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BUCKLING STRENGTH AND BENDING PERFORMANCE OF PLATE GIRDER WITH FLAT WEB AND CORRUGATED WEB

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Abstract: **The structural action of a beam is predominantly bending, with other effects such as shear, bending and buckling also being present. The corrugated steel plate is a widely used structural element in many fields of applications because of its favourable properties. Present study aimed to investigate bending and buckling performance of plate girder with flat web section and corrugated web section of different corrugation pattern namely triangular and rectangular. The finite element analysis of plate girder is carried out using SAP2000. For present study total twenty one models were obtained for analysis. Thickness of web of all models varied from 1mm to 3mm incrementally at 1mm; under corrugated web of triangular pattern different angles (30^0, 45^0 and 60^0) are studied and under corrugated web of rectangular pattern different corrugation width (100mm, 200mm and 400mm) are studied. Results obtained from analysis are then compared with plate girder with flat web section of uniform depth. It is observed that plate girder with triangular web section and rectangular web section has higher stiffness about minor axis and has lower stiffness about major axis when compared with plate girder with flat web section. Maximum buckling strength is observed in plate girder with triangular web section and rectangular web section when compared with flat web section.**

Keywords: **Plate girder, corrugated web, finite element analysis, buckling strength, bending performance.**

1. INTRODUCTION

A plate girder is basically an I- beam built up from plates using riveting or welding. Plate girders are also known as deep flexural members used to carry loads that cannot be carried economically. Plate girder provides maximum flexibility and economy. Plate girders offer a unique flexibility in fabrication and the cross section can be uniform or non-uniform along the length. It is possible for putting the exact amount of steel required at each section along the length of the girder by changing the flange areas and keeping the same depth of the girder. In other words, it can be shaped to match the bending moment curve itself. Thus, plate girder offers limitless possibilities to the creativity of the engineer.

In construction application, the web usually bears most of the compressive stress and transmits shear in the beam while the flanges support the major external loads. Thus, by using greater part of the material for the flanges and thinner web, materials saving could be achieved without weakening the load-carrying capability of the beam. Nevertheless, as the compressive stress in the web has exceeded the critical point prior to the occurrence of yielding, the flat web loses its stability and deforms transversely. This could be improved by using corrugated web, an alternative to the plane web. The main benefits of this type of beams are that the corrugated webs increase the beam's stability against buckling, which may result in an economical design via the reduction of web stiffeners. Furthermore, the use of thinner webs results in lower material cost, with an estimated cost savings of 10-30% in comparison with conventional fabricated sections and more than 30% compared with standard hot rolled universal beams.

2. PRESENT STUDY

In the present study, Buckling strength and bending performance of plate girder with flat web and triangular web and rectangular web are studied. Here plate girder with flat web and corrugated web is designed as per Indian standard. Linear static analysis and buckling analysis are carried out to compare the buckling strength, bending performance and weight of plate girder with flat web and triangular web and rectangular web.

2.1 SCOPE OF PRESENT WORK

In present study, an attempt has been made to study following aspects

1) Study of buckling strength and bending performance of welded plate girder for variation in geometry of corrugation angle, corrugation width and thickness of web plate.
2) Preparation and study of model in SAP2000.
3) Perform the static and buckling analysis.
4) Calculate the buckling strength, bending moment, stiffness and weight of corrugated web plate girders.

2.2 ANALYSIS

During analysis following cases are taken into consideration

Case 1:- Compare the buckling strength of plate girder with flat web, plate girder with triangular web and plate girder with rectangular web based on varying thickness of flat web, triangular web and rectangular web.

Case 2:- Compare the bending of plate girder with flat web, plate girder with triangular web and plate girder with rectangular web based on varying thickness of flat web, triangular web and rectangular web.

Case 3:- Compare the weight of plate girder with flat web, plate girder with triangular web and plate girder with rectangular web based on varying thickness of flat web, triangular web and rectangular web.

For all the three cases thickness of flat web, triangular web and rectangular web is varied as 1mm, 2mm and 3mm.

There are two types of analysis performed

1) Static Analysis

Structural analysis is the process to analyze a structural system to predict its responses and behaviors by using physical laws and mathematical equation.

The main objective of structural analysis is to determine internal forces, stresses and deformation of structures under various load effect.

2) Buckling Analysis

Buckling loads are critical loads where certain types of structures become unstable. Each load has an associated buckled mode shape; this is the shape that the structure assumes in a buckled condition.

Buckling is depends upon the loading conditions and on its geometrical and material properties.

