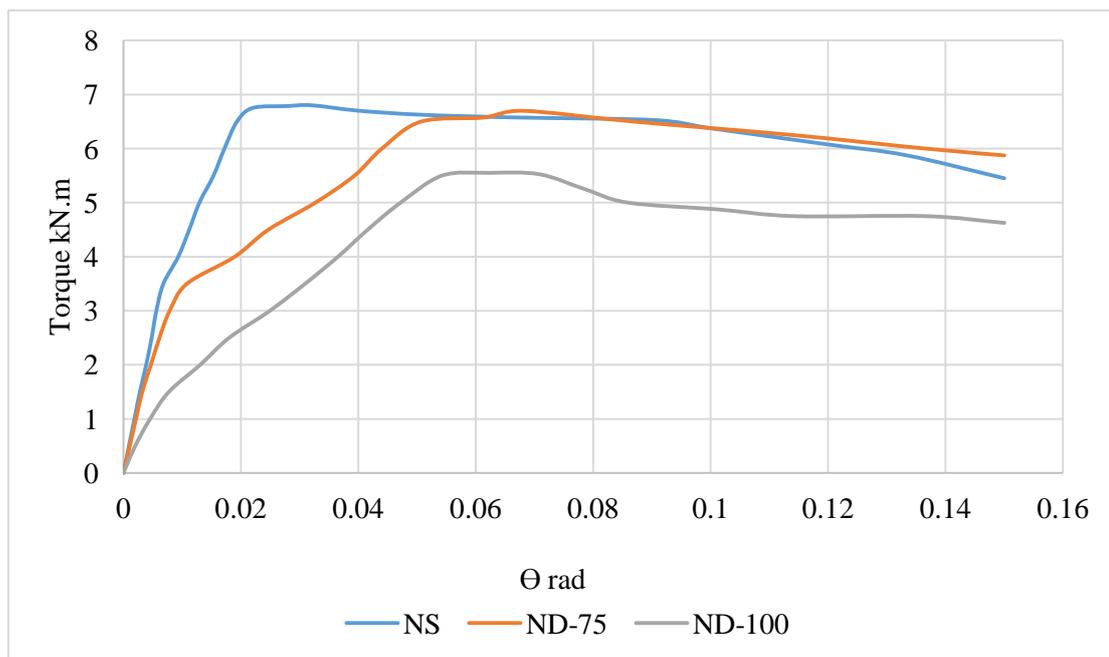
Fig. (4-10) Torque-rotation diagrams of beams NS,ND-75 and ND-100

