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TORSIONAL STRENGTHENING OF PRESTRESSED SELF COMPACTING CONCRETE BOX BEAMS USING INTERNAL TRANSVERSE CONCRETE DIAPHRAGMS TECHNIQUE

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Abstract: In the present paper, new technique by adding internal concrete diaphragms, in transverse direction, for prestressed self-compacting concrete box beams is adopted. Six SCC beam specimens have a dimension of (2200x220x350mm) for length; width and height, respectively were poured and tested. Three variables were adopted in present study; section type (Box or Solid), number of diaphragms (None, Two and Four), and type of diaphragms (Opened and Closed). Experimental results showed that the ultimate torque moment increases about (58.6%-72.4%) and (120.7%-127.6%) for beam specimens strengthened internally by two and four diaphragms, respectively. Also, increasing of internal diaphragms from two to four, led to increase the ultimate torque moment about (55.2%-62.1%). Furthermore, the change of section from box section with four internal diaphragms to solid section, led to increase in ultimate torque moment about (48.3%-55.2%). The paper conclude that the increasing in torsional capacity was attainable for box beams by using the technique of strengthening by internal diaphragms; Also, the box sections can be made with internal opened diaphragms and possess same capacity or contribution of the closed ones.

Keywords: *Torsion, Self-Compacting Concrete, Box Beam, Strengthening, Diaphragms, Prestress.*

تقوية اللي للعتبات الخرسانية ذاتية الرص الصندوقيه المسبقة الجهد باستخدام تقنية الحواجب الخرسانية الداخلية المستعرضة

الخلاصة: في هذا البحث، تقنية اضافة حواجب خرسانيه داخليه مستعرضه (في الاتجاه العرضي) للعتبات الخرسانية ذاتية الرص الصندوقيه المسبقة الجهد تم اعتمادها. ستة عتبات مصنوعه من الخرسانه المسبقة الجهد الذاتية الرص بأبعاد (350x220x2200 ملم) للطول، العرض والارتفاع على التوالي تم صنعها واختبارها. تم اعتماد ثلاثة متغيرات، نوع مقطع العتبه (صلد او صندوقي)، عدد الحواجب الخرسانيه الداخليه المستعرضه(بدون، اثنان و اربعة) ونوع الحواجب الخرسانيه الداخليه (صلده او مفتوحه). اظهرت النتائج المختبريه أن عزم اللي الاقصى زاد بمقدار (58.6٪-72.4٪) و (127.6٪ -120.7٪) للنماذج المقواة داخليا بحاجبين وأربعة حواجب على التوالي. كما أن زيادة عدد الحواجب الداخليه من اثنين إلى أربعة، أدى إلى زيادة عزم اللي الاقصى بمقدار(55.2٪ -62.1٪). اضافة الى ذلك، فإن تغيير نوع العتبه من عتبه صندوقيه ذات أربعة حواجب الى عتبه صلده، أدى إلى زيادة في عزم اللي الاقصى بمقدار(48.3٪ -55.2٪). خلصت الدراسة الى ان الزيادة في سعة المقطع لمقاومة اجهادات اللي ممكن تحقيقها في العتبات الخرسانيه المسلحه الصندوقيه باستخدام تقنية التقويه بالحواجب الخرسانيه الداخليه. كذلك، من الممكن عمل عتبات خرسانيه صندوقيه مقواة بحواجب خرسانيه مفتوحه تمتلك نفس قدرة أو مساهمة الحواجب المغلقه (الصلده).

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1. Introduction

A box concrete section (or hollow core beam or hollow beam or cellular beam) is often used for beam design, particularly for long spans bridges for reducing dead load and save the cost of construction. Many structural members such as building and bridge elements are subjected to equilibrium torsional moments. In order to avoid failure of these elements at torsional load, adequate reinforcement (longitudinal and transverse), prestress force and strengthening are required. Strengthening of concrete members to resist torsional stresses may be achievable by one of the following techniques: (i) increasing the member cross-sectional area, (ii) adding transverse reinforcement, (iii) using externally bonded steel plates, (iv) applying an axial load to the member by external prestressing[1, 2].

Reinforced concrete sections under torsional stresses and externally strengthened by CFRP are interested in several research [3, 4]. Beams reinforced internally with GFRP reinforcements under pure torsion are also interested [5]. Due to rapid development in concrete technology and construction techniques, new concrete types such as SCC has been arise. Many researches show that this type of concrete is commonly used within cast-in-place and precast construction. Furthermore, it is also used in the thin concrete sections and where the tightness of steel reinforcement is required.

However, other implementations of SCC include drilled piers, caissons, bridge abutments and walls [6].There are few researches about box reinforced concrete beams under the effect of torque moment; therefore, a torsional failure mechanism is not understood well. The concept of adding internal concrete diaphragms (closed or opened), in transverse direction is new technique for strengthening reinforced concrete box sections under the effects of torsional stresses and will be adopted in the present study. It may be noted that, additional variables can be added later to the present study as a suggestions for future researches.

2. Research Significant

Despite that many investigations on the torsional behavior of reinforced prestressed concrete beams with solid or box cross section, little has been done on the applications of SCC with a complete absent for strengthening internally by any techniques. So need to study the torsional behavior of such sections with strengthening by special technique gives more attention. The main objective of the present paper is to investigate, experimentally, the torsional behavior of reinforced SCC rectangular box beams strengthening transversely by internal diaphragms with different variables, including, type of section (solid or box), number and type of the internal diaphragms (closed or opened).

