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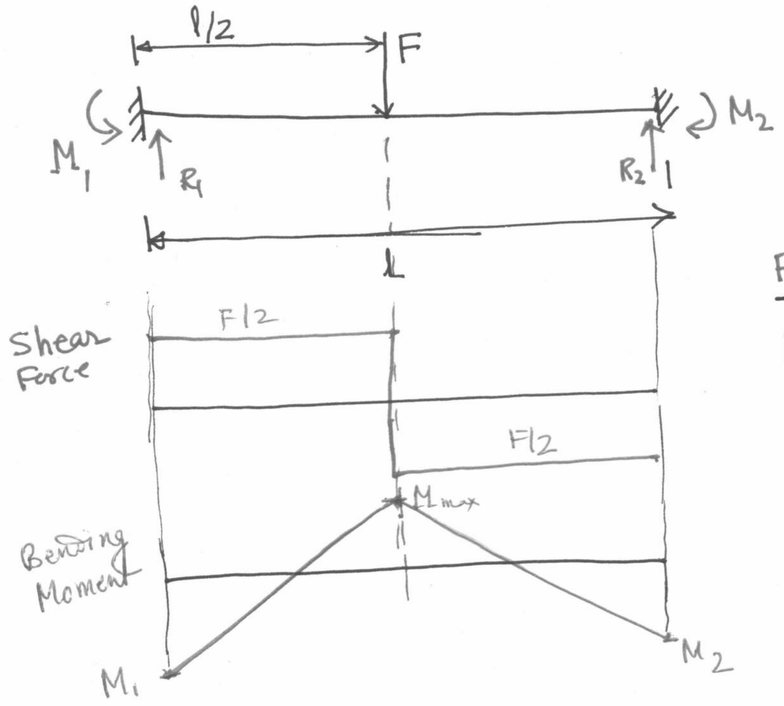
Solution: Note: - Crane position can be anywhere within the 10m span of the beam.

- Bending moment and shear force ~~reach~~ at the joint location reach maximum when crane is located at mid-span.
- Bending moment and shear force are zero when crane is close to the supports.



F = {Downward force due to Crane load.

l = 10m

From A9, Page 1019

$$\boxed{R_1 = R_2 = \frac{F}{2} \qquad M_1 = M_2 = \frac{Fl}{8} = M_{max}}$$

$\Rightarrow$ $M_{max} = 1.25F$, $V_{max} = \frac{F}{2}$, shared by two plates

When Crane is near the supports: $M = 0, V = 0$

Material Properties: For plate and beam AISI 1050 HR steel.

$\Rightarrow$ $\boxed{S_{ut} = 620 \text{ MPa}, \quad S_y = 340 \text{ MPa}}$ (Table A20)

$\Rightarrow$ (a) Choose Electrode: E60XX $\Rightarrow$ $\boxed{S_y = 345 \text{ MPa}; S_{ut} = 427 \text{ MPa}}$ Table - 9.3

Filleted weld joint, legsize $= h = 10$ mm = Plate thickness.

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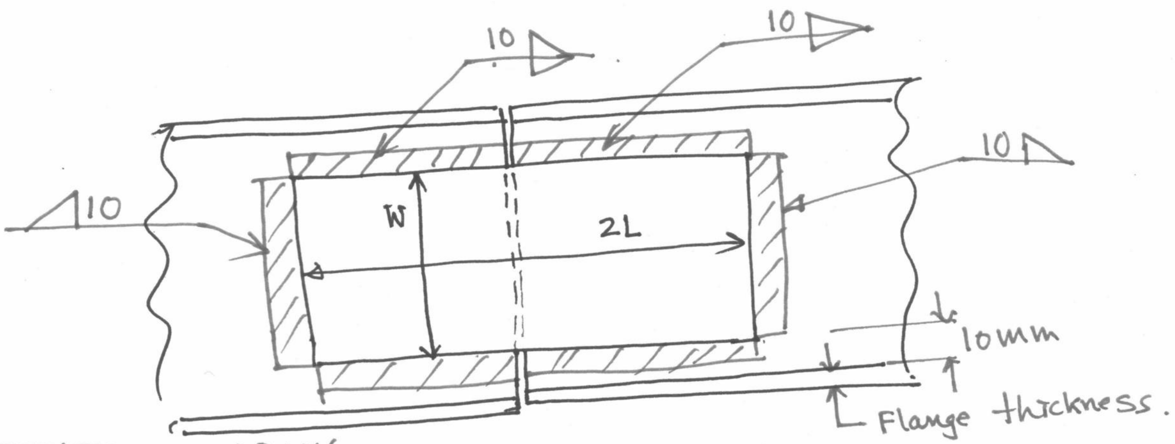

