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Investigating the Capacity of Ultimate Torsion of Concrete Prismatic Beams with Transverse Spiral Bars

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***Abstract*—**In this paper, the torsion capacity of ultimate point on rectangular beams with spiral reinforcements in the torsion direction and its anti-direction are investigated. Therefore, models of above-mentioned beams have been numerically analyzed under various loads using ANSYS software. It was observed that, spirally-reinforced prismatic beam and beam with spiral links, show lower torsion capacity than beam with normal links also in anti-direction. The result is that the concrete regulations are violated in this case.

***Keywords*—**RC Beam; Ultimate Torsion; Finite Element; Prismatic Beams; Spirally Tie

I. Introduction

Torsion happens because of integrity and continuity of members and also under the effect of external loads in concrete structure. In the past, concrete designers didn't pay more attention to the effect of torsion in concrete structure. But lately, most of the researchers investigated the effect of torsion on different kinds of structures using the best method of numerical analyses like finite element method. This led to the advent of realistic standard design and methods. Taking into consideration different torsion and stresses happening in the structures, methods are found for torsion strength such as theory of bent buckle, theory of spatial trusses and etc. For the first time, the theory of spatial truss was mentioned by Rausch in 1929 and the theory of bent buckle was mentioned by Lessing in 1985 and Yudin in 1962 [1,2]. By extending the theory of spatial truss Collins found interesting results about angles of torsion cracking in reinforced concrete beams in 1980 [3]. Also, Hsu investigated the behavior of reinforced concrete beams after cracking according to the theory of softened-truss and also the final moment of torsion in 1985 [4,5].

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In order to resist reinforced concrete members versus torsion, we should use two different kinds of bars: 1.longitudinal bars and 2.Transverse bars. According to the code ACI-318R-99 thin wall box method by ignoring central concrete core, resistance happens by external wall of section with approximately central links [9]. In this paper, torsion capacity and shaping of two different kinds of beams with concrete filled core (prismatic beam) as well as without-concrete filled core (shell beam) with three different kinds of ties, spirally positive and spirally negative were compared with each other. We used ANSYS in order to achieve the point with non-linear analysis.

Behavior of reinforced concrete beams under torsion in torsion- turning diagram is presented in Fig. 1. In this diagram, torsion limitation Tcr which is not related to cracking concrete shows the function is linear between torsion and turning. In T=Tcr concrete cracks, with constant T, it increases like stairs then bars used according to θ in order to absorb additional torsion. Also, researches in a field of torsion which made crack on concrete beams have been done by extending crack analysis and it shows affirmation of increasing θ in stair case at the time of cracking [10]. Extending crack analysis for concrete without reinforcement under the effect of torsion which was suggested by Karaynins [10] approved successfully for reinforced concrete beams in order to predict elastic behavior before cracking [8].

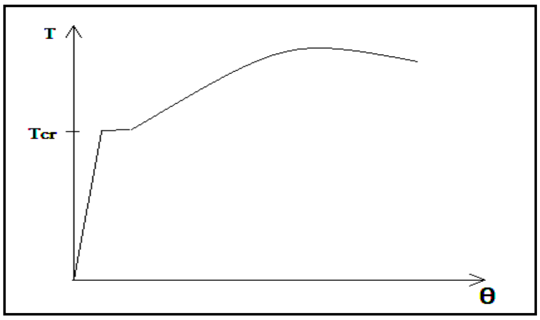


Fig. 1 Torsion- Turning diagram for torsional reinforced concrete beam

Hsu and Mitchell found the same result in different researches where in torsion member of reinforced concrete, diagonal cracks which are created is a kind of shear cracks [11, 12]. During the experiment done also spiral cracks can be noticed in torsion members [13].

II. Concrete Reinforced Mixture

Reinforced concrete combined with two kinds of materials namely steel and concrete. These two materials have two different kinds of characteristics. Steel is a kind of material which is homogenous, whereas concrete is not a homogenous material. Homogeneity of steel versus concrete mechanical attribute of this material depends on time and environment. Mechanical attribute of pressure and tensile of steel can be found due to stress and strain diagram which is related to tensile experiment [14].