Fig.(4-11) showed that ultra high performance concrete beam has higher torsional capacity and stiffness than normal concrete due to the increasing in tensile strength of UHPC but after ultimate load the normal concrete beam show more ductile behavior.
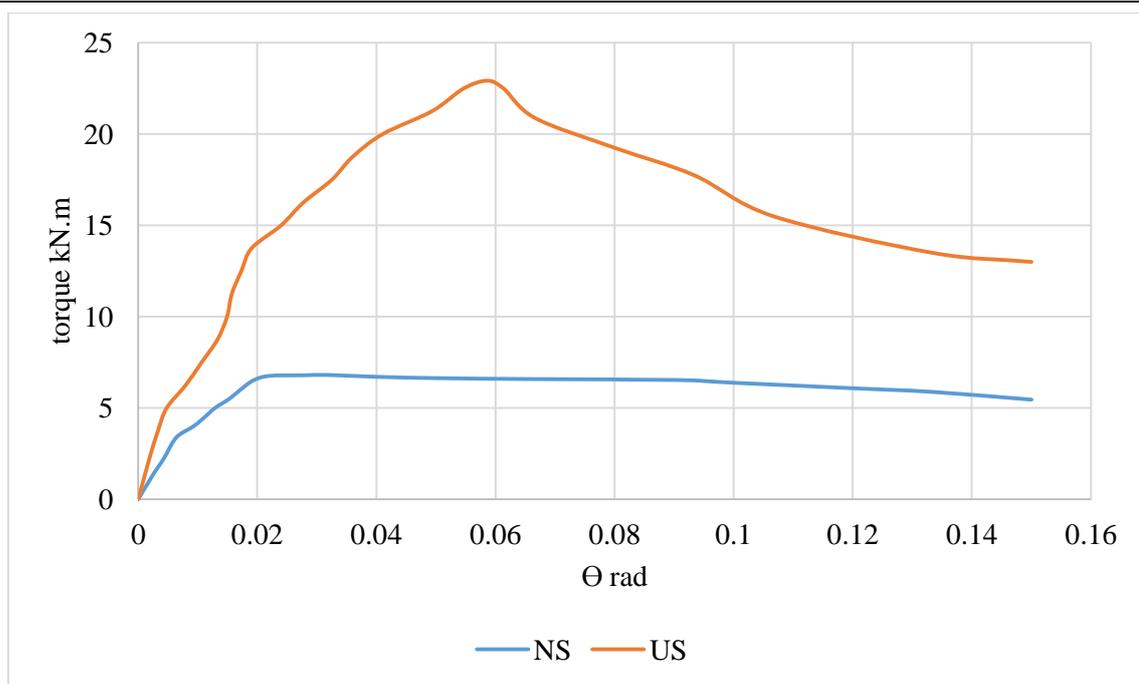
Fig. (4-11) Torque-rotation diagrams of beams NS and US

Fig. (4-12) showed the effect of UHPC on beam with small opening behavior in both cases with and without diagonal reinforcement. For both cases the UHPC enhanced the behavior of beam with small opening but the absence of diagonal reinforcement led to brittle behavior as compared with UHPC beam reinforced with diagonal reinforcement.
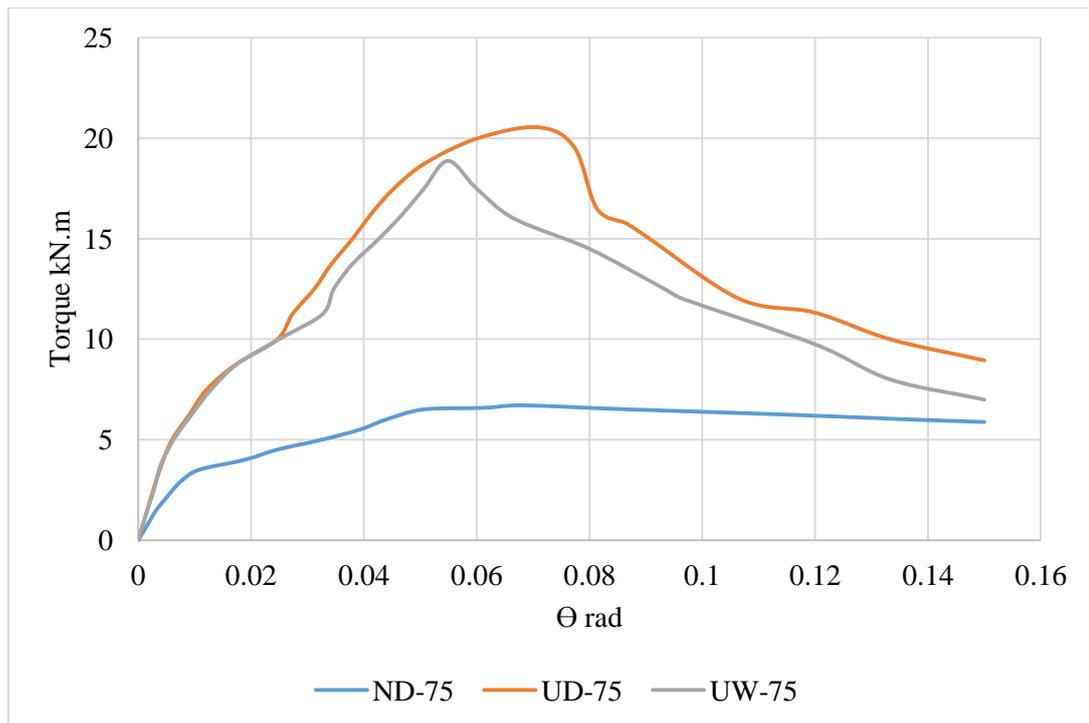
Fig. (4-12) Torque-rotation diagrams of beams ND-75, UD-75 and UW-75.

