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Behavior of curved in plan hollow tubular flange beams with corrugated webs using experimental work

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Abstract: **Using hollow tubular flange girders instead of conventional I-girders enhancing all section properties especially increasing torsional stiffness, for girders used in horizontal curves remarkable torsional shear stress take place on these girders, which lead to study such girders, using corrugated webs in such girder system increase shear and torsional resistance. Four beams were manufactured in Asyut university-faculty of engineering workshop, one straight beam with hollow tubular flange and plane web used as control beam and three cold formed curved in plan hollow tubular flange beams with plane web, trapezoidal corrugated web and triangular corrugated web, all beams were loaded gradually till failure, all data were recorded through automatic data acquisition system connected to the computer, after analyzing all recorded data including testing procedure, mode of failure and load deflection curves using curved in plan hollow tubular flange girders with corrugated webs is a viable option and requires more study in order to improve such system.**

Keywords: **Corrugated web, curved beam, experimental work, steel beam, tubular flange.**

I. INTRODUCTION

Bridges planning is an extension of road planning network in any region in order to overcome natural or human intervention obstacles, and in many cases designer forced to put bridge position in horizontal curve. The existence of horizontal curve in bridge engineering requires serious attention and special treatment due to presence of torsional force on bridge.

In most of horizontally curved steel bridges in Egypt conventional I-shaped plate girders are used. However, the behavior of curved I-girder is a serious concern. A curved I-girder is an open section with low torsional resistance, so large deflections and cross section rotation occurs under its own weight. As a result, individual curved I-girder requires bracing or temporary shoring during erection. After the system of cross frames and I-girders are erected and fully connected, the cross frames work with I-girders as one unit, so it control the I-girder cross section rotation, thereby controlling the warping stresses in the flange and the vertical deflection of the girders .In many cases the cross frames are needed to brace the girders before the girders are subjected to their own weight, which make the erection procedure is complicated.

A box-girder has a large torsional stiffness and negligible warping stress, bracing must be used inside the box to maintain the box shape and avoid cross section distortion. The internal bracing inside box-girder makes box-girder design, construction, and maintenance complex and expensive. Fatigue problems are also a concern for the box-girders due to potential cross section distortion and the bracing details.

New system of hollow tubular flange girders (HTFG) was studied, this system was suggested in order to increase the torsional stiffness to increase beam carrying capacity, **(Adrienne Smith)**[5] found that (HTFG) is a viable option as throughout his study found that tubular flange girders requires less fabrication effort than conventional I-girders, as it requires less cross frames and less transverse stiffeners, **(Mark R. Wimer, Richard Sause)**[9] studied two different innovations of steel I-shaped concrete filled tubular flanges with flat and corrugated webs, throughout these experimental and analytical analysis, tubular flanges allow for the use of large girder un-braced lengths by increasing the torsional stiffness of the girder, corrugated webs create lighter weight designs than unstiffened flat webs because the corrugated web is thinner, although the flanges are slightly larger, hybrid designs create lighter weight designs than homogeneous designs because of the increased steel yield stress, **(Zhuo Fan, Richard Sause)**[10] studied curved in plan hollow tubular flange girders (CHTFG) with flat web, and found that fewer cross frames needed for CHTFG than normal curved IPG, for a curved tubular-flange girder system with a composite concrete deck, cross section distortion can be controlled by transverse web stiffeners, bending normal stress dominates the behavior of a curved tubular-flange girder system with a composite concrete deck, and warping normal stress is small. **(Jun Dong, Richard Sause)**[13] throughout parametric study using FEM on CHTFGs, initial geometric imperfections does not significantly affect the load capacity and by comparing the behavior of individual CHTFGs with the behavior of corresponding individual curved I-girders, it was found that a curved I-girder is better at resisting primary bending, but develops much larger warping normal and total normal stresses, and much larger vertical displacements and cross section rotations than a CHTFG, these results suggest that such temporary support or bracing within the span may not be needed for CHTFGs during girder erection, which could lead to faster and more economical curved bridge construction. Using corrugated webs instead of stiffened flat webs save remarkable amount of steel used in bridge construction due to high shear resistance of corrugated webs, so corrugated webs are used in this study in order to make an entrance to study CHTFGs with corrugated webs, **(Mohamed Elgaaly)**[3] throughout experimental and analytical results local and global buckling due to coarse and dense corrugation and based on local buckling of the corrugation folds as isotropic flat folds and global buckling of entire web panel as an orthotropic plate buckling formulas were suggested, **(Mohamed Elgaaly)**[4] based on experimental and analytical results design the ultimate moment capacity for a beam can be calculated based on the flange yielding ignoring any contribution from the web.