(b) STATIC LOADING

For W250X44.8 I-Beam :

$$\boxed{\begin{array}{l} \text{Depth} = 267\text{ mm} \\ \text{Flange Thickness} = 13\text{ mm} \\ I = 70.8\times10^{-6}\ m^4 \end{array}}$$ (given on page 2)

$$\Rightarrow \quad W \le (267 - 2\times13 - 2\times10)\text{ mm} = 221\text{ mm}.$$

Choose : $\boxed{W = 220\text{ mm},\ L = 250\text{ mm}}$ $t = 10\text{mm}.$

$$\Rightarrow \quad I_{plate} = \frac{bh^3}{12} = \frac{10\times(220)^3}{12} = \underline{8.873\times10^{-6}}\ m^4$$

At the welded joint : $\boxed{M = 1.25F,\ V = \frac{F}{2},\ F_{axial} = 10kN}$

This is shared by two plates.

$\Rightarrow$ For each plate : $\boxed{M = 0.625F,\ V = \frac{F}{4},\ F_{axial} = 5kN}$

(i) Design for plate strength :

$$\sigma_{bending}\Big|_{max} = \frac{Mc}{I} = \frac{0.625F\times220\times10^{-3}}{2\times8.873\times10^{-6}}\ N/m^2$$

$$= 7748.2F\ N/m^2$$

$$\sigma_{axial} = \frac{5\times10^3}{10\times220\times10^{-6}} = 2273\times10^3\ N/m^2$$

$$\Rightarrow \quad \sigma_{max} = \left(\sigma_{bending}\Big|_{max} + \sigma_{axial}\right) = \underline{(7.748F + 2273)\times10^3}\ N/m^2$$

Factor of Safety = 2 : $\sigma_{max} \le \frac{S_y}{2}$

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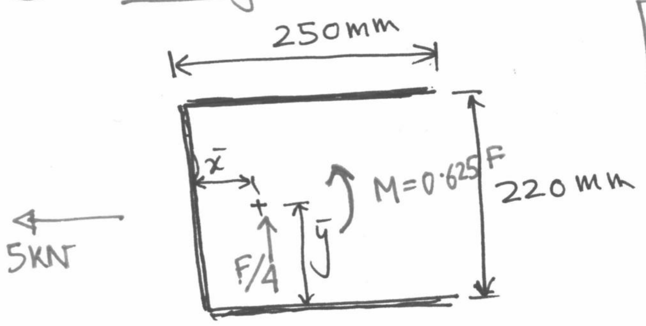
$$\Rightarrow \left(7.748F + 2273\right)\times 10^3 \leq \frac{340}{2}\times 10^6$$

$$\Rightarrow \boxed{F \leq 21.647 \text{ kN}}$$

(ii) Design based on weld metal failure:



$$J = \left(\frac{8b^3+6bd^2+d^3}{12} - \frac{b^4}{(2b+d)}\right) = 11.929\times 10^6 \text{ mm}^3$$

$$\bar{A} = (0.707h)(2b+d) = 5.09\times 10^{-3} \text{ m}^2$$

$$\bar{x} = \frac{b^2}{2b+d} = 86.81 \text{ mm}$$

$$\bar{y} = \frac{d}{2} = 110 \text{ mm}$$

(From Table 9-1, (4))

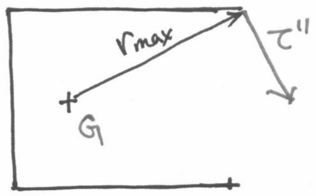
$\Rightarrow$ Primary stresses: $\tau_1' = \dfrac{5\times 10^3}{5090\times 10^{-3}}$ N/m^2 $= 0.982$ MPa. (Horizontal)

$\tau_2' = \dfrac{F}{4A} = 49.1F$ MPa (vertical)

