DESIGN OF BEAM AS A HOLLOW CROSS SECTION BY USING STEEL FIBER UNDER PURE TORSION

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CHAPTER ONE

INTRODUCTION

1.1 General:-

There are some cases that reinforced concrete beams are subjected to torsion as a result of external load, affect outside (Shear center) of the cross section, or deformations resulting from the continuity of beams or similar members that join at an angle to each other.

Shear center: have been defined as that point in the cross-section of a beam through which the lines of action of shear loads must pass for there to be no twisting of the section. It may be shown by use of the reciprocal theorem that this point is also the center of twist of sections subjected to torsion.

For many years, torsion was regarded as a secondary affect, and was not considered explicitly in design, its influence being absorbed in the overall factor of safety of rather conservatively designed structures. But during recent years, it has become necessary to take account of torsional effects in member design and there are two reasons for this consideration. *First*, development in the methods of analysis and design, such as the strength design approach now favored, have permitted a somewhat lower overall factor of safety through more accurate appraisal of load capacity, and have led to somewhat smaller member sizes. *Second*, there is increasing use of structural members for which torsion is a central feature of behavior, examples including an end beam in a floor panel, a spandrel beam receiving load from one side, a canopy or a bus-stand roof projecting from a monolithic beam on columns, peripheral beams surrounding a floor opening, curved bridge girders, eccentrically loaded box beams, and helical stairway slabs. And among these two reason, torsion failure is generally considered as brittle in concrete structure.

It is not easy to define in a precise, quantitative way what a hollow section (thin-walled) structure is. It seems sufficient to say that a hollow section structure is specify that thickness is small compared to other cross-sectional dimensions which are in turn often small compared with the overall length of the member or substructure. Important examples, often requiring high structural performance at minimum weight, include bridges, box girders & shear core in all tall buildings …etc. Hollow section structures can be designed to exhibit great torsional rigidity, for example as box girders. One property they all have in common is that they are very light compared with alternative structures and therefore, they are used extensively in long span bridges and other structures where weight and cost are prime considerations.

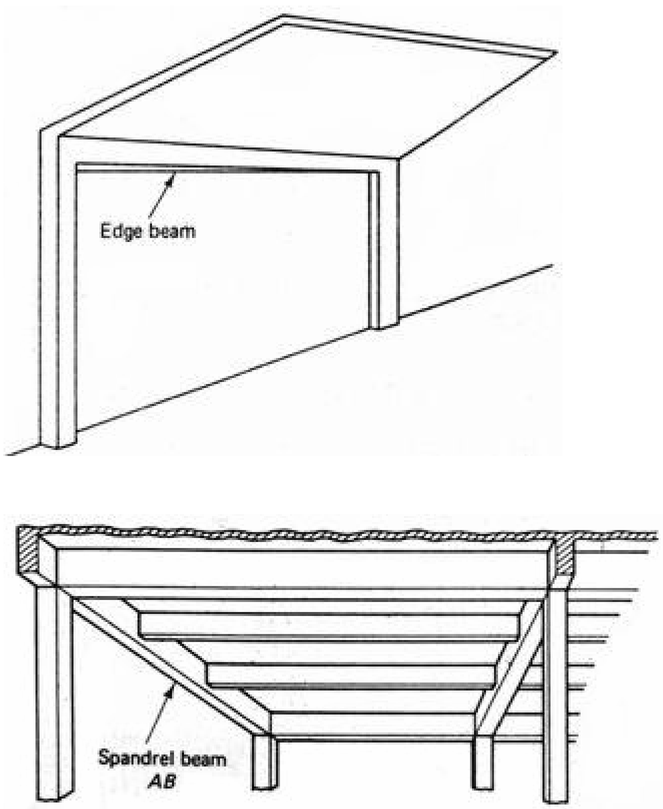

Fig.1-1 Figure of Beams Under Torsion

Continuity in the studying of researchers to find construction materials with suitable and agreed properties for construction, or promoting some weak properties of presence materials through adding additive materials, among these additive materials, ideas for using steel fiber with concrete mixture.

Concrete is considered as an important construction materials but a brittle material having low tensile strength, limited ductility, and weak during rising cracks. Recently for improving these deficiencies, different kind of fibers are used. Adding steel fibers to concrete consist of (Cement : Sand or Cement : Sand : Gravel) will improve the following properties of concrete towards more active: Tensile strength, Shear strength, Strain capacity, impact resistance, Energy Absorption, limiting crack width, strength against impact load, resist against twisting (increasing torsional capacity), increase in stiffness and the brittle characteristic of conventional concrete is converted into a ductile one.

The concrete used in the mixture is of a usual type, although the proportions should be varied to obtain good workability and take full advantage of the fibers, because the important points which should be taken into consideration during preparation of concrete mixture containing steel fibers are *uniform distribution, avoid balling at the time of mixing and casting* and this may require limiting the aggregate size, optimizing the gradation, increasing the cement content, and perhaps adding other admixtures to improve workability like GLENIUM which used in this research.

The fibers may take many shapes, their cross sections include circular, rectangular, half-round, and irregular or varying cross sections, they may be straight or bent and come in various lengths. A convenient numerical parameter called the aspect ratio is used to describe the geometry. This ratio is the fiber length divided by the diameter. If the cross section is not round, then the diameter of a circular section with the same are is used.

Many investigations have shown that use of fibers with an aspect ratio greater than 100 usually causes inadequate workability of the concrete mixture, non-uniform fiber distribution, or both if the conventional mixing techniques are used.

Steel fiber can be mixed and placed with conventional equipment and procedures use from 0.5 to 1.5 volume percent fibers. However, higher percentages of fibers (from 2 to 10 volume percent) have been used with special fiber addition techniques and placement procedures. Most properties given in this thesis are for the lower fiber percentage range.

Hollow cross section beam mean closed thin walled section beam. A thin walled beam is characterized by the relative magnitude of its dimensions; the wall thickness is small compared to the other linear dimensions of the cross section.

The advantages of hollow cross section:

1. Saving in weight, which affects especially the cost of transport, handling and erection for pre-cast cross sections.
2. Substantial reduction of material quantities, the materials required are usually much less than those needed for other conventional systems and they are little more than those required for continuously curved shells, with the advantage of utilizing relatively simple formwork.

1.2 Torsion:-

Torsion is considered with the complex subject especially in the non-circular cross sections, most concrete beams subjected to twist are components of rectangles.

For over sixty years, the torsional analysis of concrete members has been based on either (1) The classical theory of elasticity developed through mathematical formulations computed with membrane analogy verifications (Saint-Venant’s) in 1855 the method is (Semi-Inverse method) contains many assumption aimed for simplified the equilibrium equations and boundary condition. The second method (2) the theory of plasticity represented by the sand-heap analogy (Nadai's). Both theories were applied essentially to the state of pure torsion.