Behavior of reinforced concrete members versus torsion can be divided into 3 different phases: 1.The time before cracking which is assumed to be homogenous, 2.The time of cracking where we use the theory of spatial truss, 3.The time of yielding steel (plastic) [6].

III. Modeling Steel And Concrete In Ansys

In order to model concrete used SOLID65 element which has three nods and each nod has three degrees of freedom in X, Y, Z direction. This element has the ability of plasticity and also an inclusive ability to crack and squash in three directions [9, 15, 16, 17, and 18]. LINK8 element which is used to model bars in concrete has 2 knots in the beginning and the end of this element and each knot has three degrees of freedom in X, Y, Z directions and also has the capacity of plastic shaping [19].

We can use two different ways in order to model reinforced concrete members in ANSYS. The first method in SOLID65 element has the ability to show the ratio between steel and concrete area (smeared reinforcement), so we can apply steel to concrete area for SOLID65 element. However it is impossible to measure accurate forces occurring in bars. In another method which is used to model reinforced concrete members, first, reinforced concrete members are modeled with SOLID65 (ratio between steel and concrete area is zero) then bars are applied by LINK8 between nods which are made by meshes on SOLID65 element. In this way, we should create meshes in SOLID65 element in a way to model bars at the start and end point of LINK8. In this way, we can easily measure stress and strain of bars [20].

We used prismatic concrete core instead of cylindrical concrete core because of plane sides of SOLID65 element. If we use cylindrical concrete core, joint will occur between concrete core and shells by nods. For this reason, we used polygonal instead of cylindrical core. As it is clear in figure 2 for modeling spiral beam first prismatic concrete core modeled with 12 sides in section and 200 mm of diameter with 450 mm length. Then, a concrete core with transverse bars and longitudinal bar was modeled. It is noticeable to be more careful in meshing concrete core, meshing should be done in a way in which nods can model transverse bars with applied characteristics. In each three models with ties, positive and negative spirally used 6 longitudinal bars which are alternate in these 12 sides of section. The number of transverse bars used in each model is about 8 in every 60 mm step. Considering figure 3, in beams with ties twist around concrete core and after completing twisting anchor length continued about half of cores ambience. Whereas at the first step in beams with positive and negative spiral links, transverse bars after completing twisting around core and anchor length continuance, like spiral with 6cm steps continued to the end of beams. And also the same twisting should be with anchor length at the end of the beam. Transverse bars are used in all beams which are completely made of AII steel. The reason which makes difference between positive and negative spiral is the difference between moments occurred to the beam in positive and negative direction. All the beams are loaded like a cantilever beam (the beginning of the beam is strained and the end is free) then all the results achieved by investigating analysis.

