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Parts and Assemblies Engineering (Mr. Dukhnovskiy Denis)
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Report of LAB 1

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1 Problem Statement

Variant No.: 5

Table 1: List of variant

Variants	L, mm	H, mm	a, mm	P_1, N	P_2, N
5	5000	350	1000	4000	30000

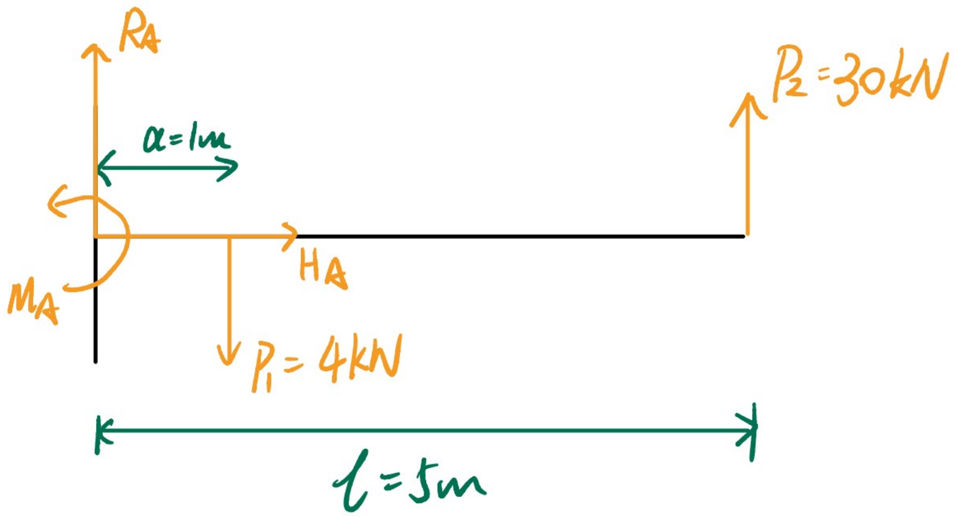

Figure 1: The setting of problem

The geometry section of the variant is shown in Fig. (2), which is a rectangular equilateral T-Bar section based on ГОСТ 13622 - 90.

2 Material Selection

The material of the caps is set to be BT20 titanium since this material has a high ultimate tensile strength and the material of the web is set to be Д16T aluminum alloy since this material is easy to process. The detailed parameters of these materials are shown in Fig. (3).

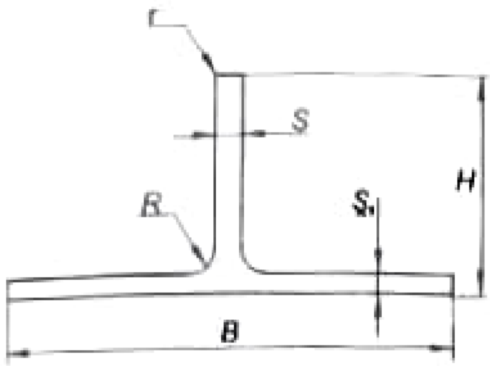

Figure 2: The geometry section of the variant

Material	Ultimate tensile strength σ_B, MPa	Proof strength σ_{02}, MPa	Shear strength* τ_B, τ_{02} (% of tensile strength)	Modulus of elasticity E, GPa	Shear modulus G, GPa	Density, ρ g/cm^3
30ХГСА	1100	850	63	210	78	7,85
Д16Т	450	300	50	72	28	2,8
ВТ20	1000	910	50	110	44	4,5

* - ultimate shear strength and proof strength are approximated by taking the denoted percentage of tensile ultimate and proof strength respectively

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Figure 3: Table of material

3 Calculations

3.1 Define the loading

$$P_2 \cdot L - P_1 \cdot a = M_{\text{C-C}} = M(0) = 146\text{kN} \cdot \text{m}, \tag{1}$$

$$P_2 \cdot (L - a) = M(a) = M(1) = 120\text{kN} \cdot \text{m}. \tag{2}$$

The load diagram is shown as Fig. (4). We can calculate the moment on the other two sections of