Buckling analysis gives buckling strength and buckling behavior of girder for different modes.

Different models with varying web thickness, corrugation angle and corrugation widths are analyzed and the results are compared with flat web plate girder. For comparison only first buckling mode is consider for both cases.

Fig. 1: 3D MODEL OF PLATE GIRDER WITH FLAT WEB

Fig. 2: 3D MODEL OF PLATE GIRDER WITH RECTANGULAR WEB

Fig. 3: 3D MODEL OF PLATE GIRDER WITH TRIANGULAR WEB

Table1: Geometric parameters for plate girder with flat web

Web Height (h_w)	Web thickness (t_w)	Flange width(b_f)	Flange thickness(t_f)	Overall depth(H)	Length
188mm	1mm,2mm, 3mm	100 mm	6mm	200 mm	5000 mm

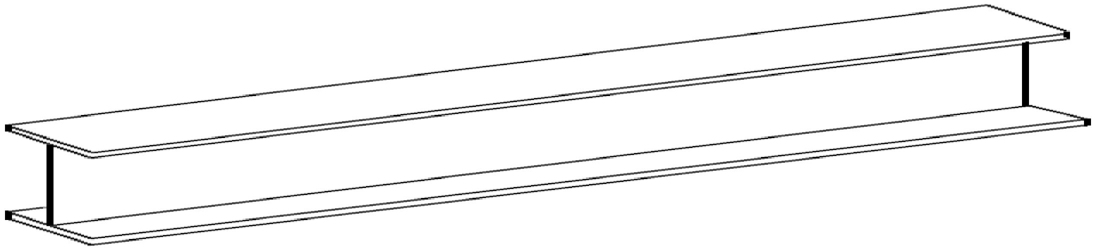

Fig.4: Isoparametric view of plate girder with flat web

Table2: Geometric parameters for plate girder with triangular web

Web Height (h_w)	Web thickness (t_w)	Flange width (b_f)	Flange thickness (t_f)	Overall depth (H)	Corrugation angle (θ)	Length
188mm	1mm,2mm, mm	100 mm	6mm	200 mm	30^0, 45^0, 60^0	5000 mm

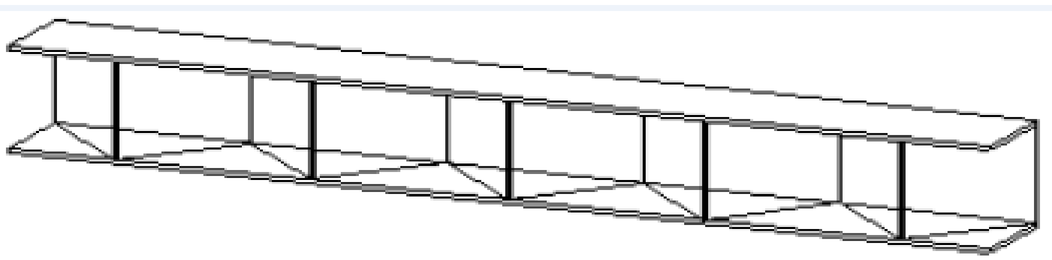

Fig.5: Isoparametric view of plate girder with triangular web

Table3: Geometric parameters for plate girder with rectangular web

Web Height (h_w)	Web thickness (t_w)	Flange width (b_f)	Flange thickness (t_f)	Overall depth (H)	Corrugation width (C_w)	Corrugation thickness (C_t)	Length
188mm	1mm, 2mm, 3mm	100 mm	6mm	200 mm	100mm, 200mm, 400mm	30mm	5000 mm

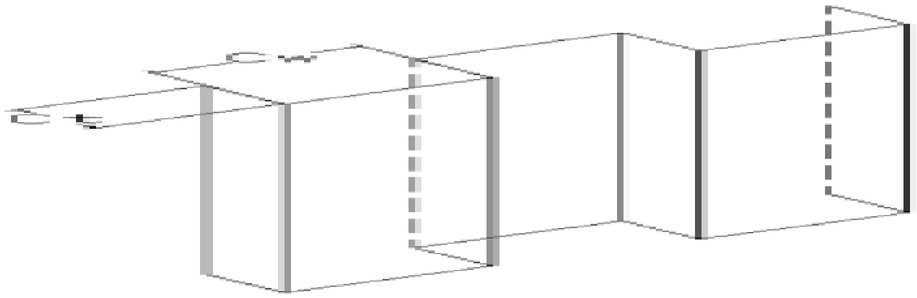

Fig.6: Rectangular corrugated web

3. RESULTS AND DISCUSSIONS

In the present study the Buckling strength and bending performance of plate girder with flat web, triangular web and rectangular web are studied. For the analysis twenty one plate girder models with varying web thickness (t_w = 1mm, 2mm and 3mm) out of which three numbers of plate girder with flat web models, nine numbers of plate girders with triangular web models with varying corrugation angle ($\theta = 30^0$, 45^0 and 60^0) and nine numbers of plate girders rectangular web models with varying width of corrugation (C_w = 100mm, 200mm and 400mm) and constant thickness of corrugation (C_t = 300) were considered. Other parameters such as H = 200, b_f = 100 and h_w = 188mm are kept constant for all twenty one models.

