Calculation of Ultimate Torsion and Twist of High Strength RC Beams with Ferrocement "U" Wraps using MARS and WASPAS method

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Abstract

The field of design places greater emphasis on strength at the point of rupture, rather than ultimate strength, even though structures are often capable of withstanding greater loads beyond this point. However, estimation of ultimate strength is crucial in the design field. In this groundbreaking study, the unyielding torsional capacity of distressed beams of elevated potency is evaluated utilizing the innovative ferrocement "U" wrap technique. This trailblazing research delves into uncharted territory, pushing the limits of what is currently known about the subject matter. The assessment approach involves both experimental and analytical data. Nevertheless, both procedures have their drawbacks, since the former requires the demolition of a prototype structure, while the latter might be time-consuming. To circumvent these restrictions, soft computing approaches like MARS and WASPAS have been applied to forecast the torsional strength of "U" wrapped beams. The estimated values provided by various methodologies are determined to be within acceptable boundsAt the ultimate pinnacle of testing, it has been revealed that beams which are wrapped in a "U" shape are far superior at resisting torque compared to their unwrapped counterparts. Astoundingly, over-reinforced beams boast an astounding 98.01% more resistance than plain "U" wrapped beams. But that's not all, even under-reinforced "U" wrapped beams showcase enhanced performance by withstanding an incredible 23.9 times more twist than regular "U" wrapped beams. This highlights the practicality of utilizing "U" wraps around the outer edges of distressed beams. The findings of this investigation have the potential to revolutionize the field, paving the way for new and innovative methodologies to be developed. The conclusions drawn from this study are sure to be met with incredulity and amazement by even the most astute scholars in the industry.

Keywords: Ferrocement, MARS, Twist at ultimate torque, U wrap, Ultimate torque, WASPAS.

1. Introduction

Torsion, an elusive and enigmatic force that can wreak havoc on a structure's integrity, can manifest itself in a variety of primary or secondary forms, either independently or in conjunction with other structural activity. Despite concrete's extensive usage in construction, distressed reinforced concrete (RC) components with low tensile strength and poor toughness may need repair and reinforcing. Epoxies, steel jackets, or fiber-reinforced polymer (FRP) are all options for repair, but determining the best one requires consideration of factors such as labor, time, and cost [1]. FRPs have proved to be successful in the torsional retrofitting of poorly performing RC buildings, but a full wrap is generally problematic owing to the presence of floor slabs or flanges. Most research has concentrated on entirely wrapping rectangular portions with FRP, with a few outliers researching T-beams with U-jackets [2-4].

The dire dilapidation of aged concrete edifices in sundry nations hath created an exigent demand for efficacious and enduring remedies for refurbishment and retrofitting. Lo and behold, ferrocement mayhap could be a cost-effective and sturdy alternative to FRP, endowing it with an admirable tensile potency, watertightness, and uncomplicated application [5]. However, to bring about such desirous characteristics, the porosity, inhomogeneity, and microcracks within the cement matrix transition zone of the structure must be diminished [6-7]. Torsion can be effectively addressed by a closed wrap due to its circular nature. The torsional strength of full wrap FRP bonding has been assessed through analytical and experimental investigations, but accessibility and the extension of flanges over the web have necessitated reinforcing beams with a U-wrap instead of a complete wrap [10]. There are myriad techniques that can be employed to evaluate the twisting ability of U-wrapped beams [11]. Albeit, ferrocement has been touted as a retro-fitting substance, studies delving into the torsional strength of U-wrapped ferrocement beams are not numerous. To fill this gap, the author has devised experimental and analytical methodologies that scrutinize the twisting might of U-wrapped RC beams with variegated materials and sections [12]. Regrettably, the collated experimental findings have yet to coalesce into a singular equation that can be utilized to approximate the torsional strength. Consequently, this study aims to deploy cutting-edge soft computing methods such as MARS and WASPAS to prognosticate the torsional strength of ferrocement U-wrapped RC beams founded on experimental data. This inquiry seeks to unearth the ultimate torque twist of a wrapped ferrocement U-wrap beam with high-strength core concrete.