This paper focus on the general behavior of curved in plan hollow tubular flange beams (CHTFBs) with corrugated web and compare these results with CHTFB with plan web, in order to summarize the all possible advantage of using corrugated web in such curved beams.

II. Experimental work

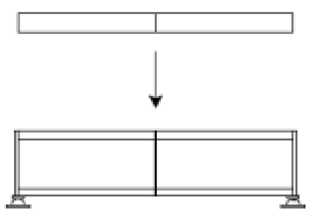
Four experimental tests were performed on 4 steel beam, beams were manufactured by local steel fabricator in welding work shop, Faculty of Engineering, Asyut University, one straight control beam model (S-P) was tested in order to test the general behavior of (HTFB), test welding efficiency and all test steps and three curved in plan beams models (T-C, Tr-C, P-C) studying and analyzing the behavior of curved in plan hollow tubular flange beams is the main target of this paper.

Notation

a	Shear span	h_r	Web corrugation depth
h_{web}	Web height	b	Corrugation fold width
t_{web}	Web thickness	C.A.	Corrugation angle
B_{flange}	Flange tube width	R	Radius of beam curvature
D_{flange}	Flange tube depth	L	Beam span length
t_{flange}	Flange tube thickness	h_T	Overall depth of beam

A. Test models

For all 4 beam models a unified span length of (1400 mm) was used, hollow tube was used as a flange for each beam (top and bottom flanges) all tubes used had a unified cross section dimension of (100 x 40 x 3 mm), 2 bearing stiffeners were used at each end and load stiffener at loading position. One point load was suggested to study the combined stress of shear and bending stresses on such beams, for (S-P) is a straight beam with plane web profile, (T-C) is a curved in plan beam with trapezoidal corrugation profile web, (Tr-C) is a curved in plan beam with triangular corrugation profile web and (P-C) is a curved in plan beam with plane web profile, figure (1) shows all tested beam chart, figure (2) shows dimension details in elevation and cross section for each beam, figure (3) shows dimension details for corrugation profiles used, all dimension details for tested beams shown in tables (1, 2, 3)



(S-P)

Figure (1-a) straight beam with plane web chart

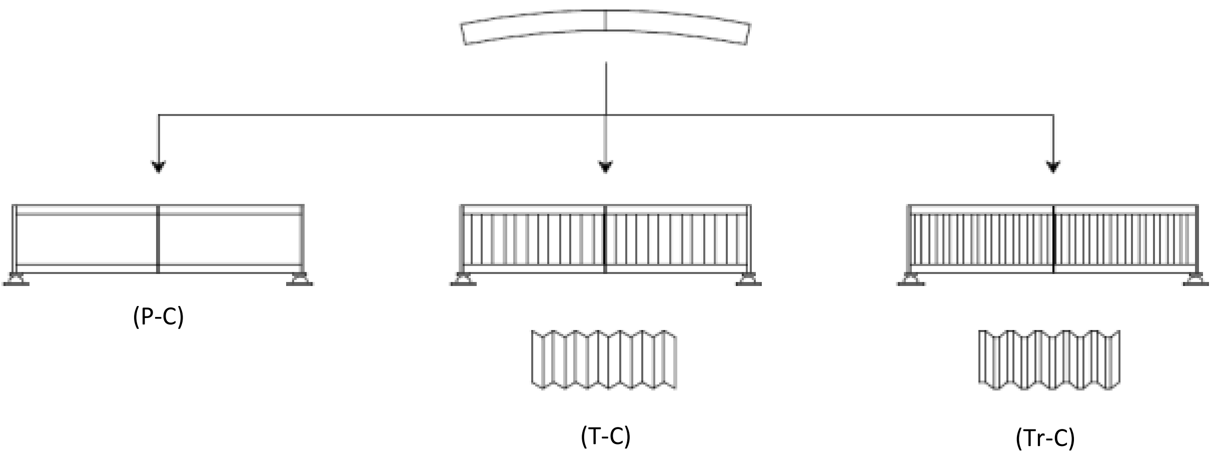


Figure (1-b) Curved beams chart.

