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Strength of Welded Plate Girder with Tapered Web

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ABSTRACT
As a result of the general acceptance of the optimum design concepts, slender and, in some cases tapered web is increasingly used in steel structures .These members will reduce dead weight of structure in tern material cost. Present research work is focusing on the determination of buckling strength and economy of tapered web. In the present study comparison is carried out between plate girder with uniform web depth and tapered web depth. Parametric studies with various geometries of tapered web plate were carried out to find the favorable and economical design situations. The present paper involves the finite element analysis of plate girder for different conditions like i) uniform web depth, ii) tapered web depth. The main comparison parameters are i) static behaviour, ii) buckling behaviour, iii) buckling strength. All models were analyzed using finite element based software ANSYS. At the end it is concluded that the tapered web plate has same buckling strength however it achieves economy.
Keywords - ANSYS, buckling strength, finite element, optimum design, tapered web

I. INTRODUCTION

It is a deep flexural member used in situations, where the loads are heavy and spans are also very large, that cannot be economically carried by rolled sections. In plate girder the top and bottom flanges resist bending moment and the deep web plate resist shear force in the section. For making the cross section efficient in resisting in plane bending, it is required that maximum material is placed as far away from neutral axis as possible. For this point of view it is economical to keep the flanges as far apart as possible. The axial force in the flanges decreases, as the depth of girder increases. In such a situation, premature failure of girder due to web buckling in shear might be occur. As far as structural efficiency is concerned, tapered i.e., non-prismatic and with a continuous varying cross sections are consider.

I.1.Purpose of tapering

Tapered (varying depth) web is one of the new technique proposed in design in order to achieve economy and to reduce its self-weight .In the past, plate girder were fabricated by riveting or bolting, but now a days it is possible to have welded plate girder. With welding it is possible to have various forms of web as tapered, cranked, and hunched girders. In order to achieve design optimization, Web-tapered members can be shaped to provide the maximum strength and stiffness with the minimum weight.
. In present paper plate girder with maximum depth at center and (1/2 maximum height) and (2/3 maximum height) tapered at support is studied.

I.2. Outlay of Thesis

Case1:-Compare displacement after buckling, buckling load of uniform web plate girder with tapered web plate girder based on variation in tapered depth (or tapering angle), for span 10m

Case2:-Compare the displacement after buckling and buckling strength of uniform web plate girder with tapered web plate girder for 20m span (multi span)

Case3:- Compare the weight of uniform web plate with tapered web plate. (For case2 only)

I.3 Aim

1) To determine the buckling strength of tapered web plate girder and compare it with uniform web plate girder.
2) To check the economy.
3) Weight comparison.

II. MODELLING OF PLATE GIRDER USING

II.1. Geometry

II.1.1. Geometric dimensions of standard plate girder and tapered plate girder for case 1:-

Span	Web Height at support (hmin)	Web Height At Center (hmax)	Web thk. (t_w)	Flange width (bf)	Flange thk. (t_f)
10m	800mm 400mm 266mm	800mm	6mm	240mm	30mm

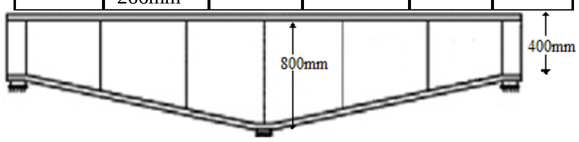


Fig.II.1 Tapered plate girder

In fig .II.1 tapered plate girder is shown having maximum height at center and 1/2 maximum height at support.

II.1.2. Geometric dimensions of standard plate girder and tapered plate girder for case 2:-

Span	Web Height at support (hmin)	Web Height At Center (hmax)	Web thk. (t_w)	Flange width (bf)	Flange thk. (t_f)
20m	1820mm	1820mm	12mm	520mm	60mm
	910mm				
	606mm				

II.2 Design of Plate Girder

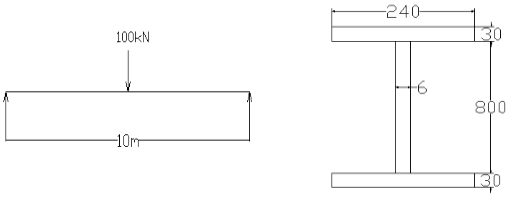


Fig.II.2. Plate girder

Maximum bending moment = $\frac{wl^2}{4} = \frac{100x10^2}{4}$

= 250 kNm

Shear force = $\frac{w}{2} = \frac{100}{2}$ = 50kN

Check for bending strength

$Z_{pz} = \frac{bf\ tf\ (D-tf)}{2} = \frac{2x240x30\ (860-30)}{2} = 5.98 \times 10^6\ mm^3$

