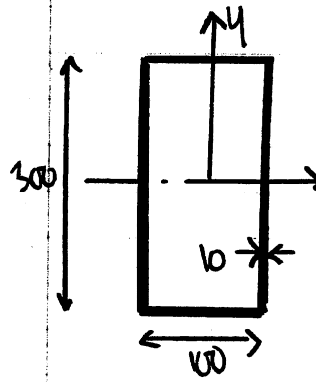
Qn 1: 4D10 2004-5



(all dimensions in mm)

$I_{xx} = \frac{100 \times 300^3}{12} - \frac{80 \times 280^3}{12} = \underline{78.7 \times 10^6 \text{ mm}^4}$

$I_{yy} = \frac{300 \times 100^3}{12} - \frac{280 \times 80^3}{12} = \underline{13.1 \times 10^6 \text{ mm}^4}$

Area $A = 300 \times 100 - 280 \times 80 = \underline{7600 \text{ mm}^2}$.

$r_x = \sqrt{\frac{I_{xx}}{A}} = \underline{101.8 \text{ mm}}$; $r_y = \sqrt{\frac{I_{yy}}{A}} = \underline{41.5 \text{ mm}}$

r_x / y (fibre dist.) $= 102/150 = \underline{0.68 (\sim 0.7)} \Rightarrow$ curve $\underline{B}$

$r_y / x = 42/50 = \underline{0.84} \Rightarrow$ curve $\underline{B}$

} welded fabrication.

a) for major axis behaviour $\underline{k = 2}$, $L_E = 2 \times l = 2 \times 5000 = 10 \times 10^3 \text{ mm}$.

$\Rightarrow \lambda = \frac{L_E}{r_x} \sqrt{\sigma_y / 355} = \frac{10000}{101.8} \sqrt{\frac{275}{355}} = \underline{86}$

$\Rightarrow \underline{\bar{\sigma}_c \simeq 0.53} \Rightarrow P_c = A \sigma_c = A \bar{\sigma}_c \sigma_y$

$= (7600 \times 1e^{-6}) \times 0.53 \times 275 \times 10^6$

$\Rightarrow \underline{P_c|_{major} = 1107.7 \text{ kN}}$

b) for minor axis behaviour $\underline{k = 0.5}$, $L_E = 2500 \text{ mm}$

$\lambda = \frac{L_E}{r_y} \sqrt{\frac{\sigma_y}{355}} = \frac{2500}{41.5} \sqrt{\frac{275}{355}} = \underline{53}$

$\Rightarrow \underline{\bar{\sigma}_c \approx 0.8} \Rightarrow P_c = A \bar{\sigma}_c \sigma_y$

$= 7600 \times \cancel{0.53}\ 0.8 \times 275$

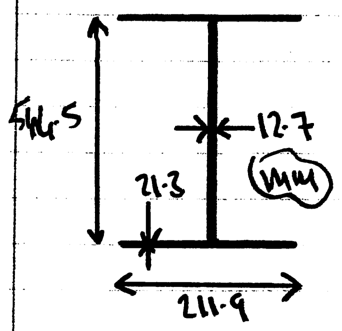
$\Rightarrow \underline{P_c|_{minor} = 1672 \text{ kN}}$

c) Bracing stiffness $> 16 P_E / L$ where $P_E = P_c / 4$

$\Rightarrow$ stiffness $= 4 P_c / L = 4 \times 1672 / 5 = \underline{1338 \text{ kN/m}}$.

(1)

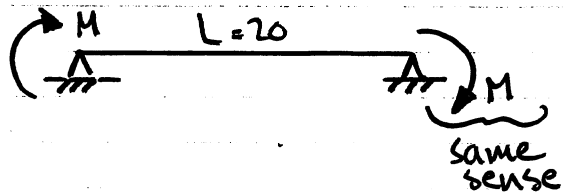
Qu 2 : 4D10 2004-5



533 x 210 x 122 UB : data book has
$\underline{I_{yy}\,(\text{minor}) = 3388\,cm^4}$; $\underline{J = 178\,cm^4}$
$\underline{Z_p = 3196\,cm^3}$