Fig. (4-13) showed the effect of UHPC on beam with large opening behavior in both cases with and without diagonal reinforcement. For both cases the UHPC enhanced the behavior of beam with large opening but the absence of diagonal reinforcement led to brittle behavior as compared with UHPC beam reinforced with diagonal reinforcement.
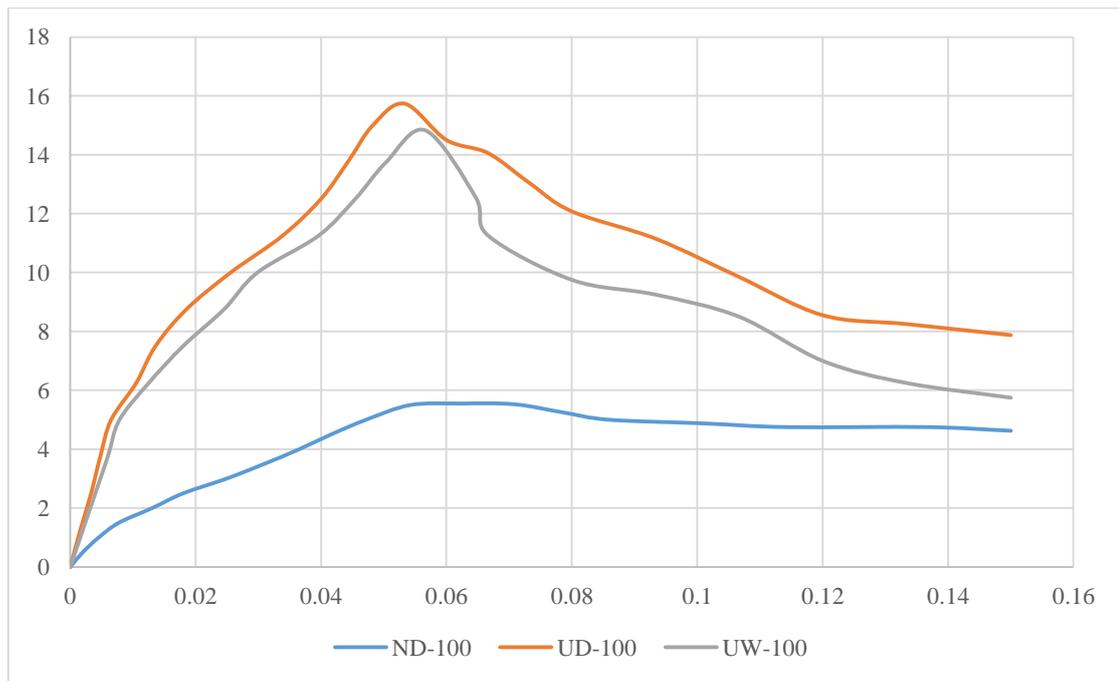
Fig. (4-13): torque-rotation diagrams of beams ND-100, UD-100 and UW-100.

4.4 Torsional ductility index

Ductility is a measure for the ability of a material to deform plastically without fracturing when the material subjected to different type of stresses. In this study, torsional ductility of members was calculated using the approach was based on index of ductility of torsion μθ identified and utilized by Bernardo and Lopes in 2015, dependent on the deformation of angle/meter (twisting). The following formula described that:

$$\mu\theta = \frac{\theta u}{\theta y}$$

where

μθ = ductility ratio

θ*u*= ultimate's twisting (matching with the torque in the ultimate point *Tu*);

θy =yielding twisting (matching with the torque in the yielding point *Ty*).