3.1 Comparison of Deflection in Major Axis and Minor Axis between Flat Web and Triangular Web

Comparison between plate girder with flat web and triangular web for their deflection in major axis and minor axis for 1mm, 2mm and 3mm thick web models are studied and the values of deflections are shown in Table 4 and Figure 7.

Table 4: Comparison of major axis and minor axis deflection between plate girder with flat web and triangular web

SI NO	MODEL	DEFLECTION-MINOR , mm	DEFLECTION-MAJOR, mm
1	FWEB-1	27.8354	5.72
2	FWEB-2	13.1628	4.732
3	FWEB-3	10.1459	4.164
4	TRIWEB30-1	7.0236	7.07
5	TRIWEB30-2	6.8436	6.533
6	TRIWEB30-3	6.5924	6.262
7	TRIWEB45-1	6.0924	7.167
8	TRIWEB45-2	5.9574	6.61
9	TRIWEB45-3	5.8251	6.405
10	TRIWEB60-1	4.4682	6.508
11	TRIWEB60-2	4.1141	5.431
12	TRIWEB60-3	3.8691	4.907

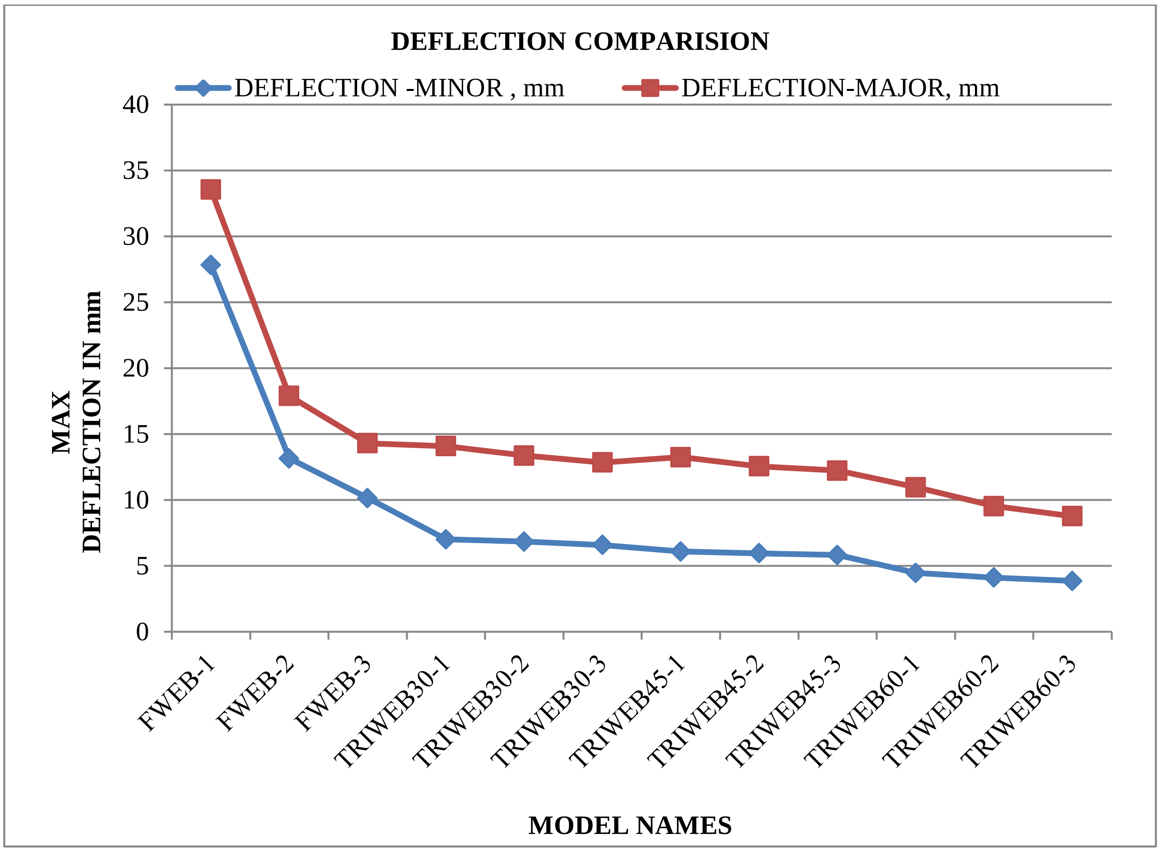

Fig.7: Comparison plot of major axis and minor axis deflection between plate girder with flat web and triangular web

