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Torsional Strength Determination of Ferrocement U-Wraps RC Beams with using Different Methods

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Abstract: Retrofitting of distressed structures is a major concern worldwide for researchers particularly against torsion. Determination of torsional strength of retrofitted RC beams "U" wraps is again a difficult task. The experimental program is taken up with 30 rectangular beams tested under pure torsion. Torque of such a "U" wrapped RC beam with other dimension and material cannot be derived from these experimental results. To compute the same; analytical method based on softened truss model of Hsu is employed with modification on material properties. Both experimental and analytical methods are unable to provide a single equation to quantify the torsional strength. To overcome the same, soft computing method MARS and WASPAS method is employed in the present investigation. The methods are easy and time saving.

Keywords: Ferrocement, U wrap, Ultimate Torque, Softened truss model, MARS, WASPAS.

I. INTRODUCTION

Concrete structures are imperiled to basic structural whereabouts such as axial, shear, flexure and torsion either individually or combinable which develop direct or indirect tensile stresses, force the designers to have a second thought for another material as concrete is having low tensile strength and poor toughness besides all of its good characteristics. The problem of low tensile strength of concrete plays a high risk to encounter the torsional loads. To engineer this problem one may have to opt for reinforced concrete or prestressed concrete or composite concrete like Fiber reinforced concrete or ferrocement. Torsion is a supreme aspect which is considered along with other basic structural actions. The torsional effects cannot be ignored in the present-day design due to (I) Large torsional moments tempted in structures and (II) Critical safety features used in project methods [1-20].

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The aim of this investigation is to apply soft computing method to predict ultimate torque of ferrocement U-wrapped RC beams with the help of these experimental results.

II. DIFFERENT APPROACHES TO PREDICT TORSIONAL STRENGTH

A. Experimental Program

Concrete Beams were casted and verified beneath torsional loading for evaluation of torsional strength of ferrocement U-wrapped sections. The distinctions measured are no. of mesh layers present in ferrocement U-wrap, concrete strength size aspect ratio, state of torsion and mortar strength, The no. of mesh layers is speckled as 3, 4 and 5 for studying the influence of no. of mesh layers proceeding torsional asset of six conceivable circumstances of conditions of torsion.

Total length of beam was fixed at 2000 mm with cross section of (125 mm X 250 MM). In all beams core concrete strength with 35 MPa and ferrocement of 40 MPa. Ferrocement wire was having diameter of 0.72 mm yield strength of 250 MPa. Table I shows the details of beams tested. The test procedure along with specimen was shown in Figure-1.

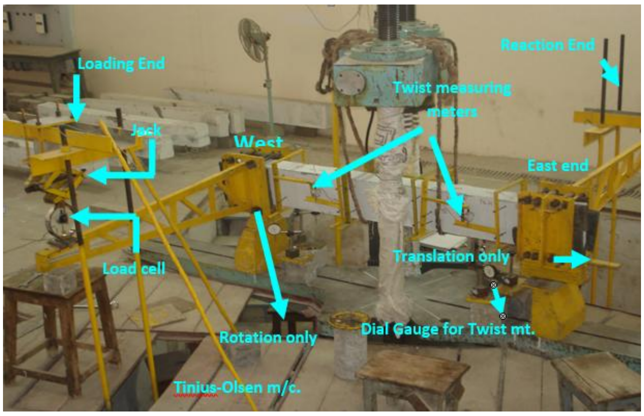

Fig. 1.Torsion test setup

Table- I: Different beams cast and tested with material properties

Sl. No.	Series	Designation	Reinforcement Details					
			Core Reinforced Concrete					Outer Wrap
			Ferrocement matrix, MPa	Longitudinal Steel		Transverse steel		No. of mesh layers
				Diameter in mm / No. of bars	Yield Strength, MPa	Diameter in mm, @ 100 mm c/c Spacing	Yield Strength, MPa	
1		BQ4N						
2	B	BQ3N						
3		BQ5N						
4		L3N						3
5	Longitudinal	L4N		12/ 4	440			4
6		L5N						5
7		T3N						3
8	Transverse	T4N				8	465	4
9		T5N						5
10		U3N						3
11	U	U4N	40	6/ 4	350			4
12		U5N				6	350	5
13		Lo3N						3
14	L	Lo4N		12/ 4	440			4
15		Lo5N						5
16		To3N						3
17	T	To4N		6/ 4	350			4
18		To5N				8	465	5
19		Co3N						3
20	C	Co4N		12/ 4	440			4
21		Co5N						5