Saint-Venant's theory on Torsion for the circular sections confirmed that Shear stress at any points of the section are perpendicular on the radius of the circle as in below fig., but in Non-circular cross sections will not remain circle during torsional affect due to (Warping displacement). This moment produces axial as well as circumferential shear stresses with zero value at the corners of the section and the centroid of the rectangle and maximum values on the periphery at the middle of the sides, as seen in Fig 1-1b. The maximum torsional shearing stress would occur at midpoints A and B of the larger dimension of the cross section. These complications plus the fact that reinforced concrete sections are neither homogeneous nor isotropic make it difficult to develop exact mathematical formulations.

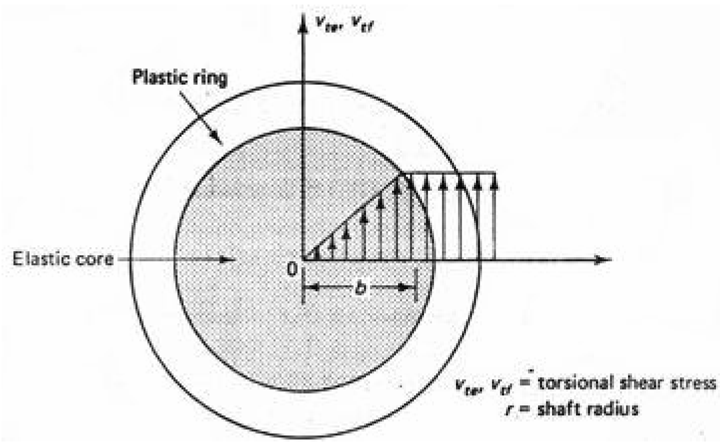

Fig.1-2a Torsional Stress distribution

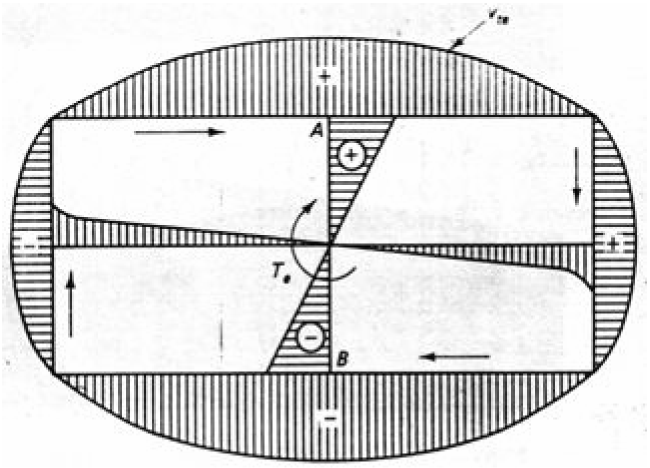

Fig.1-2b Torsional Stress distribution

The last researches clarified that the (Stress–Strain) relationship will be linear at the first stage (Elastic Stage) and change to non-linear in the second and failure stages, concerning plain concrete beams (not reinforced), sudden cracks will happen and collapse the beam for two separate parts, and the surface of failure around axis is disturb. But if the beam is reinforced (by steel bars, steel fiber or both) that mean the ultimate torque which resist is consist of strength from concrete, steels and steel fibers.

Reinforced concrete beams subjected to pure torsion can be divided into three categories: (1) under reinforced, (2) Completely over reinforced. (3) Partially over reinforced beams.

Under reinforced beam is one in which both longitudinal bars and stirrups yield before the concrete crushes at the ultimate torque. A beam is considered completely over reinforced if neither the longitudinal bars nor stirrups yield before the concrete crushes and the failure is sudden failure. A partially over reinforced beam contains an unbalanced ration of longitudinal bars to stirrups, as the concrete crushed in these beams, either yield occurs in the longitudinal bars and not in the stirrups or yield occurs in the stirrups and not in the longitudinal bars. The case of under reinforced is more acceptable in the design of beams because the failure will happen gradually and the crack will appear when shear stress due to torsion will exceed tensile strength of concrete and then increase tensile stress in the steel and the crack width will increase till the steel yield and the torque will be ultimate.

1.3 Objective of the Research:-

There are very limited researches studying the behavior of Fibrous Hollow Reinforced concrete beams under pure torsion and warping displacement affect.

Therefore, the main target of this thesis are studying the effect of different amount of steel fiber with longitudinal and stirrup steel bars on the strength and behavior of non-circular hollow cross section beams subject to torsion and also studying warping displacement which occur at the ends of beams.

The variables which taken in this thesis are: dimension of sections, volume of fraction, hollow and solid section with thickness of walls for hollow section.

It's Expect in this thesis to state the influence of steel fiber on the strength and behavior of Non-circular hollow cross section beam under pure torsion and comparison between experimental tests with theoretical equations result and confirm the best equations which result the nearest value to the experimental result.

Finally studying the factors which affect on the behavior of Fibrous Reinforced Concrete beams under pure torsion which have directly relation with the (type of steel fiber, volume of fraction, aspect ratio, Longitudinal and stirrup reinforcement & dimension of sections).

The primary objective of the experiment was to measure, observe and subsequently compare the behavior of the specimens.

The behavior of specimens under static load was studied, the load rotation curves were plotted, and the comparison of those curves was studied and analyzed. The splitting tensile strength and the compressive strength of samples and the effect of steel fiber on those were also studied.

Concrete and steel strains on the important location were measured in two direction, orthogonal and diagonal direction, in order to study the strain at the various stages of loading.

CHAPTER TWO

EXPERIMENTAL WORK

2.1 Introduction:-

The main object of the present research and experimental program was to collect as many data as possible on the influence of steel fiber on the strength and behavior of reinforced concrete hollow beams under pure torsion and studying the developed stresses on the concrete and steel bars by using electrical strain gauge.

This chapter includes presentation for: used materials during casting the beams, variables, preparing samples for testing, testing procedures, detailed description for loading instrument which used to twist the beams, and the shape and dimensions of the models as shown in Fig. 2-1.

In this chapter, the experience gained during the construction of twenty four beams through eight groups, the specimens will be outlined and the suitability with advantages of beams under pure torsion will be discussed. With casting each group, sufficient cubes and cylinders were cast from the same batches of concrete and these were tested to determine required concrete parameters; these tests were carried out on the same day as the torsion tests.

2.2 Scope of Work:-

In order to study the structural behavior and ultimate strength of fiber reinforced concrete beam under pure torsion, which can be used as non-circular hollow cross section, a total of twenty four full-scale specimens in eight groups as detailed in table 2-1 were casted in plywood forms. All the beams were made from a single mix proportion (Cement: Sand: Gravel) of 1:3:2 by weight with a water/cement ratio 0.5 in order to obtain consistent workability. And also all beams were designed to have the same longitudinal and stirrup reinforcing.

Each of the mixtures was thoroughly mixed prior to casting. The beams were cast horizontally so that the fiber orientation would be the same as would be achieved in field construction.