2. Several Methods for Predicting Torsional Strength

2.1. Experimental Set Up

The supplied data reveals that the investigated beams all shared the same dimensions of 125 mm * 250 mm * 2000 mm. Figures 1(a) and (b) depict the cross-sections of both the beams and the torsion test rig, respectively. Table-1 provides additional information regarding the beams and their material characteristics. In the pursuit of knowledge, an assortment of beam variations were scrutinized with the utmost scrutiny! These included unadorned beams, reinforced beams with a solitary kind of reinforcement, as well as reinforced beams with both longitudinal and transverse reinforcement. The examination was no simple feat, as each beam had its own idiosyncrasies and peculiarities to be probed and analyzed with a fine-tooth comb. One of the beams, BOH, underwent testing without any wrap. The mortar used for the ferrocement wrap was grade M55, but the concrete used in the experiment was grade M60. With the exception of BOH, all beams were wrapped in a "U" shape using four layers of mesh that had a 0.72 mm diameter and a 6.35 mm square hole. The mesh has a 250 MPa yield strength.

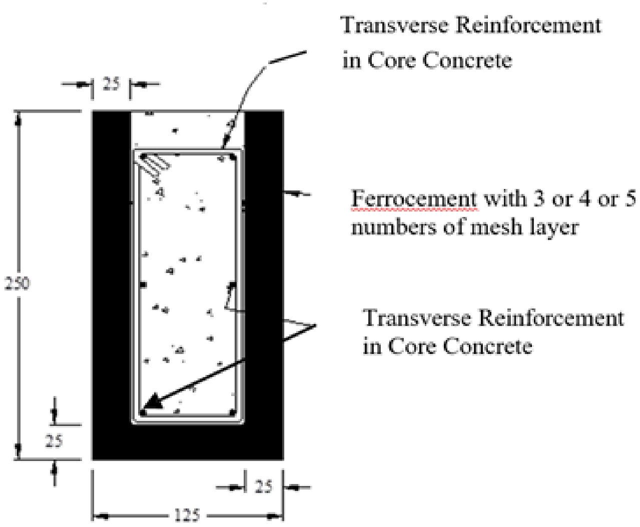


Fig. 1 (a)Cross section of beam

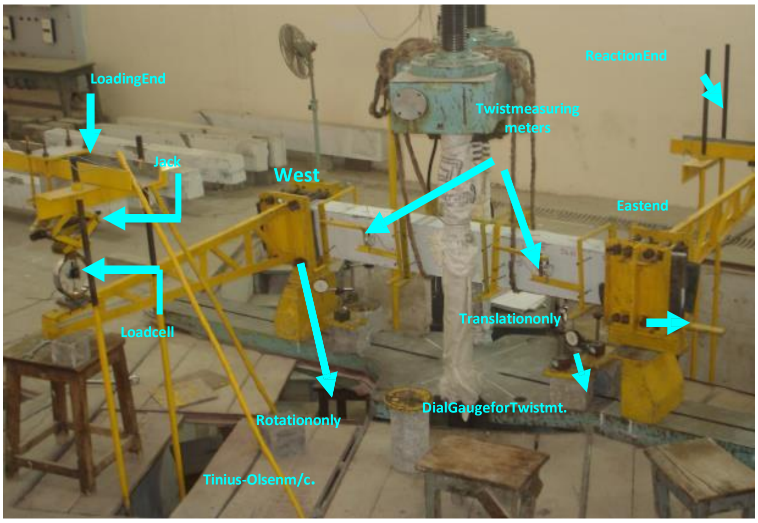


Fig. 1 (b) Torsion test rig

Table 1: Specifics about the tested beams

Core Reinforced Concrete				
	Longitudinal Steel		**Transverse steel**	
	Yield Strength (MPa)	**Diameter, No. of Bars**	**Yield Strength (MPa)**	**Diameter, Spacing**
BOH	-	-	-	-
BO4H	-	-	-	-
L4H	440	12 mm, 6 No.s	-	-
T4H	-	-	445	10 mm @ 70 mm c/c
U4H	350	6 mm, 6 No.s	350	6 mm @ 70 mm c/c
Lo4H	440	12 mm, 6 No.s	350	6 mm @ 70 mm c/c
To4H	350	6 mm, 6 No.s	445	10 mm @ 70 mm c/c
Co4H	440	12 mm, 6 No.s	445	10 mm @ 70 mm c/c