B. Soft Computing method

Determination of torque by experimental method a tedious and time dependent process and involves a destruction of specimen. For prediction of torsional capacity of beams with other dimension and material properties, soft computing is preferred. Fig. 2 shows wrapped beam's torque-twist diagram.

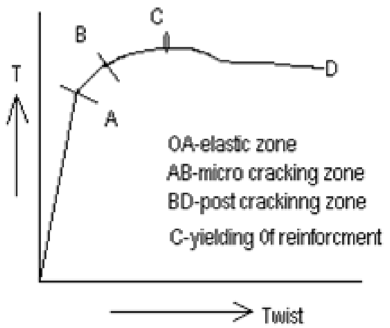

Fig. 2.Wrapped beam's torque-twist diagram

C. Multivariate adaptive regression spline (MARS)

Piecewise linear basis functions expansion is used by MARS as shown in equation (1).

$$c^{+}(x,\tau)=[+(x-\tau)]_{+}\ ,\ c^{-}(x,\tau)=[-(x-\tau)]_{+} \quad (1)$$

General model Equation (2) on relative among input & response:

$$Y = f(X)+\varepsilon \quad (2)$$

Where, Y is reaction variable, X is vector of predictors, ε is additive stochastic factor. After these arrangements, basis functions is Equation (3):

$$\delta := \{(X_j-\tau)_{+},(\tau-X_j)_{+} \mid \tau \in \{x_{1,j},x_{2,j},.......,x_{N,j}\},\ j \in \{1,2,........,p\}\} \quad (3)$$

f(X) is signified by a linear combination as shown in equation (4)

$$Y=\theta_0+\sum_{m=1}^{M}\theta_m\psi_m(X)+\varepsilon. \quad (4)$$

Figure 3 represents various values for prediction of torque by MARS method

Table- II: Values used in MARS

nsubsets	Generalized cross validation	Residual sum – of - squares	Parameters	Coeff.
V1Co4H	8100.0	100.0	(Intercept)	6.7528
V7	672.4	71.3	V1Co3N	2.3521
V11	652.7	56.9	V1Co4H	5.0055
V19	431.3	37.3	V1Co4N	2.6731
V1Co3N	329.0	31.2	V1Co5N	2.8671
V1Co4N	329.0	31.2	V1To5N	1.3965
V1Co5N	329.0	31.2	h(0.322651-V7)	-2.7323
V1To5N	110.3	15.1	h(350-V11)	-0.0022
			h(V19-40)	0.0767

$$T_{ultimate} = 6.752 - maximum[0,0.32265 - spacing\ of\ longitudinal\ reinforcement] * 2.7323 - maximum[0,350 - Fty] * 0.002276 + maximum[0,Mortar\ strength - 40] * 0.07677 \quad (5)$$

$T_{cracking}$=5.5324+max(0,Fly-350)*0.00154-max(0,350-Fly) *0.0002689+max(0, spacing)*0.0012240+ max(0,mortar strength-40)*0.0680449- max (0, 40-mortar strength)*0.0206587 (6)