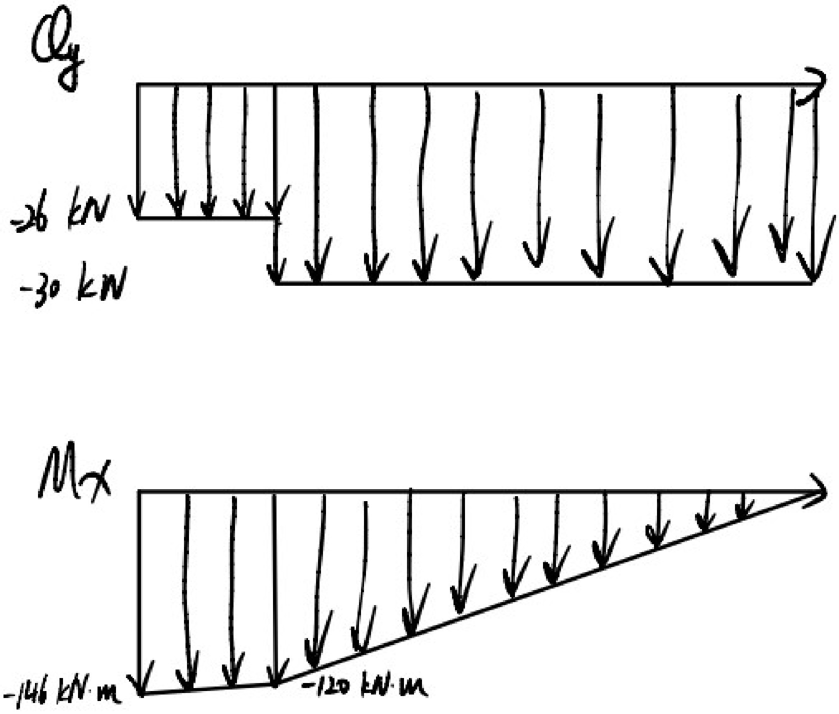


Figure 4: Load diagram

the bar, which are

$$M_{\text{B-B}} = M(0.5) = P_2 \cdot (L - 0.5) - P_1 \cdot (a - 0.5) = 133\text{kN} \cdot \text{m}, \tag{3}$$

and

$$M_{\text{A-A}} = M(4) = P_2 \cdot (L - 4) = 30\text{kN} \cdot \text{m}. \tag{4}$$

3.2 Design the cap of spar

The equivalent height is

$$H_{\text{eq}} = 0.95 H_{spar} = 332.5\text{mm}. \tag{5}$$

We can find the force in the three sections we have studied as

$$F_{\text{C-C}} = F(0) = \frac{M(0)}{H_{\text{eq}}} = 439.1\text{kN}, \tag{6}$$

$$F_{\text{B-B}} = F(0.5) = \frac{M(0.5)}{H_{\text{eq}}} = 400.0\text{kN}, \tag{7}$$

and

$$F_{\mathrm{A-A}} = F(4) = \frac{M(4)}{H_{\mathrm{eq}}} = 90.2\mathrm{kN}. \quad (8)$$

The ultimate tensile strength of the cap $[\sigma_{\mathrm{ult}}] = 1000\mathrm{MPa}$ according to Table (3), thus the ultimate section area of the cap for the three sections are,

$$A_{\mathrm{C-C,ult}} = \frac{F_{\mathrm{C-C}}}{[\sigma_{\mathrm{ult}}]} = 439.1\mathrm{mm}^2, \quad (9)$$

$$A_{\mathrm{B-B,ult}} = \frac{F_{\mathrm{B-B}}}{[\sigma_{\mathrm{ult}}]} = 400.0\mathrm{mm}^2, \quad (10)$$

and

$$A_{\mathrm{A-A,ult}} = \frac{F_{\mathrm{A-A}}}{[\sigma_{\mathrm{ult}}]} = 90.2\mathrm{mm}^2. \quad (11)$$

3.3 Determine the cross-section area

According to the "Section data" file-excel and the ultimate results in Section (3.2), the cross-section area is set as $A_{\mathrm{C-C}} = A_{\mathrm{B-B}} = 449.1\mathrm{mm}^2$ and $A_{\mathrm{A-A}} = 247.2\mathrm{mm}^2$, as shown in Table (2).