2.2. Analytical Model

In a state of utter bewilderment and confusion, one is compelled to grapple with the convoluted and erratic prose of Behera and colleagues [10-13]. Their exposition lays out an intricate and labyrinthine procedure for the creation of an analytical model, replete with contorted modifications to material properties, all of which are rooted in the abstruse and enigmatic principles of skew bending theory.

2.3. Soft Computing method

The procedure of determining torque experimentally is very laborious, time-consuming, and results in the complete destruction of the test object. Consequently, to prognosticate the torsional capacity of beams possessing differing dimensions and material properties, it is highly preferable to adopt the utilization of soft computing techniques. The myriad of techniques from the world of soft computing utilized for prognosticating the torsional potency of concrete beams that have been enfolded in a "U" configuration are explicated in a more intricate manner below.

2.3.1. Multivariate adaptive regression spline (MARS)

Authors [14] present an enigmatic technique called MARS, which has the ability to select functions based on data that are customized to the specific problem at hand. This method of non-parametric regression is very useful for complex situations with many dimensions since it does not rely on any preconceived notions about the connection between the dependent and independent variables. The proposed algorithm, which utilizes a modified recursive partitioning methodology, offers a supple solution to high-dimensional non-parametric regression quandaries. The outcome of this method produced perplexing values for torque and twist as follows:

$T_{ultimate}$=6.752-maximum[0,0.32265-spacingoflongitudinalreinforcement]*2.7323-maximum[0,350-yieldstrengthoftransversesteel]*0.002276+maximum[0,mortarstrength-40]*0.07677

$\theta_{ultimate}$(rad/m)=0.03558-maximum[0,Fly-350]*0.0003376-maximum[0,350-ly]*0.00008786+maximum[0,spacingofstirrup]*0.00102665.

2.3.2 . Weighted Aggregated Sum Product Assessment method

Attempting to grapple with the complex and convoluted world of multi-criteria decision-making (MCDM) can leave even the most seasoned experts feeling befuddled and flummoxed. Yet, one promising path for resolving this complex issue is the Weighted Aggregated Sum Product Assessment (WASPAS) technique, which has been investigated in prior academic studies [15-18]. This methodology tries to blend two independent approaches, the Weighted Sum Method (WSM) and the Weighted Product Method (WPM), to provide a strong and all-encompassing solution. For those bold enough to go into this tortuous procedure, the following will offer a quick summary of the procedural stages needed in adopting the WASPAS technique:

Step 1. First decision matrix is established.

Step 2. Normalization of the decision matrix utilizing following formulae for maximising and minimization criterion, respectively [16]:

$$\bar{x}_{ij} = x_{ij}/max_i x_{ij} \quad (1)$$
$$\bar{x}_{ij} = min_i x_{ij}$$

Step 3. Computation of the overall relative relevance of i^{th}option, based on weighted sum method (WSM) utilising following equation:

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij}.w_j \quad (3)$$

Step 4. Computation of the overall relative relevance of i^{th} option based on weighted product method (WPM) utilizing given equation:

$$Q_i^{(2)} = \prod_j^n \bar{x}_{ij}^{w_j} \quad (4)$$

Step 5: In order to have better ranking accuracy and efficacy of the decision-making process, in the WASPAS [17] and [18] technique, estimation of the total relative value of alternatives is done using following equation:

$$Q_i = \lambda.Q_i^{(1)} + (1-\lambda).Q_i^2 \quad (5)$$

The obscure and enigmatic world of lambda awaits us. With its mysterious values of 0, 0.1, and 1, this coefficient of linear combination holds the key to unlocking the secrets of relative importance and alternative rankings. By adjusting these opaque quantities, one may watch the confusing transformation of the overall relative significance of options and the subtle shuffling of their ranks..