Figure (1) tested beams charts.

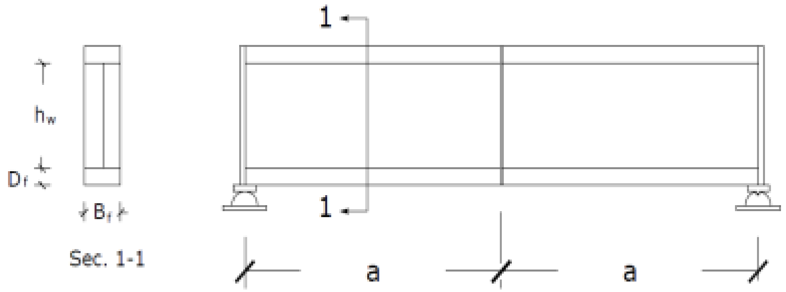


Figure (2) span length and cross section details.

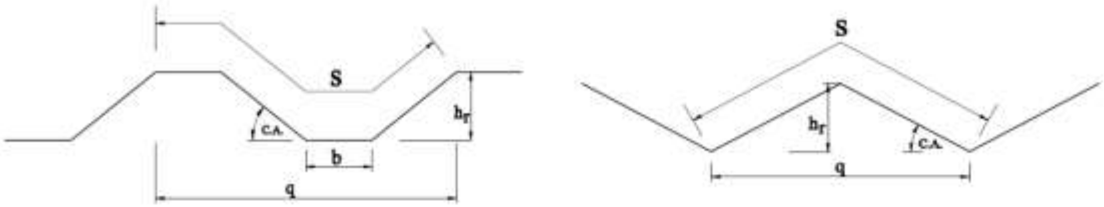


Figure (3) Corrugation details

Girder	a (mm)	h_{web}(mm)	t_{web}(mm)	B_{flange}(mm)	D_{flange}(mm)	t_{flange}(mm)
S-P	700	250	3	100	40	2.8
P-C	700	250	1.28	100	40	2.8
T-C	700	250	1.28	100	40	2.8
Tr-C	700	250	1.28	100	40	2.8

Table (1) Girders cross section dimension and span length

Girder	Corrugation details		
	h_r (mm)	***Corrugation angle (C.A.)***	***b (mm)***
T-C	30	38°	30
Tr-C	30	29°	0

Table (2) Corrugation details for tested beams.

Girder	Radius (mm)	Span (L) (mm)	L/R	(h_T) (mm)	Web slenderness ratio (h_{web}/t_{web})	D_{flange}/h_T
S-P	∞	1400	zero	330	83.33	0.12
P-C	3500	1400	0.4	330	195.3125	0.12
T-C	3500	1400	0.4	330	195.3125	0.12
Tr-C	3500	1400	0.4	330	195.3125	0.12

Table (3) Girders radius, span to radius ratio, web depth to thickness ratio and flange depth to overall depth ratio.

All of beams have 250mm web depth and 1.28mm thickness expect (S-P) has3mm web thickness. All beams have shear-span 700 mm. The dimension of hollow tube flange was 100*40*2.8 mm. The over all of beam depth was 330 mm and have D_{flange} /h_T = 0.12.

B. Manufacturing and installation

The manufacturing and installation process done carefully in order to avoid any local distortion due to welding heat, consumable electrode of 2mm diameter and 300mm long was used throughout the process of welding, it should be emphasized that only one layer of arc welding was done on all specimens, which is sufficient for static loading and in mean-time reduces the influence of welding to the specimen's behavior.

C. Material properties

Three test specimens were collected for each part of the cross section component of beam (at top, bottom flanges and the web) and were tested for its material properties, size of the tensile specimens fabricated was referred to the standard test methods and definitions for mechanical testing and materials (ASTM), tensile testing machine capacity 100 ton attached to a computer system was used to define material properties, mechanical properties listed in table (4).