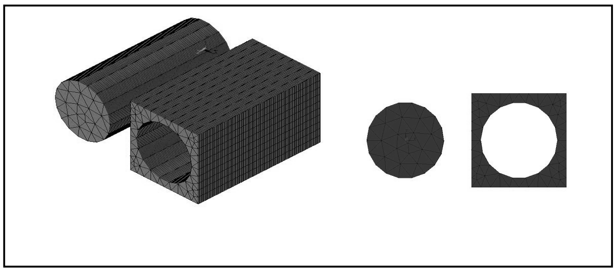


Fig. 2 The steps of making core, concrete shell and meshing

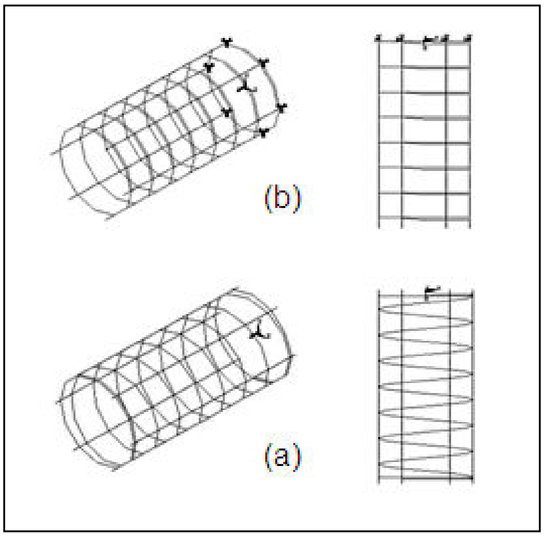


Fig. 3 The way of reinforcing concrete core: a) with spiral links, b) with ties

We used Chalioris experimental results on torsion concrete beams in order to affirm the accuracy of the results [21]. So, we chose two experimental models Ras and Rbs with the characteristics mentioned in table 1, and analyzed and investigated with the same modeling used here in this section. The results of experimental and software program are given in table 2. The comparison and analyses between these results show the accuracy of modeling in this study. The accuracy of modeling method for beams with ties also used this kind of modeling for beams with spiral tie.

TABLE I
SPECIFICATION OF CHALIORIS EXPERIMENTAL SAMPLES

Beam code name	b/h (mm/mm)	f_c' (MPa)	$A_{s\lambda}$ (mm^2)	$f_{ys\lambda}$ (MPa)	f_{yst} (MPa)
RaS	100/200	27.5	201	560	350
RbS	150/300	28.8	201	560	350

Note: 1 MPa=145 Psi; 1 mm=0.0394 in

TABLE II
CHALIORIS EXPERIMENTAL RESULTS AND COMPARING WITH THE RESULTS IN THIS STUDY

Beam code name	Experimental results of the tested beams		The results of analyzing experimental samples modeled with program	
	T_{cr} (kN m)	T_u (kN m)	T_{cr} (kN m)	T_u (kN m)
RaS	2.25	2.41	2.25	2.43
RbS	6.90	7.15	6.93	7.38