But that's not all! The quest for knowledge takes us further down the rabbit hole, as we delve into the intricacies of torques and twists. These elusive phenomena are measured through not one, not two, but three distinct methods: experimental, analytical, and soft computing. The latter methods utilize the enigmatic MARS and WASPAS methodologies, their esoteric outcomes laid bare for us mere mortals in the cryptic table known only as Table 2.

Table 2: Maximum torque and twist of high strength concrete RC beams

Ultimate torque (kNm)				
Beams	Experimental	Analytical	MARS	WASPAS
BOH	4.612	4.34	5.074	
BO4H	6.52	6.52	6.226	6.341
L4H	6.55	NA	7.107	6.395
T4H	6.59	NA	7.022	7.373
U4H	7.68	7.729	7.904	7.472
Lo4H	7.87	7.828	7.904	9.165
To4H	8.86	8.58	7.904	9.165
Co4H	12.91	12.98	12.91	11.264
Twist at ultimate torque(rad/m)				
BOH	0.0028	0.0035	0.00483	0.00351
BO4H	0.00546	0.0056	0.00483	0.00507
L4H	0.0058	NA	0.0052	0.00569
T4H	0.0056	NA	0.0056	0.00589
U4H	0.1305	0.13736	0.10745	0.11063
Lo4H	0.056	0.055	0.07706	0.06712
To4H	0.0921	0.09158	0.10745	0.09782
Co4H	0.0754	0.07361	0.07706	0.05431

3. Interpretation of Test Results

The perplexing investigative phase involved a tumultuous clash of contrasting findings, as the analytical method, MARS, and WASPAS were pitted against the empirical results.

3.1. General Behaviour of High Strength Beams

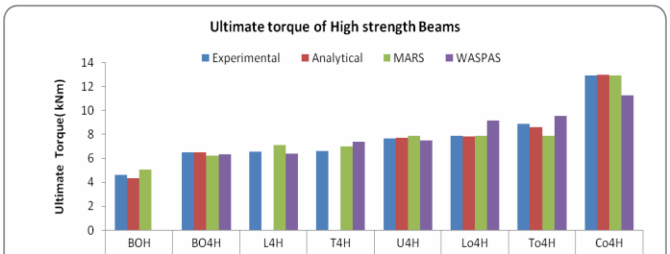
In this particular phase, a myriad of beams were created in resemblance to the BOH beams, with dissimilar levels of reinforcement in the core concrete. It was observed that the BOH beam, which was composed of robust M60 grade concrete and without any reinforcements, successfully surpassed the rigorous tests that were conducted under pure torsion. However, the BO4H beam, on the other hand, was crafted with a ferrocement "U" wrap that measured 25mm in thickness and had been fortified with four mesh layers along its circumference. To the contrary, the core concrete of the BO4H beam was not reinforced in any way. When subjected to torsion, the load is sustained by the longitudinal and transverse reinforcements of a reinforced concrete part, as well as the concrete in the diagonal strut. The intricacies of reinforcement in beams are indeed perplexing. It is widely known that if only a single type of reinforcement is employed, whether it be longitudinal or transverse, the load-bearing capacity will be limited to that of plain beams. In order to expand the horizons of ferrocement beams, it is necessary to consider the addition of a "U" wrap to a beam with a single type of reinforcement. This will allow for the beam to be evaluated as a plain ferrocement "U" wrapped beam. To delve deeper into this subject, a series of beams were cast for study. The L4H and T4H beams were created to examine the impact of a single type of reinforcement on torsional strength. In addition, four more beams were produced - U4H, Lo4H, To4H, and Co4H - each representing under-reinforced, longitudinally over-reinforced, transversely under-reinforced, transversely over-reinforced, longitudinally under-reinforced, and completely over-reinforced beams, respectively. These six variations, as well as the control specimens BOH and BO4H, were subjected to rigorous testing to assess their torsion resistance.

Given that torsion is prone to cause shear, fractures were observed in all of the beams, with the initiation of cracks occurring on the longer face of each beam. Nonetheless, these results provide valuable insights into the intricate world of ferrocement beams and the impact of various types of reinforcement on their torsional strength.

