COMPARISON OF EXPERIMENTAL SHEAR CENTRE OF VARIOUS SECTIONS WITH THEORETICAL ANALYSIS THROUGH RESPONSE SURFACE METHODOLOGY

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Abstract- In this experimental study, three cross-sections of mild steel were studied to locate their shear center concerning the rotation of the load. Z-cross section was symmetrical, whereas L-section and semicircular section were symmetrical on one axis and unsymmetrical on another. The shear center's location is vital to designers in structural analysis. For the symmetrical section, the shear center was found to be zero in experimental as well as in Response Surface Methodology (RSM). The location of the shear center for the L-section was 43 mm, and for semicircular, the shear center was 28.5 mm. At the same time, the difference in error for L-section and semicircular section was found to be 45% and 0.77%. This study shows that an excellent theoretical and experimental relation has been established through RSM.

Keywords- shear center, symmetrical, unsymmetrical, Response Surface Methodology

1 Introduction

Thin-walled sections are produced through fabrication or extrusion method, are getting popularity, and become increasingly important due to the cost and manufacturing techniques of the materials. Although the level of shear stresses is small and sometimes negligible, however, the location of the shear center is of vital importance among the designers due to the twisting of the section [1]. Moreover, in structural analysis, the determination of the geometrical properties of cross-sections is necessary for the true depiction of the material. The shear center is defined as the point where the resultant of the shear stresses acts on it or the torsional rise due to axial force on a point in a flexural-torsional problem [2]. In the beam theory, several assumptions are made such as the beam is a thin structure, long as well as the cross-sectional dimension is very small compared to the rest of the dimensions. Hedgehog is a technique that could be effectively used in thin-walled sections to counter the horizontal effects on structure [3]. In recent research, optimization and algorithms has been successfully implemented to locate the shear point of complex thin-walled section [4]. There are several beam sections for which the shear center is determined. For instance, [5] studied the shear center and centroid of composite beam box cross-section. In the parallel study, [6] determine the properties of laminated composite tubes, and [7] studies the shear center of arbitrary sections through mathematical analysis by developing matrices for finding shearing and torsional rigidity. Response Surface Methodology is an optimization tool that could be efficiently implemented in many research studies to determine the best relation of experimental with theoretical study [8], [9].

In this research, various cross-sections of mild steel including semi-circular, Z-section, and L-sections are studied to find the shear center location. Moreover, the results were compared with statistical and mathematical modeling through Response Surface Methodology (RSM). This research will be helpful in assessing thin-walled sections position of load and point of rotation. When thin walled are subjected to lateral forces such as seismic or wind, torsional effect may encounter and twist the section. Moreover, RSM is an optimization tool which could be used to locate the point of zero shear which will benefit designers with economic and time constraints.

2 Research Methodology

In this study, 3 cross-sections of mild steel are studied for the location of the shear center. The cross-section section includes the Z-cross-section which is unsymmetrical, and L-section as well as semi-circular cross-sections are symmetrical on one axis and unsymmetrical on another axis. The materials, thickness, and length of all the cross-sections are constant so that only the shear location is focused. The dimensions of all cross-sections were carefully examined including the diameter and cross-section. Each beam was also visually observed for any dents or flaws. The sections were fixed in shear center apparatus and made sure no other movements/motions is influencing. The load was applied at an equal angle at various positions marked on sections. The front and back dial gauge reading was noted for every load position. The dial gauge reading was later converted to displacements by applying the least count. The rotations were calculated for every marked position on the section. The results were plotted for the position of load against the rotation. The experimental results were analyzed and modeled in Design-Expert software for Response Surface Methodology (RSM).

2.1 Materials.

The properties of sections are given in table 1. All sections were created with the same material (mild steel) having the same modulus of elasticity 210 (GPA) and the thickness of the flange is approximately 2.52 (mm). All the cross-sections were made through the fabrication method from M/S Smart Tech Multan through proper machining and tools after providing them dimensions. The cross-sections of different sections are shown in figure 1.