Note: 1 KN=224.82 lbf; 1 m=39.4 in

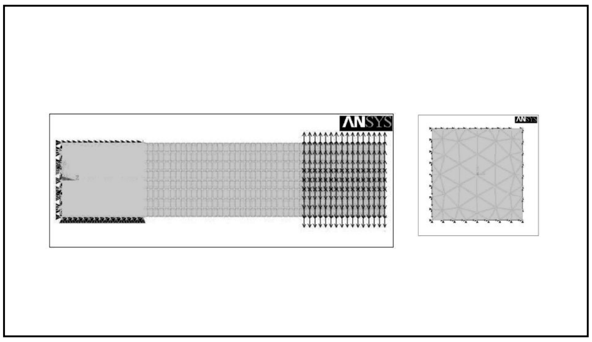


Fig. 4 Samples models of spiral in ANSYS

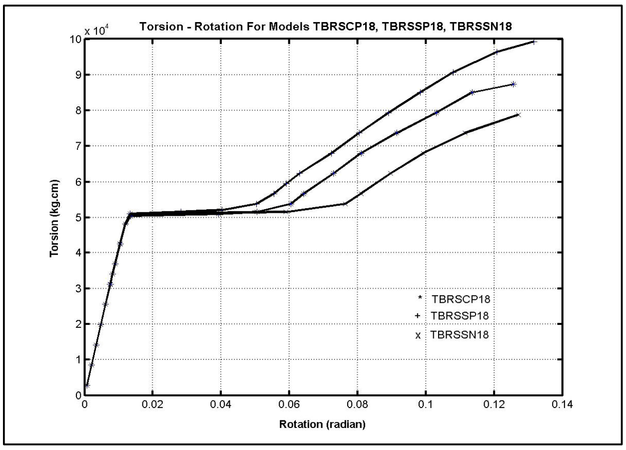
IV. INTRODUCING MODEL

At the beginning of this research, 18 samples of spiral beams used with transverse spiral bars in positive and negative direction and links. As it is clear in figure 4, it is considerable that all the beams in this series have the dimension about 250 mm. [10 in] x 250 mm. [10 in] and 450 mm. [18 in] in length. All of these reinforced beams include 6 longitudinal of grade 10 on a circle with about 200 mm.[8 in] of diameter. It is clear that in all the beams mentioned we used transverse bars with grade 6 and circle with 200 mm. [8 in] of diameter at every 60 mm. [2.4 in] steps. In order to prevent the beams of locally cracking where there is a concentration stress which occurs at 80 mm. [3.2 in] of beginning of these models restrained at every 3 directions X, Y, Z (boundary condition of cantilever beams). And the loading on models located at 80 mm. [3.2 in] from the end of model with 45 force segments in every sides of reinforced concrete beam where all the forces have the same direction of torsion. The distance between bars in spiral condition is according to ACI code. Also, in positive and negative spiral beams transverse bars are used with continual spiral with the same characteristics for transverse bars used in beams with tie. The difference between these kinds of beams and the beams with tie is that continual of transverse bars are on the length of the beam.

TABLE III
MODELS CHARACTERISTICS IN ALL SERIES
Note: 1 MPa= 145 Psi

Transverse bar	Longitudinal bar	f_c' (MPa)	Kind of links	samples
10Φ	20Φ	18	tie	TBRSCP18
10Φ	20Φ	18	Spirally positive	TBRSSP18
10Φ	20Φ	18	Spirally negative	TBRSSN18
10Φ	20Φ	21	tie	TBRSCP21
10Φ	20Φ	21	Spirally positive	TBRSSP21
10Φ	20Φ	21	Spirally negative	TBRSSN21
10Φ	20Φ	25	tie	TBRSCP25
10Φ	20Φ	25	Spirally positive	TBRSSP25
10Φ	20Φ	25	Spirally negative	TBRSSN25
10Φ	20Φ	30	tie	TBRSCP30
10Φ	20Φ	30	Spirally positive	TBRSSP30
10Φ	20Φ	30	Spirally negative	TBRSSN30
10Φ	20Φ	35	tie	TBRSCP35
10Φ	20Φ	35	Spirally positive	TBRSSP35
10Φ	20Φ	35	Spirally negative	TBRSSN35
10Φ	20Φ	40	tie	TBRSCP40
10Φ	20Φ	40	Spirally positive	TBRSSP40
10Φ	20Φ	40	Spirally negative	TBRSSN40

Later, we modeled 18 samples with filled prismatic beams and also 18 shell beams with three different kinds of link ties, spiral in positive direction (moment direction) and spiral in negative direction (opposite of moment direction). In all the models mentioned above filled prismatic beam with 250 mm. [10 in] × 250 mm. [10 in] in section and 1100 mm. [44 in] in length which is reinforced by 6 numbers of longitudinal bars in grade of 20 which are located on 12 sides and transverse bars in grade of 10 with 220 mm. [8.7 in] distance from each other (it doesn't satisfied with this step of links spiral condition with out codes in the beams mentioned) with tensile strength about 300 MPa. [43.5 Ksi]. In the beam shells model used 12 sides shell of 100 mm. [3.9 in] average of radius and 40 mm. [1.6 in] diameter and 1100 mm. [44 in] length and it has the same condition with reinforced filled beams with longitudinal and transverse bars. Characteristics of two different kinds of beams are given in table 3. In these models, in order to prevent local cracking as it is shown in figure 5, in all beams mentioned all nodes are located at 270 mm. [10.6 in] at the beginning of models where they were restrained in all three directions of x, y, z (cantilever beam boundary condition) and also loadings are located at the end of 270 mm. [10.6 in] of the model which has 112 force segments at each sides where all of them are in the same direction of torsion. Shear transition coefficient for all models taken as 0.7 for analyzing [22].



