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Proposed Expressions for Torsional Capacity of RPC Beams

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Abstract

In this study, two theoretical models were used to propose expressions for the ultimate torsional capacity of Reactive Powder Concrete (RPC) beams, by using regression analysis on test results through the use of the trail version 9 of data Fit software of Oakdale Engineering computer programs. The first model depends on the well known codes provisions for torsional capacity with adding the effect of steel fibers to the proposed expressions. The second model is regression analysis of the results of experimental torsion tests conducted on RPC beams in this investigation and previous study . Both the cracking and ultimate torsional strengths are established by this method.

The proposed expression of Tcr and Tn showed good agreement with the experimental results provided by reverences.

Key Words: RPC, Regression Analysis, Tcr and Tn

الصيغ التخمينية لحسلب المقاومة القصوى للي للعتبات ذات المساحيق الفعالة

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الخلاصة

في هذه الدراسة تم اشتقاق نوجين استخدما لوضع صيغ تخمينية لحساب مقاومة اللي القصوى للعتيات الخرسانية المسلحة ذات المساحيق الفعالة اعتمادا على Regression Equation باستخدام النتائج التي تم الحصول عليها من هذا البحث وبحث سابق بواسطة النسخة التاسعة لبرنامج DtatFit 9 . النموذج الاول اعتمد على المدونات العالمية للخرسانة العادية مضافا لها تاثير الياف الحديدية للوصول للصيغ النهائية لحساب عزم لي التشقق ومقاومة اللي القصو ى بينما اعتمد النموذج الثاني على اجراء Regression Analysis لنتائج تم الحصول عليها في بحوث سابقة . نتائج التحليل النظري لحساب Tcr and Tn بينت تطابق وتقارب كبير مع النتائج العملية لمعظم العتبات مع نسبة تحفظ مناسبة .

Introduction

As tall buildings are being built, the demand for high strength concrete with compressive strength over 100 N/mm^2 [1] has been increasing year by year. Demands for materials with much higher strength will be far larger later. Richard et al. (1994) [2] invented a new cement-based material born from an innovative concept of ultra-high strength combined with high toughness named RPC (reactive powder concrete) for the reactive powder they used, (although did not contain coarse aggregate ,it was named "concrete" , this was because of its structural applications). There were two classes of it; i.e. RPC800 that requires high degree of heating and pressing curing which is unpractical for commercial production, and RPC200 which can be obtained by steam-curing. RPC has been used to describe a fiber-reinforced, superplasticized, silica fume-cement mixture with very low water-cement ratio (w/c) characterized by the presence of very fine quartz sand (0.15-0.40mm) instead of ordinary aggregate. Compressive strength between 150 and 230 MPa, flexural strength between 20 and 50 MPa, and Young's modulus of elasticity between 45 and 65 GPa can be attained [3]. However, due to the use of very fine sand instead of ordinary aggregate, the cement factor of RPC is as high as (900-1000 kg/m^3) [4].

The first two road bridges overpasses on the Bourg lès Valence made from Ultra High Performance Fiber-Reinforced Concrete (UHPFRC), each consist of two spans of 22 m length. Their decks as shown in Fig. (1) are 12 m wide, each is an assembly of five T-shaped precast beams made of UHPFRC of the type BSI. All beams are prestressed by pre-tension of strands [5]. The equivalent thickness of the deck is 0.25 m, compared to 0.75m for conventional prestressed slab bridges and 0.37 m for HPC deck. Use of UHPFRC therefore reduces the self-weight of the beams to one third.

Fig. (1) Bourg Lès Valence Bridge View at Central Pier[5]

2. Regression Analysis

The objective of regression analysis is to evaluate the coefficients of an expression relating the criterion variable to one or more other variables, which are called predictor variables .The predictor variables are variables whose variation is believed to cause, or agree with, variation in the criterion variable. A predictor variable is often called an independent variable; this is a misnomer in that independent variables are usually neither independent of the criterion variable nor independent of other predictor variables.

Regression analysis is an important statistical method .It can be employed to determine whether the relationship is linear or nonlinear, direct or indirect and if there are any extreme events that will control the relationship. After the regression equation is calibrated, it is very important to examine the rationality of the regression coefficient. In addition to checking for rationality, the goodness-of-fit statistics mean (μ), standard deviation (*SD*), and coefficient of variation (*COV*), should be computed to assess the accuracy of predictions .If the expected accuracy is not acceptable, one may elect to collect more data or to develop a model that uses other predictor variables.