Table 2: Rectangular Equilateral T-Bar Sections ГОСТ 13622 - 90

No.	Number of Profile	H	B	S	$S1$	R	r	Cross-sectional Area, mm^2	Weight, kg/m	Moment of Inertia, cm^4	
		mm								I_x	I_y
5	420159	26	40	3.0	4.5	2.5	0.0	247.2	0.704	1.44	1.05
10	420325	40	50	3.5	6.5	4.0	0.0	449.1	1.280	4.65	6.78

3.4 Check stress safety factor

$$\eta_{\mathrm{C-C}} = \frac{[\sigma_{\mathrm{ult}}]}{F_{\mathrm{C-C}}/A} = \frac{1000}{977.7} = 1.02, \quad (12)$$

$$\eta_{\mathrm{B-B}} = \frac{[\sigma_{\mathrm{ult}}]}{F_{\mathrm{B-B}}/A} = \frac{1000}{890.67} = 1.12, \quad (13)$$

$$\eta_{\mathrm{A-A}} = \frac{[\sigma_{\mathrm{ult}}]}{F_{\mathrm{A-A}}/A} = \frac{1000}{364.9} = 2.74. \quad (14)$$

3.5 Local buckling for cap of spar

The local buckling for the cap is

$$\sigma_{\mathrm{loc}} = \frac{0.9kE}{(b/\delta)^2}, \quad (15)$$

where $b = \frac{B-S}{2}$, $k \approx 0.45$, $\delta = S1$ and $E_{\mathrm{cap}} = 110\mathrm{GPa}$. Therefore,

$$\sigma_{\mathrm{loc,C-C}} = \sigma_{\mathrm{loc,B-B}} = \frac{0.9 \cdot 0.45 \cdot 110}{(23.25/6.5)^2} = 3.482\mathrm{GPa}, \quad (16)$$

$$\sigma_{\mathrm{loc,A-A}} = \frac{0.9 \cdot 0.45 \cdot 110}{(18.5/4.5)^2} = 2.636\mathrm{GPa}. \quad (17)$$

The safety factor for the cap then would be

$$\eta_{\text{buckling,C-C}} = \frac{\sigma_{\text{loc,C-C}}}{\sigma_{\text{C-C}}} \geq 1, \tag{18}$$

$$\eta_{\text{buckling,B-B}} = \frac{\sigma_{\text{loc,B-B}}}{\sigma_{\text{B-B}}} \geq 1, \tag{19}$$

$$\eta_{\text{buckling,A-A}} = \frac{\sigma_{\text{loc,A-A}}}{\sigma_{\text{A-A}}} \geq 1. \tag{20}$$

3.6 Design web of spar

The shear stress in the web is

$$\tau_{\text{web}} = \frac{Q}{H_{\text{eq}} \cdot \delta_{\text{web}}}. \tag{21}$$

The ultimate shear strength of the web $[\tau_{\text{ult}}] = 225\text{MPa}$ according to Table (3), thus thus the ultimate thickness of the web for the three sections are

$$\delta_{\text{C-C,ult}} = \frac{Q}{H_{\text{eq}} \cdot [\tau_{\text{ult}}]} = \frac{26}{332.5 \cdot 225} = 0.35\text{mm}, \tag{22}$$

and

$$\delta_{\text{B-B,ult}} = \delta_{\text{A-A,ult}} = \frac{Q}{H_{\text{eq}} \cdot [\tau_{\text{ult}}]} = \frac{30}{332.5 \cdot 225} = 0.4\text{mm}. \tag{23}$$