Secondary Shear: $J = (0.707h)J_u = 84.338\times 10^{-6}$ m^4

$$\tau'' = \frac{(0.625F)r}{J} = 7410.66\,Fr \text{ N/m}^2$$

$r_{max} = \sqrt{(250-86.81)^2 + (110)^2} = 196.8$ mm



Note: Compared to τ_1' and τ_2', Secondary shear τ'' is much higher. So, we ignore primary shear for further calculation.

$$\tau''_{max} = (7410.66\,Fr_{max}) = 1458.43\,F \text{ N/m}^2$$

$$\tau_{allowable} = \min\{0.3S_{ut},\ 0.4S_y\} = 128.1 \text{ MPa}$$

$$\Rightarrow \boxed{F \leq \frac{128.1\times 10^6}{1458.43} \text{ N} = 87.83 \text{ kN}}$$

$\Rightarrow$ Finally: $\boxed{F_{max} = 21.647 \text{ kN} \Rightarrow \text{Max Crane load} \simeq 2200 \text{ kg}}$

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(C) Fatigue Loading:

(i) For the weld material: $\boxed{K_a = a(S_{ut})^b \quad a = 57.7, \quad b = -0.718}$ (Eq. 6.19, Table 6-2).

$\Rightarrow K_a = 0.745$

$k_b = 1, \quad k_c = 0.59, \quad k_d = k_f = 1.$

Fatigue Stress Concentration Factor: $K_{fs} = 2.7$ (Table 9-5)

$\Rightarrow$ Endurance limit: $S_e = (0.745)(1)(0.59)(1)(1)\ 0.5\ S_{ut}$

$\Rightarrow \boxed{S_e \doteq 93.84 \text{ MPa}}$

$\boxed{S_{su} = 0.67 S_{ut} = 286 \text{ MPa}}$ (Eq 6-54)

$$\tau_a'' = \tau_m'' = (K_{fs}) \cdot \frac{\tau''_{max}}{2} = 42.62 \text{ MPa}.$$

$\Rightarrow$ Fatigue factor of safety: $n_f = \dfrac{1}{\dfrac{\tau_a''}{S_e} + \dfrac{\tau_m'}{S_{su}}}$

$\Rightarrow \boxed{n_f = 1.658}$ (okay)

(ii) For the Plate material:

$\underline{k_a} = 57.7\,(620)^{-0.718} = \underline{0.57}$

$k_b = 1.24\, d_e^{-0.107}$ (eq 6-20)

$d_e = 0.808\sqrt{bh} = 37.898\text{mm}$ (Table 6-3)

$k_b = 0.84$

k_c for axial component only. (use later)

$\Rightarrow S_e = (0.57)(0.84)(1)(1)(1)\ 0.5\ (620) \text{ MPa}$

$= 148.43 \text{ MPa}.$

$\sigma_{bending} = 167.73 \text{ MPa}, \quad \sigma_{axial} = \dfrac{2.273}{\underbrace{0.85}_{\text{load factor}}} \text{ MPa} = 2.67 \text{ MPa}$ (Preload)

Note:

$\Rightarrow$ σ_{axial} acts as a preload as in bolt in tension case.

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$$\sigma_a = \frac{\sigma_{bending}}{2} = 83.87 \text{ MPa}$$

$$\sigma_m = \frac{\sigma_{bending}}{2} + \sigma_{axial} = 86.54 \text{ MPa},$$

$\sigma_i = 2.67$ MPa. ← Pretension.

Fatigue factor of safety:

$$n_f = \frac{S_e (S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} = 1.42.$$

Note: ~~Sxxxx~~ n_f value would be almost the same if we ignored σ_{axial} as it is small compared to $\sigma_{bending}$. Infact; in that case $\boxed{n_f = 1.427}$

⇒ The joint is safe in fatigue loading also.

(d) If the material of the plate was AISI 1050 cold drawn steel.

Then $S_y = 580$ MPa, $S_{ut} = 690$ MPa, yield strength is ~~more~~ larger than hot-rolled steel.

However, after welding, ~~near~~ adjacent to weld material the parent metal will also be like hot-rolled, due to heat treatment.

$\boxed{\text{Hence, the calculations for hot-rolled steel case will continue to apply.}}$