Table 4 and fig 7 shows the comparison of deflection in major axis and minor axis between flat web and triangular web. It shows that, it was noted that TRIWEB60-3 has lowest deflection value when compared with FWEB. This is because increase in corrugation angle increases the number of slanting web increased throughout the length. This will lead to minimum deflection occurred. While for the corrugation angle less than 60^0 sections tends to behave like flat web sections

3.2 Comparison of Deflection in Major Axis and Minor Axis between Flat Web and Rectangular Web

Comparison between plate girder with flat web and rectangular web for their deflection in major axis and minor axis for 1mm, 2mm and 3mm thick web models are studied and the values of deflections are shown in Table 5 and Figure 8.

Table 5: Comparison of major axis and minor axis deflection between plate girder with flat web and rectangular web

SI NO	MODEL	DEFLECTION -MINOR , mm	DEFLECTION-MAJOR, mm
1	FWEB-1	27.8354	5.72
2	FWEB-2	13.1628	4.732
3	FWEB-3	10.1459	4.164
4	RECWEB100-1	6.212	7.495
5	RECWEB100-2	5.7138	6.735
6	RECWEB100-3	5.3651	6.068
7	RECWEB200-1	7.4784	8.796
8	RECWEB200-2	7.1016	7.301
9	RECWEB200-3	6.777	6.408
10	RECWEB400-1	7.8474	9.766
11	RECWEB400-2	7.3937	8.12
12	RECWEB400-3	7.0049	7.052

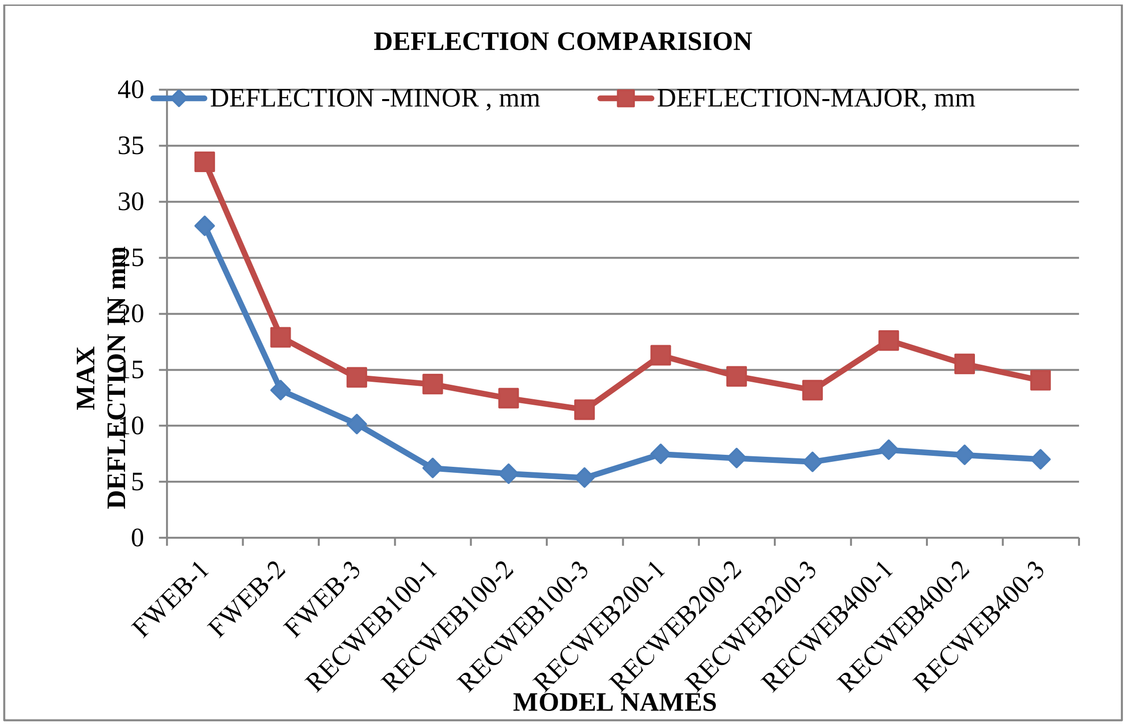

Fig.8: Comparison plot of major axis and minor axis deflection between plate girder with flat web and rectangular web