3. Proposed Expressions for Torsional Capacity of RPC Beams

Two methods were considered to propose expressions for both the cracking and ultimate torsional strengths of RPC beams. The first method depends on the well known codes provisions while the second method is regression analysis of the results of experimental torsion tests. The proposed expressions for torsional capacity of RPC derived by these two methods are based on the results of thirty seven beams tested in previous studies [1, 6].

3.1 First Proposed Design Equation

The Torsional capacity can be written as follows:

$$T_n = T_s + T_{RPC} \qquad (1)$$

Depending on the results of thirty seven beams tested in previous studies [1, 6]., it was found that the contribution of steel fibers to the torsional capacity could be computed by subtracting the test results of the ultimate torsion of the nonfibrous beam from the test results of the ultimate torsion of the corresponding fibrous beam (Eq. 2).

$$T_{fi\ test} = T_{u1\ test} - T_{u2\ test}, \qquad \text{N.mm} \qquad (2)$$

where:

$T_{fi\ test}$: experimental test results of the torsion capacity carried by steel fiber reinforcement.

$T_{u1\ test}$: experimental test results of the ultimate torsion capacity of fibrous RPC beam.

$T_{u2\ test}$:experimental test results of the ultimate torsion capacity of nonfibrous beam.

Nonlinear multiple stepwise regression analysis by Data Fit software was adopted to relate the (T_{fi}) in terms of the affecting parameters. The general expression can be written as:

$$T_{fi} = k_0\ (x)\ k_1 \qquad (7)$$

where

T_{fi} :predicted torsion capacity which is carried by steel fiber reinforcement MPa.

x :independent variables (f'_{cf}, ρ_s ,ρ_l ,F,…..,etc.), k_o , k_1 :constants.

The following expression is proposed for the prediction of the ultimate torsion capacity carried by steel fibers in RPC beams..

$$T_{fi} = 83\, A_{0h}\, {f'_{cf}}^{0.6} \left(t + \frac{A_t f_{ys}}{S}\right)^{0.02} \quad \text{, N.mm} \qquad (3)$$

where,(A_t) cross section area of Stirrups reinforcement,(A_{oh}) area enclosed by centerline of stirrups, (t) wall thickness of shear flow, (S) spacing of stirrups respectively, and (f'_{cf}) compressive strength of fibrous RPC, (f_{ys}): yield strength of stirrups

Eq.(3) gives a mean value (μ)of ($T_{fi\ test}$ / $T_{fi\ \ proposed}$) for the investigated test results of 1.0146 with standard deviation (*SD*) of 0.3514 and coefficient of variation (*COV*) of 34.63%. Figure (2) shows the test values versus the proposed values of (T_{fi}) for (37) available test results using Eq.(3) .

After this stage, the proposed expression for predicting T_{fi}, Eq.(3), can be added to the expressions of reinforced concrete beams given by the different Codes, (which are: Eq.(4) for AS3600, Eq.(5) for BS8110, Eq.(6) for ACI318M.05, Eq.(7) for Eurocode2 ,Eq.(8) for Eurocode2.

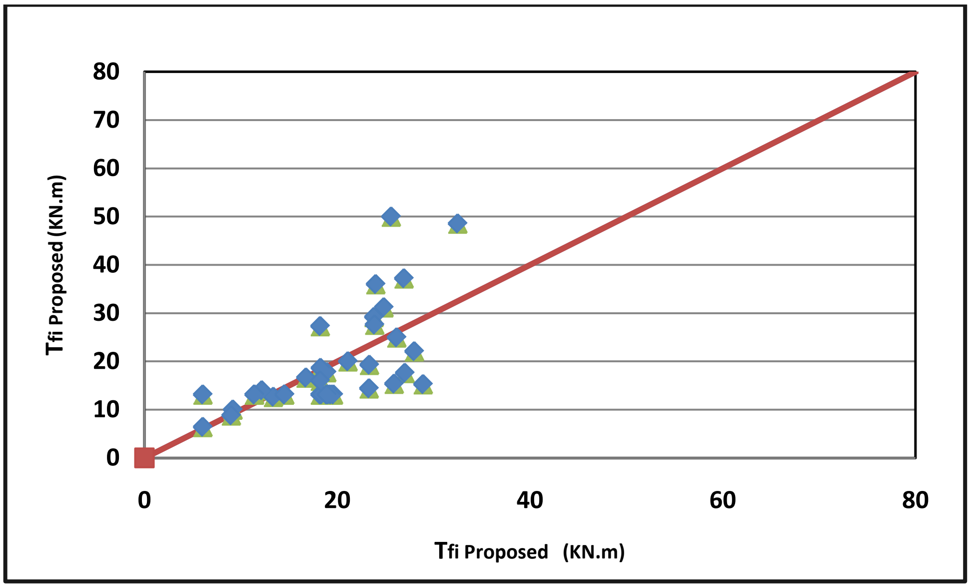


Fig.(2) :Tests Values Versus Proposed Values of Tfi of RPC Beams Using Eq. (3).