The elastic deformation determined by drawing two tangents. The first one tangent to the torque- rotation curve and intersect with the curve at the origin. The second tangent is a horizontal line that touches the torque-rotation curve at the ultimate torque. Then, a vertical line is drawn from the intersection of these two tangents. The point that the vertical line intersects the torque- rotation curve represents the yield point Hadi et al (2016).

Evaluation of structural parameters of the torsional ductility index is illustrated in Table (4.2). The results showed that openings increased ductility for both NC and UHPC beams. Also, diagonal reinforcement has obvious contribution in ductility in the case of UHPC beams.

Table (4.2). Torsional ductility of beams.

Specimen code	Torsional ductility μ
NS	2.5
US	4.5
ND-75	6.3
ND-100	3.5
UD-75	5.9
UD-100	4.8
UW-75	4.6
UW-100	4.1

4.5 Torsional toughness

Because of their fundamental energy absorption and ductility, the fundamental essence of Reinforced concretes members seem to be the transfer of mechanical energies into internally potential energies. Concretes members absorbed energies via complex mechanisms that include fracturing mechanics, which corresponds to concrete's cracking, as well as plastic and elastic deflections. Numerous investigations have shown a proportional relationship between absorption of energy and Reinforced concretes members ductility. By using the torsion model presented in Fig.(4-14) the torsional toughness of the three parts was calculated from for each beam.
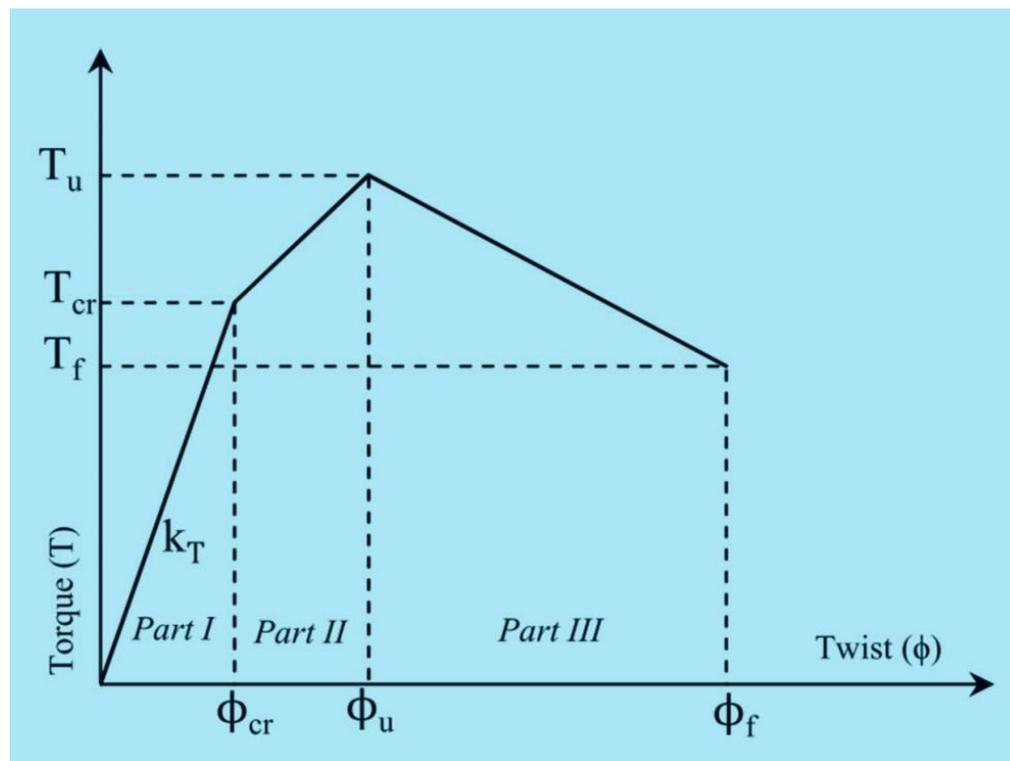
Fig.(4-14) Torsion model. Okay and Engin (2012).