For the sake of safety, we round up the thickness of the web to $\delta = 2.8\text{mm}$. Therefore, the area of the web is

$$A_{\text{web}} = H_{\text{eq}} \cdot \delta = 332.5 \cdot 2.8 = 931\text{mm}^2, \tag{24}$$

and the shear stress on the web is

$$\tau_{\text{C-C}} = \frac{F}{A_{\text{web}}} = \frac{26}{931} \times 10^3 = 27.93\text{MPa}, \tag{25}$$

and

$$\tau_{\text{B-B}} = \tau_{\text{A-A}} = \frac{F}{A_{\text{web}}} = \frac{30}{931} \times 10^3 = 32.22\text{MPa}. \tag{26}$$

3.7 Check the Stress safety factor for web

$$\eta_{\text{C-C}} = \frac{[\tau_{\text{ult}}]}{\tau_{\text{C-C}}} = \frac{225}{27.93} = 8.06, \tag{27}$$

$$\eta_{\text{B-B}} = \eta_{\text{A-A}} = \frac{225}{32.22} = 6.98. \tag{28}$$

3.8 Local buckling of the web without stiffeners

Local buckling shear stress in the web without stiffeners is

$$\tau_{\text{loc,web}} = \frac{0.9kE_{\text{web}}}{(b/\delta_{\text{web}})^2}, \quad k = 5.6 + \frac{3.8}{(a/b)^2}, \tag{29}$$

where $E_{\text{web}} = 72\text{GPa}$, $a = 5000$ and $b = 332.5$. Therefore,

$$\tau_{\text{loc,web}} = \frac{0.9 \cdot 5.62 \cdot 72}{(332.5/2.8)^2} = 25.83\text{MPa}, \tag{30}$$

and the safety factors are

$$\eta_{\text{buckling,C}-\text{C}} = \frac{\tau_{\text{loc,web}}}{\tau_{\text{C}-\text{C}}} = \frac{25.83}{27.93} = 0.92 \leq 1, \tag{31}$$

and

$$\eta_{\text{buckling,B}-\text{B}} = \eta_{\text{buckling,A}-\text{A}} = \frac{\tau_{\text{loc,web}}}{\tau_{\text{C}-\text{C}}} = \frac{25.83}{32.22} = 0.80 \leq 1. \tag{32}$$

Due to that the safety factors are less than 1 but larger than 0.6, **it is necessary to add some stiffeners**.

3.9 Local buckling of the web with stiffeners

Local buckling shear stress in the web with stiffeners is

$$\tau_{\text{loc,web}} = \frac{0.9kE_{\text{web}}}{(b/\delta_{\text{web}})^2}, \quad k = 5.6 + \frac{3.8}{(a/b)^2}, \tag{33}$$

where $E_{\text{web}} = 72$GPa and $a/b = 1$ in the optimal case. We assume that $a = b = 2.5$mm, and therefore,

$$\tau_{\text{loc,web}} = \frac{0.9 \cdot 9.4 \cdot 72}{(332.5/2.8)^2} = 43.2\text{MPa}, \tag{34}$$