Thus, five expressions are obtained for the ultimate torsional capacity of RPC beams as follows:

$$T_n = f_{ys}\left(\frac{A_{sw}}{S}\right)2A_t \cot\theta_t + 83\, A_{0h}\, {f'_{cf}}^{0.6}\left(t + \frac{A_t f_{ys}}{S}\right)^{0.02} \tag{4}$$

$$T_n = \frac{0.8 x_1\, y_1 (0.87\, f_{ys}) A_{sv}}{S} + 83\, A_{0h}\, {f'_{cf}}^{0.6}\left(t + \frac{A_t f_{ys}}{S}\right)^{0.02} \tag{5}$$

$$T_n = f_{ys}\left(\frac{A_{sw}}{S}\right)2A_o \cot\theta_t + 83\, A_{0h}\, {f'_{cf}}^{0.6}\left(t + \frac{A_t f_{ys}}{S}\right)^{0.02} \tag{6}$$

$$T_n = f_{ys}\left(\frac{A_{sw}}{S}\right)2A_k \cot\theta_t + 83\, A_{0h}\, {f'_{cf}}^{0.6}\left(t + \frac{A_t f_{ys}}{S}\right)^{0.02} \tag{7}$$

$$T_n = f_y\left(\frac{A_s}{u_k}\right)2A_k \tan\theta_t + 83\, A_{0h}\, {f'_{cf}}^{0.6}\left(t + \frac{A_t f_{ys}}{S}\right)^{0.02} \tag{8}$$

Where,(x_1 and y_1) shorter and longer distances between the central line of stirrups, (A_l)Total longitudinal steel area, (A_o)Area enclosed by a line around the tube at the mid-thickness of the wall, (A_k) area enclosed by the centerlines of the effective wall thickness ,(A_{sw}) cross sectional area of stirrups and, (U_k) is the perimeter of the area(A_k).

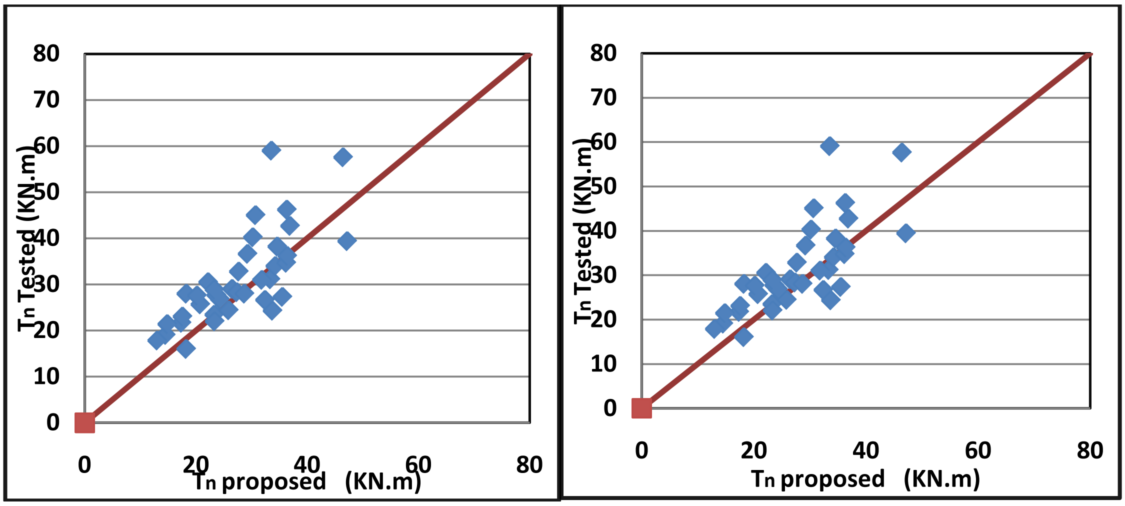
It is important to notice that no reduction factors are used in all above equations. To test these equations, the ratio of torsional capacities values ($T_{test}/ T_{proposed}$) were found for the results of thirty seven beams tested in previous studies [1, 6]. Using each of these equations, then the mean (μ), standard deviation (*SD*), and the coefficient of variation (*COV*) were calculated for these equations as listed in Table (1).