The toughness was calculated by calculating the area under the curves for each part shown in the Fig. (4-14), (part I: pre-cracking zone), (part II: post cracking zone, and (part III: transition zone). which represent the

absorbed energies/lengths by the elements throughout the testing process and it is gained from the areas that located under the rotation's angle unit against plots of torque for both testing, and the results were arranged as shown in the table (4.3). This specifies that the UHPC beams displayed high cracked torsional toughness. Using steel fiber in concrete mix interfacial connection strength reduces the crack and fixes the concrete apparatus mutually.

Table (4.3). Torsional toughness for all models in three parts

Beam name	Torsional toughness (kN.m.rad)			Percent of change w.r.t. control beams		
	PI	PII	PIII	PI%	PII%	PIII%
NS	0.0296	0.130345	0.746608	----	----	----
US	0.070833	0.814517	1.519567	139.3007	524.8932	103.5294
ND-75	0.022567	0.31035	0.515543	-23.7601	138.0989	-30.9486
ND-100	0.0459	0.169933	0.433967	55.06757	30.37171	-41.8749
UD-75	0.054417	0.897637	1.019503	83.84122	588.6624	36.55131
UD-100	0.038917	0.479439	1.033733	31.47635	267.8231	38.45726
UW-75	0.03525	0.554683	1.125067	19.08784	325.5499	50.69046
UW-100	0.019417	0.494285	0.809967	-34.402	279.2129	8.486247

4.6 Initial stiffness and service stiffness

The initial stiffness was calculated by dividing the crack torque by the angle of twist of the model at the cracking stage. Normally, the stiffness measured from the slope of the pre-crack loading 30% of ultimate load to the yield load segment of the torque-rotation curve was defined as the service stiffness. The service load level for a reinforced concrete beam normally corresponded to 60% of the ultimate torque of the beam Baran and Arsava(2012). It was noted from the results of NC beams the opening reduced both initial and service stiffness while the UHPC beams with openings showed increased in initial stiffness and reduction in service stiffness because of the increment in ultimate torque and the corresponding rotation resulted from the tensile strength of UHPC.

Table (4.4). Initial stiffness and service stiffness of tested beams.

Beam code	Initial Stiffness (kN.m/rad)	Percent of change w.r.t. control beam %	Service Stiffness (kN.m/rad)	Percent of change w.r.t. control beam %
NS	401.8	-----	365.8537	------
US	773	92.38427	667	82.31516
ND-75	324	-19.3629	125	-65.833
ND-100	120	-70.1344	87	-76.2198
UD-75	660	64.26083	283	-22.6459
UD-100	543	35.14186	278	-24.0126
UW-75	658	63.76307	220	-39.8661
UW-100	540	34.39522	214	-41.5061

Chapter Five

Conclusions and Recommendations

5.1 General

In this chapter, the conclusions of the present study obtained from the empirical results with the limitations of the study. And this chapter was finished with mentioned recommendations for future researchers.

5.2 Conclusions

From the results of the present study, the following conclusions are obtained:

1. It can be noticed that the ultimate torque capacity of normal concrete beam was not affected by small opening with the existence of the additional diagonal reinforcement but the first cracking load, initial stiffness and service stiffness were affected by small opening.