3. Experimental Program

The experimental program consists of cast and test of six reinforced prestress concrete SCC beam specimens. One specimen was control beam; four beams were strengthened using internal diaphragms while the last beam was a solid. Three variables were adopted in the present study, section type (box or solid), number and type of the internal diaphragms (closed or opened). The specimen's dimensions, clear span, concrete grade, load location, prestressing force and reinforcement (longitudinal and transverse) were kept constant thought out this study. The experimental work includes, also, a series of tests carried out on raw materials and control specimens (cubes and cylinders). Cracking load, ultimate load, mode of failure, torque-angle of twist behavior and torque-strain curve were recorded, discussed and presented in this study.

3.1. *Beam Specimens Description*

The specimens have a dimension of (2200x220x350mm) for length, width and height, respectively. Since, the box and solid reinforced concrete beams can be design directly according to ACI-318 code [7], the longitudinal and transverse reinforcement were calculated based on code requirement for torsion. Each beam were reinforced by (2ϕ12mm) bars at the top and bottom, while, the transverse reinforcement consists of (ϕ10@60mm) stirrups at edges and (ϕ10@120mm) stirrups at the mid, see Fig. 1. As mentioned before, the concept of strengthening of box sections by transverse internal diaphragms (to resist torsional stresses) were adopted in the present paper.

Therefore, lateral (transverse) closed or opened diaphragms with thickness of (50mm) were creating (during concrete poured) inside the box beam specimens. It may be noted that, all diaphragms were reinforced longitudinally and transversely by (6ϕ10mm and 4ϕ10mm) bars, respectively. The prestressing reinforcement was (2ϕ12.7mm) standard strands (7-wires strands), with (f_{py} = 1570MPa), (f_{pu}=1770MPa), (A_{ps}=2x93=186mm^2), and (E_s=195000MPa). Each beam specimen was designated in a way to refer to section type (PHB=Prestressed Hollow Beam or PSB= Prestressed Solid Beam), number of internal diaphragms (0, 2 and 4) and type of diaphragm (CD= Closed Diaphragm, OD= Opened Diaphragm). Therefore, for example, the beam specimen (PHB-4CD) was a Prestressed Hollow Beam made with four transverse closed diaphragms. Description and details of tested beam specimens are shown in Table 1,and Fig. (2) to (7).

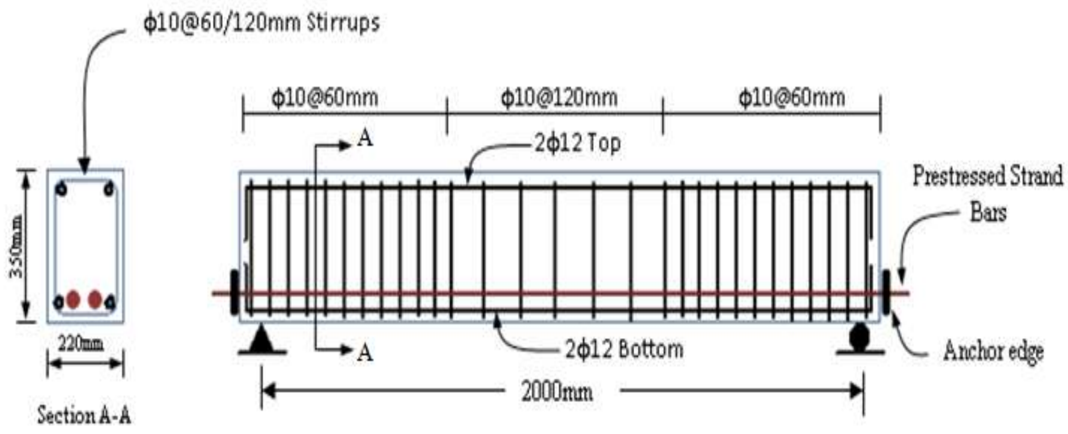

Figure 1. Reinforcement Details and Dimensions of the Tested Beams

Table 1. Description of Beam Specimens

Beam Designation	Dimensions (mm)			Description
	Length	Width	Depth	
PHB-0D*	2200	220	350	Prestressed Box Beam
PHB-2CD				Prestressed Box With Two Closed Diaphragms
PHB-2OD				Prestressed Box With Two Opened Diaphragms
PHB-4CD				Prestressed Box With Four Closed Diaphragms
PHB-4OD				Prestressed Box With Four Opened Diaphragms
PSB				Pre stressed Solid beam

*Reference Beam Note: PHB= Hollow Beam, PCD=Closed Diaphragm, POD=Opened Diaphragm, PSB=Solid Beam

Plate 1. Reinforcement Details and Diaphragms Location

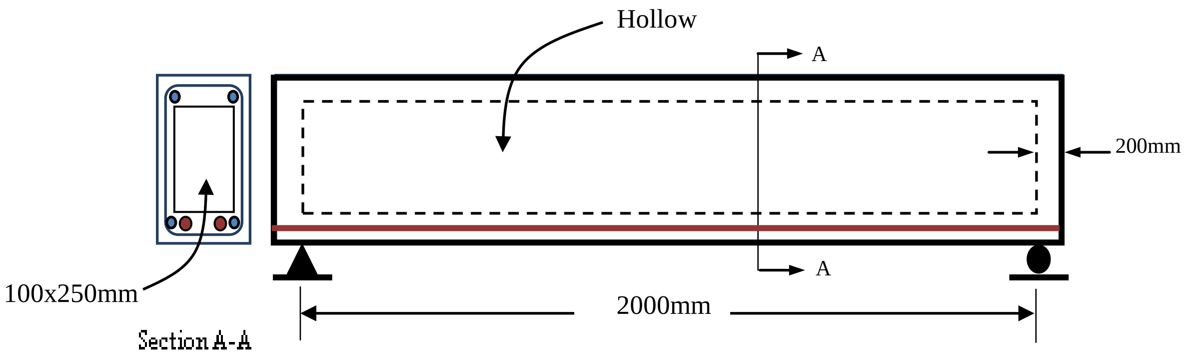

Figure 2. Description of Beam Specimen (PHB-0D)