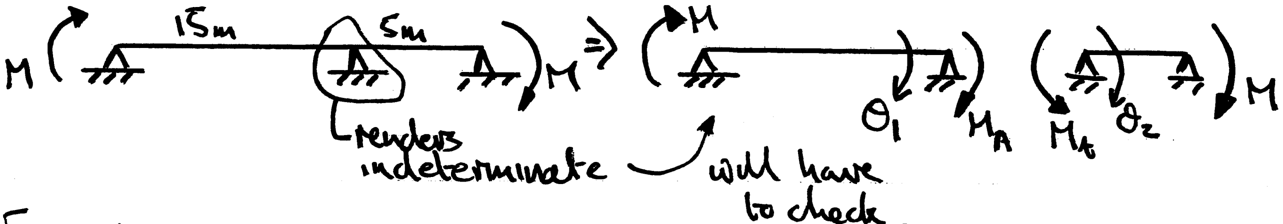
$L = 20\,m$ (initially) ; $G = 81\,GPa$, $E = 205\,GPa$
$\sigma_y = 355\,MPa$

(a) Tackle by DS2 on Lat. tors. buck



DS2 $\Rightarrow$ $\underline{\beta = -1 \Rightarrow M_u = 0.4M}$

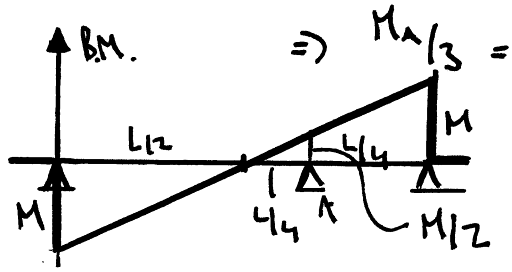
(b)



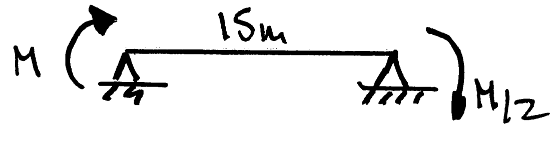
From data book :
$$\theta_1 = -\frac{M(3L/4)}{3EI}\cdot\frac{1}{2} + \frac{M_A(3L/4)}{3EI}$$
$$\theta_2 = -\frac{M_A(L/4)}{3EI} - \frac{M(L/4)}{3EI}\cdot\frac{1}{2}$$

Compatibility $\Rightarrow$ $\theta_1 = \theta_2$ $\Rightarrow$ $-\frac{3M}{24} + \frac{M_A}{4} = -\frac{M_A}{12} - \frac{M}{24}$

$\Rightarrow$ $M_A/3 = M/6$ $\Rightarrow$ $M_A = M/2$



$\Rightarrow$



DS2 $\Rightarrow$ $\beta = -1/2$ $\Rightarrow$ $\underline{M_u = 0.4M}$.

[N.B. could have determined M_A by inspecting bending moment diagram for previous case but it's not obvious that it should be M/2 from indeterminate viewpoint]

P.T.O.

(2)

Qu2: 4D10 2004-5

D = depth to mid-flanges = 544.5 (overall) − 21.3 (flange thickness)
= <u>523.2 mm</u>

DS2	(a) L = 20 m	(b) L = 15 m
$M_1 = \frac{\pi}{L}[GJEI_{yy}]^{1/2}$ (kNm)	157.2	209.6
$M_2 = \frac{\pi^2}{L^2} \cdot EDI_{yy}/2$ (kNm).	44.8	79.7
$M_E = [M_1^2 + M_2^2]^{1/2}$ (kNm)	163.5	224.2
$M_p = Z_p \sigma_y$ (kNm)	1134.6	1134.6
$\lambda_{LT} = 75[M_p/M_E]^{1/2}$	198	169
$\bar{M}_c$ $(= M_c/M_p)$ (to level of accuracy of m'ment)	~0.13	~0.16

for strength, $M \le M_p \Rightarrow M_{max}$ for both = 1134.6 kNm.