It is clear from this table that Eq.(7) for T_n has the lowest values of *$\mu$and SD of* of 1.06 and 0.2046 respectively, with *COV*= 19.22%.

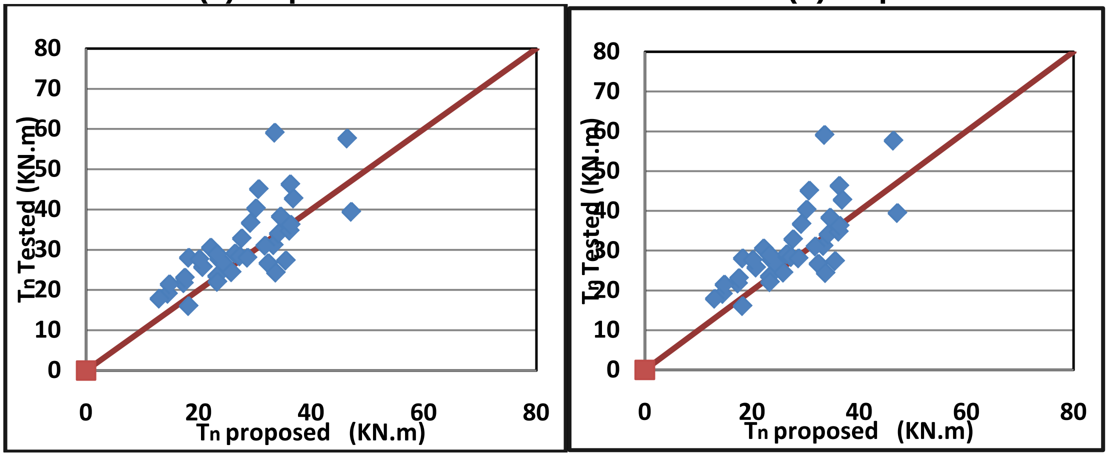
Figure (3) show the test values versus the proposed values of (*Tn*) for the results of thirty seven beams tested in previous studies [1, 6]. using Eq.(4) to Eq.(8) .

Table (1): Mean, Standard Deviation, and Coefficient of Variation Values of the Relative Torsional Capacity Values.

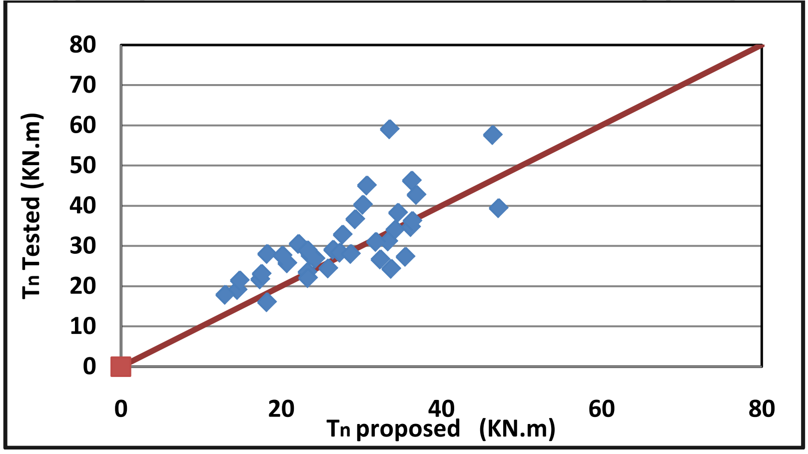
Eq.	Details of the Proposed Equations of	$T_{n\ test}/T_{n\ prposed}$		
		μ	SD	COV%
4	T_n=T_s, (AS3600), Eq.(2-20) + T_{fi}, Eq.(5-13)	1.25	0.36318	29.40
5	T_n=T_s, (BS8110), Eq.(2-23) + T_{fi}, Eq.(5-13)	1.16	0.2345	20.20
6	T_n=T_s, (ACI318), Eq.(2-25) + T_{fi}, Eq.(5-13)	1.10	0.2128	19.43
7	T_n=T_s, (Eurocode2), Eq.(2-27) + T_{fi}, Eq.(5-13)	1.06	0.2046	19.22
8	T_n=T_s, (Eurocode2), Eq.(2-28) + T_{fi}, Eq.(5-13)	1.13	0.2293	20.32



(a)- Eq 4 **(b)- Eq 5**



(c)- Eq 6 **(d)- Eq 7**



(e)- Eq 8

Fig.(3):Tests Values Versus Proposed Values of Tn of RPC Beams Using Eqs. (4, 5, 6, 7, 8).