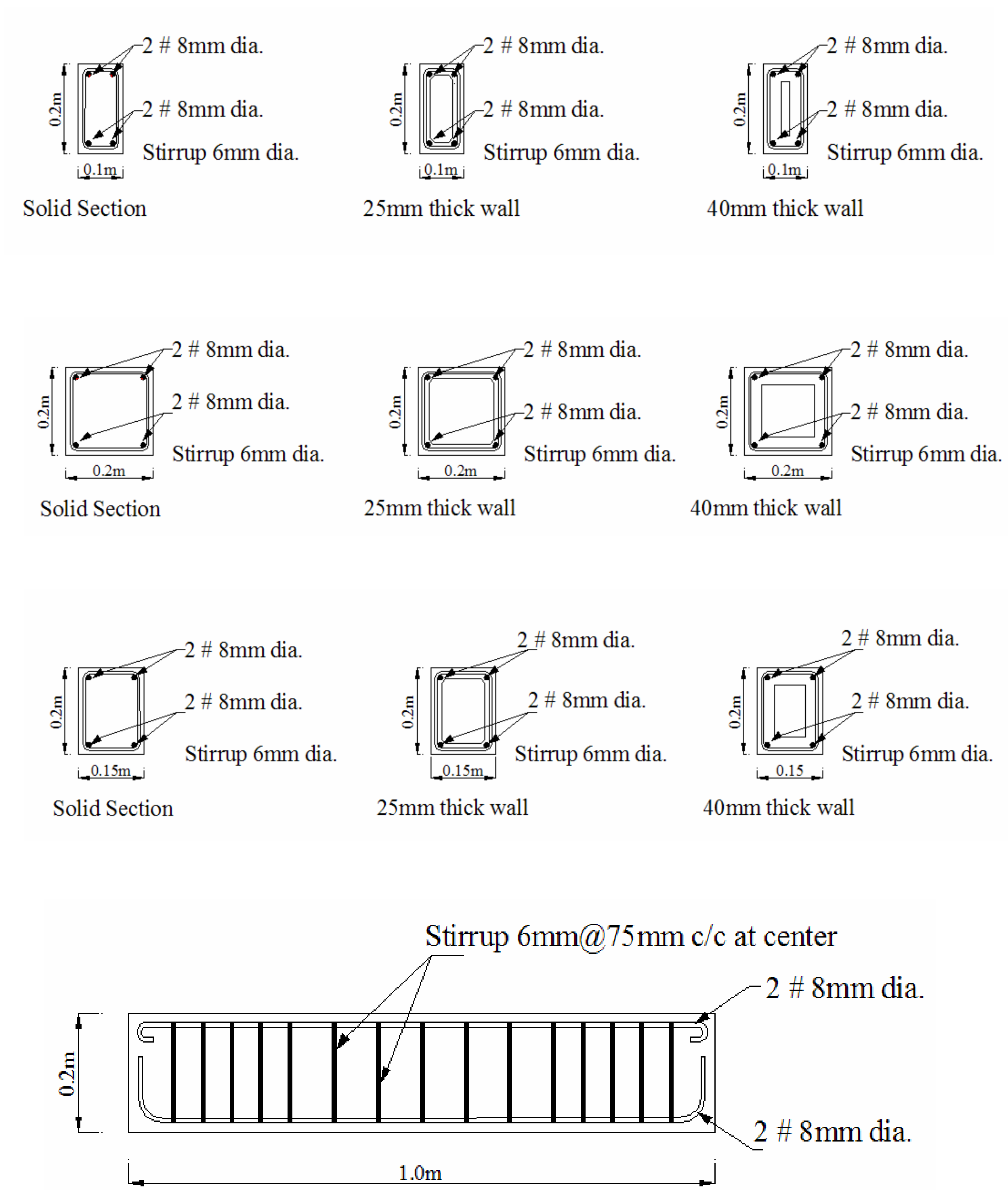

Fig. 2-1 Cross-Section & Longitudinal shape of the beam

Table 2-1 Details of the Specimens

Group No.	Specimen symbol	Width (mm)	Thick (mm)	Rate of Long. Reinf. %	Rate of Stirrup %	Steel Fiber Content %	Total Steel Content %	Section pro.
G1	B1S	100	---	1.0	0.94	0	1.94	Solid
	B2S	150		0.67	0.75		1.42	
	B3S	200		0.5	0.66		1.16	
G2	$B4S_f$	100	---	1.0	0.94	0.75	2.69	Solid
	$B5S_f$	150		0.67	0.75		2.17	
	$B6S_f$	200		0.5	0.66		1.91	
G3	B7H	100	25	1.0	0.94	0	1.94	Hollow
	B8H	150		0.67	0.75		1.42	
	B9H	200		0.5	0.66		1.16	
G4	$B10H_f$	100	25	1.0	0.94	0.75	2.69	Hollow
	$B11H_f$	150		0.67	0.75		2.17	
	$B12H_f$	200		0.5	0.66		1.91	
G5	$B13H_f$	100	25	1.0	0.94	1.0	2.94	Hollow
	$B14H_f$	150		0.67	0.75		2.42	
	$B15H_f$	200		0.5	0.66		2.16	
G6	B16H	100	40	1.0	0.94	0	1.94	Hollow
	B17H	150		0.67	0.75		1.42	
	B18H	200		0.5	0.66		1.16	
G7	$B19H_f$	100	40	1.0	0.94	0.75	2.69	Hollow
	$B20H_f$	150		0.67	0.75		2.17	
	$B21H_f$	200		0.5	0.66		1.91	
G8	$B22H_f$	100	40	1.0	0.94	1.0	2.94	Hollow
	$B23H_f$	150		0.67	0.75		2.42	
	$B24H_f$	200		0.5	0.66		2.16	

2.3 Considered Parameters:-

In the present investigation, eight group parameters were chosen to study the behavior and ultimate torque of beams and to collect as many data as possible on the influence of steel fibers in concrete beams when subjected to pure torsion.

Group 1: Consists of three specimens with variable width (100, 150 & 200) mm and a constant depth (200mm), length (1000mm), longitudinal bars (4 - Ø8 mm) with stirrups of (Ø6mm @ 7.5cm c/c). All three specimens were solid sections.

Group 2: Consists of three specimens, as in group 1, but the concrete includes steel fiber with 0.75% volume of fraction.

Group 3: Consists of three hollow specimens, variable width (100, 150 & 200)mm with 25mm wall thickness and a constant depth (200mm), length & reinforcement (longitudinal & stirrups) as the same of group 1.

Group 4: Consists of three hollow specimens with the same properties of group 3, but the concrete includes steel fiber with 0.75% volume of fraction.

Group 5: Consist of the same specimens of group 4 but volume of fraction of steel fiber is 1.0%.

Group 6: Consists of three hollow specimens, variable width (100, 150 & 200)mm with 40mm wall thickness and a constant depth (200mm), length (1000mm) & longitudinal bars (4 - Ø8 mm) with stirrups of (Ø6mm @ 7.5cm c/c).