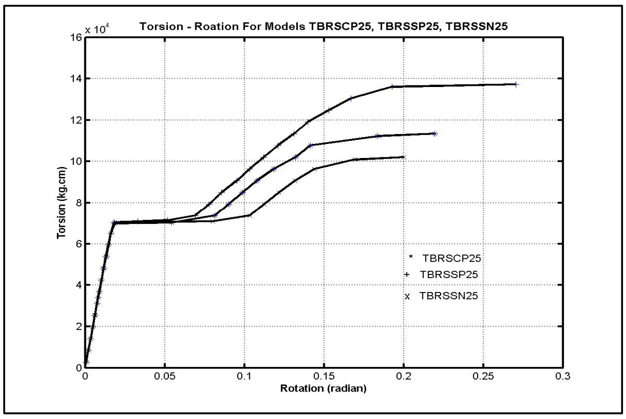
Note: 1 KN= 224.82 lbf; 1 m= 39.4 in

Fig. 5 Turning changes ratio to torsional moment changes with concrete strength 18 MPa

V. Investigating Beams With Spiral Bars

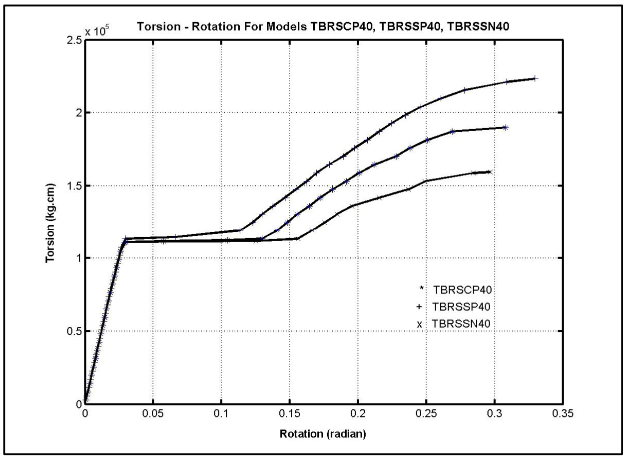
In this section 18 samples of prismatic spiral beams with transverse bars where the spiral condition is according to code in 4 steps of loading were investigated: 1. applying half of moment before crack (same step of loading for all samples), 2. Threshold cracking moment. 3. Moment cracking, 4. Final torsion moment. In these series of models used, filled beams (prismatic) with tie links, spirally positive links (spirally same direction with torsion moment direction), and spirally negative links (spirally in opposite direction of applying torsion moment) .Changes of torsion-circuit for spiral beam models with $f_c' = 18$ MPa. [2.61 Ksi] shown in figure 5.

As it is considerable from changes of torsion-circuit, it coincides with figure 1, and it is shown in the beginning of cracking and multiplication of cracking. And also the figures 6 and 7 show Torsion-Turing for models of prismatic spiral beams with concrete strength in pressure about 25 MPa. [3.63 Ksi] and 40 MPa. [5.8 Ksi], respectively.Element stress changes in longitudinal and transverse bars at the length of beam TBRSSP25 in 4 steps of loading elastic limitation, cracking limit, cracking initiation and final break shown in figure 8 and 9, respectively.



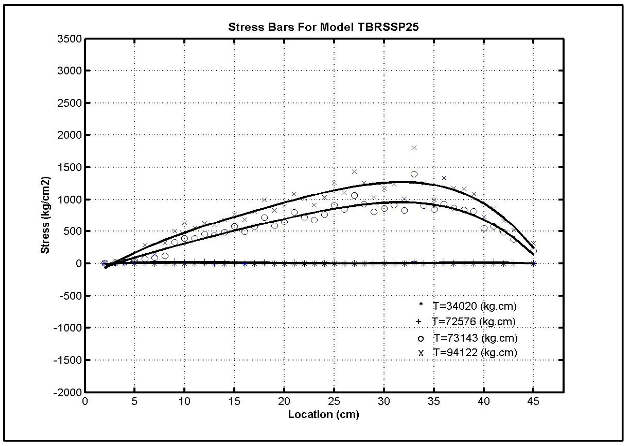
Note: 1 KN= 224.82 lbf; 1 m= 39.4 in

Fig. 6 Turning changes ratio to torsional moment changes with concrete strength 25 MPa