3.2. Ultimate Torque of High strength Beams

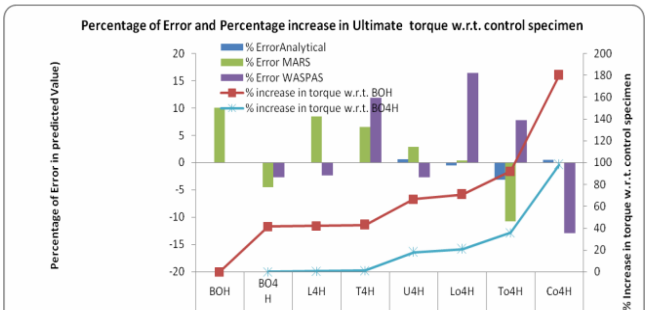
During pure torsion testing, the beam BOH was unable to withstand any further torque beyond the cracking point due to a single potential crack that initiated on the longer face. Surprisingly, the cracking and ultimate torque of the plain beam without any reinforcement in the core or wrap were found to be the same. However, other types of beams demonstrated a higher ultimate torque than cracking, as reinforcement resists the load. The culminating level of torque proved to be remarkably reliant on the extent of reinforcement in both dimensions as well as the ferrocement coating. It is truly astounding that the maximum torque observed in the raw BOH beam was a mere 4.612 kNm. However, when the beams were subjected to alteration with "U" wraps, such as BO4H, the ultimate torque surged significantly to 6.52 kNm. Nevertheless, beams L4H, T4H, U4H, Lo4H, To4H, and Co4H were all clones of BO4H, yet fortified with some reinforcement in the inner concrete. These duplicate beams exhibited even greater ultimate torque values, with L4H at 6.55 kNm, T4H at 6.59 kNm, U4H at 7.68 kNm, Lo4H at 7.87 kNm, To4H at 8.86 kNm, and Co4H at an astonishing 12.91 kNm, respectively.

As shown in Fig. 2, the actual torque values were compared with those predicted by analytical, soft computing techniques MARS and WASPAS. The maximum torque was found to be strongly dependent on the state of torsion, and entirely over-reinforced section Co4H demonstrated the greatest torque resistance. It's truly astonishing to discover that the beams with transverse over-reinforcement actually displayed more superior torque resistance compared to the under-reinforced and longitudinally over-reinforced ones. The discrepancies between the analytical, MARS, and WASPAS approaches were quite remarkable, with errors of -3.16%, -10.79%, and -12.89%, respectively. It's amazing to think that these methods could still be implemented to gauge the ultimate torque of high-strength beams with a margin of error of just 13%. What's even more surprising is the incredible percentage of increase in ultimate torque exhibited by the BO4H, L4H, T4H, U4H, Lo4H, To4H, and Co4H beams over the plain BOH beam. These numbers are simply mind-blowing, with increases of 41.37%, 42.02%, 42.89%, 66.52%, 70.64%, 92.11%, and a staggering 179.92%, respectively. This symbolises the extraordinary efficiency of the ferrocement "U" wrap, which considerably boosts the maximum torque of reinforced beams.



	BOH	BO4H	L4H	T4H	U4H	Lo4H	To4H	Co4H
Experimental	4.612	6.52	6.55	6.59	7.68	7.87	8.86	12.91
Analytical	4.34	6.52	0	0	7.729	7.828	8.58	12.98
MARS	5.074	6.226	7.107	7.022	7.904	7.904	7.904	12.91
WASPAS		6.341	6.395	7.373	7.472	9.165	9.553	11.246