2. Large opening has significant effect on torsional behavior of normal concrete beams.

3. Using UHPC enhanced torsional behavior and substitute the missing strength due to small and large openings.

4. When the beam casting with UHPC, the diagonal reinforcement can be removed from steel cage.

5. Openings increased ductility for both NC and UHPC beams. Also, diagonal reinforcement has obvious contribution in ductility in the case of UHPC beams

6. UHPC beams showed enhancement in toughness especially in post crack zone. The increment in post crack stage rounded 280%-588%. While , The increment in transition stage rounded 8%-

50%.

7. All tested UHPC beams showed sharp drop in torque-rotation diagrams.

5.3 Recommendations For The Future Works

1. Investigating the performance of hollow concrete beams casted with UHPC in both flexure and torsion condition.
2. Theoretical investigation on torsional behavior of UHPC beams.
3. Repair the damaged beams with UHPC under different load conditions.
4. Research of the behavior of reinforced concrete (beams elements) with various cross-sectional areas for example (L-section, T-section and trapezoidal) reinforced.

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تحسين السلوك ألالتوائي للأعتاب الخرسانية المسلحة الحاوية على فتحات مستعرضة باستخدام خرسانة فائقة الاداء

بــحث

مقدم الى كليَّةِ الهندسة / جامعةِ بابل كجزءٍ مِنْ متطلبات نيل درجةِ الدبلوم العالي في الهندسة المدنيةِ/ (هندسة الإنشاءات)

من قبل

لينا حسين علي

بكالوريوس علوم في الهندسة المدنية

أشراف

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الخلاصة

يهدف هذا البحث إلى دراسة من سلوك الالتواء للأعتاب الخرسانية المسلحة والمتضمنة فتحات دائرية مستعرضة , والضرر الناتج عنها ودراسة طرق معالجتها باستخدام الخرسانة فائقة الأداء (UHPC) والتسليح القطري.

يتكون البحث من دراسة عملية تتضمن صب ثمانية اعتاب بأبعاد (150 × 200 × 1200 مم) واختبارها تحت تأثير الالتواء فقط . اثنان من هذه الاعتاب لا تحتوي على فتحة عرضية ، أحدهما مصبوب بالخرسانة العادية والآخر مصبوب بخرسانة فائقة الاداء ، بينما الاعتاب الأخرى لها فتحة عرضية وتنقسم إلى مجموعتين (فتحات صغيرة وكبيرة). تحتوي كل مجموعة على ثلاث عوارض بفتحة دائرية في منتصف الكمرة (تم صب الأولى بخرسانة اعتيادية ومُقوّاة بتسليح قطري ، والثانية مصبوبة بخرسانة فائقة الاداء ومُقوّاة بتسليح قطري والثالث بخرسانة فائقة الاداء ولكن بدون تسليح قطري.

أظهرت جميع الاعتاب المختبرة الحاوية على الفتحة والمصبوبة باستخدام بخرسانة فائقة الاداء زيادة كبيرة في عزم الالتواء الاقصى مقارنة مع العتب غير الحاوي على فتحة. وكذلك أظهرت النتائج ان مقاومة اللي القصوى للعتب الخرسانية الاعتيادية ذات الفتحة الصغيرة انخفاضًا طفيفًا في عزم الالتواء الاقصى (1.47٪) ولكن الاعتاب ذات الفتحات الكبيرة أظهرت انخفاضًا ملحوظًا في الالتواء الاقصى (17.65٪). وبذلك فان استخدام الخرسانة فائقة الاداء عوض القوة المفقودة الناتجة عن إزالة التسليح القطري لكل من الفتحات الصغيرة والكبيرة.

الصلابة الأولية للأعتاب ذات الخرسانة الاعتيادية ابدت انخفاضًا لكل من الفتحات الصغيرة والكبيرة بنسبة 19.4٪ و 70.1٪ على التوالي ، بينما أظهرت الاعتاب المصبوبة بخرسانة فائقة الاداء والحاوية على فتحات تحسنًا في الصلابة الأولية تقريبًا بين 64٪ للفتحات الصغيرة و 34٪ للفتحات الكبيرة