However, $M_u \le M_c$: case (a) $\underbrace{0.4M}_{M_u} \le 0.13 \cdot M_p$

$\Rightarrow$ $\underline{M_{max} = 368.7 \text{ kNm}}$

case (b) $0.4M \le 0.16M_p$

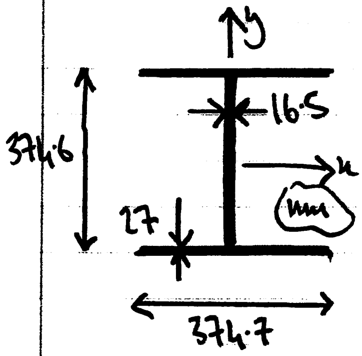
$\Rightarrow$ $\underline{M_{max} = 453.8 \text{ kNm}}$

$\Rightarrow$ (a) $M_{max} = 369$ kNm
(b) $M_{max} = 454$ kNm } stability governs

$\Rightarrow$ factor of increase of (a) → (b) = $\frac{454-369}{369} \times \frac{100}{1} \% = \underline{\underline{23\%}}$

① –

Qu 3: 4D10 2004-5



356×368×202 UC grade S355.

$I_{xx} = 66260\ cm^4$, $I_{yy} = 23690\ cm^4$
$r_x = 16.1\ cm$, $r_y = 9.6\ cm$
$y(\text{outer}) = \frac{374.6}{2}\ mm$, $x(\text{outer}) = \frac{374.7}{2}\ mm$ } S.D.Bk

Area = $257\ cm^2$; $E = 205\ GPa$, $L = 15\ m$.
$\sigma_y = 355\ MPa$.

(a) Use DS1. $L_E = L$ (k=1, pinned).

$r_x/y = 161\times2/374.6 = 0.86 \Rightarrow$ curve (A) [pre-fab sectn, hot rolled]
$r_y/x = 96\times2/374.7 = 0.51 \Rightarrow$ curve (B) " " "

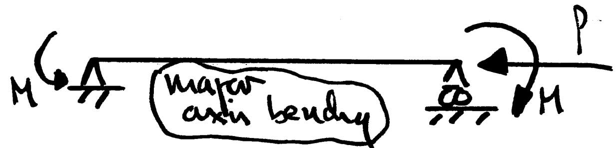
$\lambda(\text{major}) = \frac{L_E}{r_x}\sqrt{\frac{\sigma_y}{355}} = \frac{15}{0.161}\sqrt{\frac{1}{1}} = \underline{93}$

$\lambda(\text{minor}) = \frac{L_E}{r_y}\sqrt{\frac{\sigma_y}{355}} = \frac{15}{0.096}\sqrt{\frac{1}{1}} = \underline{156}$ ← critical slenderness

$\Rightarrow \bar{\sigma}_c \sim 0.2 \Rightarrow \sigma_c = 0.2\times\sigma_y$ and $P_c = A\sigma_c$

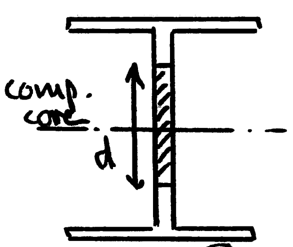
$\Rightarrow$ $\underline{P_c(\text{minor axis}) = 257\times10^{-4}\times0.2\times355\times10^6 = 1824.7\,kN}$

(b) $P = \frac{1}{2}P_c = \underline{912.4\,kN}$



[N.B. major axis bending → affect calculation of L_c by CDC method].

(i) Assume that P is carried by a compressive portion in the web alone, at yield; the depth needs to be found.



$P = \sigma_y \times d \times (0.0165)$ ~ web thickness

$\Rightarrow d = 912.4\times10^3 / 0.0165\times355\times10^6$
$= \underline{0.156\,m}$ (which is much less than depth of web.)

$\therefore \underset{\text{reduced}}{M_p'} = \overset{\text{full}}{M_p} - \sigma_y \underbrace{\frac{bd^2}{4}}_{\text{rectangular portn}}$

$\Rightarrow M_p' = \underbrace{3972\times10^{-6}}_{Z_p(m^3)}\times355\times10^6 - 355\times10^6\times\frac{1}{4}\times0.0165\times d^2$

$= \underline{\underline{1374.4\,kNm}}$.