Table 1 Material properties of cross-sections

Material	Modulus of elasticity (GPa)	Flange thickness (mm)	Material thickness (mm)	Maximum constant load (N)
Mild steel	210	2.52 ± 2	1.7 ± 2	6.86

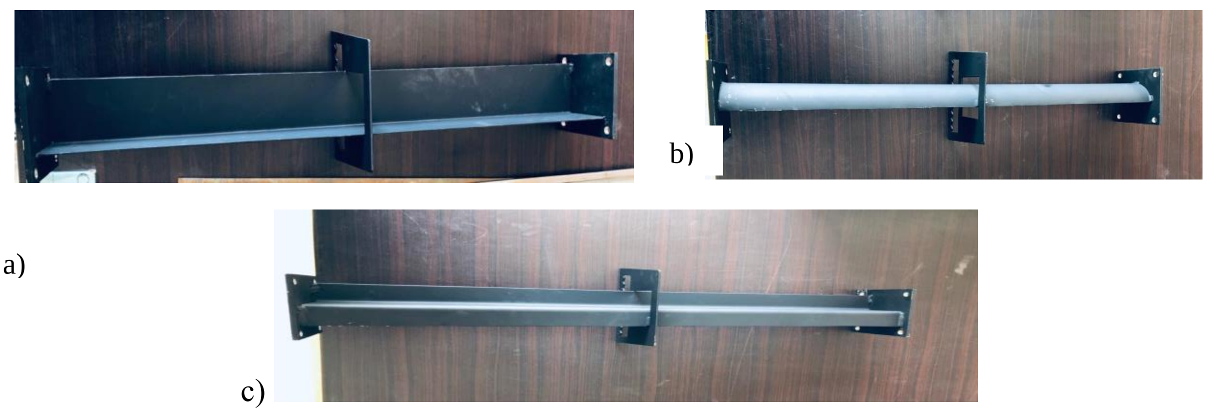


Figure 1: cross sections used in experiment, a. L-cross section, b. semi-circular cross section, and c. Z-cross section

3 Results

3.1 Experimental calculations

The plots between the position of load at the x-axis and rotation on the Y-axis were plotted after the necessary correction of dial gauges. The point where the graph crosses the zero notation is the exact point of the shear center. For instance, for all the load positions, the shear center for the Z-cross section was found to be zero as shown in figure 2.

The cumulative interpretation of the shear center for all three sections is shown in figure 4. It shows that the z-section is symmetric on all axis as the shear center lies at zero however, the L-section and semicircular section is symmetrical on one axis and unsymmetrical on another axis. The response surface methodology was carried out for all three sections. The experimental data load of position and rotation were input parameters in RSM. The output parameters rotation in mm were fixed for all three cross-sections. The ANOVA analysis and contours graphs are shown in figure 5.

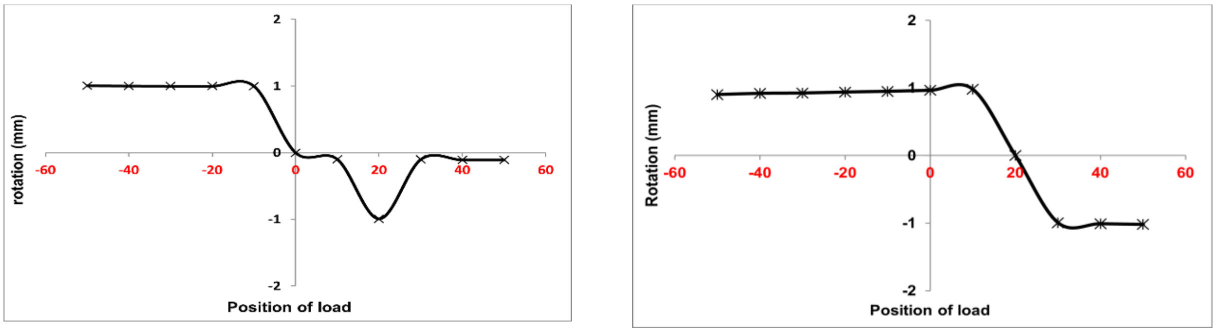


Figure 2: Z-cross section (left) and semi-cross section (right)

