

Design Aid for Unstiffened Triangular Steel Brackets based on Elastic Stability

K. Sai Vivek* and K. Siva Kiran

Department of Civil Engineering, Kallam Haranadhareddy Institute of Technology,
Chowdavaram, Guntur-522019, A.P., India.

Abstract

Steel triangular brackets are used for various connections in steel structures. The brackets when subjected to load may undergo buckling. Providing inadequate thickness may result in buckling failure of the bracket. Hence using a simple elastic stability theory, the required thicknesses of unstiffened triangular steel brackets for various depths, aspect ratios and grades of steel are presented, which serve as a design aid for practicing engineers.

Keywords: Aspect ratio, Buckling, Elastic stability, Triangular bracket, Unstiffened

I. INTRODUCTION

Steel triangular brackets are used to support a beam at some eccentricity to column (Gantry girder to column connection), stiffened seated connections and

base plate to column connections (Gusseted base). The brackets may be unstiffened or stiffened.

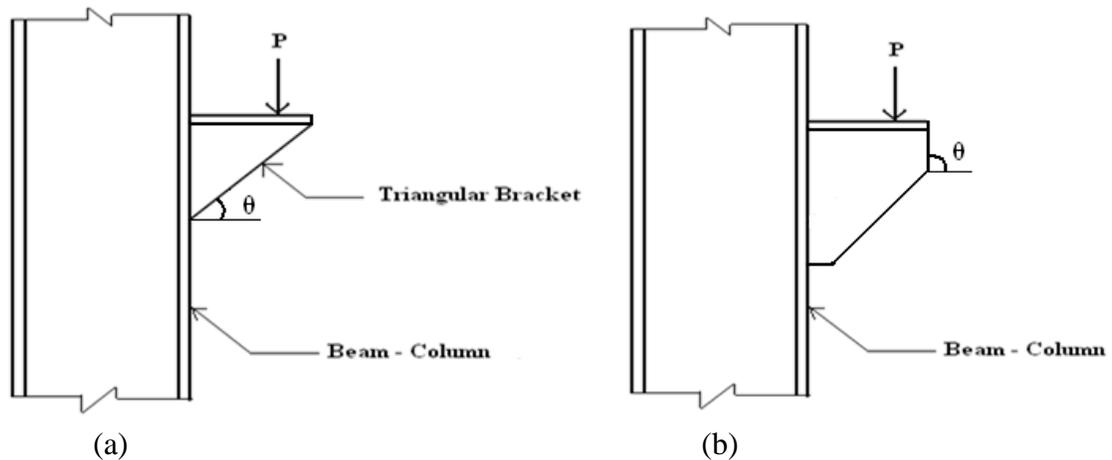


Figure 1: Bracket to Column connection

The angle of cut (θ) in typical unstiffened triangular brackets is less than 90° as shown in Figure 1(a). The bracket may also be cut such that the angle of cut equal to 90° as shown in Figure 1(b). A bracket when subjected to load may fail by buckling. The bracket may buckle before yielding occurs (elastic buckling) or after some portion of the bracket has yielded (inelastic buckling). The bracket should be designed such that, buckling failure does not occur. The elastic and inelastic behavior of the triangular brackets has been studied by Salmon and et al. [1], Martin [2], Raghupathi [3] and Shakia and Vinnakota [4]. In this paper, design

method based on elastic stability is considered. Critical thicknesses of the unstiffened triangular brackets are determined for various aspect ratios and depths. The critical thicknesses are presented in tables for various grades of steel which serve as design aid for practicing engineers. The aspect ratio of the triangular brackets normally lies between 0.5 and 2.0. Aspect ratio of bracket shown in Figure 2(a) is d/a .