[c.f. $M_p = Z_p\sigma_y = 1410\,kNm$]

(2)

Qu3: 4D10 2004-5

(ii) $\lambda_{web} = 375/16.5 = 22$ (< 56 ⇒ use CDC approach).

For $P = 912.4$ kN, major axis bending, $\bar{\sigma}_c = \frac{1}{2} \times 0.2 = 0.1$ part (c)

$\Rightarrow \lambda = \frac{L_c}{r_x}\sqrt{\frac{\sigma_y}{355}} = 235$ (must use curve A) $\Rightarrow L_c = 235 \times 0.161 = \underline{37.8\text{ m}}$

major axis

$L_c \equiv$ pin-ended strut length

$\Rightarrow L/L_c = 15/37.8 \simeq 0.4 \Rightarrow$ CDC UB major axis curves given, for $\beta = 1$ (equal + opposite moments).

$$\underline{M_c/M_p' = 0.71}$$

⇒ Since $M_c = M \Rightarrow \underline{M = 0.71 \times 1374.4 = 975.8\text{ kNm}}$.

If instead, interaction equation used, then must combine information for DS1 and DS2.

$$P_c = \underbrace{0.55}_{\lambda=93,\text{ curve A}} \times (355\times10^6)\times(257\times10^{-4}) = \underline{5017.9\text{ kN}}\ (\text{DS1})$$

For M_c, $M_1 = \frac{\pi}{L}[GJEI_{yy}]^{1/2} = \frac{\pi}{15}\times[81\times10^9 \times 558\times10^{-6} \times 205\times10^9 \times 23690\times10^{-8}]^{1/2}$

$= \underline{981.2\text{ kNm}}$

$M_2 = \frac{\pi^2}{L^2}E.D\,I_{yy}/2 = \frac{\pi^2}{15^2}.205\times10^9\times(\frac{23690\times10^{-8}}{2})\times\underbrace{(0.574-0.027)}_{D}$

$= \underline{369.6\text{ kNm}}$

$\Rightarrow M_E = [M_1^2 + M_2^2]^{1/2} = 1048.5\text{ kNm} \Rightarrow \lambda_{LT} = 75\sqrt{\frac{M_p}{M_E}} = \underline{87}$ full

$\Rightarrow \bar{M}_c = 0.57 \Rightarrow M_c \simeq \underline{803.7\text{ kNm}}$.

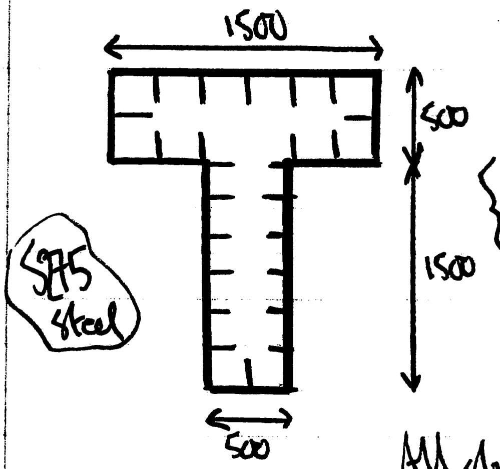
<u>For strength</u>: $\frac{P}{P_p} + \frac{M_{MAX}}{M_p} \leq 1 \Rightarrow \underline{M_{MAX} \leq 1269\text{ kNm}}$ ($P_p = A\sigma_y$; $M_{MAX} \sim M$)

<u>For stability</u> $\frac{P}{P_c} + \frac{M}{M_c} \leq 1 \Rightarrow \underline{M \leq 657.6\text{ kNm}}$.

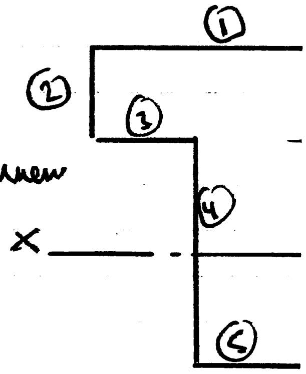
$\Rightarrow \underline{M_{max}\text{ by IE} = 658\text{ kNm}}$. much lower since more conservative

(1)

Qu 4: 4D10 2004-2005.