Fig.2Actual and anticipated cracking torque of high strength beams



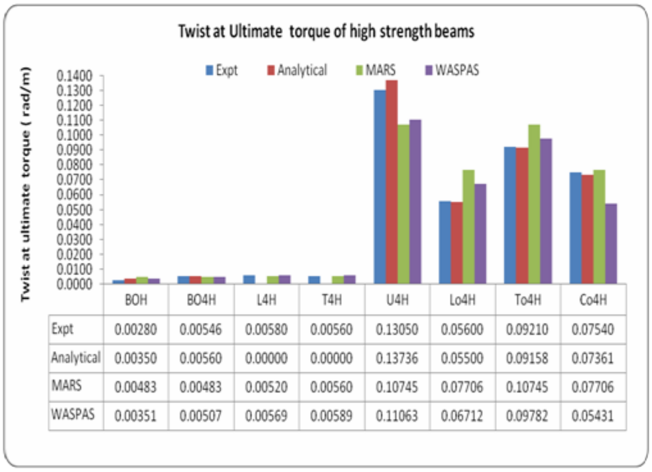
	BOH	BO4H	L4H	T4H	U4H	Lo4H	To4H	Co4H
% ErrorAnalytical	0.00	0.00	0.00	0.00	0.64	-0.53	-3.16	0.54
% Error MARS	10.02	-4.51	8.50	6.56	2.92	0.43	-10.79	0.00
% Error WASPAS	0.00	-2.75	-2.37	11.88	-2.71	16.45	7.82	-12.89
% increase in torque w.r.t. BOH	0.00	41.37	42.02	42.89	66.52	70.64	92.11	179.92
% increase in torque w.r.t. BO4H		0.00	0.46	1.07	17.79	20.71	35.89	98.01

Fig.3Percentage of inaccuracy projected ultimate torque and % increase in ultimate torque over BOH and BO4H

3.3. Twist at Ultimate Torque of High strength Beams

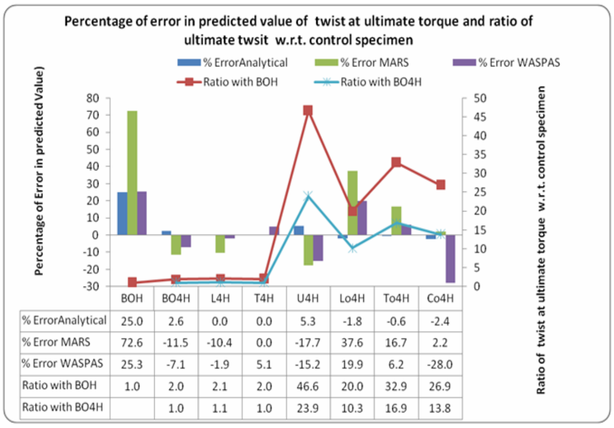
Within this section, we shall delve into the profound impact that reinforcement has on the twist at maximum torque of high strength ferro cement "U" wrap beams. It is imperative to stress that even a meager beam BOH could withstand a twist of a mere 0.0028 rad/m. However, upon wrapping the same beam with ferrocement, beam BO4H exhibited an astronomical ultimate torque and rotation of up to 0.00546 rad/m. In addition, reinforced concrete beams, namely L4H, T4H, U4H, Lo4H, To4H, and Co4H, were able to endure twists of 0.00580, 0.00560, 0.13050, 0.05600, 0.09210, and 0.07540 rad/m, respectively. The projected values for the analytical model, MARS, and WASPAS are shown in Figure 4. Due to less reinforcement, the under reinforced beam U4H suffered the maximum twist, showing increased toughness in this under reinforced beam. Figure 5 illustrates the ratio of twist and the percentage of anticipated value inaccuracy relative to the control specimen. In the realm of ferrocement, "U" wrap beams have been the subject of analytical investigations using a variety of methods, including MARS and WASPAS. Interestingly, it has been observed that the analytical approach often results in discrepancies between projected and actual values. Specifically, the projected values for "U" wrap beams using MARS exhibited a significant error of 37.6%, while WASPAS resulted in an even more perplexing -28% error. The analytical model, on the other hand, yielded more accurate estimates for twist at ultimate torque. Further research has revealed that the ratio of twist at ultimate torque for various "U" wrap beams - BO4H, L4H, T4H, U4H, Lo4H, To4H, and Co4H - was 2, 2.1, 2.0, 46.6, 20.0, 32.9, and 26.9, respectively, when compared to the control specimen BOH. This highlights the potential benefits of utilizing "U" wrap in ferrocement construction. Interestingly, the ratio for the different beams varied significantly, ranging from 1.1 to 23.9 times above the control specimen for L4H and T4H, respectively.