Table 5 and fig 8 shows the comparison of deflection in major axis and minor axis between flat web and rectangular web. It shows that RECWEB100-3 has lowest deflection value when compared with FWEB. This is because increase in corrugation width decreases the rectangular web throughout the length. This will lead to minimum deflection occurred. While for the corrugation width more than 100mm sections tend to behave like flat web sections

3.3 Comparison of Flexural Stiffness between Plate Girder with Flat Web and Triangular Web

Comparison between plate girder with flat web and triangular web for their flexural stiffness for 1mm, 2mm and 3mm thick web models are studied and the values of buckling strength are shown in Table 6

Table 6: Comparison of flexural stiffness between plate girder with flat web and triangular web

Si No	Model	Flexure Stiffness -Minor, Kn/Mm	Flexure Stiffness-Major, Kn/Mm	Ratio, Minor Axis Flexure Stiffness Of Corrugated Web To Flat Web	Average	Ratio, Major Axis Flexure Stiffness Of Corrugated Web To Flat Web	Average
1	Fweb-1	0.359254762	1.748251748	-		-	-
2	Fweb-2	0.759716778	2.113271344	-		-	
3	Fweb-3	0.985619807	2.401536984	-		-	
4	Triweb30-1	1.423771285	1.414427157	3.963124324	2.47517593	0.809052334	0.732779
5	Triweb30-2	1.461219241	1.530690341	1.923373663		0.72432267	
6	Triweb30-3	1.516898246	1.596933887	1.539029792		0.664963271	
7	Triweb45-1	1.641389272	1.39528394	4.568872694	2.84003852	0.798102414	0.721368
8	Triweb45-2	1.678584617	1.512859304	2.20948736		0.715885023	
9	Triweb45-3	1.716708726	1.56128025	1.741755506		0.650117096	
10	Triweb60-1	2.238037689	1.536570375	6.229667428	4.01713098	0.878918254	0.866265
11	Triweb60-2	2.430665273	1.841281532	3.199436086		0.871294421	
12	Triweb60-3	2.584580393	2.037905034	2.622289421		0.848583656	

Table 6 shows the flexural stiffness in major axis and minor axis for flat web sections and triangular web sections. The value of I_x is in a range of 0.732779 to 0.721368 to 0.866265 times the I_x of flat web sections. On the other hand, the deflection in minor axis for TRIWEB has higher values than flat web sections. The value of I_y for TRIWEB is in the range of 2.47517593 to 2.84003852 to 4.01713098 times the I_y of flat web sections.

3.4 Comparison of Flexural Stiffness between Plate Girder with Flat Web and Rectangular Web

Comparison between plate girder with flat web and rectangular web for their flexural stiffness for 1mm, 2mm and 3mm thick web models are studied and the values of buckling strength are shown in Table 7

Table 7: Comparison of flexural stiffness between plate girder with flat web and rectangular web

SI NO	MODEL	FLEXURE STIFFNESS - MINOR, kN/mm	FLEXURE STIFFNESS-MAJOR, kN/mm	RATIO, minor axis flexure stiffness of corrugated web to flat web	AVERAGE	RATIO, major axis flexure stiffness of corrugated web to flat web	AVERAGE
1	FWEB-1	0.359254762	1.748251748	-		-	-
2	FWEB-2	0.759716778	2.113271344	-		-	
3	FWEB-3	0.985619807	2.401536984	-		-	
4	RECWEB100-1	1.609787508	1.334222815	4.48090792	2.89189539	0.76317545	0.717332
5	RECWEB100-2	1.750148763	1.484780995	2.303685813		0.702598367	
6	RECWEB100-3	1.863898157	1.647989453	1.891092431		0.686222808	
7	RECWEB200-1	1.337184424	1.1368804	3.722106333	2.35757067	0.650295589	0.649413
8	RECWEB200-2	1.408133378	1.369675387	1.853497803		0.648130393	
9	RECWEB200-3	1.475579165	1.560549313	1.497107865		0.649812734	
10	RECWEB400-1	1.274307414	1.02396068	3.547085659	2.25858615	0.585705509	0.586312
11	RECWEB400-2	1.352502806	1.231527094	1.780272394		0.582758621	
12	RECWEB400-3	1.427572128	1.418037436	1.448400405		0.590470788	

Table 7 shows the flexural stiffness in major axis and minor axis for flat web sections and rectangular web sections. The value of I_x is in a range of 0.717332 to 0.6499413 to 0.586312 times the I_x of flat web sections. On the other hand, the deflection in minor axis for TRIWEB has higher values than flat web sections. The value of I_y for RECWEB is in the range of 2.89189539 to 2.35757067 to 2.25858615 times the I_y of flat web sections.