$\Big\{$ all thicknesses $= 10$mm



All stiffeners fully effective (=

Geometric properties of panels with smeared thicknesses to be found [labelled

Panel	no stiff.	h (smeared thick)	A (area)
1× (1)	5	40/3 mm	20000 mm²
2× (2)	1	12 "	6000 "
2× (3)	2	14 "	7000 "
2× (4)	6	14 "	21000 "
1× 5	1	12 "	6000 "

total $A = 20000 + 2\times6000 + 2\times7000 + 2\times21000 + 6000$
$= \underline{94000 \text{ mm}^2}$

$\Rightarrow A\bar{y} = \sum Ay = 20000 \times 2000 + 2\times(6000\times1$
$+ 2\times(7000\times1500) + 2\times(21$

$\Rightarrow \bar{y} = \dfrac{113.5\times10^6}{94000} = \underline{1207.4 \text{ mm}}$

I_{xx} (ignoring about own c.g. of panel hor

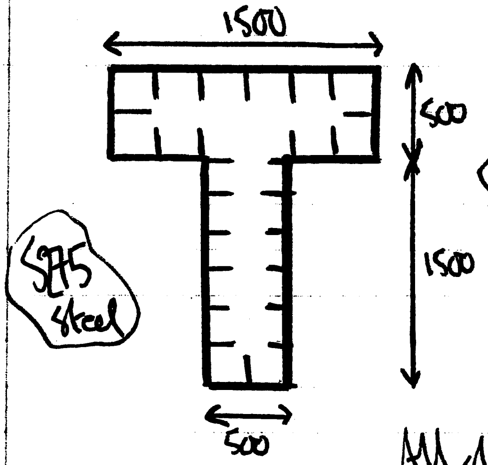
$= \underbrace{793^2\times20000}_{(1)} + 2\times\Big[\underbrace{543^2\times6000 + \tfrac{1}{12}\cdot12\times500^3}_{(2)}\Big] -$

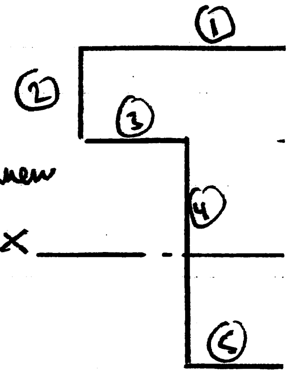
$+ 2\times\Big[\underbrace{457^2\times21000 + \tfrac{1}{12}\times14\times1500^3}_{(4)}\Big] + 1$

(|| axis, and smeared thickness of $bd^3/12$ terms) $= \underline{4.290\times10^{10}}$

①

Qu 4: 4D10 2004-2005.





All stiffeners fully effective (

Geometric properties of panels with smeared thicknesses to be found [labelled

Panel	no stiff.	h (smeared thick)	A (area)
1× ①	5	40/3 mm	20000 mm^2
2× ②	1	12 "	6000 "
2× ③	2	14 "	7000 "
2× ④	6	14 "	21000 "
1× 5	1	12 "	6000 "

total $A = 20000 + 2\times6000 + 2\times7000 + 2\times21000 + 6000$
$= \underline{94000\ mm^2}$

$\Rightarrow A\bar{y} = \sum Ay = 20000\times2000 + 2\times(6000\times17$
$+ 2\times(7000\times1500) + 2\times(21$

$\Rightarrow \bar{y} = \dfrac{113.5\times10^6}{94000} = \underline{1207.4\ mm}$

I_{xx} (ignoring about own c.g. of panel hor

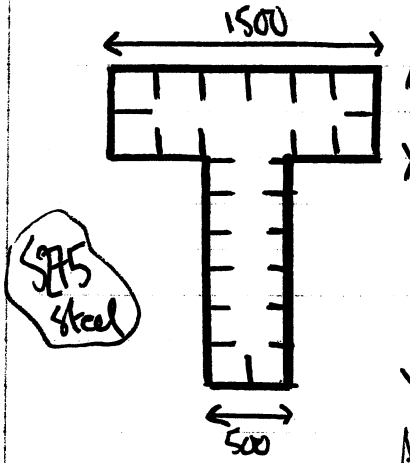
$= \underbrace{793^2\times20000}_{①} + 2\times\Big[\underbrace{543^2\times6000 + \tfrac{1}{12}\cdot12\times500^3}_{②}\Big] -$