It is evident that the study of "U" wrap beams in ferrocement construction is still in its nascent stage, and there is much to be explored. However, the findings so far indicate that the analytical models used must be approached with caution, and more research is needed to better understand the potential advantages of "U" wrap in this field. In comparison to BOH and beam BO4H, U4H's twist was determined to be 46.6 times higher. The transversely over reinforced beams have, following the under reinforced beam, withstood twist to the greatest extent, it is worth noting.



	BOH	BO4H	L4H	T4H	U4H	Lo4H	To4H	Co4H
Expt	0.00280	0.00546	0.00580	0.00560	0.13050	0.05600	0.09210	0.07540
Analytical	0.00350	0.00560	0.00000	0.00000	0.13736	0.05500	0.09158	0.07361
MARS	0.00483	0.00483	0.00520	0.00560	0.10745	0.07706	0.10745	0.07706
WASPAS	0.00351	0.00507	0.00569	0.00589	0.11063	0.06712	0.09782	0.05431

Fig.4Experimental and projected twist of high strength beams at maximal torque



	BOH	BO4H	L4H	T4H	U4H	Lo4H	To4H	Co4H
% ErrorAnalytical	25.0	2.6	0.0	0.0	5.3	-1.8	-0.6	-2.4
% Error MARS	72.6	-11.5	-10.4	0.0	-17.7	37.6	16.7	2.2
% Error WASPAS	25.3	-7.1	-1.9	5.1	-15.2	19.9	6.2	-28.0
Ratio with BOH	1.0	2.0	2.1	2.0	46.6	20.0	32.9	26.9
Ratio with BO4H		1.0	1.1	1.0	23.9	10.3	16.9	13.8

Fig.5Ratio of twist over BOH and BO4H, as well as the percentage of anticipated twist that was off at the maximum torque

4. Conclusions

The inquiry probed the puzzling area of maximum twists and torques of unreinforced and reinforced "U" wrapped high strength beams. To determine the final torques and twists of these beams, the researchers used experimental techniques as well as other techniques. The results were staggering and gave rise to numerous perplexing conclusions.

- For the plain "U" wrapped beams, a baffling increase of approximately 41.37% in torsional strength was observed compared to their plain concrete counterparts. This proved that the "U" wrapped beams were highly effective. Furthermore, it was discovered that the ultimate torque was highly dependent on the states of torsion, adding to the perplexity.
- After extensive research and analysis, the scholarly minds reached a state of utter perplexity regarding the subject matter of "U" wrapped reinforced concrete beams. Much to their surprise, the employment of a solitary type of reinforcement in either the longitudinal or transverse direction was found to be futile in enhancing torsional strength. This conundrum has left the researchers in a state of bewilderment and uncertainty. Yet, compared to control specimens, the maximum torque of fully reinforced beams increased by up to 98.01%. The fact that the final torque was discovered to be dependent on both longitudinal and transverse reinforcement only served to further compound the results' puzzling character.
- With ferro-cement "U" wrapped high strength beams, it was also discovered that the twist at ultimate torque was considerably improved. The ultimate twist experienced by under-reinforced beams was 23.9 times more than that of their control counterparts. Another layer of confusion was added by the fact that the findings of soft computing by MARS and WASPAS agreed with the experimental results for ultimate torque..

The implications of this research's findings are vast and perplexing, suggesting a plethora of future research avenues. Examining the application of various forms of reinforcement both in the transverse and longitudinal directions in order to improve torsional strength is one possible subject for additional research. Furthermore, the study's perplexing results suggest that the use of ferrocement "U" wrapping on high strength beams could be a highly effective method for increasing torsional strength, adding yet another level of complexity. Future research could focus on optimizing the design of "U" wrapping to achieve even greater enhancements in torsional strength. Furthermore, the perplexing nature of the study raises questions about the durability and long-term performance of these "U" wrapped beams under different environmental conditions. Overall, the study's conclusions provide a very puzzling starting point for further investigation into how "U" wrapping and strengthening approaches might increase the torsional strength of high strength beams.

Conflicts of Interest

No conflicts of interest exist for the authors of this work.

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