$M_d = \frac{B_b Z_{pz} f_y}{\Gamma_{mo}} = 1538 \times 10^6$ kNm > 250 kNm

hence ok

Shear capacity of web

$\frac{d}{t_w} = 133.33 > 6.7\varepsilon$

clause 8.4.2.1, IS 800: 2007

As $\frac{d}{t_w} > 6.7\varepsilon$, shear buckling need to consider i.e. web is fail by shear buckling. Thus shear buckling resistance as per clause 8.4.1, IS 800: 2007 is calculated as

$\tau_{cr} = k_v \frac{\pi^2 E}{12(1-\mu^2)\left(\frac{d}{t_w}\right)^2}$

$= 5.35 \frac{\pi^2\ 2x10^5}{12(1-0.3^2)(133.33)^2} = 101.03\ N/mm^2$

$\lambda_w = \frac{f_{yw}}{\sqrt{3}\tau_{cr}} = 1.42 > 1.2$

$\tau_b = \frac{f_{yw}}{\sqrt{3}\lambda_w^2} = 71.58 > 50$ hence ok

II.3.Check for Shear Strength

Checking reduced cross section for shear strength (IS 800:2007)

Factored design shear force, V, in a beam due to external actions shall satisfy

$V \le V_d$

Where V_d = design strength

$V_d = \frac{V_n}{\gamma_{mo}}$

Where, γ_{mo} = partial safety factor against shear failure

$V_n = V_p$

$V_p = \frac{A_v f_{yw}}{\sqrt{3}}$ ....clause 8.4, IS 800: 2007

Where, A_v = shear area = d t_w

f_{yw} = yield strength of web

II.3.1. check shear strength of uniform web depth.(for case 1.)

overall depth is = 860mm,

d = 800mm, t_w = 6mm

Shear Strength, Vp = $\frac{A_v f_{yw}}{\sqrt{3}}$

V_p = [(800 x 6)*250] / $\sqrt{3}$

= 692.82 KN > 50 KN............. Safe

II.3.2. check shear strength of uniformly reduced cross section (at depth 1/2)

overall depth is = 460mm

d = 400mm, t_w = 6mm

Shear Strengt, $V_p = \frac{A_v f_{yw}}{\sqrt{3}}$

V_p = [(400 x 6)*250] / $\sqrt{3}$

= 346.41 KN > 50 KN .... Safe

II.3.3. check shear strength of uniformly reduced cross section (at depth 2/3 from top)

overall depth is = 326mm,

d = 266mm,t_w = 6mm

shear strengt, $V_p = \frac{A_v f_{yw}}{\sqrt{3}}$

V_p = [(257 x 6)*250] / $\sqrt{3}$

= 222.56 KN > 50 KN ....Safe

same procedure is carried out for case 2

II.4 Finite element analysis using ANSYS

ANSYS is software which is based on the finite element method is one of the leading commercial finite element programs in the world and can be applied to a large number of applications in engineering. Finite element solutions are available for several engineering disciplines like statics, dynamics, heat flow, fluid flow, electromagnetic and also coupled field problems. It is well known that a finite element solution is always an approximate solution of the considered problem and one always has to decide whether r it is a good or a bad solution.

To analyze any structure in ANSYS, software required some inputs like material property, element type, boundary conditions, proper meshing, to get the precise results.

I.4.1 Models of plate girder in ansys

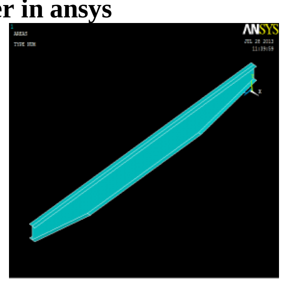
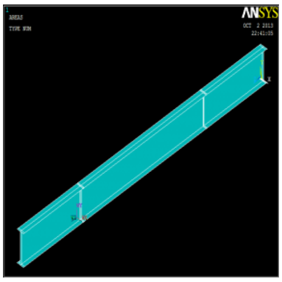


Fig.4.1 Standard plate girder Fig.4.2 Tapered plate girder
(Fig.4.1,Fig 4.2 for case:-1)



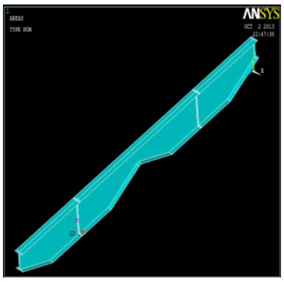


Fig.4.3 Standard plate girder Fig.4.4 Tapered plate girder
(Fig.4.1, Fig 4.2 for case:-2)