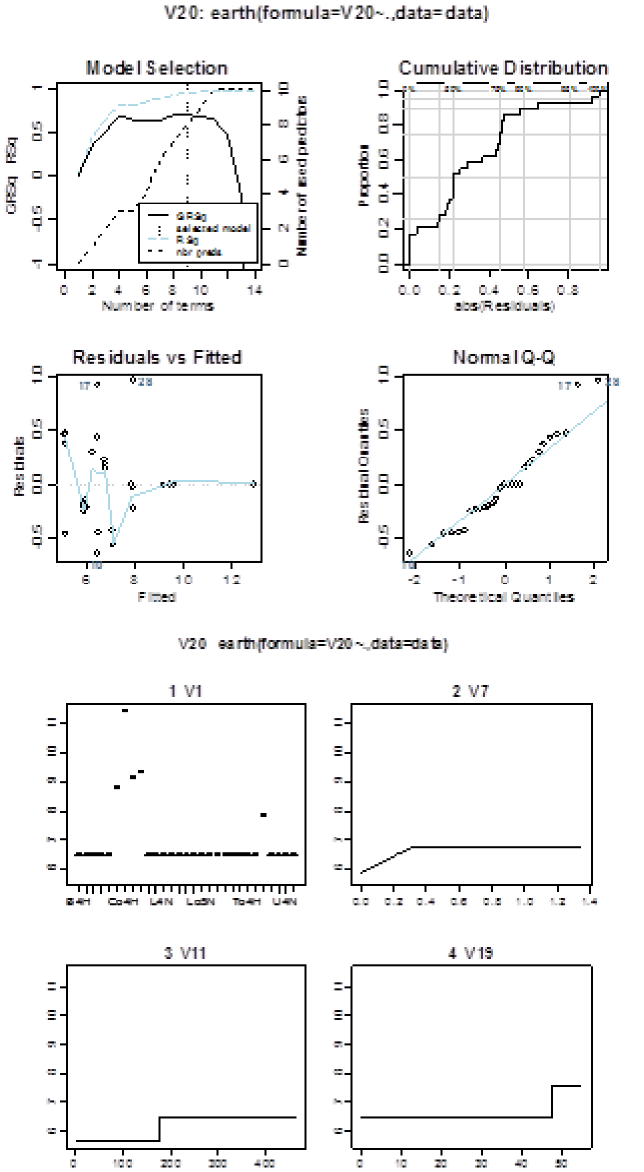

Fig. 3.Various Values for Prediction of Torque by MARS method

D. Weighted Aggregated Sum Product Assessment Method

The chief technique of WASPAS method for answering MCDM problems are [21], [22].

Step 1. Initial decision matrix is set.

Step 2. Decision matrix normalization using following equations (7) and (8) for maximization and minimization criteria, respectively:

$$\bar{x}_{ij} = x_{ij}/max_i x_{ij} \quad (7)$$

$$\bar{x}_{ij} = min_i x_{ij}/x_{ij} \quad (8)$$

where x_{ij} is the assessment value of i^{th} alternate with respect to j^{th} measure.

Step 3. Calculation of total comparative significance of i^{th} alternate, based on weighted sum method (WSM) using equation (8):

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} \, . \, w_j \quad (9)$$

Step 4. Calculation of total comparative significance of i^{th} alternate, based on weighted product method (WPM) using equation (9):

$$Q_i^{(2)} = \prod_{j=1}^{n} \bar{x}_{ij}^{\,w_j} \quad (10)$$

Step 5: Calculation of total comparative significance of alternatives is done using equation (11) and ranked from higher value to lower value [23]:

$$Q_i = \lambda \, . \, Q_i^{(1)} + (1 - \lambda) \, . \, Q_i^{(2)} \quad (11)$$

The cracking and ultimate torque of beams by all four methods was presented in Table-III.