Specimen	Yield stress (N/mm^2)	ultimate stress (N/mm^2)
Web	242.6	358.9
Flange	240.8	366.0

Table (4) Mechanical properties for steel used in tested beams

D. Test set-up.

All tests done on the beams was on the 60 ton capacity testing machine attached to automatic data acquisition system connected to the computer as shown in Figure (4), The monotonic concentric compression was applied at a very slow rate to capture the post-peak part of the measured load-deformation curve by manually controlling the oil pressure. A load cell was used to measure the applied load from the machine on the tested-beam. Deflections measured using linear variable differential transformer (LVDTs) also connected to the data logger.

Simply supported end conditions was selected as a supporting system for the tested beams, displacements prevented using the supporting system and support dimensions shown in Table (5) support details shown in Figure (5) and support installation shown in Figure (6), test set-up sketch shown in Figure (7), loading phase managed carefully in order to have low rate of load increase.

All beams subjected to 3 cycles of load start from 150 kg as head testing machine load to 2 ton then back to zero again and so on, these cyclic loads was suggested in order to provide initial beam relaxation to guarantee all welded parts of beam working as one unit.

E. Test results and discussion.

For the all tested beams load-deflection curves represented in Figures (8, 9, 10, 11), yield and ultimate loads for each beam determined from the curves and the ultimate moment calculated all values tabulated in Table (6), all the analysis will be based on these data provided about the tested beams and on the documented data through recorded videos for each beam.

Figure (4) testing system showing LVDT, Load cell and data logger

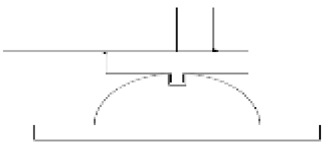


Figure (5-a) detail of hinged support used

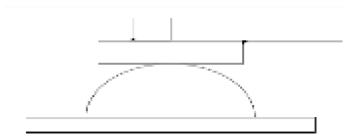


Figure (5-b) detail of roller support used

Figure (5) support details used

Support type	Cylinder diameter	Vertical displacement	Longitudinal displacement
Hinged support	8 cm	-z = 0 , +z is allowed	L.D. prevented
Roller support	8 cm	-z = 0 , +z is allowed	L.D. allowed

Table (5) support dimension, displacements allowed

Figure (6) support installation

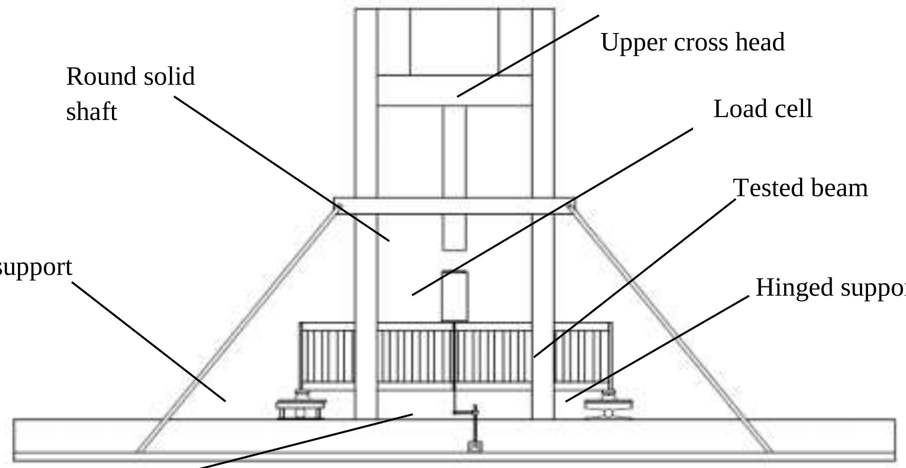


Figure (7) test set-up

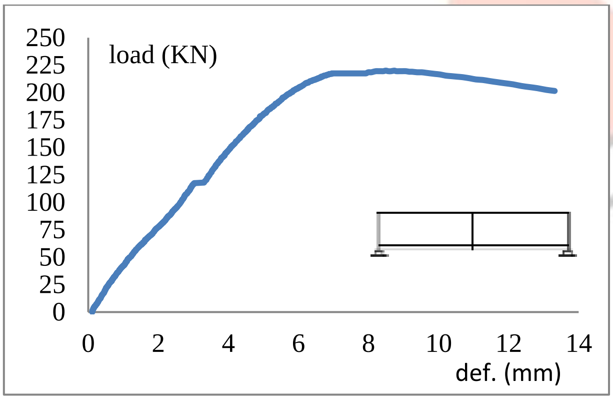


Figure (8) load deflection curve (S-P)