II. DESIGN METHOD BASED ON ELASTIC STABILITY

Raghupathi [3] proposed design methodology for triangular brackets based on elastic stability. The buckling coefficient is estimated from the flexural deflection of triangular plates under a uniformly

distributed transverse load. The flexural deflection of the bracket depends upon the stiffness of the plate. The buckling coefficient for a triangular plate/bracket was assumed to be 2.5 [5]. The assumed coefficient is valid for the range of aspect ratio 0.5 to 2.0. The critical stress at which plate may buckle is determined from

$$\sigma_{cr} = \frac{2.5 \pi^2 E}{12 (1-\nu^2) \left(\frac{b}{t}\right)^2} \tag{1}$$

where σ_{cr} = critical stress
 E = modulus of elasticity/ young’s modulus
 ν = poisson’s ratio
 b = free edge length
 t = thickness

Equating σ_{cr} to σ_y , equation (1) can be written as

$$\sigma_y = \frac{2.5 \pi^2 E}{12 (1-\nu^2) \left(\frac{b}{t}\right)^2} \tag{2}$$

For $E = 2 \times 10^5 \text{ N/mm}^2$ and $\nu = 0.3$

$$\frac{b}{t} = \frac{672}{\sqrt{\sigma_y}}$$

Say

$$\frac{b}{t} = \frac{670}{\sqrt{\sigma_y}} \tag{3}$$

$$\text{For } \sigma_y = 250 \text{ N/mm}^2, \quad t = \frac{b}{42} = \frac{b}{40} \text{ (say)} \tag{4}$$

$$\sigma_y = 300 \text{ N/mm}^2, \quad t = \frac{b}{38.68} = \frac{b}{36} \text{ (say)} \tag{5}$$

$$\sigma_y = 350 \text{ N/mm}^2, \quad t = \frac{b}{35.8} = \frac{b}{34} \text{ (say)} \tag{6}$$

$$\sigma_y = 410 \text{ N/mm}^2, \quad t = \frac{b}{33.08} = \frac{b}{32} \text{ (say)} \tag{7}$$

Figure 2 represents the parameters of the brackets. Note that ‘a’ is the length of the loaded edge and ‘d’ is the

depth of the bracket. The bracket shown in Figure 2(b) can be idealized as a triangular bracket.

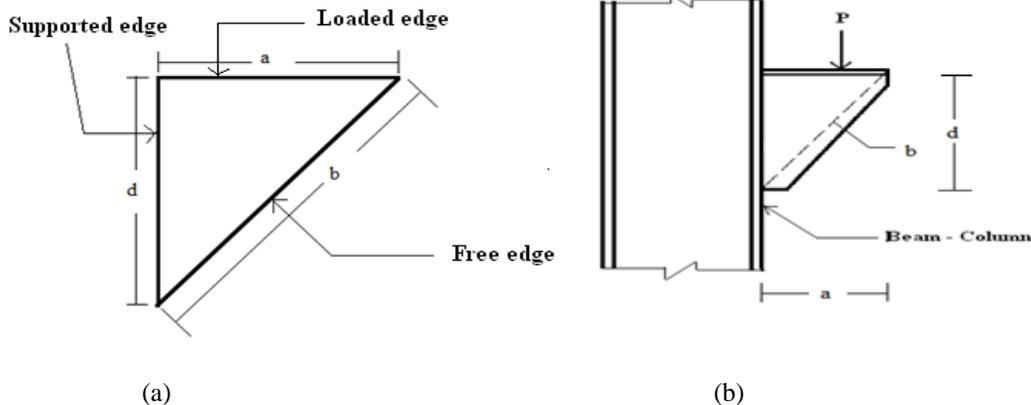


Figure 2: Parameters of brackets

III. DESIGN AID TABLES

From Equations 4-7, required thicknesses of triangular brackets with various depths, aspect ratios and grades of steel [6] are presented in Tables 1- 8, which help in design of unstiffened triangular brackets.

Table 1: Thicknesses of Triangular Brackets ($\sigma_v = 250 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
0.5	200	11.18 (11.5)
	225	12.58 (13)
	250	14.98 (15)
	275	15.37 (15.5)
	300	16.77 (17)
	325	18.17 (18)
	350	19.57 (20)
	375	20.96 (21)
	400	22.36 (22.5)
	425	23.75 (24)
	450	25.16 (25.5)
	475	26.55 (27)
	500	27.95 (28)
	525	29.35 (29.5)
	550	30.75 (31)
1.0	200	7.08 (7)
	225	7.97 (8)
	250	8.85 (9)
	275	9.74 (10)
	300	10.62 (11)
	325	11.51 (12)
	350	12.39 (12.5)
	375	13.28 (13.5)
	400	14.16 (14.5)
	425	15.05 (15)
	450	15.93 (16)
	475	16.82 (17)
	500	17.7 (18)
	525	18.59 (19)
	550	19.47 (19.5)
575	20.36 (20.5)	
600	21.24 (21.5)	