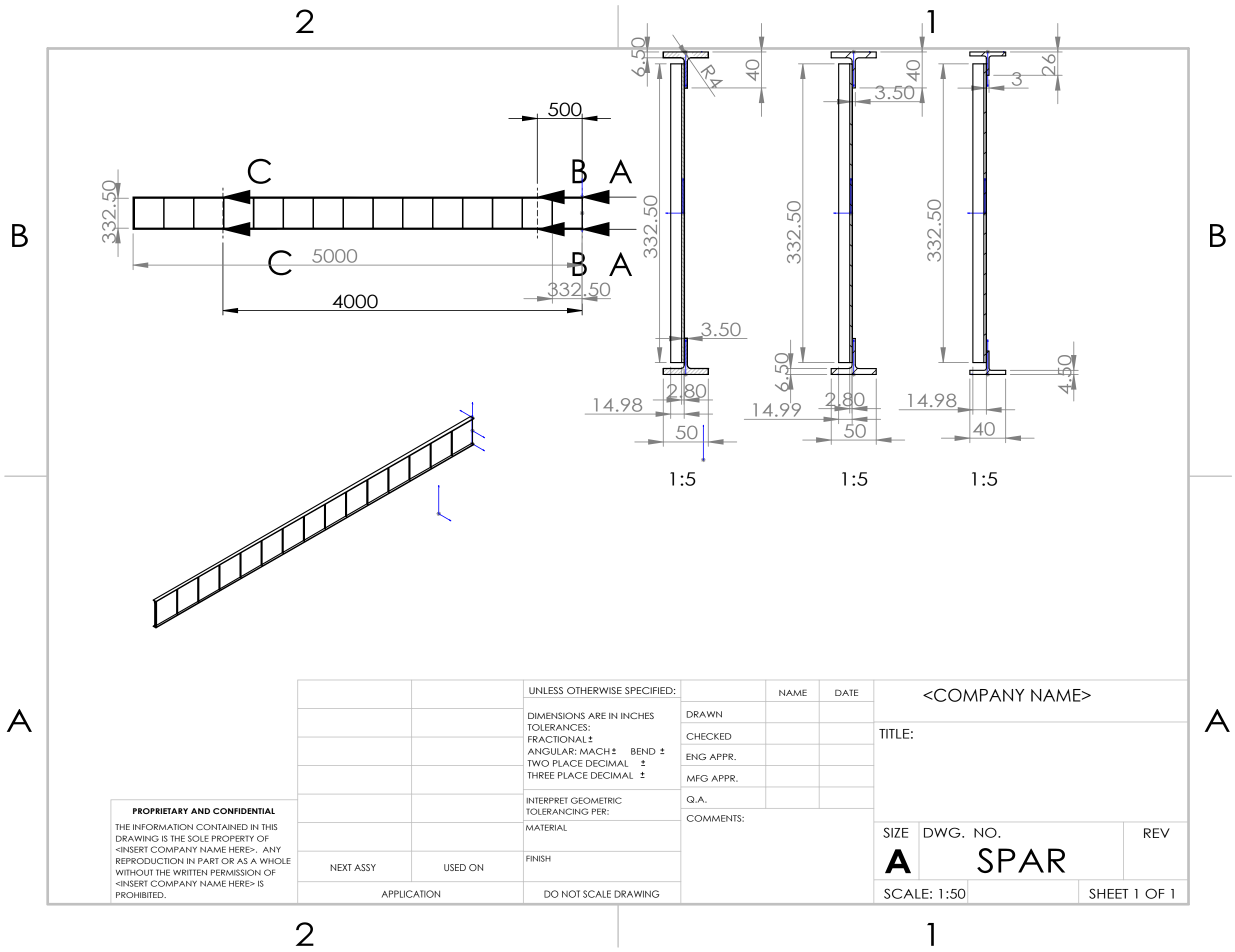
and the the safety factor is

$$\eta_{\text{buckling,C}-\text{C}} = \frac{\tau_{\text{loc,web}}}{\tau_{\text{C}-\text{C}}} = \frac{43.2}{27.93} = 1.55, \tag{35}$$

$$\eta_{\text{buckling,B}-\text{B}} = \eta_{\text{buckling,A}-\text{A}} = \frac{\tau_{\text{loc,web}}}{\tau_{\text{C}-\text{C}}} = \frac{43.2}{32.22} = 1.34. \tag{36}$$

In all, 15 stiffeners are needed.

4 Sketch



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1
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332.50
5000
4000
332.50
6.50
R4
40
3.50
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3.50
2.80
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1:5
14.99
1:5
26
3
14.98
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4.50
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ANGULAR: MACH± BEND ±
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