III. ANALYSIS AND WEIGHT COMPARISON

For analysis following cases are taken into account

Case1:-Compare the displacement after buckling, buckling load of uniform web plate girder with tapered web plate girder based on variation in tapered depth (or tapering angle), for span 10m

Case2:-Compare the displacement after buckling and buckling strength of uniform web plate girder with tapered web plate girder for 20m span (multi span)

Case3:- Compare the weight of uniform web plate with tapered web plate.(for case2 only)

III.1 Two types of analysis is carried out by using Ansys.

III.1.1.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.

III.1.2 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.

Here we discuses only buckling analysis.

III.2. Weight comparison

Considering the buckling resistance self-weight of
both the girders are calculated and compared.

1) For plane web plate girder –

Web plate thk. = 6 mm
Total length = 10m
d = 800 mm
Buckling Resistance = 276.07 kN
SELF WEIGHT =10 x 0.006 x 7850 x 0.8
= 376.8 kg

2) For tapered web plate girder –

Web plate thk. = 6 mm
Total length = 10m
d = 400 mm
Buckling Resistance = 276.64 kN
SELF WEIGHT = [2x (0.4x0.006x2.5)
+ (2.5x0.4x0.006) +(0.8x5x0.006)]x7850
= 329.7kg

3) For tapered web plate girder –

Web plate thk. = 6 mm
Total length = 10m
d = 266 mm
Buckling Resistance = 277.02 kN
SELF WEIGHT = [2x (0.266x0.006x2.5)
+ (2.5x0.266x0.006) + (0.8x5x0.006)] x7850
= 282.36kg

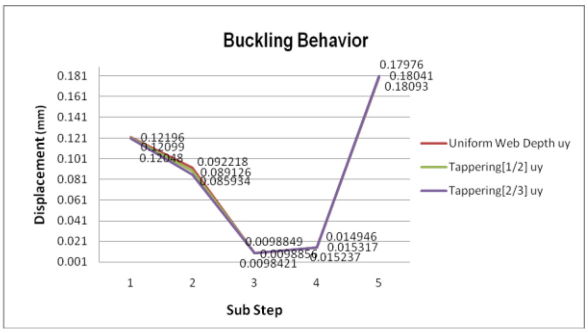
such type of calculations are done for case 2 (20m single span and multi span respectively) .which is shown in table no IV.5 and IV.6

IV. RESULT AND DISCUSSION

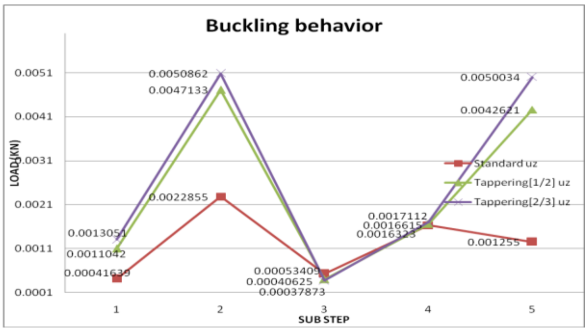
Table IV.1,IV.3 shows the buckling behaviour of plate girders of case(1) and case(2).In this table displacement in y direction and displacement in z direction are compared. In table.IV.1 displacement of uniform depth web, web tapered at 1/2 and tapered at 2/3 in y direction is nearly same up to set3 and after 3rd set it slightly increases. Displacement in y direction is shown in graph no IV.1.Graph IV.2 shows the displacement in z direction. Table IV.2 shows the buckling load comparison, buckling load is nearly same for three different web depths.

Table IV.1.Comparsion of buckling behaviour

Buckling [10m]						
Set	Uniform web depth		Tapering[1/2]		Tapering[2/3]	
	uy	uz	Uy	uz	uy	uz
1	0.122	0.000416	0.12196	0.0011	0.12048	0.001305
2	0.092218	0.002286	0.092218	0.00471	0.08593	0.005086
3	0.009884	0.000534	0.0098849	0.00041	0.00984	0.000379
4	0.014946	0.001632	0.014946	0.00166	0.01524	0.001711
5	0.17976	0.001255	0.17976	0.00426	0.18093	0.005003