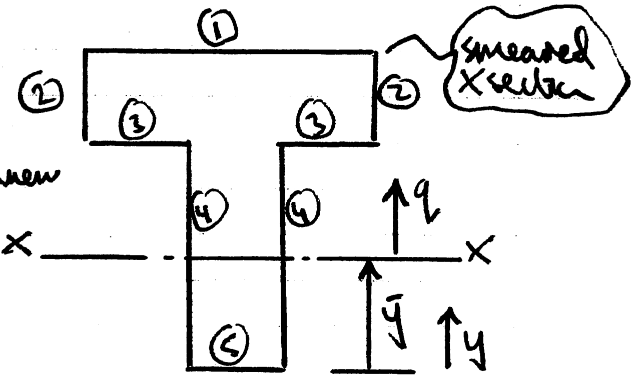
$+ 2\times\Big[\underbrace{457^2\times21000 + \tfrac{1}{12}\times14\times1500^3}_{④}\Big] + 12$

(|| axis, and smeared thickness of $bd^3/12$ terms) $= \underline{4.290\times10^{10}}$

①

Qu 4: 4D10 2004-2005.





All stiffeners fully effective @ 100×10 mm. (250mm centres)

Geometric properties of panels with smeared thicknesses to be found [labelled ① → ⑤ above]

Panel	no. stiff.	h (smeared thick)	A (area)	y (mm)	q (// axis)
1× ①	5	40/3 mm	20000 mm²	2000	793
2× ②	1	12 "	6000 "	1750	543
2× ③	2	14 "	7000 "	1500	293
2× ④	6	14 "	21000 "	750	457
1× 5	1	12 "	6000 "	0.	1207

enables this.

$$\text{total } A = 20000 + 2\times6000 + 2\times7000 + 2\times21000 + 6000 = \underline{94000\ mm^2}$$

$$\Rightarrow A\bar{y} = \sum Ay = 20000\times2000 + 2\times(6000\times1750) + 2\times(7000\times1500) + 2\times(21000\times750)$$

$$\Rightarrow \bar{y} = \frac{113.5\times10^6}{94000} = \underline{1207.4\ mm}$$

I_{xx} (ignoring about own c.g. of panel horizontal)

$$= \underbrace{793^2\times20000}_{①} + 2\times\Big[\underbrace{543^2\times6000 + \tfrac{1}{12}\cdot12\times500^3}_{②}\Big] + 2\times\Big[\underbrace{293^2\times7000}_{③}\Big]$$

$$+ 2\times\Big[\underbrace{457^2\times21000 + \tfrac{1}{12}\times14\times1500^3}_{④}\Big] + \underbrace{1207^2\times6000}_{⑤}$$

(// axis, and smeared thickness of $bd^3/12$ terms) $= \underline{4.290\times10^{10}\ mm^4}$

②

Qn4: 4D10 2004-2005

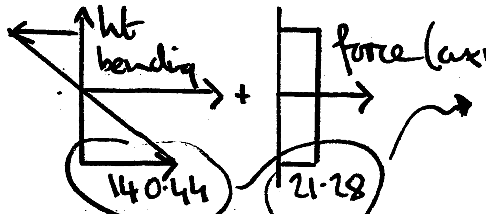
Summary $I_{xx} = 4.3\times10^{10}\ mm^4$, $A = 94\times10^{3}\ mm^2$

$$Z_e = I/y_{max} = 4.3\times10^{10}/1207 = \underline{35.59\times10^{6}\ mm^3}$$

(a) Loading: $M = 5\times10^{6}$ Nm (tension top), $P = 2000$ kN (comp)
$S = 2000$ kN (carried uniformly in vertical webs)

$$\Rightarrow \underset{(btm)}{\sigma_{max}} = \frac{M}{Z_e} + \frac{P}{A} = \frac{5\times10^{6}}{35.6\times10^{6}\times10^{-9}} + \frac{2\times10^{6}}{94\times10^{3}\times10^{-6}}$$
$$= \underline{140.44\ MPa} + \underline{21.28\ MPa}.$$

These results yield stresses as follows.