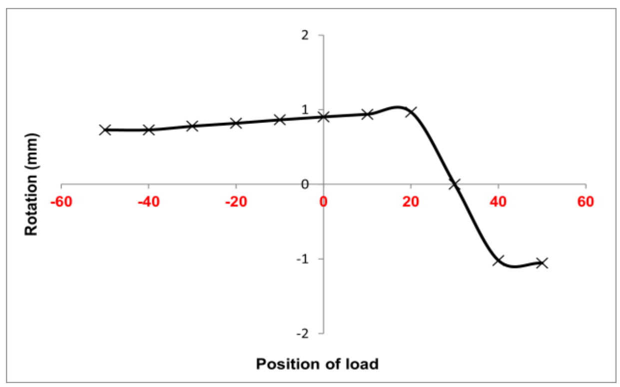


Figure 3: shear center of L-section

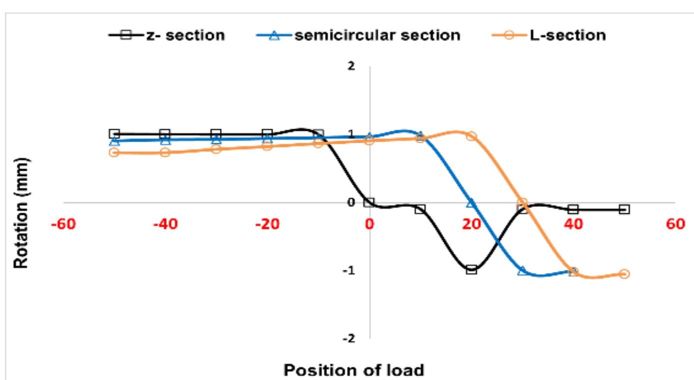


Figure 4: Cumulative representation of shear center for all sections

The position of load is mapped against various cross-sections. The means and standard deviations are also shown in the table. The value of rotation is plotted against the position of load. For instance, at zero position of load, the value of rotation noted for Z-section, Semi-circular and L-section were 0, 0.965 and 0.905 respectively.

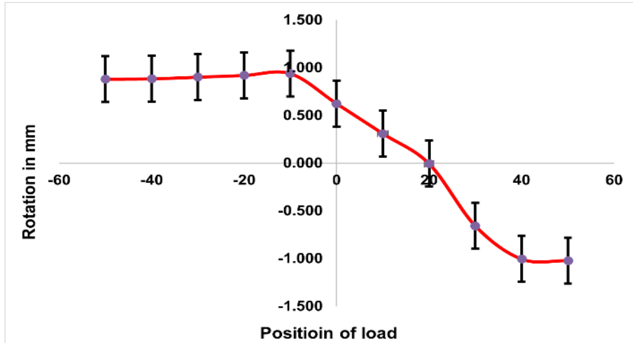
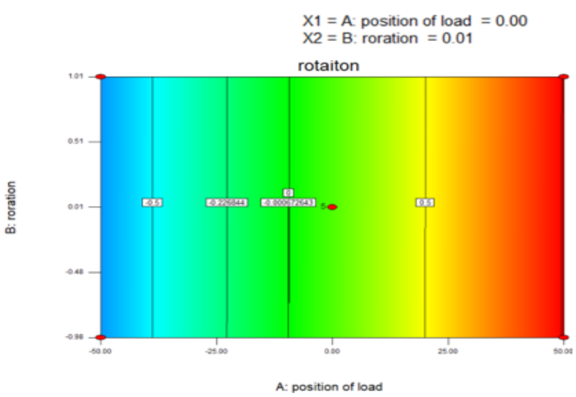


Figure 5: Mean and standard deviation of combined shear center.

3.2 Theoretical calculations

3.2.1 Z-section

Compared to the experimental value of the Z-section, which was zero rotation at zero position of load, the RSM predicted the values of 0.01 mm rotation at zero position of load. The ANOVA analysis predicted that there is a 3.18% chance that a value greater than this could occur. The ANOVA result of the Z-section is shown in figure 6.



ANOVA for Response Surface Linear Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.77	2	2.88	4.96	0.0318	significant
A-position of	*5.77*	*1*	*5.77*	*9.93*	*0.0103*	
B-roration	*5.828E-006*	*1*	*5.828E-006*	*1.003E-005*	*0.9975*	
Residual	5.81	10	0.58			
Lack of Fit	*1.84*	*6*	*0.31*	*0.31*	*0.9028*	*not significant*
Pure Error	*3.97*	*4*	*0.99*			
Cor Total	11.58	12				

The Model F-value of 4.96 implies the model is significant. There is only a 3.18% chance that a "Model F-Value" this large could occur due to noise.