3.5 Comparison of Buckling Strength between Plate Girder with Flat Web and Triangular Web

Comparison between plate girder with flat web and triangular web for their buckling strength for 1mm, 2mm and 3mm thick web models are studied and the values of buckling strength are shown in Table 8 and Figure 9.

Table 8: Comparison of buckling strength between plate girder with flat web and triangular web

SI NO	MODEL	BUCKLING LOAD , KN
1	FWEB-1	2.96
2	FWEB-2	7.33
3	FWEB-3	10.049
4	TRIWEB30-1	11.57
5	TRIWEB30-2	12.43
6	TRIWEB30-3	11.95
7	TRIWEB45-1	16.57
8	TRIWEB45-2	17.18
9	TRIWEB45-3	17.76
10	TRIWEB60-1	3.39
11	TRIWEB60-2	17.32
12	TRIWEB60-3	31.76

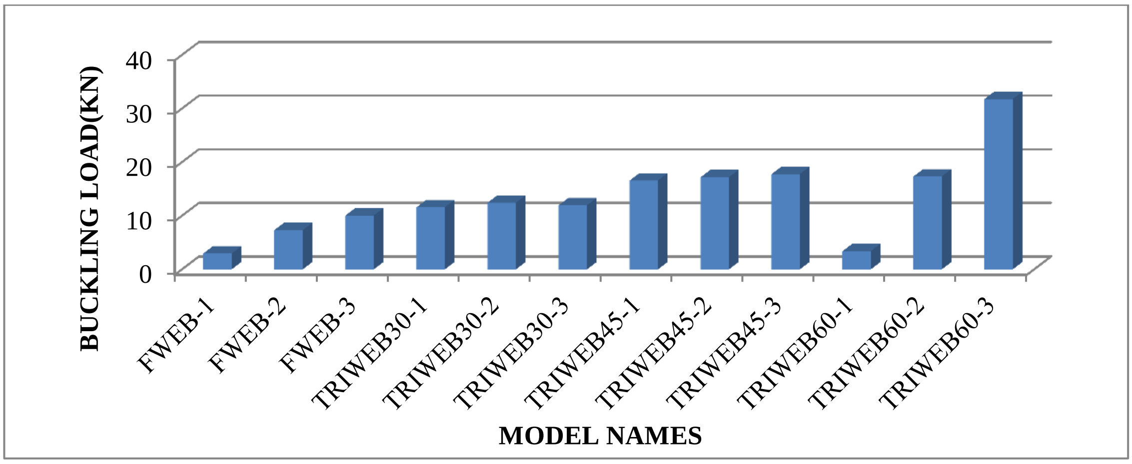

Fig.9: Comparison plot of buckling strength between plate girder with flat web and triangular web

Table 8 and fig 9 shows the comparison of buckling strength between plate girder flat web and triangular web. It shows that increase in the corrugation angle there is increase in the buckling strength as compared to plate girder with flat web.

3.6 Comparison of Buckling Strength between Plate Girder with Flat Web and Rectangular Web

Comparison between plate girder with flat web and rectangular web for their buckling strength for 1mm, 2mm and 3mm thick web models are studied and the values of buckling strength are shown in Table 9and Figure 10.

Table 9: Comparison of buckling strength between plate girder with flat web and rectangular web

SI NO	MODEL	BUCKLING LOAD , KN
1	FWEB-1	2.96
2	FWEB-2	7.33
3	FWEB-3	10.049
4	RECWEB100-1	9.7
5	RECWEB100-2	16.63
6	RECWEB100-3	21.27
7	RECWEB200-1	7.21
8	RECWEB200-2	12.76
9	RECWEB200-3	15.92
10	RECWEB400-1	6.33
11	RECWEB400-2	11.78
12	RECWEB400-3	14.85