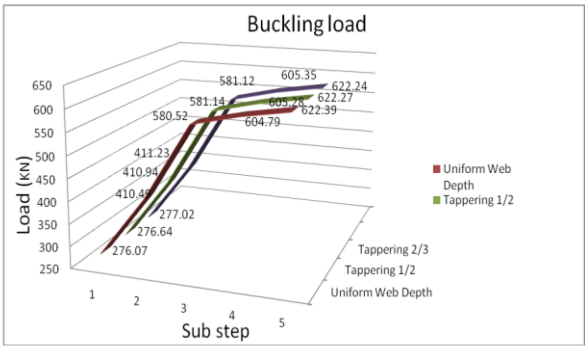
Grapg.IV.1. Comparision of displacement in U_Y direction



Grapg.IV.2. Comparision of displacement in Uz direction

Table IV.2.Comparsion of buckling load

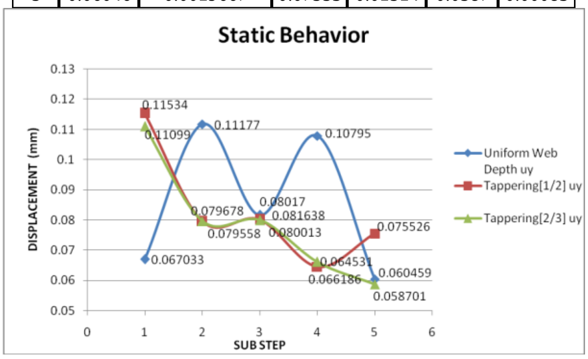
Buckling Load [Span 10m]			
Set	Uniform web depth	Tapering 1/2	Tapering 2/3
1	276.07	276.64	277.02
2	410.49	410.94	411.23
3	580.52	581.14	581.12
4	604.79	605.28	605.35
5	622.39	622.27	622.24



Grapg.IV.3. Comparision of buckling load

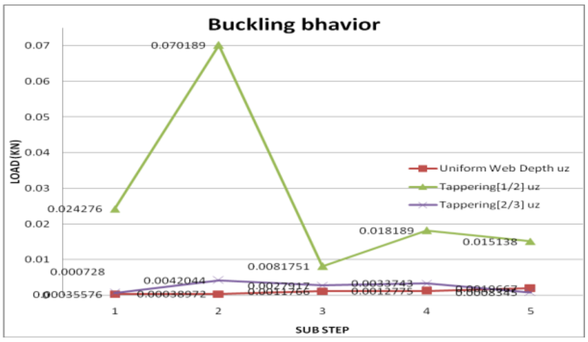
Table IV.3.Comparsion of buckling behaviour

Buckling [20m]						
Set	Uniform web depth		Tapering[1/2]		Tapering[2/3]	
	uy	uz	Uy	uz	Uy	uz
1	0.06703	0.00035576	0.11534	0.02428	0.111	0.00073
2	0.11177	0.00038972	0.07956	0.07019	0.0797	0.0042
3	0.08164	0.0011766	0.08017	0.00818	0.08	0.00279
4	0.10795	0.0012775	0.06453	0.01819	0.0662	0.00337
5	0.06046	0.0019667	0.07553	0.01514	0.0587	0.00083



Grapg.IV.4. Comparision of displacement in Uy direction

Graph IV.4. shows the displacement in y direction at 1st set,displacement of uniform web depth is less than taperd web(1/2,1/3) ,at set 3rd all three having same displacement and at 5th set show that displacement of tapered (1/2) web is less than other two.

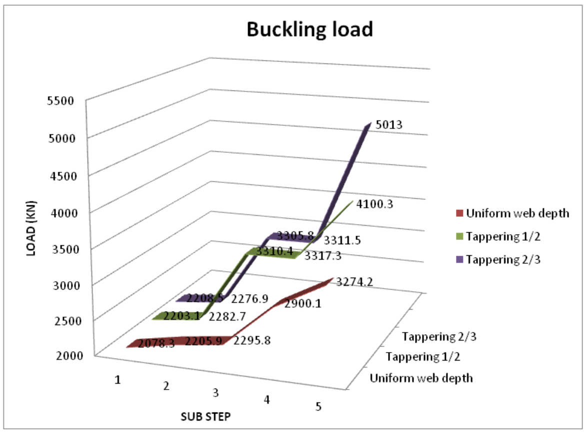


Graph.IV.5. Comparision of displacement in Uz direction

Graph.IV.5 shows the displacement in z direction it clearly see that displacement of uniform web depth and tapered depth at(2/3) is nearly same and displacement of tapered web depth (1/2) is more.