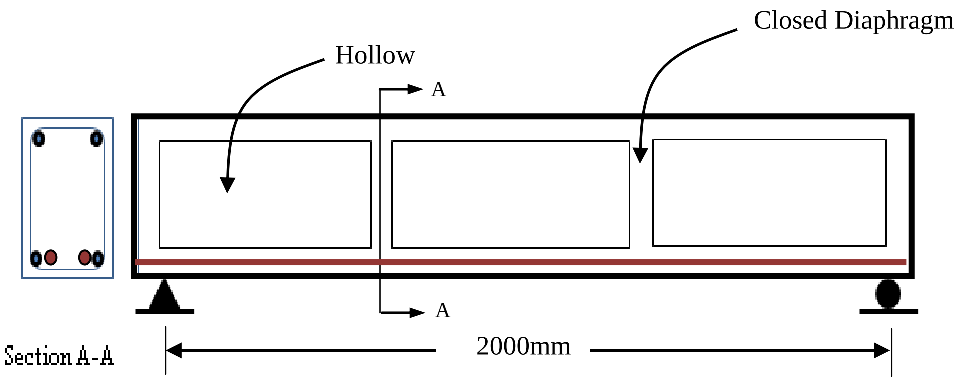

Figure 3. Description of Beam Specimen (PHB-2CD)

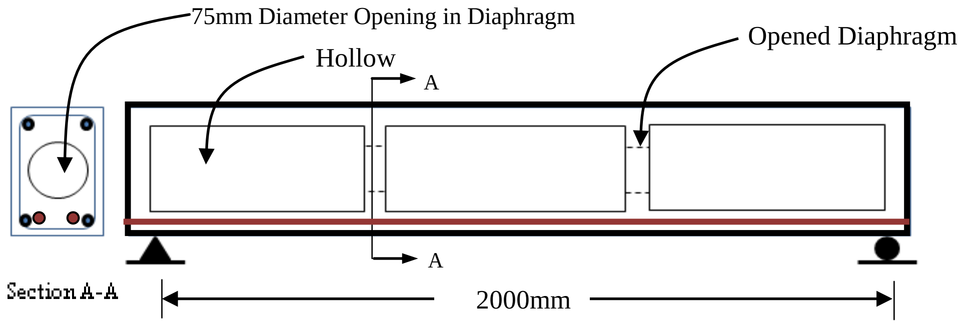

Figure 4. Description of Beam Specimen (PHB-2OD)

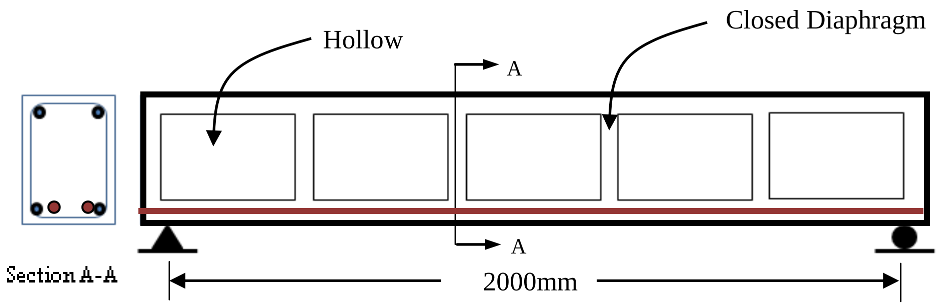

Figure 5. Description of Beam Specimen (PHB-4CD)

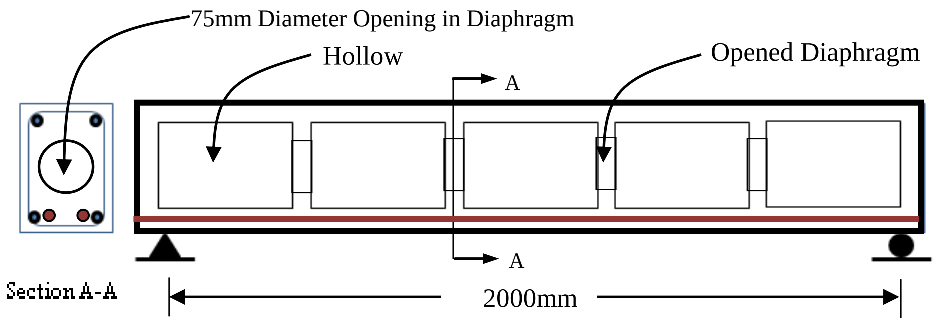

Figure 6. Description of Beam Specimen (PHB-4OD)