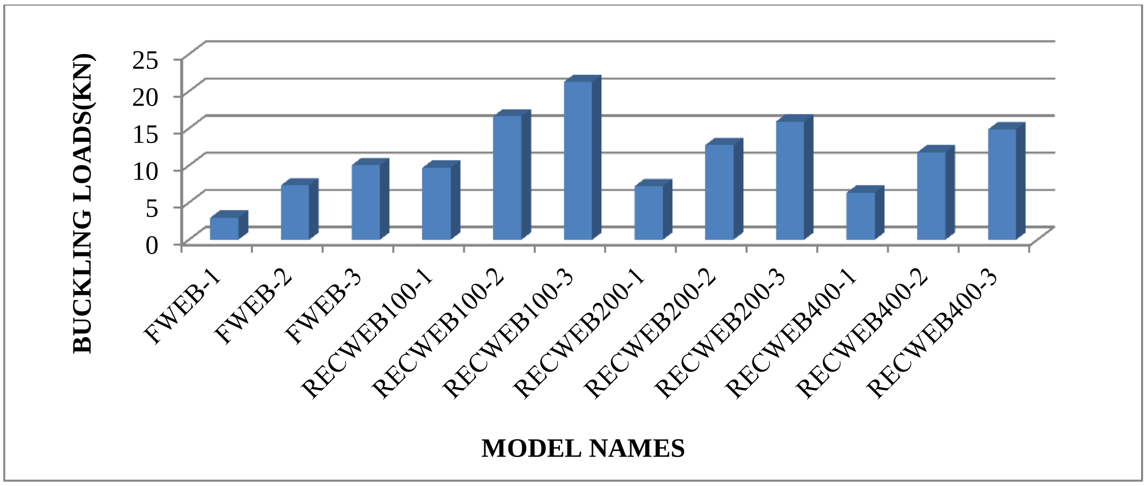

Fig.10: Comparison plot of buckling strength between plate girder with flat web and rectangular web

Table 9 and fig 10 shows the comparison of buckling strength between plate girder flat web and rectangular web. It shows that decrease in the corrugation width there is increase in the buckling strength as compared to plate girder with flat web

3.7 Comparison of Weight between Plate Girder with Flat Web and Triangular Web

Comparison between plate girder with flat web and triangular web for their weight for 1mm, 2mm and 3mm thick web models are studied and the values of buckling strength are shown in Table 10 and Figure 11.

Table 10: Comparison of weight between plate girder with flat web and triangular web

SI NO	MODEL	WEIGHT ,KN
1	FWEB-1	0.539
2	FWEB-2	0.616
3	FWEB-3	0.693
4	TRIWEB30-1	0.551
5	TRIWEB30-2	0.64
6	TRIWEB30-3	0.729
7	TRIWEB45-1	0.571
8	TRIWEB45-2	0.68
9	TRIWEB45-3	0.788
10	TRIWEB60-1	0.611
11	TRIWEB60-2	0.76
12	TRIWEB60-3	0.91

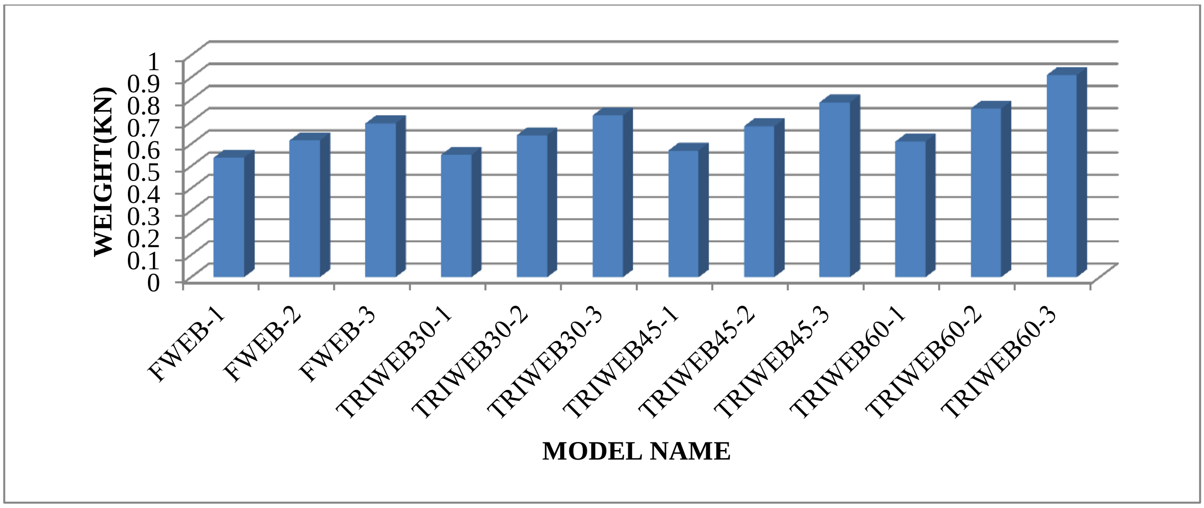

Fig.11: Comparison plot of weight between plate girder with flat web and triangular web

Table 10 and fig 11 shows the comparison of weight between plate girder flat web and triangular web. It shows that increase in the corrugation angle there is increase in the weight as compared to plate girder with flat web.