Table- III: Values of Cracking and Ultimate Torque

Beams	Cracking Torque, kNm				Ultimate Torque, kNm			
	Expt.	*Analytical*	*MARS*	*WASPAS*	*Expt.*	*Analytical*	*MARS*	*WASPAS*
BQ3N	5.415	5.548	5.438347	5.323	5.443	5.54	5.074	5.555
BQ4N	5.415	5.548	5.438347	5.372	5.546	5.54	5.074	4.791
BQ5N	5.491	5.548	5.438347	5.414	5.54	5.54	5.074	5.855
L3N	5.61	-	5.671128	5.647	5.73	-	5.956	5.671
L4N	5.61	-	5.671128	5.694	5.74	-	5.956	5.817
L5N	5.69	-	5.671128	5.741	5.82	-	5.956	5.962
T3N	5.53	-	5.560746	5.502	5.62	-	5.871	5.148
T4N	5.53	-	5.560746	5.549	5.67	-	5.871	5.294
T5N	5.53	-	5.560746	5.596	5.69	-	5.871	5.439
U3N	5.53	5.548	5.654864	5.577	5.816	5.5604	6.458	5.499
U4N	5.61	5.548	5.654864	5.624	6.01	5.8902	6.458	5.644
U5N	5.615	5.548	5.654864	5.672	6.01	5.9039	6.458	5.79
Lo3N	5.816	5.548	5.793526	5.742	6.899	6.8845	6.752	7.176
Lo4N	5.816	5.548	5.793526	5.789	6.939	6.92	6.752	7.321
Lo5N	5.816	5.548	5.793526	5.836	6.979	6.96	6.752	7.467
To3N	5.735	5.548	5.654864	5.615	6.899	6.8926	6.463	7.307
To4N	5.73	5.548	5.654864	5.662	7.38	7.427	6.463	7.453
To5N	5.73	5.548	5.654864	5.71	7.86	7.8334	7.86	7.598
Co3N	5.816	5.548	5.793526	5.78	9.105	9.1163	9.105	8.984
Co4N	5.816	5.548	5.793526	5.827	9.426	9.3728	9.426	9.129
Co5N	5.85	5.548	5.793526	5.875	9.62	9.5916	9.62	9.275

III. INTERPRETATION OF TEST RESULTS

The experimental outcomes acquired were related with the results of attained by analytical method, MARS and WASPAS.

A. Torsional Performance of Normal Strength Beams

1) Torsional Actions of Standard Asset Beams

Cracking strength and ultimate strength of beams are found to be same as after cracking the beams were unable to sustain any load due to absence of any reinforcement in top face. When a beam of same size is without any wrapping, the beam can take a torsional load of 3.66 kNm as predicted by Skew bending theory. The same when provided with a wrap of ferrocement with three layers with mortar strength 40 N/mm^2, the same beam is capable of resisting a load of 5.415 kNm. The load carrying capacity is increased by 47.95 % than the unwrapped beam. This proves efficacy of "U" wrapped beams.

A comparison of predicted values by analytical model, by MARS and by WASPAS of plain concrete beams displays that values were more than 2,45%, 2.451% & 1.038%; 0.431%, 0.431% & -0.95889 %; -1.698%, -0.794 % & -1.0 % over experimental values for BQ3N, BQ4N and BQ5N respectively.

2) Torsional performance of RCC regular strength beams

Behavior of concrete beams with reinforcement in the core concrete and ferrocement "U" wrap on periphery is to be discussed here.

- L3N, L4N and L5N beams' ultimate torque were 5.73 kNm, 5.74 kNm & 5.82 kNm against their cracking torque of 5.61 kNm, 5.61 kNm & 5.69 kNm respectively. The cracking and ultimate torques predicted by soft computing MARS of the beams was found to be 5.671 and 5.956 kNm for all the three beams L3N, L4N and L5N respectively. The cracking torques predicted by soft computing method WASPAS were found to be 0.66 %, 1.5 % and 0.90 % higher than experimental values of the beams L3N, L4N and L5N respectively.
- Cracking torque of beams T3N, T4N & T5N were found 5.53 kNm and ultimate torsional strength were reported as be 5.62 kNm, 5.67 kNm & 5.69 kNm respectively. By MARS, cracking torque of beams are predicted as 5.56 kNm while ultimate torque was found 5.871 kNm. In WASPAS method, cracking torque values were predicted as 5.502 kNm, 5.549 kNm & 5.596 kNm, ultimate torque was 5.148 kNm, 5.294 kNm & 5.439 kNm for beams T3N, T4N & T5N respectively. However, it can be noticed that cracking and ultimate torque are found to be less in comparison of beams provided only with longitudinal reinforcement. The ultimate torque predicted by WASPAS method is found to be less than that of cracking torque.