Table 2: Thicknesses of Triangular Brackets ($\sigma_v = 250 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
1.5	200	6 (6)
	225	6.75 (7)
	250	7.5 (7.5)
	275	8.25 (8.5)
	300	9 (9)
	325	9.75 (10)
	350	10.5 (10.5)
	375	11.25 (11.5)
	400	12 (12)

	425	12.75 (13)
	450	13.5 (13.5)
	475	14.25 (14.5)
	500	15 (15)
	525	15.75 (16)
	550	16.5 (16.5)
	575	17.25 (17.5)
	600	18 (18)
2.0	200	5.58 (6)
	225	6.28 (6.5)
	250	6.98 (7)
	275	7.67 (8)
	300	8.37 (8.5)
	325	9.07 (9.0)
	350	9.77 (10)
	375	10.46 (10.5)
	400	11.16 (11.5)
	425	11.86 (12)
	450	12.56 (13)
	475	13.25 (13.5)
	500	13.95 (14)
	525	14.65 (15)
	550	15.35 (15.5)
	575	16.04 (16)
	600	16.74 (17)

Table 3: Thicknesses of Triangular Brackets ($\sigma_v = 300 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
0.5	200	12.42 (12.5)
	225	13.97(14)
	250	15.53 (16)
	275	17.08 (17)
	300	18.63 (19)
	325	20.18 (20.5)
	350	21.74 (22)
	375	23.28 (23.5)
	400	24.84 (25)
	425	26.39 (26.5)
	450	27.94 (28)
	475	29.49 (29.5)
	500	31.05 (31)
	525	32.60 (33)
	550	34.16 (34.5)
	575	35.71 (36)
	600	37.26 (37.5)
1.0	200	7.86 (8)
	225	8.85 (9)
	250	9.83 (10)
	275	10.81 (11)
	300	11.79 (12)
	325	12.77 (13)
	350	13.76 (14)
	375	14.74 (15)
	400	15.72 (16)

	425	16.70 (17)
	450	17.69 (18)
	475	18.67 (19)
	500	19.65 (20)
	525	20.63 (21)
	550	21.62 (22)
	575	22.6 (23)
	600	23.6 (24)

Table 4: Thicknesses of Triangular Brackets ($\sigma_v = 300 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
1.5	200	6.66 (7)
	225	7.49 (7.5)
	250	8.33 (8.5)
	275	9.16 (9.5)
	300	9.99 (10)
	325	10.82 (11)
	350	11.66 (12)
	375	12.49 (13)
	400	13.32 (13.5)
	425	14.15 (14.5)
	450	14.99 (15)
	475	15.82 (16)
	500	16.65 (17)
	525	17.48 (18)
550	18.32 (18.5)	
575	19.15 (19.5)	
600	19.98 (20)	
2.0	200	7.86 (8)
	225	8.84 (9)
	250	9.83 (10)
	275	10.81 (11)
	300	11.79 (12)
	325	12.77 (13)
	350	13.76 (14)
	375	14.74 (15)
	400	15.72 (16)
	425	16.70 (17)
	450	17.69 (18)
	475	18.67 (19)
	500	19.65 (20)
	525	20.63 (21)
550	21.62 (22)	
575	22.60 (23)	
600	23.58 (24)	

Table 5: Thicknesses of Triangular Brackets ($\sigma_v = 350 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
0.5	200	13.2 (13)
	225	14.85 (15)
	250	16.5 (16.5)
	275	18.15 (18.5)
	300	19.8 (20)
	325	21.45 (21.5)
	350	23.1 (23.5)
	375	24.75 (25)
	400	26.4 (26.5)
	425	28.05 (28)
	450	29.7 (30)
	475	31.35 (31.5)
	500	33 (33)
	525	34.65 (35)
	550	36.3 (37)
	575	37.95 (38)
600	39.6 (40)	
1.0	200	8.32 (8.5)
	225	9.36 (9.5)
	250	10.4 (10.5)
	275	11.44 (11.5)
	300	12.48 (12.5)
	325	13.52 (13.5)
	350	14.56 (15)
	375	15.6 (16)
	400	16.64 (17)
	425	17.68 (18)
	450	18.72 (19)
	475	19.76 (20)
	500	20.8 (21)
	525	21.84 (22)
	550	22.88 (23)
	575	23.92 (24)
600	24.96 (25)	