Group 7: Consists of three hollow specimens as the same of group 6 with volume of fraction of steel fiber 0.75%.

Group 8: Consist of the same specimens of group 6 but volume of fraction of steel fiber is 1.0%.

And table 2-1 shows detail of the specimens classified according to the following symbols:

B1S = Refer to ***Beam*** No. 1 & ***S*** refer to Solid section.

B4Sf = Refer to ***Beam*** No. 4 & $\boldsymbol{S_f}$ refer to fibrous solid section.

B8H = Refer to ***Beam*** No. 8 & ***H*** refer to Hollow section.

$B10H_f$ = Refer to ***Beam*** No. 10 & ***Hs*** refer to Fibrous Hollow section.

2.4 Additional Materials:-

Steel Fiber:-

Only one type of Steel fibers was used from plain type with length 25mm and diameter 0.25mm having aspect ratio $\frac{L}{D}=100$ and prepared by (British National Standard Company BNSC). Ultimate tensile strength 512Mpa, density of about 7800 kg/m3, and modulus of elasticity 210 Gpa were used as in Fig 2-2.

Fig. (2-2) Steel Fiber

2.5 Concrete strain measurements:

Electrical resistance strain gauges (5 to 50 mm in length) as in Fig 2-3 were used for measuring the strain of the concrete, axially at top of section, diagonally at center of smaller & longer side of a sections, diagonally at length of (h) after the support (after distortion length as per Saint-Venant's theory).

For concrete strains the concrete surfaces were cleaned and the strain gauges were cemented in place then the load wires soldered to the strain gauges as shown in Fig (2-3). All the electrical strain gauges were connected to the digital model P-3000 strain indicator in series to eliminate any stray of strain which may be present as shown in Fig (2-4) & Fig. (2-5).

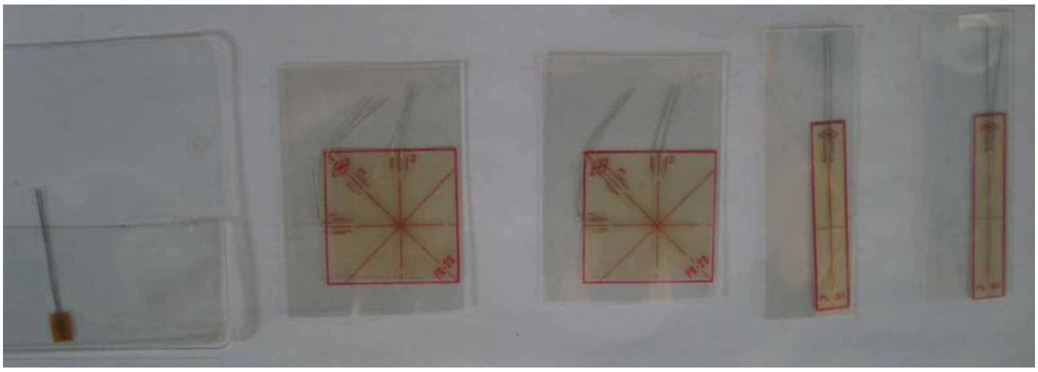

Fig. 2-3 Samples of Strain Gauge

Fig 2-4 Soldering Strain gauge on the beam

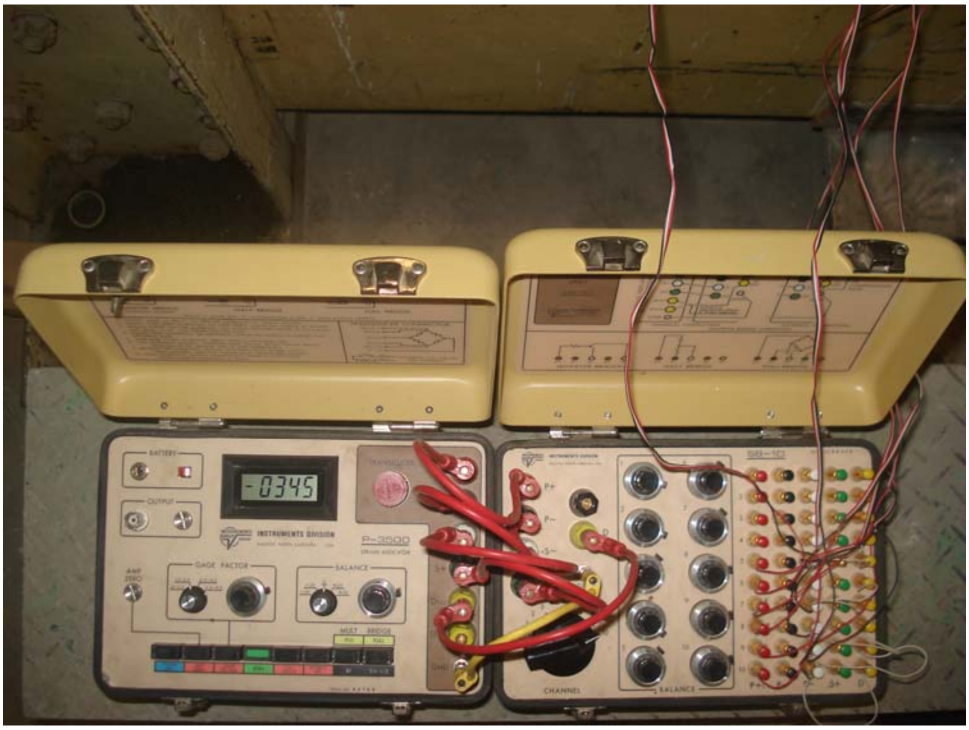

Fig 2-5 Digital P-3000 Strain indicator

CHAPTER THREE

TEST RESULT & DISCUSSION

3.1 Introduction:-

After analysis the experimental result we got that there are several reasons why hollow section structures must be given special consideration in their analysis and design. In a hollow section beam the shear stresses and strains are relatively much greater than those in a solid rectangular beam (as per the result analysis). It is easily demonstrated that when certain hollow section structures are twisted here is a so-called *warping* of the cross-section. The term warping is defined as the out-of-plane distortion of the cross-section of a beam in the direction of the axis. Warping of the cross-section can be greatly inhibited by introducing direct stresses in the axial direction and shear stresses in the cross-section. These stresses are called the warping stresses.

Because of the importance of shear stresses in the plane of the plates making up the cross-section of a beam, it is necessary to study how they are distributed through the cross section. It is found that the shear stresses appear to flow through the cross-section as if they were a fluid.

This chapter includes presentation for the experimental test result of (24) hollow & box cross section beams, result of cracking and ultimate torque. These (24) samples were selected so that to cover the variables which mentioned in the previous chapters.

3.2 Crack and Ultimate Torque:

As per the experimental result and theoretical analysis, the torsional capacity of any beam is influenced by: (1) The provision of longitudinal and transverse steel; (2) the presence of fibers, and (3) the contribution of concrete cross section, depending on its strength. The increase in the torsional capacity of a beam due to conventional reinforcement or fibers can only be estimated if the torsional capacity of the concrete cross section is evaluated.