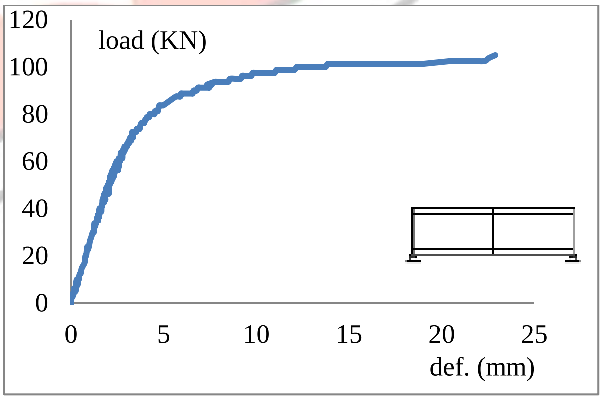


Figure (9) load deflection curve for (P-C)

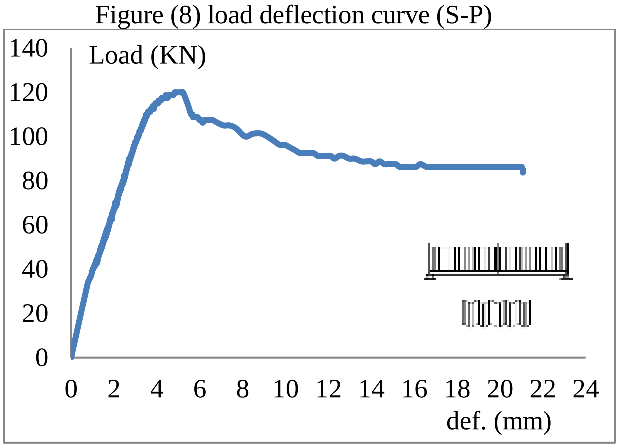


Figure (10) load-deflection curve for (T-C)

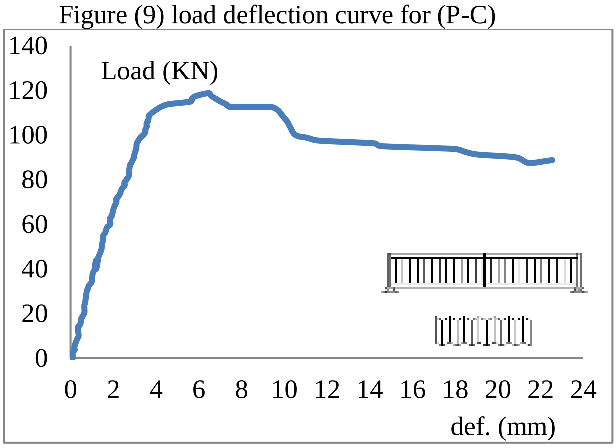


Figure (11) Load-deflection curve for (Tr-C)

Beam model	Yield load	Ultimate load	Ultimate moment	Max. deflection

	(KN)	(KN)	(KN.m)	(mm)
S-P	120	220	77	11.83
P-C	50	105	36.75	22.91
T-C	78	120	42	21.07
Tr-C	80	118.75	41.5625	22.55

Table (6) yield, ultimate loads, ultimate moment and maximum deflection for each beam

For S-P the main purpose of testing this beam model is to make sure that all the circumstances of beam fabrication and testing of beam, for this model web thickness was chosen as 3 mm to avoid any possible local deformations and to make clear overview about all techniques used in fabrication and about all testing details, yield load observed clearly noted from load-deflection curve, during loading phase no deformations or local buckling noted till ultimate load local buckling in compression flange observed and buckling in load stiffener, then load drops gradually fail load.

For curved in plan beams all web thickness selected as 1.28 mm as it is the minimum available steel sheet thickness in order to reach maximum web slenderness ratio, T-C and Tr-C corrugation profiles was selected taking into consideration same amount of steel used for each model, but for P-C model amount of steel used less than used for both corrugated profile as the depth used for all 4 beams is constant 250 mm depth.