Table 6: Thicknesses of Triangular Brackets ($\sigma_v = 350 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
1.5	200	7 (7)
	225	7.88 (8)
	250	8.75 (9)
	275	9.63 (10)
	300	10.5 (10.5)
	325	11.38 (11.5)
	350	12.25 (12.5)
	375	13.13 (13.5)
	400	14 (14)
	425	14.88 (15)
	450	15.75 (16)
	475	16.63 (17)
	500	17.5 (18)
	525	18.38 (18.5)
	550	19.25 (19.5)

	575	20.13 (20.5)
	600	21 (21)
2.0	200	6.6 (7)
	225	7.43 (7.5)
	250	8.25 (8.5)
	275	9.08 (9)
	300	9.9 (10)
	325	10.73 (11)
	350	11.55 (12)
	375	12.38 (13)
	400	13.2 (13)
	425	14.03 (14)
	450	14.85 (15)
	475	15.68 (16)
	500	16.5 (16.5)
	525	17.33 (17.5)
	550	18.15 (18.5)
	575	18.98 (19)
	600	19.8 (20)

Table 7: Thicknesses of Triangular Brackets ($\sigma_v = 410 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
0.5	200	14 (14)
	225	15.75 (16)
	250	17.5 (17.5)
	275	19.25 (19.5)
	300	21 (21)
	325	22.75 (23)
	350	24.5 (25)
	375	26.25 (26.5)
	400	28 (28)
	425	29.75 (30)
	450	31.5 (32)
	475	33.25 (33.5)
	500	35 (35)
	525	36.75 (37)
	550	38.5 (39)
	575	40.25 (40.5)
	600	42 (42)
1.0	200	8.8 (9)
	225	9.9 (10)
	250	11 (11)
	275	12.1 (12.5)
	300	13.2 (13)
	325	14.3 (14.5)
	350	15.4 (15.5)
	375	16.5 (16.5)
	400	17.6 (18)
	425	18.7 (19)
	450	19.8 (20)
	475	20.9 (21)
	500	22 (22)
	525	23.1 (23.5)
	550	24.2 (24.5)

	575	25.3 (25.3)
	600	26.4 (26.5)

Table 8: Thicknesses of Triangular Brackets ($\sigma_y = 410 \text{ N/mm}^2$)

(d/a)	d (mm)	t (mm)
1.5	200	7.6 (8)
	225	8.55 (9)
	250	9.5 (9.5)
	275	10.45 (10.5)
	300	11.4 (11.5)
	325	12.35 (12.5)
	350	13.3 (13.5)
	375	14.25 (14.5)
	400	15.2 (15.5)
	425	16.15 (16)
	450	17.1 (17.5)
	475	18.05 (18)
	500	19 (19)
	525	19.95 (20)
	550	20.9 (21)
2.0	575	21.85 (22)
	600	22.8 (23)
	200	7 (7)
	225	7.88 (8)
	250	8.75 (9)
	275	9.63 (10)
	300	10.5 (11)
	325	11.38 (11.5)
	350	12.25 (12.5)
	375	13.13 (13.5)
	400	14 (14)
	425	14.88 (15)
	450	15.75 (16)
	475	16.63 (17)
	500	17.5 (17.5)
525	18.38 (18.5)	
550	19.25 (19.5)	
575	20.13 (20.5)	
600	21 (21)	

IV. EXAMPLES

Example 1: Determine the thickness of a welded triangular bracket shown in Figure 4. Modulus of elasticity is $2 \times 10^5 \text{ N/mm}^2$ and yield stress is 250 N/mm^2 .