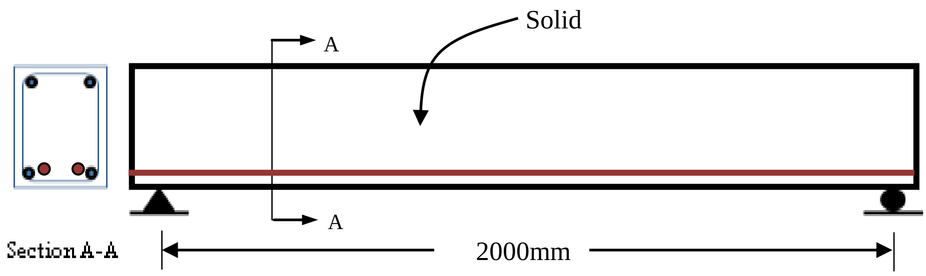

Figure 7. Description of Beam Specimen (PSB)

3.2. *Molds*

One wooden mold with (18mm) thickness had been used to cast the beam specimens. The mold consists of a bed and four movable sides, these sides had been fixed to the bed by screws. The clear dimensions of the mold were (2200x220x350mm) for length, width and height, respectively. For casting, the mold was oiled and the required reinforcement cage was placed inside the mold before cast the concrete batch. Details of mold are shown in Plate 2.

Plate 2. Beam Specimen Mold

To form the box beam, the cross section contains a polystyrene void that blocks out the center of the beam over specified lengths. The void was included to block out concrete where it does not add much resistance to the section and reduce the self-weight of the beam. It may be noted that, the closed diaphragms were created directly when the spacing between Polystyrene blocks filled by SCC during poured process. While, to create opened diaphragms, PVC pipe of diameter of (75mm) was restrict between polystyrene pieces, Plate 3. For all tested beams, beyond the cells (at the ends), whole beam section (220x350mm) was solid concrete.

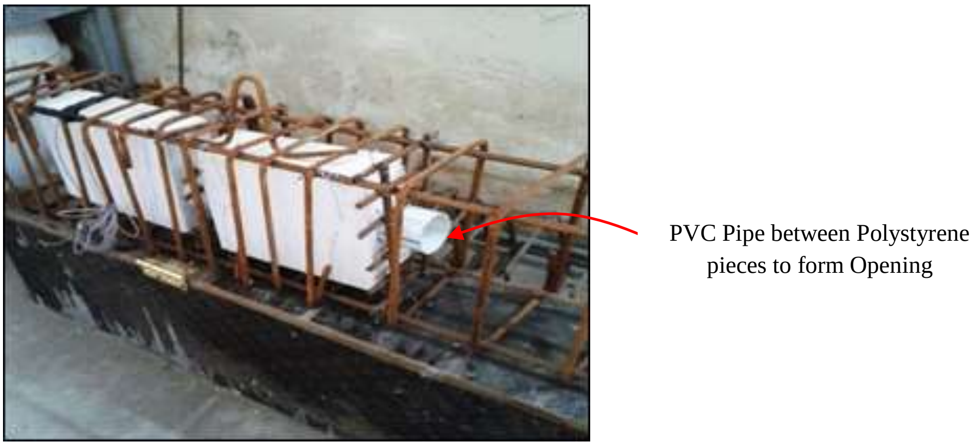

Plate 3. Opened Diaphragms Doing

3.3. *Materials*

In manufacturing the test specimens, the properties and description of the used materials were reported and presented in Table 2; and the concrete mix proportions (by weight) were reported and presented in Table 3.

Table 2. Properties of Construction Materials

Material	*Descriptions*
Cement	Ordinary Portland Cement (Type I).
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm).
Gravel	Crushed gravel of maximum size (10 mm).
Limestone powder	fine limestone powder (locally named as Al-Gubra) of Jordanian origin.
Superplasticizer	Sika viscocrete-5930 manufactured by BASF Construction Chemicals.
Non-Prestressing Reinforcement	(ϕ12mm) deformed steel bar, having (495 MPa) yield strength (f_y). (ϕ10mm) deformed steel bar, having (510 MPa) yield strength (f_y).
Prestressing Reinforcement	(ϕ12.7mm) standard strands (7-wires strands), with (f_{py} = 1570MPa), (f_{pu}=1770MPa), (A_{ps}=93mm²), and (E_s=195000MPa).
Water	Clean tap water

Table 3. Concrete Mixture Details

Material	*Quantity*	*Ratio*	*Limits*
Cement (Kg/m^3)	450		350-600
Sand (Kg/m^3)	750	33%[a]	<40%
Gravel (Kg/m^3)	900	40%[b]	<50%
Silica fume (Kg/m^3)	30		
Limestone (Kg/m^3)	130		
Super plasticizer (L/m^3)	10	1.64%[c]	<2%
Water (L/m^3)	190		
W/P (%)		31.1[d]	28% - 38%

a-Sand ratio=Sand/(cement+ sand+ gravel+ silica fume+ limestone)
b-Gravel ratio=Gravel/(cement+ sand+ gravel+ silica fume+ limestone)
c-Super plasticizer ratio= Super plasticizer/(cement content +silica fume+ limestone)
d-W/P=Water/(cement content+ silica fume+ limestone)

3.4. *Test Measurements and Instrumentation*

3.4.1. *Prestressing Machine*

The prestressing force (prestressing tensile force) in strands (cables) were take place by using Hydraulic Machine (MFL system), as shown in Plate 4. It consists of a system of a hydraulic joints, electrical pump, main measuring gauge to observe the applied pressure with (bar unit) that is graduated (0 to 600 bars), and main steel jack operating by an electrical manual control that contains interior nuts as cone-shape working as a pincer and pinches the strand after entrance through it. Then, the stressing force is applied at stages or (increments), while the machine is operating.