Table IV.4.Comparsion of buckling load

Buckling Load [Span 20m]			
Set	Uniform web depth	Tapering 1/2	Tapering 2/3
1	2078.3	2203.1	2208.5
2	2205.9	2282.7	2276.9
3	2295.8	3310.4	3305.8
4	2900.1	3317.3	3311.5
5	3274.2	4100.3	5013



Comparison of buckling load between plane web plate girders with tapered web plate girder is carried out. After comparison it is found that the buckling load is slightly increases in tapered plate girder

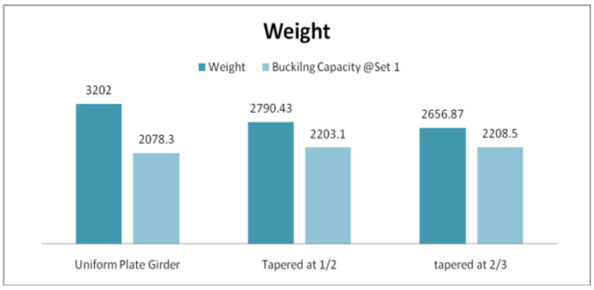
Above table shows the buckling load. Buckling load carrying capacity of tapered (2/3) webs more than other two.

Grapg.IV.6. Comparision of buckling load

Table IV.5 and IV.6 shows the comparision of weight and buckling load carring capacity. Comparison of buckling load between uniform web plate girder with tapered web plate girder is carried out, for different one span and multispan after comparison it is found that the buckling load is slightly increases in tapered plate girder and weight is decreases.

Table IV.5.Comparsion of weight

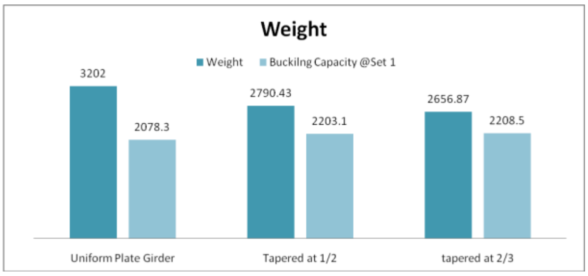
Span (20)			
Sr. No.	Geometry	Weight	Buckling Load @ set 1
1	uniform web depth	3202	1052.5
2	tapered at 1/2	2790.43	1054.6
3	tapered at 2/3	2656.87	1055.99



Grapg.IV.7. Comparision of weight and buckling load for single span plate girder

Table IV.5.Comparsion of weight

Span (20)			
Sr. No.	Geometry	Weight	Buckling Load @ set 1
1	uniform web depth	3202	2078.3
2	tapered at 1/2	2790.43	2203.1
3	tapered at 2/3	2656.87	2208.5



Grapg.IV.8. Comparision of weight and buckling load for multi span plate girder

V. CONCLUSION

A study has been carried out to determine the buckling strength and economy of tapered web plate girder. Three different cases have been analyzed using ANSYS. The results obtained are then compared with standard web plate girder. The study leads to following conclusions

1.It is concluded that tapering the web as per profile in the present study there is not much difference in displacement as well as buckling resistance.

2. However tapering the web reduces weight of the girder by about 12%

3. Thus tapering of web will be economical by weight but showing not much variation in the buckling resistance.

REFERENCES

[1] Bedynek , E. Real, E. Mirambel "Tapered plate girders under shear: Tests and numerical research" *Engineering Structures 46[2013]350-358*

[2] Anı´sio Andrade a, Dinar Camotim b, P. Borges Dinis, (2007) " Lateral-torsional buckling of singly symmetric web-tapered thin-walled I-beams: 1D model vs. shell FEA" *Computers and Structures 85, 1343–1359.*

[3] Siu lai chan1 (1990), " Buckling analysis of structures composed of tapered members" *Journal of Structural Engineering, ASCE Vol. 116, No.*

[4] Sung C.Lee and Chai H.Yoo (1990), "strength of plate girder web panels under pure shear" *Journal Of Structural Engineering*

[5] Dimos Polyzois1 and Ioannis G. Raftoyiannis (1990), "Lateral-torsional stability of steel web-tapered I-beams."

[6] Mark a. Bradford and Peter e. Cuk, "Elastic buckling of tapered mono-symmetric i-beams" *Journal of Structural Engineering, Vol.114, No. 5, May, 1988.*

Books:

[1] S.K Duggal *"Limit state design of steel structures"*, Tata McGraw Hill Education Private Limited, New Delhi

[2] M.R. Shiyekar *"Limit state Design in Structural Steel"*, PHI Learning Private Limited, New Delhi.

[3] N. Subramanian *"Steel Structures Design and Practice"*, Oxford University Press, New Delhi.