Ultimate strength of beams under pure torsion was confirmed through recording the maximum load indicated by (Hydraulic jack load indicator) & (Proving Ring), but the cracking load was specified with developing the first crack on the surface of concrete which is not accurate, because many times the crack was developed with a small scale without observing by eyes and that will lead to indicate a wrong cracking load, therefore to get the exact cracking load, electrical strain gauge were used. The idea is at the time of developing first crack on the concrete a sudden increase will observe in the strain of steel bars, and that is easily controlled by capturing electrical strain gauge result at the time of testing by video camera. The presented charts are indicate the result of Ultimate and Cracking Torque for all specimens.

3.3 Angle of twist at Cracking & Pattern of Failure

As in the pure torsion tests when fiber reinforced beams were tested, the twist was continued even after the peak load had been reached. In fiber reinforced concrete beams a decrease in load was observed after the first crack formed; subsequently, there were large rotations until the beams ultimately collapsed.

As per the experimental & Electrical strain gauge indicator result analysis concluded that the torsional moments induce shear stresses which produce principal tensile stresses at 45^{o} to the longitudinal axis of the beam as shown in Fig 3-1. When these stresses exceed the tensile strength of concrete, diagonal cracks are formed, causing instantaneous failure in plain concrete beams. The crack will develop at one of the wider side of concrete beam, by increasing the applied torque (increasing cracking torque) crack will develop at the other side of concrete beam and extend towards both shorter sides of beam and round at helical shape towards wider side again and complete helical rotation around the beam, and then small cracks will appear at the sides of main cracks

In fiber reinforced concrete beams under pure torsion, a greater torsional moment can be applied (beyond the stage of first crack) until eventually failure occurs; a redistribution of internal forces from the concrete to the fibers took place until a new mechanism had been fully mobilized, that mean the fiber reinforced test beams did not fail immediately after formation of the first crack.

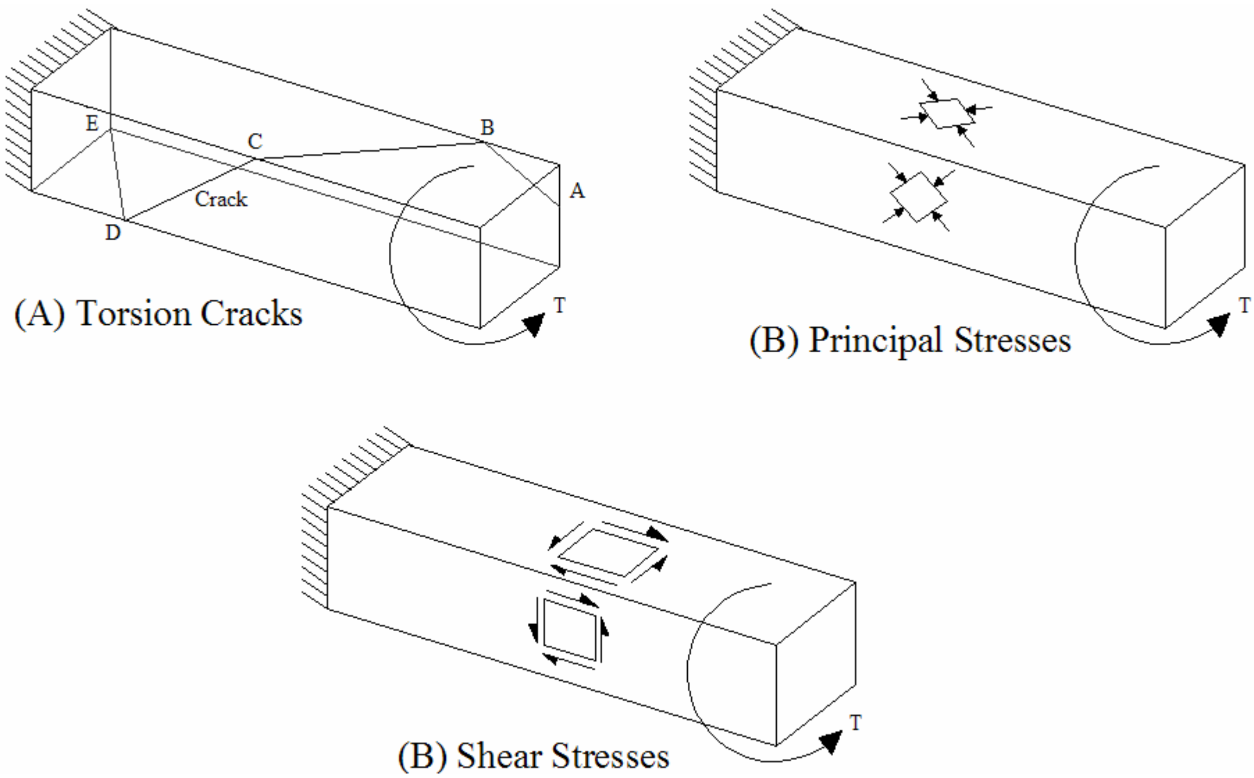

Fig (3-1) Stresses on Beam Elements Under Pure Torsion

In fact there was a considerable unloading zone beyond the ultimate load extending down to about 25% of the ultimate load and the beams went through large rotations before collapse. It can be say that the fibers contributed largely to the ductility of the concrete members. Also the phenomenon of crushing the concrete cover (Spalling down) was observed in the normal concrete beam while not observed in the fibrous concrete beam, as shown in Fig (3-2)

One of the main problem during testing of specimens are difficulty getting the exact angle of twist at failure because of continuity in the increment angle of twist near failure range, therefore using video camera solved this problem.

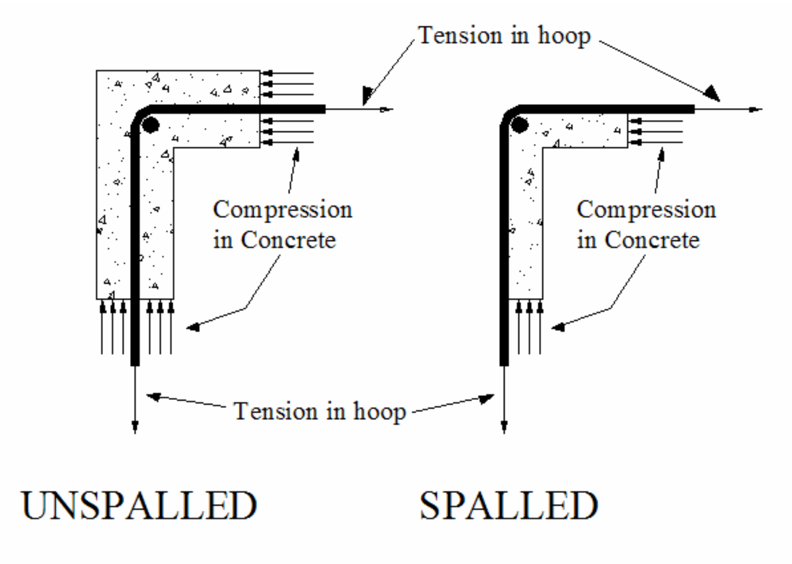

Fig. (3-2) Spalling of the concrete cover due to Torsion

3.4 Effect of Steel Fiber on the Strength of Beams under pure Torsion:

For indicating the effect of steel fiber on the specimens under pure torsion two amount of volume friction were used which is (0.75% & 1.0%) with present specimens without containing steel fiber. Starting with 0.75% volume fraction is to observe the active effect of steel fiber because the previous researches indicate that (0.5%-0.6%) volume fraction is approximately minimum to see the effect of fiber. Therefore these two ranges were selected to feel the clear affect of steel fiber. Following clarify the effect of steel fiber for each of the (Solid, thin walled, thick walled) beams.