Plate 4. Prestressing Machine

3.4.2. *Test Machine*

All beams as well as control specimens were tested by using the Hydraulic Universal Testing Machine (MFL system) with a maximum range capacity of (3000kN), Plate 5.

Plate 5. Test Machine

3.4.3. *Strains Measurement*

Strains were measured to determine the degree and behavior of structural member against the applied stresses. The use of devices with high accuracy is required to calculate the amount of strain in the steel bars and concrete. Two type of strain gauges were used, first type for steel reinforcement (KFH-20-120-C1-11L1M2R 120 20) produced by Omega company and the second for concrete (PL-60-11) produced by TML company. Data logger type (TML/ TC-32K) was used to measure the strains in steel reinforcements and concrete. It is an automatic, multichannel, scanning data logger for reading strain gauges and transducers. The strain gauges were fixed in five different locations as shown in Plate 6. and Table 4.

Plate 6. Strain Gauges and Data Logger Setup

Table 4. Strain Gauges Locations

Gauge No.	Location
0	At First Stirrup (200mm Distance From The End)
1	At Longitudinal Steel Reinforcement (200mm Distance From The End)
2	At the top of diagonal location for end after 200mm distance from the end perpendicular to angle of twist (45^o).
3	At the bottom of diagonal location for end after 200mm distance from the end perpendicular to angle of twist (45^o).
4	At the middle of diagonal location for another edge and opposite side after 200mm distance from the end perpendicular to (45^o) angle.

3.4.3. *Angle of Twist Measurements*

A simple method was used to estimate the angle of twist by using dial gauge attached to the bottom fiber of the end of the beam at a point (45 mm) from the center of the longitudinal axis of the beam as shown in Plate 7. The dial gauge (0.01mm/div. accuracy) recorded the down value (Vertical deflection) to find the twist angle in radians at every load stage.

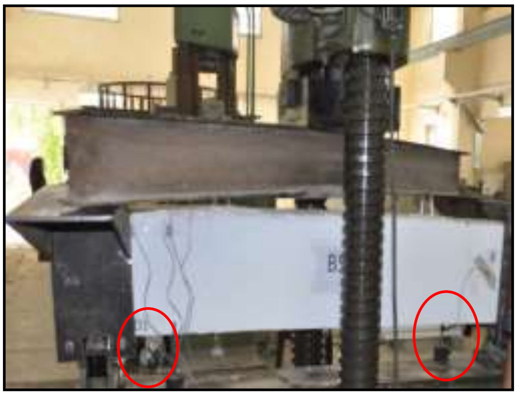

Plate 7. Locations of Dial Gauges

4. Testing Procedure

The hydraulic universal testing machine (MFL system), shown in Plates (5) to (7), was used to test all beam specimens as well as control specimens. The normal load can just be applied by this machine on the specimen at several points and the supports should be remaining fixed without rotating around the longitudinal axis. In this research the applied loads outside the bed of the universal machine are needed in order to get torsional movement.

The experimental requirements need to move the supports circularly (ball bearing) and transmitting the load from the center of the universal machine to the two external points that represent the moment arm. The special clamping loading frame used in this research is shown in in Plates (5) and (7). This frame consists of two steel clamps which work as arms for applied torque with separated faces to connect them over the sample by large bolts; four bolts are used for each arm. This frame is made of thick steel Plate (20mm) with two steel shafts attached by welding. This final shape is similar to a bracket. These arms were capable of providing a maximum eccentricity of (600 mm) with respect to the longitudinal axis of the beam. The steel girder of (250 mm) depth and (2 m) length is used to transmit the loads from the center of the universal machine to the two arms. This girder was clamped to the universal machine as shown in Plates (5) and (7).

5. Results and Discussion

5.1. *Test Results of Control Specimens*

5.1.1. *Characteristics of Fresh SCC*

Three characteristics are made to check self-compacting concrete. SCC requires modified fresh concrete testing methods compared with conventional concrete. Table 5. indicates the test methods of workability and its requirement for SCC. So far, no single method consideration achieved universal approval in the world. Similarly, no single method has been found which characterizes all the relative workability aspects so; each mix design should be tested by more than one test method for the different workability parameters. For initial mix design of SCC, all three workability parameters need to be assessed to ensure that all aspects are fulfilled.

Table 5. Test Results of Fresh SCC

Property	*Unit*	*Test Result*	*Limitations*[8]
Slump Flow Diameter (Filling ability)	mm	800	650-800
T_{50} Slump flow (Filling ability)	Sec	2.81	2.0-5.0
V-funnel time at $T_{5\ min}$ Segregation resistance)	Sec	8.28	6.0-12
L-Box (Passing ability)	H2/H1%*	1.0	0.8-1.0

*H_2/H_1 the height of concrete at the end of horizontal section to that remaining in the vertical section of L-box.

5.1.2. *Characteristics of Hardened SCC*

All control specimens (cylinders and cubes) had been removed from curing at the age of (28 days). Compressive strength of SCC for cylinders and cubes were measured based on ASTM C39-96 [9] and BS1881-116 [10], respectively. Tests results are reported and presented in Table 6.