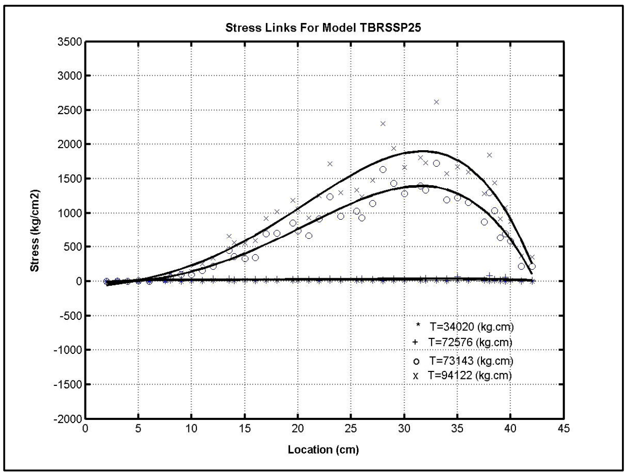
Note: 1 KN= 224.82 lbf; 1 m= 39.4 in

Fig. 7 Turning changes ratio to torsional moment changes with concrete strength 40 MPa



Note: 1 KN= 224.82 lbf; 1 m= 39.4 in

Fig. 8 Stress element changes of bars at the length of beam for model TBRSSP25



Note: 1 KN= 224.82 lbf; 1 m= 39.4 in

Fig. 9 Stress element changes of links at the length of beam for model TBRSSP25

Amounts of final moment and moment cracking and maximum stress occurring in longitudinal and transverse bars for all spiral samples shown in Table IV. As it is clear from torsion-circuit diagrams after cracking, the stress suddenly increases in longitudinal and transverse bars. According to the theory of reinforce concrete behavior versus torsion like shown in figure 1. In this figure till the torsion moment Tcr when the concrete is not cracking, relation between T and θ is linear and when T=Tcr concrete cracks, θ with constant T, like stair increases until the bars used for reinforcing start to act and absorb additional moment of torsion. Steps are explained before cracking, cracking limit, cracking initiation and final moment are shown in moment of torsion-circuit diagram which are the results of analyzing. Criterions used for measuring cracking moment are criterion theory that limit cracking with θ and constant T increase like stairs. Otherwise affirmation for measuring cracking moment, start acting of reinforced bars after cracking. As it is shown in figures 8 and 9 (they are the stresses occurred in longitudinal and transverse bars), stress in reinforced bars increases a lot by increasing a little of torsion moment. This increasing in amount stress in bars under the effect of cracking moment found from torsion-circuit diagram. The results taken from the experiments on different samples by Panchacharan, Chalioris Karayanis in the field of reinforced concrete torsion beams looks completely same [21, 23, 24, 25]. Using the results found from this research show that ultimate torsion capacity for the spiral beam with torsion moment T- , 16.88 percentages is less than ultimate torsion capacity for spiral beam with torsion moment T+. Figure 10 shows changes of ultimate torsion; moment for the samples with different concrete strength. It is considerable for series of samples, the samples with positive spiral links have higher ultimate strength than tie and tie ratio to negative spiral. Also figure 11 shows a different percentage of samples with ultimate strength ratio to tie. As it is clear from these figures, torsion capacity of spiral beam and torsion capacity of spiral beam with torsion moment T- , 12.83 percentages is less than torsion capacity of beam with tie.