3.4.1 Solid beams

Although the main title of this thesis is on hollow specimens, but two groups (six beams) of solid beams were casted & tested just for comparison purpose. Both groups consist of specimens with & without steel fiber. Specimens with fiber just one type of volume fraction were taken which is (0.75%). The experimental test result of six solid specimens section clarified that there is increasing in the ultimate torque about (36.76%) of solid section during using (0.75%) of steel fiber, as shown in Fig 3-3.

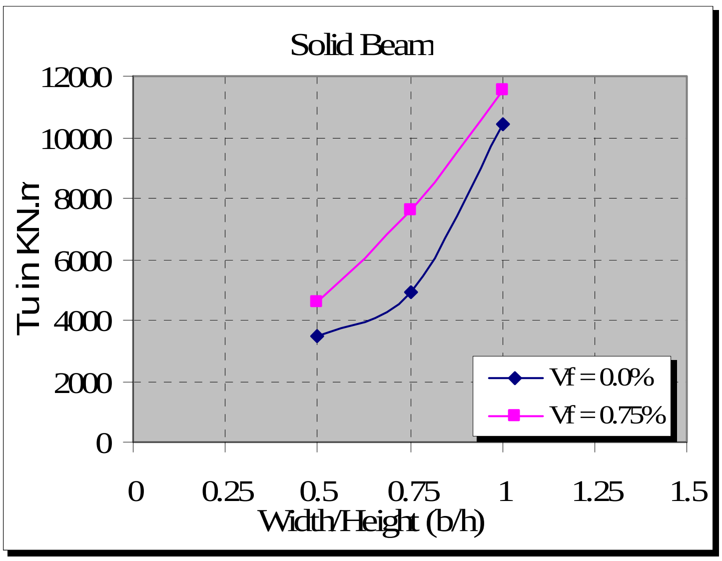

Fig. (3-3) Effect of Steel Fiber on the Solid Beams (different Width)

3.4.2 Hollow beams (Thin walled):

As per the ACI-11.6.1.2, the beam consider as a thin walled beam if the wall thickness (t) is equal or less than (x/10). The term of x mean shorter dimension of beam. Three groups (nine beams) among the specimens group were casted with (25mm thick wall) and this amount is applicable with the specimens of (20x20)cm, that mean it is possible to consider the specimens with 25mm thick wall is thin walled section. The experimental result clarified that effect of steel fiber for the hollow thin walled beams is about (32.56% & 42.62%) for the volume fractions of (0.75% & 1.0%) respectively As shown in Fig 3-4.

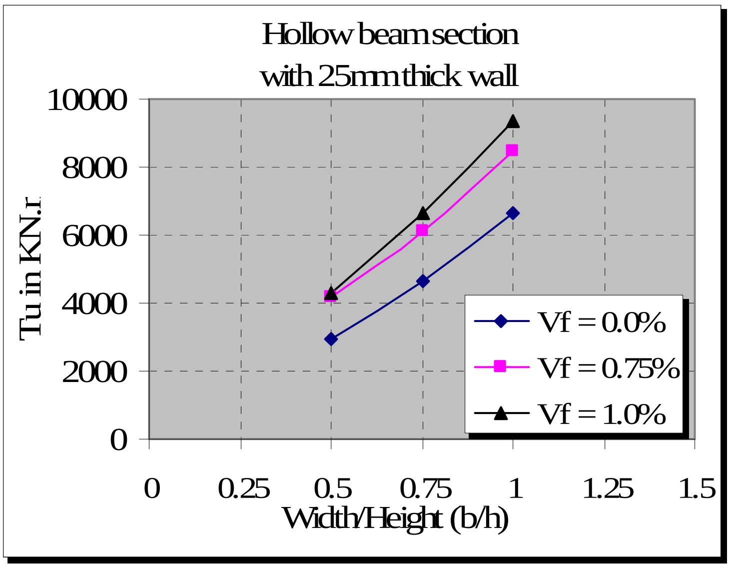

Fig. (3-4) Effect of Steel Fiber on the Hollow Beams (different Dimensions)

3.4.3 Hollow beams (Thick walled):

Another three groups (nine beams) were casted with (40mm thick wall). The experimental result clarified that effect of steel fiber for the hollow thick walled beams is about (35.18% & 47.87%) for the volume fractions of (0.75% & 1.0%) respectively as shown in Fig 3-5.

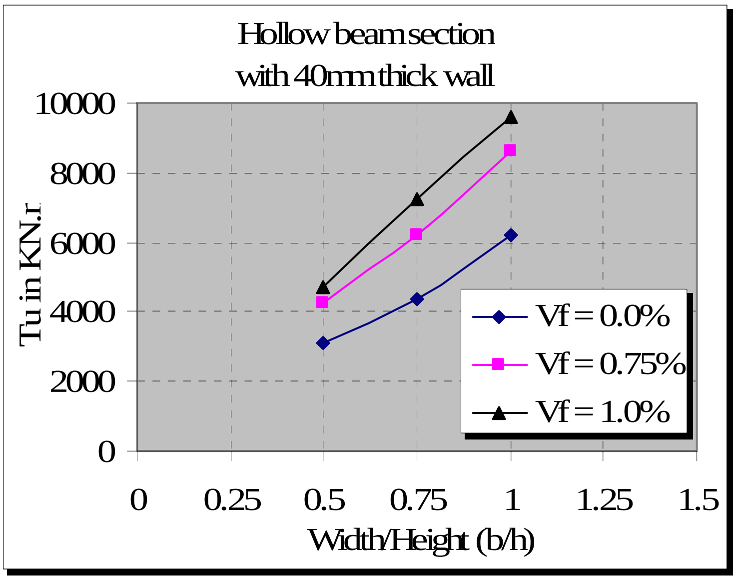

Fig. (3-5) Effect of Steel Fiber on the Hollow Beams (different Dimensions)

3.5 Effect of Solid & Hollow on the Strength of Beams under pure Torsion:

One of the main objectives of this research is to indicate whether comparison between the strength of Solid & Hollow section under pure torsion so that to construct the hollow sections with reinforced concrete in the constructions. The experimental result for three categories of beams (Solid, Thin Hollow & Thick Hollow) sections and for three different section dimensions (10x20, 15x20 & 20x20)cm under three different volume fractions (0.0%, 0.75% & 1.0%) indicate as in the following:

3.5.1 Beams Section (10x20)cm:

The experimental result indicate that the strength of solid section of the beams with dimensions (10x20)cm cross-section is greater than Hollow thin section by (12.57%), while the strength of the same solid section is greater than Hollow thick section by (6.26%). That mean the difference between the strength of Thick & Thin section compared with the Solid section is about (6.31%) as shown in Fig 3-6.