3.2 Second Proposed Design Equation

In this section, two empirical expressions are proposed to estimate the cracking and the ultimate torsional capacities of the RPC beams. These expressions are obtained by performing nonlinear multiple regression analysis on the results the results of thirty seven beams tested in previous studies [1, 6]. The proposed expression for the cracking torsional moment of RPC beams is :

$$T_{cr} = 0.65 \left[\frac{A_{cp}}{P_{cp}} f'_{cf}\right]^2 \qquad ,\text{N.mm} \qquad (9)$$

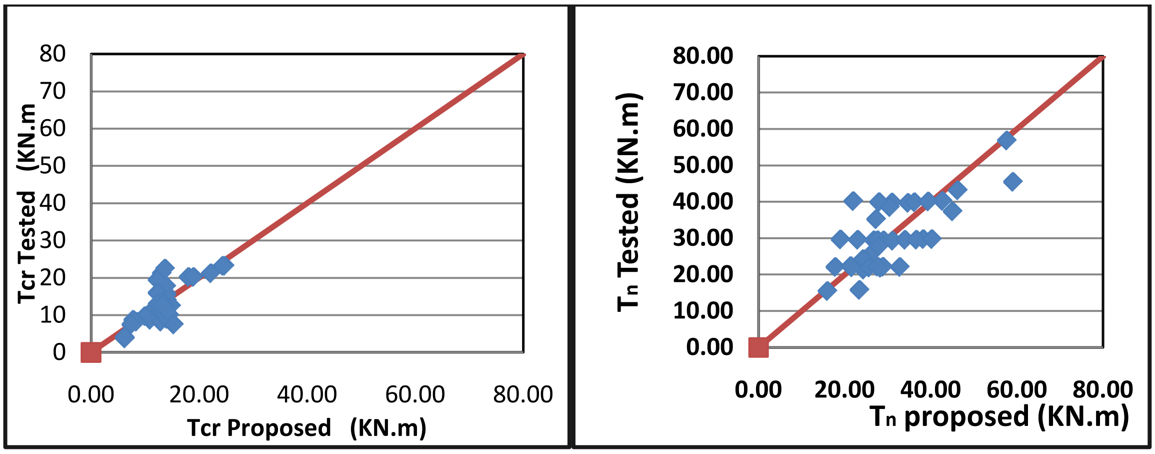
And the proposed expression for the ultimate torsional capacity of RPC beams is :

$$T_n = 21.6\, A_{oh} \left[\left(t\, f'_{cf}\right)^{0.6} + \left(\frac{A_t}{S} f_{sy} \frac{A_l}{P_h} f_{ly}\right)^{0.27}\right] \qquad ,\text{N.mm} \qquad (10)$$

Where, (t) thickness of the wall of the tube, (P_h) Perimeter of the cross section, (f_{sy} and f_{ly}) are the yield strength of stirrups and main reinforcement.

The accuracy of these two equations are examined by calculating respectively the ratios ($T_{cr\ test}$/ $T_{cr\ proposed}$) and ($T_{n\ test}$ / $T_{n\ proposed}$) for the results of thirty seven beams tested in previous studies [1, 6]. It was fond that Eq.(9) gave a mean value (μ)of ($T_{cr\ test}$/ $T_{cr\ proposed}$) for all the investigated test results of 0.9604 with standard deviation (*SD*) of 0.3067 and coefficient of variation (*COV*) of 31.94%. Figure (4-a) shows the test values versus the proposed values of (*Tcr*) for the results of thirty seven beams tested in previous studies [1, 6] using Eq.(9). It was also found that Eq.(10) give a mean value (μ) of ($T_{n\ test}$ / $T_{n\ proposed}$) for all the investigated test results of 0.9981 with standard deviation (*SD*) of 0.1551 and coefficient of variation (*COV*) of 15.53%. Figure (4-b) shows the test values versus the proposed values of (*Tn*) for the results of thirty seven beams tested in previous studies [1, 6]. using Eq.(10) .