TABLE IV

RESULTS OF ANALYZING SPIRAL SAMPLES INVESTIGATED IN ANSYS

Note: 1 KN= 224.82 lbf; 1 m= 39.4 in

Tu (KN.m)	Tcr (KN.m)	sample	Tu (KN.m)	Tcr (KN.m)	Sample
8.16	6.18	TBRSCP21	6.69	4.93	TBRSCP18
8.67	6.12	TBRSSP21	6.86	5.27	TBRSSP18
7.09	6.18	TBRSSN21	5.84	4.87	TBRSSN18
Tu (KN.m)	**Tcr (KN.m)**	**sample**	**Tu (KN.m)**	**Tcr (KN.m)**	**Sample**
10.49	8.73	TBRSCP30	9.13	6.80	TBRSCP25
10.94	8.45	TBRSSP30	9.41	7.31	TBRSSP25
9.64	8.16	TBRSSN30	8.62	6.58	TBRSSN25
Tu (KN.m)	**Tcr (KN.m)**	**sample**	**Tu (KN.m)**	**Tcr (KN.m)**	**Sample**
14.52	10.89	TBRSCP40	12.59	10.09	TBRSCP35
15.08	10.77	TBRSSP40	13.04	10.32	TBRSSP35
12.59	10.89	TBRSSN40	11.17	9.64	TBRSSN35

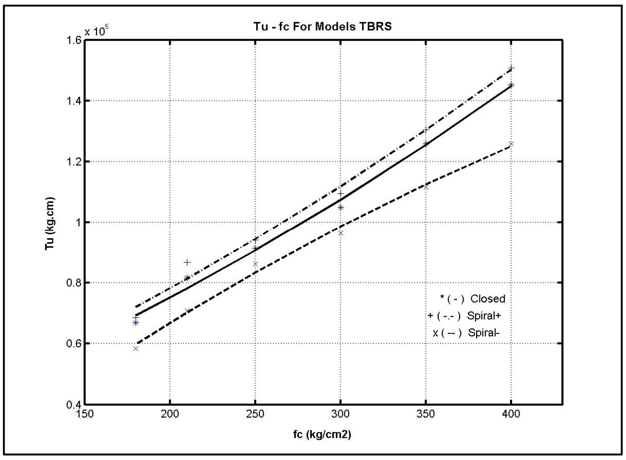


Fig. 10 Final strength changes of samples related to concrete material changes

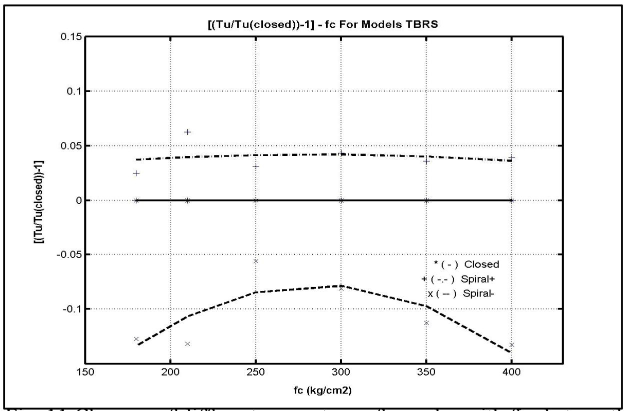


Fig. 11 Changes of different percentage of samples with final strength ratio to tie

VI. Conclusion

1- Relation between torsion-circuit is linear up to Tcr. These linear results and also increasing stair like turning for increasing torsion where T=Tcr shows the most results in this research and the results indicate the accuracy of the theory.

2- Moment cracking Tcr with constants of section parameters, just all depended on the concrete material and for the same kind of concrete material, prismatic spiral beams, prismatic and shell spiral with different kinds of links have the same Tcr.

4- For torsion of cracking in beams, θ with a constant T, increases like stair. The stress cracking in reinforced bars for increasing partially in torsion moment, increases a lot which shows the beginning of cracking.

5- The capacity of ultimate torsion for the spiral beam with torsion moment T- , 16.88 percentages is less than ultimate torsion capacity for spiral beam with torsion moment T+.

6- The capacity of spiral beam and torsion capacity of spiral beam with torsion moment T- , 12.83 percentages is less than torsion capacity of beam with tie.

7- If a beam with spiral links does not satisfy the spiral condition and changes to wraparound, we can use it instead of beam with tie only when the applying of torsion moment is the direction of spiral.

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