3.8 Comparison of Weight between Plate Girder with Flat Web and Rectangular Web

Comparison between plate girder with flat web and rectangular web for their weight for 1mm, 2mm and 3mm thick web models are studied and the values of buckling strength are shown in Table 11 and Figure 12.

Table 11: Comparison of weight between plate girder with flat web and rectangular web

SI NO	MODEL	WEIGHT, KN
1	FWEB-1	0.539
2	FWEB-2	0.616
3	FWEB-3	0.693
4	RECWEB100-1	0.562
5	RECWEB100-2	0.662
6	RECWEB100-3	0.763
7	RECWEB200-1	0.55
8	RECWEB200-2	0.639
9	RECWEB200-3	0.728
10	RECWEB400-1	0.545
11	RECWEB400-2	0.628
12	RECWEB400-3	0.712

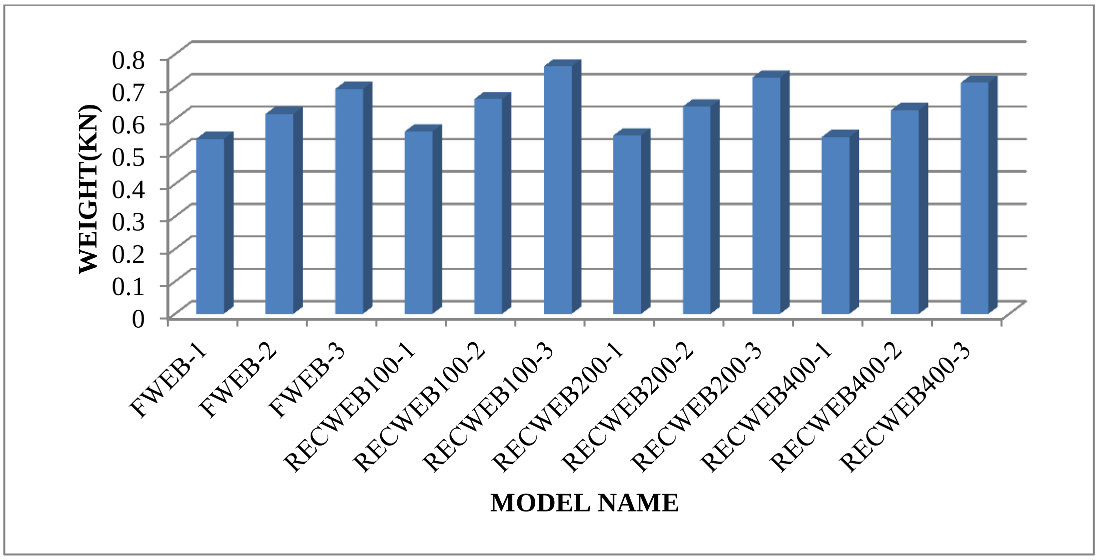

Fig.12: Comparison plot of weight between plate girder with flat web and rectangular web

Table 11 and fig 12 shows the comparison of weight between plate girder flat web and rectangular web. It shows that increase in the corrugation width there is increase in the weight as compared to plate girder with flat web.

4. CONCLUSIONS

From the analytical study on the buckling and bending performance of plate girder with flat web and corrugated web sections it can be concluded that Plate girder with corrugated web section has less deflection in minor axis when compared with plate girder with flat web section. In this regard corrugated web sections have a higher resistance to bending about minor axis than flat web section.

Similarly plate girder with corrugated web section has more deflection in major axis when compared with plate girder with flat web section. It means that flat web sections are stiffer than corrugated web sections about major axis.

From stiffness analysis in minor axis corrugated web sections are more stiffer when compared to flat web sections and flat web section have more stiffness in major axis when compared with flat web section From buckling analysis, buckling strength of triangular web section increases as corrugation angle increases similarly in case of rectangular web sections buckling strength increases with the decrease of corrugation width.

From weight comparison it can be concluded that increase in corrugation angle and corrugation width increase the weight per unit length of sections.

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