It can be seen from Fig..(5) to (6) that the two proposed equations for estimating the ultimate torsional capacity of RPC beams, namely Eq.(7) and Eq. (10) give satisfactory predictions in comparison with test results.



(a): Eq(9) *(b):Eq(10)*

Fig.(4) :Tests Values Versus Proposed Values of Cracking and Ultimate Torsional Moment of RPC Beams Using Eq. (14) and. Eq. (15)

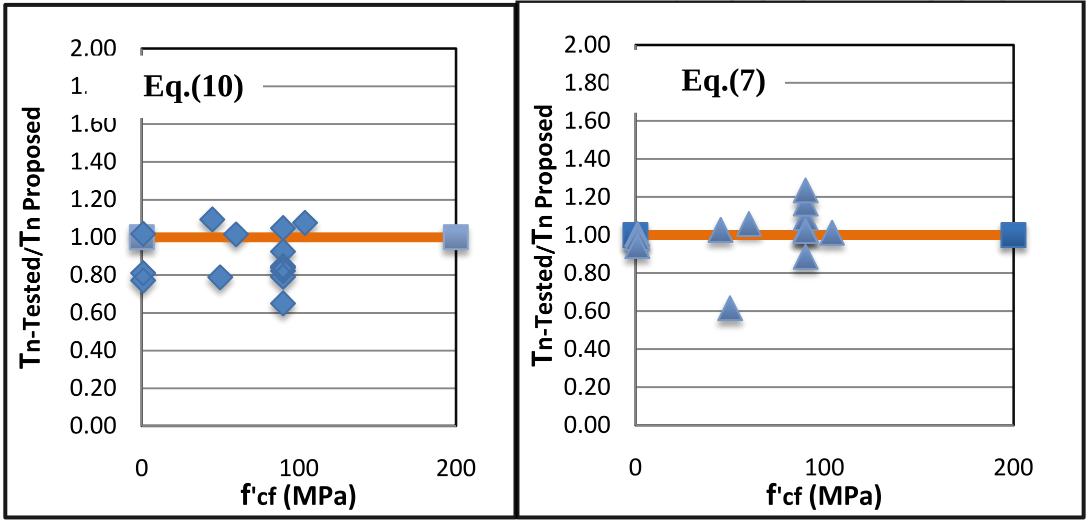


Fig.(5): f'cf Versus the Relative Torsional Strength Prediction.

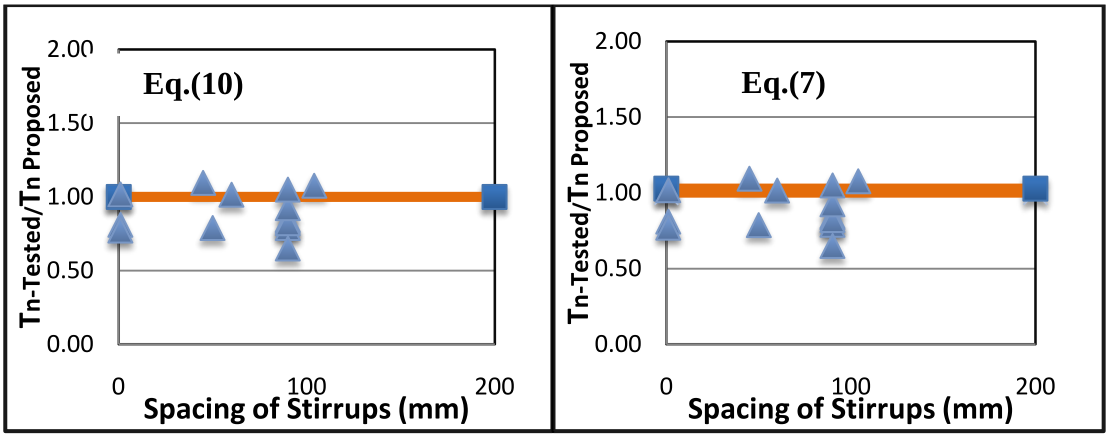


Fig.(6): Spacing of Stirrups Versus the Relative Torsional Strength

4. Conclusions

1. Based on test results obtained from this investigation, the two best expressions for predicting the ultimate torsional capacity of reinforced RPC beams as proposed in this study .
2. Comparisons with experimental data indicate that the proposed expressions properly estimate the effects of primary factors, such as concrete compressive strength and spacing of stirrups reinforcement.
3. The two proposed expressions, Eq.(7) and Eq.(10), were found to have low *COV* values of 19.22% and 15.53% respectively.

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