After checking and studying the load-deflection curves for all CHTFB's yield load cannot be determined from these curves accurately so the yield load was suggested to be the load in which the web start to buckle during loading phase or when slight drop in load value during loading take place, for P-C start to buckle and the buckling shape increases till failure, bearing stiffener (at hinged support) deformed at beam failure this deformation due to deflections and restraint condition for the lower part of flange.

T-C and Tr-C during loading phase no remarkable deformation take place and buckling for (T-C) start a local buckling at maximum capacity then this buckling phenomenon expand across multiple corrugation folds, and for (Tr-C) local buckling start just before the maximum capacity then expands across multiple corrugation folds, mode of failure for all beams shown in Figures (12, 13, 14, 15).Comparison between (P-C, T-C, Tr-C) shown in Figure (16) neglecting deflection beyond ultimate load, beam with corrugated webs carrying capacity larger than beam with plane web, larger deformations take place in CHTFB with plane web, all deformation and load carrying capacity of CHTFB with corrugated webs percentage with respect to CHTFB with plane web in Table (7).

Figure (12) failure mode for (S-P)

Figure (13) failure mode for (P-C)

Figure (14) Failure mode for (T-C)

Figure (15) Failure mode for (Tr-C)

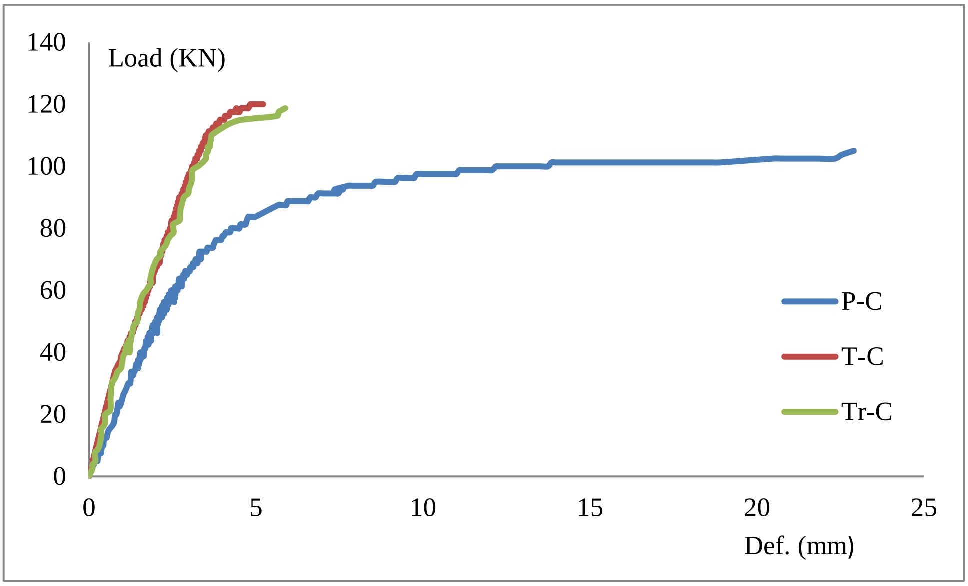


Figure (16) comparison between the three CHTFB at Ultimate load for each tested beam

Beam model	Yield load percentage	Ultimate load percentage	Deflection value at beam maximum capacity (mm)	Deflection percentage at beam maximum capacity
T-C	156 %	114.29 %	5.21	22.74 %
Tr-C	160 %	113.10 %	6.46	28.20 %

Table (7) yield load, ultimate load and deflection at maximum capacity percentage for CHTFB with corrugated web with respect to CHTFB with plane web

Applying data available for T-C beam model on equation formed by (Galambos)1 in order to calculate the global elastic buckling shear stress on beam panel:-

$$\tau_{cre} = k_s\,[(D_x)^{0.25}\,(D_y)^{0.75}]\;t_{web}/\,h_{web}{}^{2}$$

τ_{cre} = elastic global buckling, k_s= buckling coefficient, D_x = $(\frac{q}{s})$ x$\frac{E\;x\;t_{web}{}^{2}}{12}$, D_y =$\frac{E\;x\;I_y}{q}$, q= corrugation wave width, s= inclined fold width, I_y= 2 b t_{web} x $(\frac{h_r}{2})^2$ + $(\frac{t_{web}\;h_r{}^{3}}{6\;sin\theta})$.