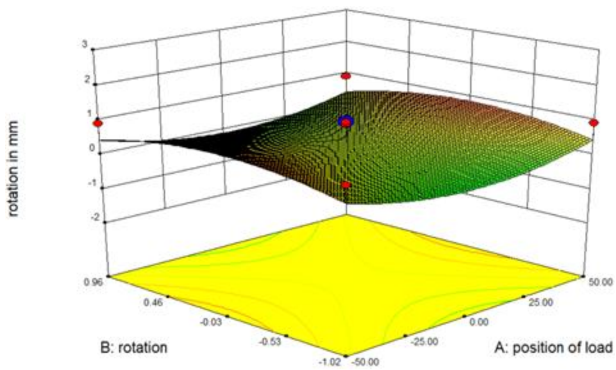
Figure 6: ANOVA results and 3D graphs of Z-section

3.2.2 Semi Circular

For the Semi-circular section, the results from the ANOVA analysis were found to be "no significant" due to error variation. Out of the 13 runs, the error probability was found to be 43% which is above the recommended value. Hence, the experimental results could not be compared with theoretical results in this case. The contour and ANOVA results of semi-circular are shown in figure 7.

3.2.3 Standard error of rotation

The standard error for the position of load against the rotation of the section is shown in figure 9. The std error of design showed good agreement between theoretical and experimental values. For instance, at load position -50, the rotation is 0.94 mm, showing an error of 0.472. In the same way, at position load 0,0, the rotation of the section is 0.73 showing an error of 0.361.



Analysis of variance table [Partial sum of squares - Type III]

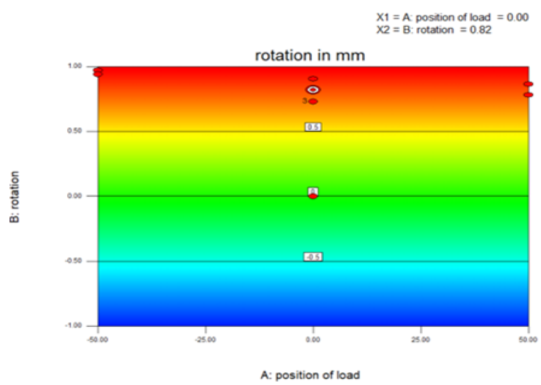
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3.74	5	0.75	1.06	0.4550	not significant
A-position of	8.393E-005	1	8.393E-005	1.189E-004	0.9916	
B-rotation	4.553E-004	1	4.553E-004	6.450E-004	0.9804	
AB	3.063E-004	1	3.063E-004	4.338E-004	0.9840	
A^2	1.88	1	1.88	2.66	0.1468	
B^2	1.37	1	1.37	1.95	0.2055	
Residual	4.94	7	0.71			
Lack of Fit	1.89	3	0.63	0.83	0.5443	not significant
Pure Error	3.05	4	0.76			
Cor Total	8.68	12				

The "Model F-value" of 1.06 implies the model is not significant relative to the noise. There is a 45.50 % chance that a "Model F-value" this large could occur due to noise.

Figure 7: ANOVA results and 3D graphs of semicircular section

3.2.4 L-section

The optimization and ANOVA analysis of RSM of the L-section is shown in figures 8 and 9. In this analysis, as shown, the predicted value for the analysis is 0.89, which establishes a good relationship between the actual experimentation and the predicted value. The predicted value for the rotation is 0.82 mm when the positioning load is 0.0, whereas the actual value observed was 0.86 when the positioning load is 0.0. the difference in error between the actual and predicted value is 4.6%. This difference shows that optimized and actual results have established a good relationship. This also suggests that the experiment was conducted in a controlled way following the codes. However, the difference could be attributed to laboratory conditions and human error.



Factor	Name	Level	Low Level	High Level	Std. Dev.
A	position of loac	47.52	-50.00	50.00	0.000

Response	Prediction	Std Dev	SE Mean	95% CI low	95% CI high
rotation in mm	0.89852	0.605939	0.437138	-0.109523	1.90656

Figure 8: ANOVA results and 3D graphs of L-section

4 Practical implementation

The shear center is the point of a cross-section, where loads can be applied without causing torsion over the longitudinal axis (normal to the cross-sectional plane). Theoretical and experimental procedures may enhance calculations and save time by improving analytic methodologies to obtain correct results for various specimens. The point of no torsion can be determined without lengthy and hectic calculations; however, Shear Centre is particularly useful in designing thin-walled open steel sections as they are weak in resisting torsion and can be implemented in the construction sector to enhance the performance capabilities and utilize the resources effectively. However, if a seismic force acts on a structure. In non-scientific words, it is a collection of horizontal forces operating at each level's center of mass (gravity). However, depending on the stiffness of the lateral resisting system, the Centre of mass may differ from the Centre of rigidity (comparable to the shear Centre of a cross-section). If this occurs, twisting will occur and must be accommodated in the design.