Table 6. Test Results of Hardened SCC

Property	*Unit*	*Test Result*
Cube Compressive Strength (F_{cu})	MPa	41
Cylinder Compressive Strength (f_c')	MPa	38

5.2. *Test Results of Beam Specimens*

5.2.1. Cracking and Ultimate Load

Table 7. shows the results of cracking torque (Tc), ultimate torque (Tu) and ultimate angle of twist (θ) for all tested beam specimens. It can be seen that the ultimate torque moment increases about (72.4%) and (127.6%) for beam specimens (PHB-2CD and PHB-4CD) which strengthened internally by two and four closed diaphragms respectively. While, for beam specimens (PHB-2OD and PHB-4OD) which

strengthened internally by two and four opened diaphragms, the ultimate torque increased about (58.6%) and (120.7%) respectively. In comparison with the reference beam, (PHB-0D), it can be seen that the cracking torque moment decreased about (10%) and increased for (30%) for beam specimens (PHB-2CD and PHB-4CD) which strengthened internally by two and four closed diaphragms, respectively. While, for beam specimens (PHB-4OD), which strengthened internally by four opened diaphragms, the cracking torque increased about (10%). It may be noted that, no change in cracking torque was recorded for beam specimens (PHB-2OD) in comparison with reference beam. This means the presence of internal diaphragms improves the torsional resistance and allowing higher forces to be carried through internal diaphragms.

When the beam section changes from box section (PHB-0D) (without internal diaphragms) to solid section (PSB), the cracking torque and ultimate torque increased by (50%) and (175.9%), respectively. For box beam specimen, only the thinned wall (ribs) was contributed to resist both, cracking and ultimate loads. From the other hand, full section of solid beam (PSB) was contributed to resist both, cracking and ultimate loads. The results indicated that the increasing in torsional capacity was attainable for box beams by using the concept of strengthening by internal opened or closed diaphragms.

Table 7. Test Results of Prestressed Beam Specimens

Beam Designation	*Tc (kN.m)*	*Increase in Tc* (%)*	*Tu (kN.m)*	*Increase in Tu* (%)*	*θ (Rad.)*	*Increase in (θ)* (%)*
PHB-0D	7.5	-	21.75	-	0.6646	-
PHB-2CD	6.75	-10%	37.5	72.4%	0.7964	19.8%
PHB-2OD	7.5	0%	34.5	58.6%	0.8479	27.6%
PHB-4CD	9.75	30%	49.5	127.6%	1.0312	55.2%
PHB-4OD	8.25	10%	48	120.7%	1.1744	76.7%
PSB	11.25	50%	60	175.9%	0.7333	10.3%

*With Respect to Reference Beam (PHB-0D)

5.2.2. *Modes of Failure*

The progress of cracks provided useful information regarding the failure mechanism of tested specimens. First crack of all specimens occurred at mid span and increased gradually. When the torque moment was increased, cracks appeared on each side and finally took the spiral shape. Plates (8) and (9) shows the failure modes for the tested beams. All beam specimens were failed by extensive diagonal concrete crack (torsional spiral cracks). For box beams, the extensive concrete cracking was bounded between diaphragms which ultimately resulted in beam failure.

Plate 8. Beam Specimens Failure Mode

Plate 9. Failure Mechanism of Beam Specimens

5.2.3. *Effect of Strengthening*

5.2.3.1. *Number of Internal Diaphragms*

In Table 7. it can be seen that the ultimate torque moment increased about (58.6%-72.4%) for beam specimens (PHB-2OD and PHB-2CD) which strengthened internally by two diaphragms, respectively. While, for beam specimens (PHB-4OD and PHB-4CD) which strengthened internally by four diaphragms, the ultimate torque increased about (120.7%-127.6%), respectively. Also, increasing of internal diaphragms from two to four, led to increase the ultimate torque moment about (100.2%-62.1%) for beam specimens (PHB-CD and PHB-OD), respectively. From the other hand, the change of section from hollow section with four internal diaphragms to solid section, led to increase in ultimate torque moment about (48.3%-55.2%). This is my be due to increase in torsional stiffness due to presence of internal diaphragms or full solid section.

5.2.3.2. *Type of Internal Diaphragms*

When the internal diaphragms changed from opened to closed type, the ultimate capacity increased about (8.7%-3.13%) for beam specimens containing two and four internal diaphragms, respectively. Since the increase is marginal (can be negligible), it can be concluded that the box sections can be strengthened by internal opened diaphragms and possess same capacity or contribution of the closed ones.

5.2.3.3. *Effect of Hollowness*

When the beam section changes from box section (PHB-0D) (without internal diaphragms) to solid section (PSB), the cracking torque and ultimate torque increase by (50%) and (175.86%) respectively, see Table 7. For hollow beam specimen, only the thinned wall (ribs) was contributed to resist both, cracking and ultimate loads. From the other hand, full section of solid beam (PSB) was contributed to resist both, cracking and ultimate loads.

5.2.4. *Torque-Angle of Twist Behavior*

The toughness may be considered as a ductility indicator. The toughness was measured as the area under the torque - rotation curve for each beam. Fig. 8, shows the relation between the applied torque and the angle of twist (T-θ Diagram) for all beam specimens. In Fig. 8, it was noticed that toughness of the strengthened beam specimens (PHB-2CD), (PHB-2OD), (PHB-4CD) and (PHB-4OD) was higher than reference beam (PHB-0D). This might be because the location of internal diaphragms not provides any restraint against rotation of the beam. Also, the strengthening with internal diaphragms decreased the angle of twist of the beam specimens (PHB-2CD), (PHB-2OD), (PHB-4CD) and (PHB-4OD). Generally, all hollow core beams exhibits ductile behavior in comparison with the solid beam.