Solution: From Figure 4, $a = 200 \text{ mm}$
 $d = 300 \text{ mm}$

$$\begin{aligned} \text{Free edge length (b)} &= \sqrt{(200^2 + 300^2)} \\ &= 360.55 \text{ mm} \\ &= 362 \text{ mm (Say)} \end{aligned}$$

$$\text{Aspect ratio} = (d/a) = 300/200 = 1.5$$

From Table 2, $t = 9 \text{ mm}$.

$$\text{Or } t = b/40 \text{ (for } \sigma_y = 250 \text{ N/mm}^2\text{)}$$

$$\Rightarrow t = 362/40 = 9.05 \text{ mm.}$$

Hence, theoretically bracket of 9 mm thickness may be provided.

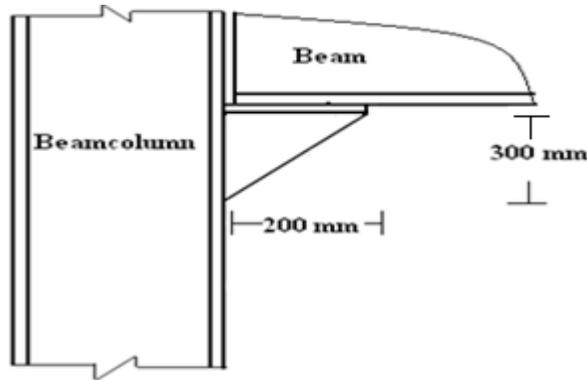


Figure 4: Seat Connection

Example 4.2: Determine the thickness of a welded bracket shown in figure 5. Modulus of elasticity is $2 \times 10^5 \text{ N/mm}^2$ and yield stress is 250 N/mm^2 .

Solution: From Figure 5, $a = 250 \text{ mm}$
 $d = 350 \text{ mm}$
 Free edge length $(b) = \sqrt{(250^2 + 350^2)}$
 $= 430 \text{ mm}$
 Aspect ratio $(d/a) = 350/250 = 1.4$

From Table: 2 ,
 for $(d/a) = 1.5$, thickness for $d = 350 \text{ mm}$ is 10.5 mm
 for $(d/a) = 1.0$, thickness for $d = 350 \text{ mm}$ is 12.5 mm
 By interpolation,
 For $(d/a) = 1.4$, $t = 10.9 \text{ mm}$.
 Or $t = b/40$; $t = 430/40 = 10.75 \text{ mm}$.
 Hence, theoretically bracket of 11 mm thickness may be provided.

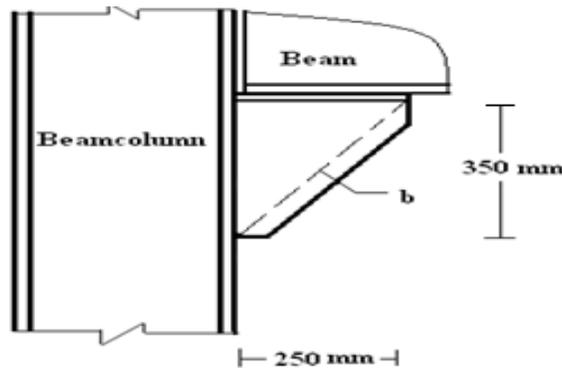


Figure 5: Seat Connection

V. CONCLUSIONS

The following inferences could be drawn from observing the Tables 1-8

- The required thickness increases with decrease in aspect ratio for the same depth of bracket
- Higher yield strength steel results in thicker brackets for the same aspect ratio

REFERENCES

- [1] Salmon. C.G, "Analysis of Triangular Bracket-Type Plates", Journal of Engineering Mechanics Division, Vol.88, pp. 41-87, 1962.
- [2] Martin. L. H. "Methods for Limit State Design of Triangular Steel Gusset Plates", Building and Environment, Vol.14, pp.147-155, 1979.
- [3] Raghupathi. M, "Design of Steel Structures", Tata McGraw-Hill, 1995.
- [4] Shakia.S and Vinnakota.S, "Design Aid for Triangular Bracket Plates Using AISC Specifications", Engineering Journal, 3rd Quarter, pp. 187- 196, 2008.
- [5] Timoshenko.S and Woinowsky Krieger.S, "Theory of Plates and Shells", McGraw-Hill, 1959.
- [6] "IS 2062- 2006: Hot rolled low, medium and high tensile structural steel", in, New Delhi: Bureau of Indian Standards.