By comparing the shear stress when beam web start to buckle with the elastic critical shear stress we find that the equation mentioned above which is for straight beams with flat flanges cannot even give approximate value of the actual elastic shear stress for CHTFB with trapezoidal corrugated web.

III. Conclusion.

From all previous data provided from experimental data we can conclude that:-

1- Using corrugated webs increase beam strength as it clearly noted from figure (16).
2- Deflections at maximum load for CHTFB with corrugated web less than CHTFB with plane web.
3- Beam carrying capacity increase while using corrugated webs.
4- During beam fabrication of CHTFB with plane web required high level of care in order to avoid local deformation during welding process owing to using small web thickness, for CHTFB with corrugated webs welding process is easier than plane webs as corrugated folds works as stiffening plates.

IV. Future work.

- Buckling analysis in order to find equation to calculate elastic buckling load.
- Parametric study for CHTFB's studying different effective variables like slenderness ratio, corrugation profile (corrugation depth, width, angle) and effect of girder span radius of curvature ratio.
- Studying curved in plan hollow tubular flange girders with plane and corrugated webs under the case of moving load according to design codes, the effect of cross girders on this case and effect of composite action.
- Deduce design formulas for straight and curved in plan hollow tubular flange girders.
- Studying dynamic effect on straight and CHTFGs with plane and corrugated webs.

References.

[1] Galambos, T. V. (Ed.). (1998). Guide to stability design criteria for metal structures. John Wiley & Sons.

[2] Smith, D. A. (1992). Behavior of corrugated plates subjected to shear (Master's thesis, in Civil Engineering, University of Maine).

[3] Elgaaly, M., Hamilton, R. W., & Seshadri, A. (1996). Shear strength of beams with corrugated webs. Journal of Structural Engineering, 122(4), 390-398.

[4] Elgaaly, M., Seshadri, A., & Hamilton, R. W. (1997). Bending strength of steel beams with corrugated webs. Journal of Structural Engineering, 123(6), 772-782.

[5] Smith, A. (2001). Design of HPS bridge girders with tubular flanges.

[6] Khalid, Y. A., Chan, C. L., Sahari, B. B., & Hamouda, A. M. S. (2004). Bending behaviour of corrugated web beams. Journal of materials processing technology, 150(3), 242-254.

[7] Anami, K., Sause, R., & Abbas, H. H. (2005). Fatigue of web-flange weld of corrugated web girders: 1. Influence of web corrugation geometry and flange geometry on web-flange weld toe stresses. International Journal of Fatigue, 27(4), 373-381.

[8] Anami, K., & Sause, R. (2005). Fatigue of web-flange weld of corrugated web girders: 2. Analytical evaluation of fatigue strength of corrugated web-flange weld. International journal of fatigue, 27(4), 383-393.

[9] Wimer, M. R., & Sause, R. (2004). Rectangular tubular flange girders with corrugated and flat webs.

[10] Fan, Z. (2007). Behavior of horizontally curved steel tubular-flange bridge girders. Lehigh University.

[11] Dong, J., & Sause, R. (2009). Flexural strength of tubular flange girders. Journal of Constructional Steel Research, 65(3), 622-630.

[12] Dong, J., & Sause, R. (2009). Behavior of hollow tubular-flange girder systems for curved bridges. Journal of structural engineering, 136(2), 174-182.

[13] Dong, J., & Sause, R. (2010). Finite element analysis of curved steel girders with tubular flanges. Engineering Structures, 32(1), 319-327.

[14] Hassanein, M. F., & Kharoob, O. F. (2010). Shear strength and behavior of transversely stiffened tubular flange plate girders. Engineering Structures, 32(9), 2617-2630.

[15] El-Amin, F.M., Abdelkhalek, M.F., Ahmed, M.M.and Gad& S.R. (2012). Non-linear behavior of cantilever girder bridge with corrugated web.

[16] Hassanein, M. F., & Kharoob, O. F. (2013). Behavior of bridge girders with corrugated webs:(I) Real boundary condition at the juncture of the web and flanges. Engineering Structures, 57, 554-564.

[17] Hassanein, M. F., & Kharoob, O. F. (2013). Flexural strength of hollow tubular flange plate girders with slender stiffened webs under mid-span concentrated loads. Thin-Walled Structures, 69, 18-28.