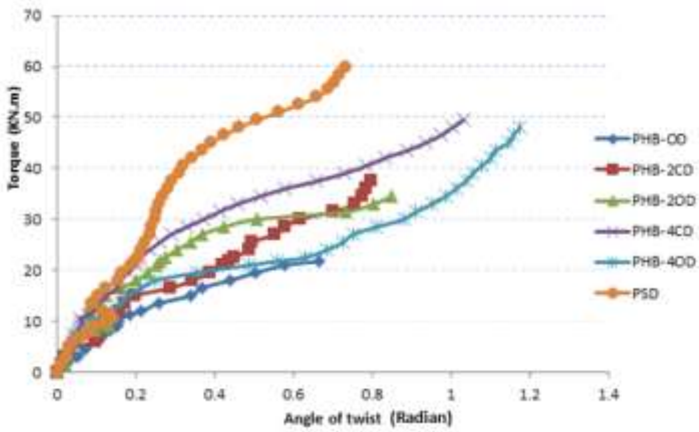

Figure 8. Torque-Angle of Twist Behavior

5.2.5. *Reinforcement and Concrete Strains*

5.2.5.1. *Longitudinal Bars Strains*

Longitudinal bars strains were measured and presented in Fig. 9. As shown, two things can be concluded, the strain in longitudinal bars at cracking torsional moment was less than 15% of the maximum strain; and the bars doesn't reached it yield strain. These means the longitudinal bars can carry additional torsional moment beyond the moment corresponding to the recorded maximum strain.

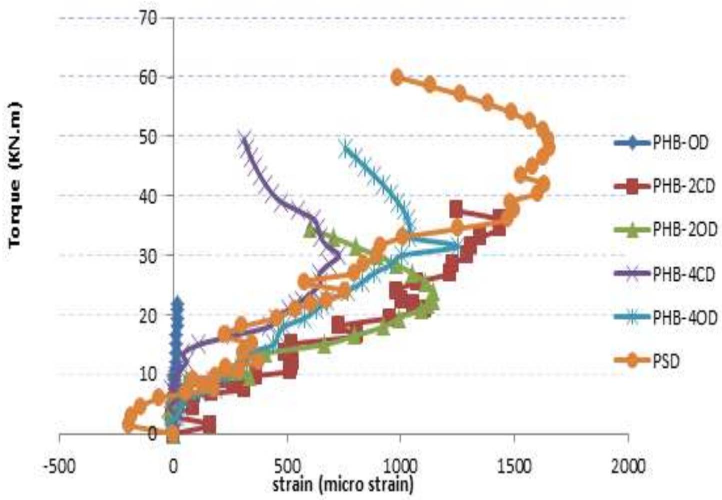

Figure 9. Longitudinal Bars Strains

5.2.5.2. *Stirrups Strains*

The variation of the torque with strain in stirrups is shown in Fig. 10; The contribution of concrete layers to resist torsional stresses was reflected on stirrups strains. The maximum strain in stirrup at specimen without internal diaphragm (HB-0D) was higher than the maximum strain in stirrup in solid specimen (SB) nearly by (83%) at failure load. This means, in the beginning, the thinned concrete wall in a hollow beam carry torsional stresses to a certain stage; beyond this stage, the stresses are carried by stirrups.

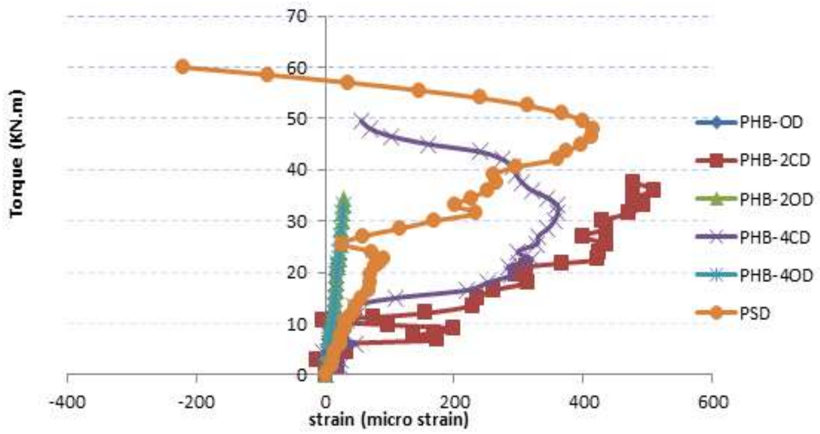

Figure 10. Stirrups Strains

With increasing the concrete in the core of section, the ability to sustain strains was increased. The stirrups strains can be reduced by redistribution of internal forces if the section changed from hollow to solid one. In the other hand, the maximum strain in stirrup at specimen without internal diaphragm (HB-0D) was higher than the maximum strain in stirrup in specimens (HB-2CD), (HB-2OD) and (HB-4CD) nearly by (59%-72%) at failure. This may be due to the uniform distribution of the normal forces due to the existing of internal diaphragms through the beam length.

5.2.5.3. Concrete Strains

The variation of the torque with strain in concrete in three different locations is shown in Fig. (11) to (13). According to ACI-318-14[7], the maximum compressive strain of concrete at crushing was (0.003) to higher than (0.008) under special conditions.

However, the strain at which ultimate moments are developed is usually about (0.003) to (0.004) for members of normal proportions and materials. In the present paper, the value of strain was recorded every (5 kN). Fig. 11, shows the curves representing the torque moment-strain of concrete at the top of diagonal location for end after 200mm distance from the end perpendicular to angle of twist (45^o). All beam specimens were failed with a diagonal concrete crack (torsional spiral cracks) failure, this means the ultimate load exceeds the ultimate stress and the concrete approaches to peak response.