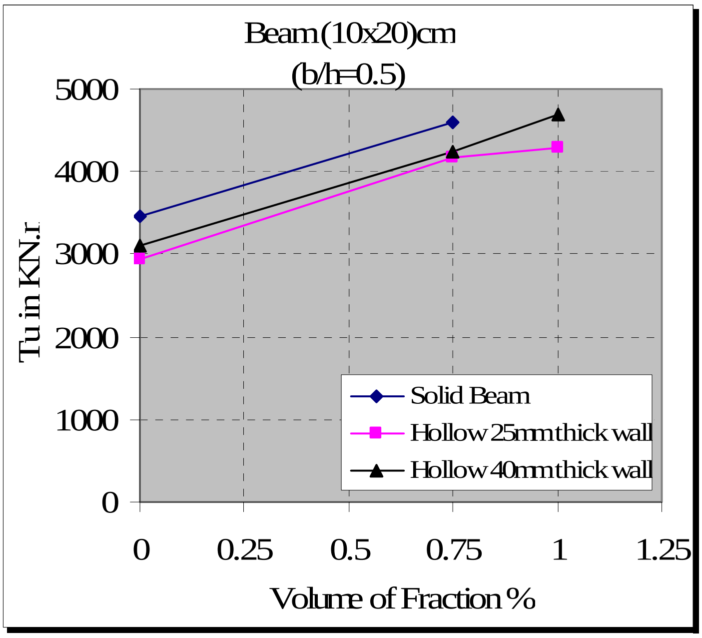

Fig. (3-6) Effect of Solid & Hollow Section under pure Torsion (b/h = 0.5)

3.5.2 Beams Section (15x20)cm:

For the section of (15x20)cm the experimental result indicate that the strength of solid section is greater than Hollow thin section by (12.49%), while the strength of the same solid section is greater than Hollow thick section by (5.41%). That mean the difference between the strength of Thick & Thin section compared with the Solid section is about (7.08%) as shown in Fig 3-7.

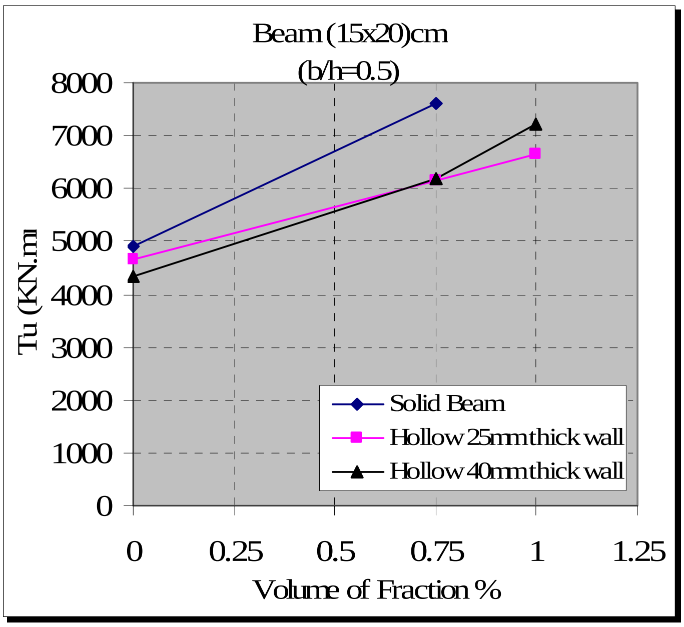

Fig. (3-7) Effect of Solid & Hollow Section under pure Torsion (b/h = 0.75)

3.5.3 Beams Section (20x20)cm:

For the section of (20x20)cm the experimental result indicate that the strength of solid section is greater than Hollow thin section by (9.42%), while the strength of the same solid section is greater than Hollow thick section by (7.16%). That mean the difference between the strength of Thick & Thin section compared with the Solid section is about (2.26%) as shown in Fig 3-8.

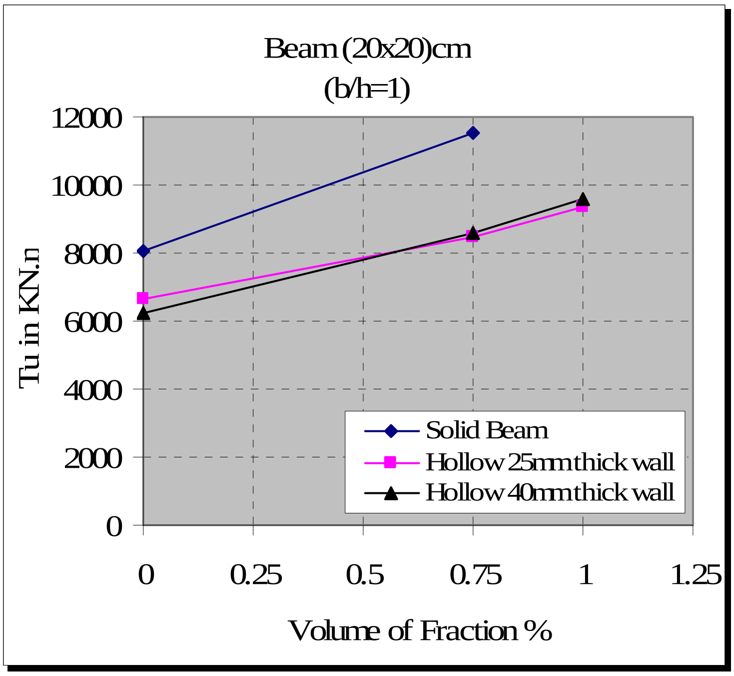

Fig. (3-8) Effect of Solid & Hollow Section under pure Torsion (b/h = 1.0)

The average of mentioned three sections (10x20, 15x20 & 20x20)cm will be:

1. The strength of Solid section is greater than thin walled hollow section under pure torsion about (11.49%).
2. The strength of Solid section is greater than thick walled hollow section under pure torsion about (6.28%).
3. The strength of thick walled hollow section is greater than thin walled section under pure torsion about (5.21%).

That mean there are just about (11.49% for thin wall & 6.28% for thick wall) different between the strength of solid and hollow sections under pure torsion and this different is not too much compared with the saving in materials and weight between solid & hollow sections which is about (128%) and possible to strengthen the materials components of beam so that to compensate this amount of strength by using admixture to increase strength and bond and also by using high strength concrete mixture.