U3N, U4N and U5N beams' cracking torques were 5.53 kNm, 5.61 kNm and 5.615 kNm, ultimate torques were 5.816 kNm, 6.01 kNm and 6.01 kNm for beams U3N, U4N and U5N respectively. Predicted values of cracking torque employing dissimilar methods is within 1.19% while for ultimate torque the maximum error was -4.39% for analytical model, 11.04 % for MARS and -6.09% by WASPAS method. The ultimate torque of these beams increased by 5.17%, 7.13 % and 7.03 % over their cracking torque. When these beams are analyzed by Hsu's softened truss model, the ultimate torque was 5.55 kNm, 5.89 kNm & 5.90 kNm for beams U3N, U4N and U5N respectively. Here softened truss model better predicts the values rather than MARS. The ultimate torque values of underneath reinforced beams are presented in Fig.4.

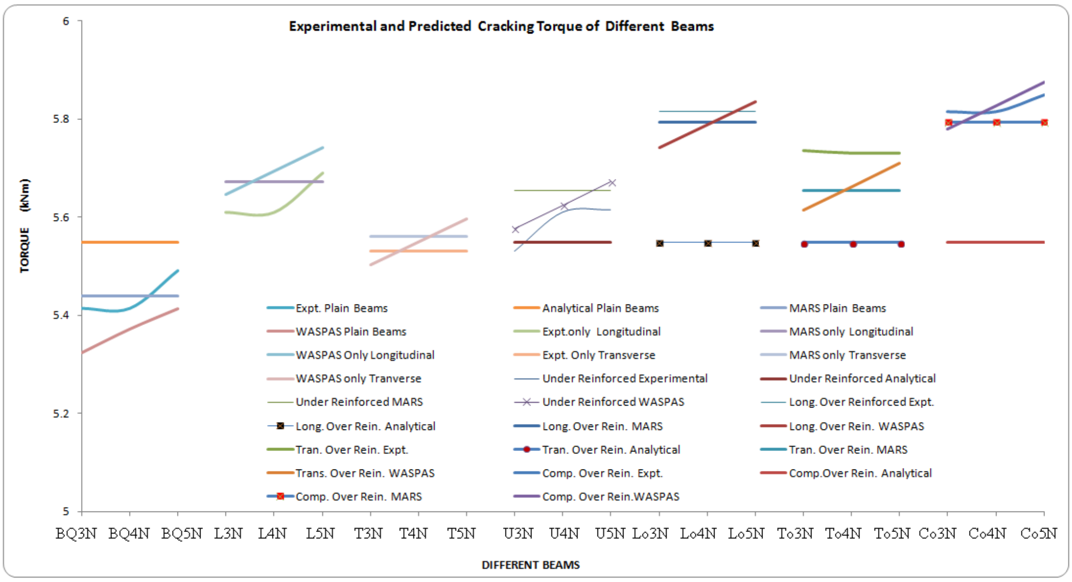

Fig. 4.Variation of Experimental & Predicted Cracking Torque for all Beams

- The experimental ultimate torque of beams Lo3N, Lo4N & Lo5N are found to 6.899 kNm, 6.939 kNm & 6.979 kNm against their cracking torque 5.816 kNm for all beams respectively. In all types of beams cracking torque was found to be 5.54 kNm by analytical method, which may be due to not considering the participation of reinforcement in cracking torque. Predicted values using MARS were 6.752 kNm for all 3 beams. The predicted values by softened truss model were found 6.88 kNm, 6.92 kNm & 6.96 kNm for Lo3N, Lo4N and Lo5N beams respectively.

The variation of experimental and predicted as revealed in Fig.5. The error in prediction of ultimate torque and % increase in ultimate torque over their control specimen is presented in Fig.6.

- The torsional reinforcement in core concrete inside transverse direction is more and in longitudinal direction it is less than that of a balance section. The difference in cracking torque and ultimate torque was found 1.164kNm, 1.65kNm and 2.13kNm for the To3N, To4N and To5N beams respectively. Fig.7 shows this was the highest percentage of increase over layers of all beams. This escalates ultimate torque for these series of beams over number of layers may be due to participation of transverse reinforcement as shear can be resisted by closed loops more. The predicted values by MARS are found to be 6.463kNm, 6.463kNm and 7.86kNm respectively. The predicted values by softened truss model were found 6.89 kNm, 7.43 kNm and 7.83 kNm respectively for beams T3N, T4N and T5N.The predicted values by softened truss model varies by 0.09%, 0.64% and 0.34% over their experimental values.
- Ultimate torques of Co3N, Co4N and Co5N beams were 9.015kNm, 9.426kNm and 9.62kNm respectively over the same predicted values by MARS. The predicted values by soften truss model was found to be 9.11 kNm, 9.37 kNm & 9.59 kNm for beams Co3N, Co4N & Co5N respectively. There was appraisal in ultimate torque of Co4N beam over Co3N beam was 4.5% and 6.71% for Co5N beam over Co3N beam. Here absolutely the predicted values were equal to the experimental values and increase in torque relating to no. of layers was plotted in Figure.7