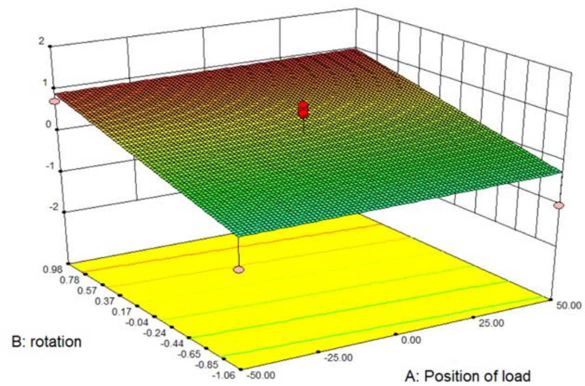


Figure 9: Std error of rotation of L-section against the position of load

5 Conclusion

Following conclusions are drawn from this experimental as well as theoretical study:

- Experimental calculations show that the Z-Section is symmetrical along both axes. At the same time, L-section and semi-circular section are symmetrical on one axis and unsymmetrical on the other.
- In comparison to the experimental Z-section value of zero rotation at zero position of load, the RSM predicted 0.01 mm rotation at zero position of load.
- The experimental and theoretical values for the semi-circular section were 0.965 and 0.455, respectively, indicating a 45.5 percent error.
- At load position -50, the rotation is 0.94 mm, indicating an error of 0.472. Similarly, at position load 0,0), the rotation of the section is 0.73, with a 0.361 error.
- The experimental rotational value of the L-section has been 0.905, and the RSM value has been 0.898, with a 0.77 percent error.

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References

[1]. C. Grant, "Shear center of thin-walled sections," The Journal of Strain Analysis for Engineering Design, vol. 27 (3) , pp.151–155, 1992. doi:10.1243/03093247v273151.

[2]. H. Katori, "Consideration of the Problem of Shearing and Torsion of Thin-Walled Beams with Arbitrary Cross- Section." Thin-Walled Structures, vol. 36, pp.671-68, 2001. http://dx.doi.org/10.1016/S0263-8231(01)00029-5.

[3]. W. Zhiquan., X. Xianghong., "Numerical study on impact resistance of novel multilevel bionic thin-walled structures," Journal of Materials Research and Technology, vol.16,2022, pp.1770-1780, 2022, https://doi.org/10.1016/j.jmrt.2021.12.105.

[4]. X. Xiang., X. Gaoxiang., C.Jiawei., L. Zhe., C.Xinbo.,"Multi-objective design optimization using hybrid search algorithms with interval uncertainty for thin-walled structures," Thin-Walled Structures, Vol.175, PP.109218, 2022, https://doi.org/10.1016/j.tws.2022.109218.

[5]. W. S. Chan and K.A.Syed, "Determination of Centroid and Shear Center Locations of Composite Box Beams.", ICCM International Conferences on Composite Materials, 2009.

[6]. W. S. Chan and Demirhan K. C, "A Simple Closed-Form Solution of Bending Stiffness for Laminated Composite Tubes. J.", of Reinforced Plastic & Composites, vol.19(4), p p. 278-291, 2000.

[7]. H. Katori,(2016),"Determination of Shear Centre of Arbitrary Cross-Section.", World Journal of Mechanics, vol 6, pp.249-256, 2001. http://dx.doi.org/10.4236/wjm.2016.68020.

[8]. L.Junru., W.Zhenyu., C. Jiankang., "An advanced Bayesian parameter estimation methodology for concrete dams combining an improved extraction technique of hydrostatic component and hybrid response surface method",Engineering Structures,Vol. 267,pp. 114687, 2022, https://doi.org/10.1016/j.engstruct.2022.114687

[9]. K. K. Senthil., L. Lufan., L.Tung-Chai Ling., "Response surface methodology for the optimization of CO2 uptake using waste concrete powder", Construction and Building Materials, Vol. 340, 2022,https://doi.org/10.1016/j.conbuildmat.2022.127758