CHAPTER FOUR

ANALYSIS AND EVALUATION OF RESULTS

4.1 Introduction:-

In this chapter tried to use some proposed methods (Equations) which used in last literatures, to find the ultimate strength of concrete beams under pure torsion and finding the amount of suitability with the experimental results which has been get in this thesis.

4.2 Torque equation based on previous literature:-

4.2.1 Plain Concrete beams:

Narayanan proposed the following equation to find the ultimate torque of plain concrete:

$$T_p = 0.13 x^2 y \sqrt{f_{cu}} \quad \ldots\ldots\ldots\text{4-1}$$

4.2.2 Concrete beams containing steel fiber:

Narayanan & Kareem proposed the following equation to find the ultimate torque of concrete containing steel fiber:

$$T_f = T_p (0.42 F) \quad \ldots\ldots\ldots\text{4-2}$$

And space truss of Narayanan & Kareem

$$T_f = 0.22 \lambda \frac{x_o\, y_o}{x_o + y_o} x\, y\, F \sqrt{f_{cu}} \quad \ldots\ldots\ldots\ldots\ldots\text{4-3}$$

Which:

T_p giving in equation 4-1

And the space truss Narayanan, Kareem has been estimated the compressive strength of concrete cubic containing steel fiber by normal concrete with the following equation:

$$f_{cuf} = f_{cu} (1 + 0.1F)$$

f_{cu} : Compressive strength of concrete containing steel fiber and the equation will become:

$$T_f = 0.22 \lambda \frac{x_o\, y_o}{x_o + y_o} x\, y\, F \sqrt{\frac{f_{cuf}}{1 + 0.1F}} \quad \ldots\ldots\ldots\ldots\ldots\text{4-4}$$

4.2.3 Reinforce concrete beams:

Muthukrishuan, ictor has been found ultimate strength of reinforced concrete under pure torsion by the following equation:

$$T_r = 2\frac{x_1\, y_1}{s_1} A_s\ f_{sy} \qquad \text{……….4-5}$$

4.2.4 Ultimate torque of Reinforce concrete beams:

$$T_u = T_p + T_r \text{ ……………….4-6}$$

Which:

T_p : Given by equation 4-1

T_r : Given by equation 4-5

4.1 Experimental & Theoretical Ultimate torque of R.C Beams

Group No.	Specimen symbol	*Ultimate Torque (KN.mm) From*		
		Exper. Result	***Equ. (4-6)***	***Equ. (4-10)***
G1	B1S	3468	4022	2775
	B2S	4900	5584	5619
	B3S	8058	8001	8880
G3	B7H	2142	4078	2583
	B8H	4653	5710	5231
	B9H	6630	8225	8267
G6	B16H	2346	4110	2667
	B17H	4100	5784	5400
	B18H	6222	8355	8533

4.2.4 Ultimate torque of Reinforced concrete beams containing steel fiber:

Table (4-1) clarify experimental test result with the result of approximate equations which mentioned above:

$$T_u = T_p + T_f + T_r \text{ ……………….4-7}$$

Which:

T_p : Given by equation 4-1

T_f : Given by equation 4-2

T_r : Given by equation 4-5

$T_u = T_p + T_f + T_r$ ………………….4-8

Which:

T_p : Given by equation 4-1

T_f : Given by equation 4-3

T_r : Given by equation 4-5

$T_u = T_p + T_f + T_r$ ………………….4-9

Which:

T_p : Given by equation 4-1

T_f : Given by equation 4-4

T_r : Given by equation 4-5

$T_u = (1/2 - x/6y)\, x^2\, y\, f_t$ ………………….4-10

Which:

x: Shorter dimension of cross section in (mm)

y: Longer dimension of cross section in (mm)

f_t : Splitting tensile of concrete in (Mpa)

4.2 Experimental & Theoretical Ultimate torque of R.C Beams

Group No.	Specimen symbol	*Ultimate Torque (KN.mm) From*				
		Exper. Result	*Equ. (4-7)*	*Equ. (4-8)*	*Equ. (4-9)*	*Equ. (4-10)*
G2	B4S	4590	4329	4320	4319	
	B5S	7600	6276	6268	6266	
	B6S	11526	9231	9217	9213	
G4	B10Hs	4182	4516	4506	4505	
	B11Hs	6138	6696	6687	6684	
	B12Hs	8466	9978	9963	9958	
G5	B13Hs	4300	4671	4657	4655	
	B14Hs	6633	7045	7033	7027	
	B15Hs	9350	10598	10577	10567	
G7	B19Hs	3672	4491	4480	4479	
	B20Hs	4851	6639	6630	6627	
	B21Hs	6630	9876	9861	9855	
G8	B22Hs	4692	4705	4691	4689	
	B23Hs	7227	7122	7110	7104	
	B24Hs	9588	10735	10714	10704	

CHAPTER FIVE

Conclusions and Recommendations

5.1 Conclusion:-

In this research it has become to study the behavior and strength of hollow concrete beams under pure torsion and warping displacement affect with analysis the experimental and theoretical result, finally we got the following conclusions:

1- It has been observed from the tests carried out that the slope of cracks under pure torsion for Non-Fibrous concrete is about 45^o while the fibrous concrete is about 53^o.

2- The experimental test result shown that presence of steel fiber has important rule to increase the torsional rigidity even in the linear stage.

3- As per the result of strain gauge, concrete beams fails under pure torsion when the max. principle tensile stress reaches the tensile strength of the concrete.

4- As per the result of strain gauge, the stress in steel bars at the beginning of loading is too little until the max. Principle tensile stress reaches the tensile strength of concrete after that a sudden increase of strain in steel observed by electrical strain gauge.

5- Strain gauges result clarified that the max. stresses of beams locate at the wider face and most of the steels at the center of the wider face reached yield before others.

6- Steel fiber will decrease all the deformations at all stages of loading, but particularly after initial cracking.

7- Increase ultimate torque of beam with increasing the amount of steel fiber.

8- Ductility is increased in all cases for torsional loadings when using fibers in concrete.
9- The phenomenon of crushing concrete cover (Spalling down) was avoided by using steel fiber in the reinforced concrete beam under pure torsion.
10- When a thin-walled beam having restrained cross section against warping is subjected to longitudinal stresses which is not evaluated in the Space Truss Analogy method.

5.2 Recommendations for Future Research:

In this research we have studied the behavior and strength of hollow concrete beams under pure torsion, and I see that number of laboratories casted & tested samples isn’t enough if compared with the requirement of this research, therefore there is a need to continue casting more samples to support more result of this research. The following are some suggestions for future research:

1- The study of a beam by using mortar cement especially in the hollow sections.
2- The study of the pre-cast pre-stressed beams under pure torsion.
3- The study of continuous hollow beams under pure torsion.
4- The study of recycle torsion loading on the hollow cross section beams.
5- The study of the Ferro cement beams under pure torsion.

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