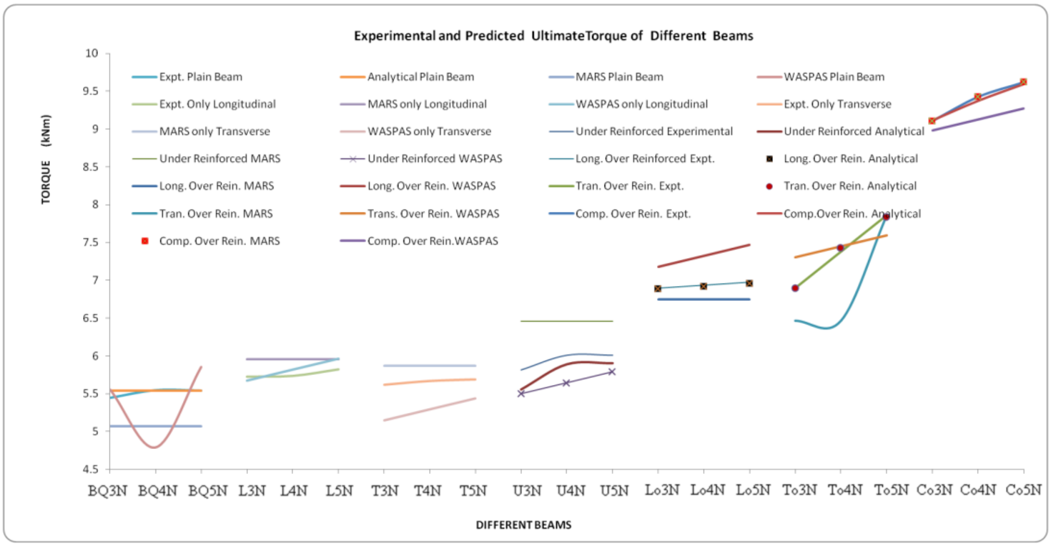

Fig. 5. Distinction of Experimental and Predicted Ultimate Torque of all Beams

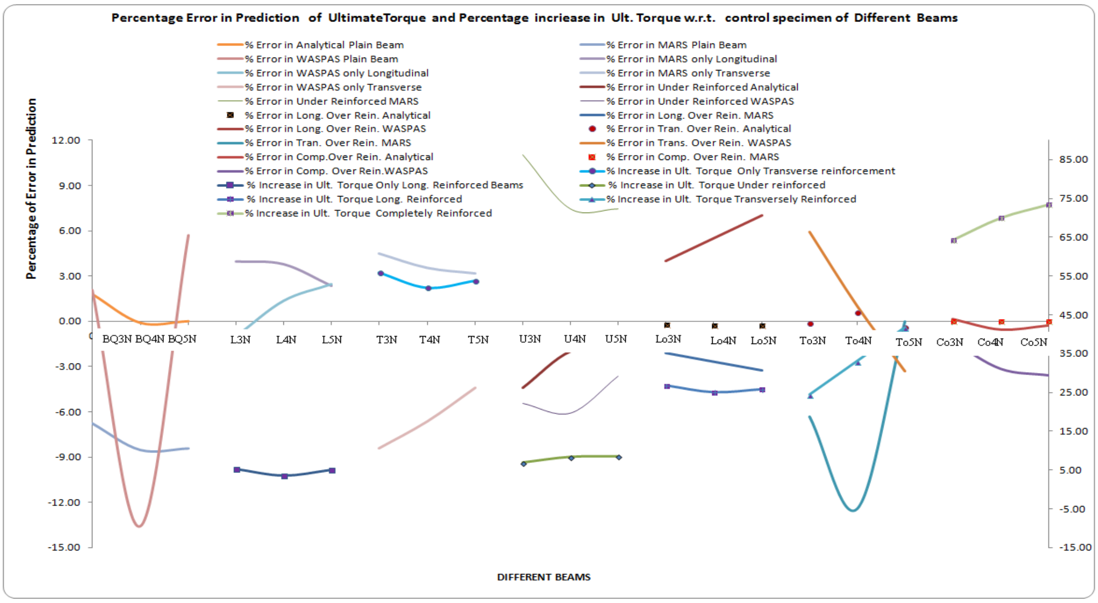

Fig. 6. Error in prediction of ultimate torque and % rise in ultimate torque on control specimen

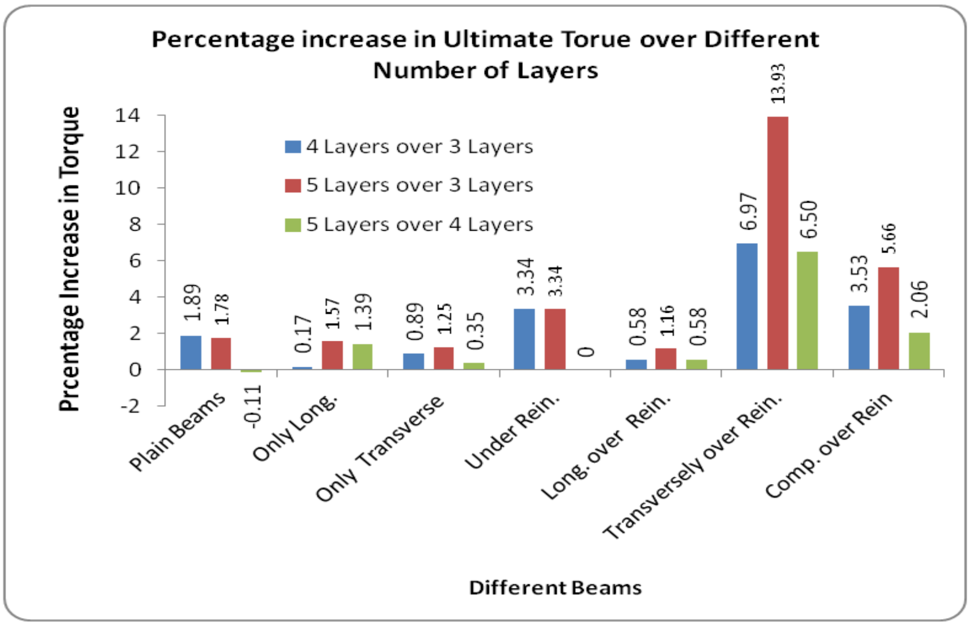

Fig. 7. % increase in Ultimate Torque of 4 and 5 Layers over 3 Layers; 5 layers over 4 Layers

IV. CONCLUSIONS

Ultimate torques and cracking torques of plain and reinforced ferrocement U-wrapped beams were computed from investigational and from other methods. From results, it was concluded that:

A. Plain U-Wrapped Beams

- Torsional strength was increased to 48% in ferrocement U-wrapped standard strength concrete beams above ordinary concrete beams which proves the efficacy of U-wrapped beams.
- Ultimate torque is reliant on mortar strength, core concrete and mesh layers combined.

B. U-Wrapped Reinforced Concrete Beams

- Rise in torsional strong suit above no. of layers for some state of torsion was less except transversely over reinforced beams.
- The enhancement of ultimate strength of entirely over reinforced beams was found up to 73.46 % over their control specimen.
- Cracking torque is dependent on longitudinal reinforcement.
- Transverse reinforcement and ferrocement layers are more capable in resisting torsion than longitudinal reinforcement.
- Experimental, analytical and soft computing model revealed that ultimate torque of ferrocement U-wrap beam was more subjective by state of torsion than amount of ferrocement reinforcement.
- The results of MARS and WASPAS methods were in covenant with experimental results.

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