Fig. 12 show the torque moment-strain curves for concrete at the bottom of diagonal location for end after 200mm distance from the end perpendicular to angle of twist (45^o). Fig. 13 show the torque moment-strain curves for concrete at the middle of diagonal location for another edge and opposite side after 200mm distance from the end perpendicular to (45^o) angle.

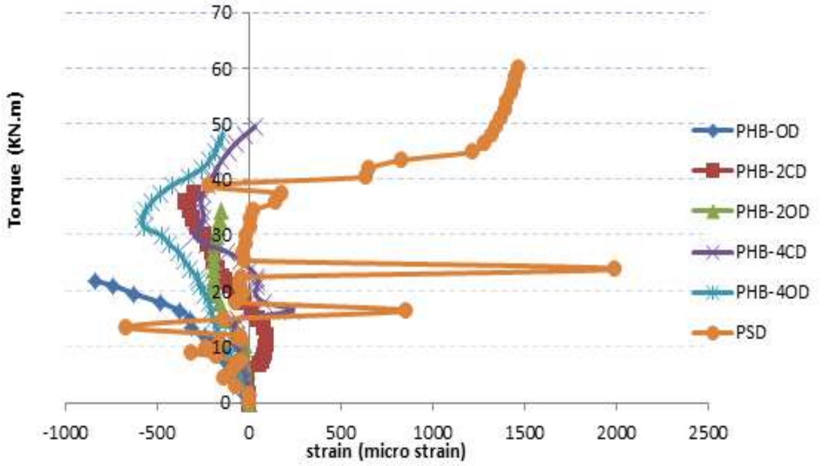

Figure 11. Concrete Strains (Location-2)

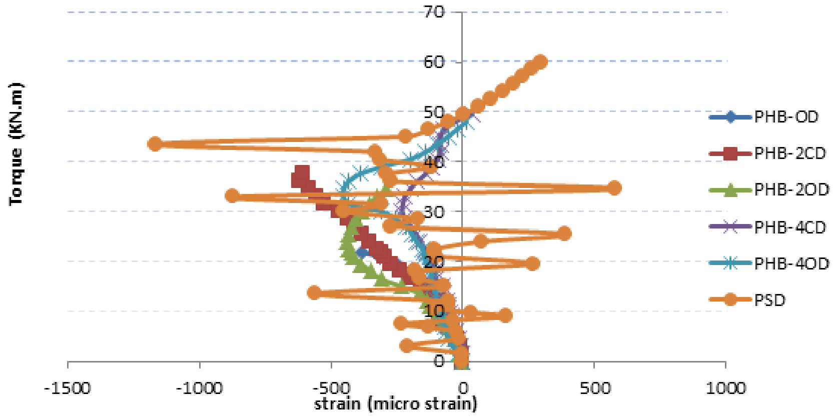

Figure 12. Concrete Strains (Location-3)

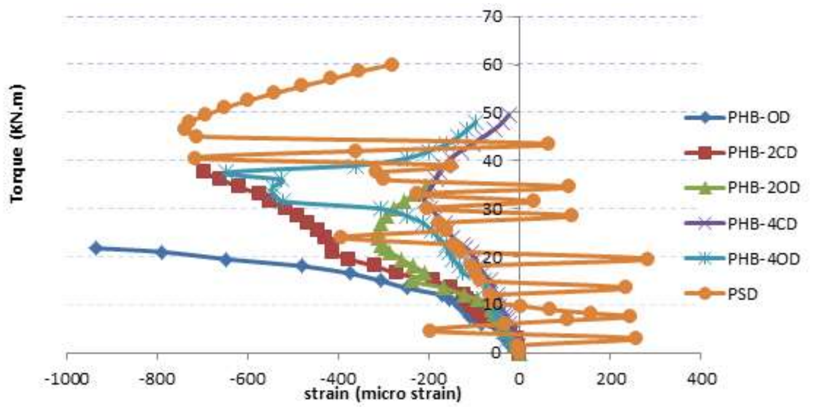

Figure (13) Concrete Strains (Location-4)

6. Conclusions

Based on experimental results, the following conclusions can be drawn:-

1-The ultimate torque moment was increased about (72.4%) and (127.6%) for beam specimens which strengthened internally by two and four closed diaphragms respectively. While, for beam specimens which strengthened internally by two and four opened diaphragms, the ultimate torque increases about (58.6%) and (120.7%) respectively. This means that the increasing in torsional capacity is attainable for box beams by using the concept of strengthening by internal opened or closed diaphragms.

2- The cracking torque moment was increased about (30%) for beam specimens which strengthened internally by four closed diaphragms. While, for beam specimens which strengthened internally by four opened diaphragms, the cracking torque increases about (10%).

3- When the section changes from the box section, (without internal diaphragms), to solid section, the cracking and ultimate torque was increased about (50%) and (175.9%), respectively. For the box beam specimen, only the thinned wall (ribs) was contributed to resist both, cracking and ultimate loads, while, a full section of solid beam was contributed to resist both, cracking and ultimate loads

4- When the internal diaphragms changed from opened to closed type, the ultimate capacity was increased about (8.7%-3.13%) for beam specimens containing two and four internal diaphragms respectively. Since this increasing was marginal (can be negligible), it can be concluded that the box sections can be strengthened by internal opened diaphragms and possess same capacity or contribution of the closed.

5- The toughness of the strengthened beam specimens (by internal closed or opened diaphragms) was higher than the hollow beam without any strengthened. This might be because the location of internal diaphragms not provides any restraint against rotation of the beam.

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