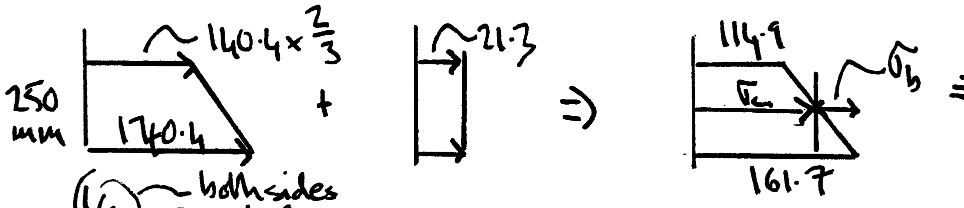


$\sigma_{max} = 161.72$ $(<\sigma_y)$

The bottom panel is most heavily loaded in compression, so only need to check there.

$$\lambda = b/t\sqrt{\sigma_y/355} \cdot \frac{250}{10}\sqrt{275/355} = \underline{\underline{22}} \Rightarrow (K_c = 1,\ K_b = 1.25,\ K_q = 1)$$ DS4

Panel stresses.



$\Rightarrow \sigma_c = 138.3\ MPa$, $\sigma_b = 23.4\ MPa$

$$\tau = \frac{\overset{\text{bothsides}}{1/2} \times 2000kN}{\underbrace{[\underset{(2)}{6000} + \underset{(4)}{21000}]}_{A_{webs}\text{ (vertical panels only)}}\times10^{-6}} = \underline{37.0\ MPa}.$$

Strength (DS4) $\Rightarrow \left(\frac{\sigma_{MAX}}{\sigma_y}\right)^2 + 3\left(\frac{\tau}{\sigma_y}\right)^2 \le 1$

$$\Rightarrow \left(\frac{161.72}{275}\right)^2 + 3\left(\frac{37}{275}\right)^2 = 0.4\ \underline{(\le 1, OK)}.$$

Stability (DS4) $\frac{\sigma_c}{K_c\sigma_y} + \left(\frac{\sigma_b}{K_b\sigma_y}\right)^2 + 3\left(\frac{\tau}{K_q\sigma_y}\right)^2 \le 1$

P.T.O.

(3)

Q4: 4D10 2004-2005.

$$\frac{138.3}{275} + \left(\frac{13.4}{275}\right)^2 + 3\left(\frac{37}{275}\right)^2 = \underline{0.56 \quad (<1)}$$

∴ All panels adequate (tensile stress in top flange also less $< \sigma_y$).

(b) New loads. $M = 6000\,kNm$, $P = 3000\,kN$, $S = 2000\,kN$.

$$\Rightarrow \sigma_{max} = \underbrace{140.44}_{\text{old } M} \times 1.25 + \underbrace{21.3}_{\text{old } P} \times 1.5 = \underline{\underset{(MPa)}{207.5}} \quad (\text{still less than } \sigma_y)$$

$$\Rightarrow \quad \sigma_c = \tfrac{1}{2}(207.5 + 149.0) = \underline{178.2\ MPa}$$

$$\sigma_b = \tfrac{1}{2}(207.5 - 149.0) = \underline{29.25\ MPa}$$

τ (unchanged) at $\underline{37\ MPa}$.

__Strength (DS4)__ $\left(\frac{\sigma_{max}}{\sigma_y}\right)^2 + 3\left(\frac{\tau}{\sigma_y}\right)^2 = \underline{0.62} \ (\leq 1, \text{OK})$

__Stability (DS4)__ $\left(\frac{\sigma_b}{K_b\sigma_y}\right)^2 + \frac{\sigma_c}{K_c\sigma_y} + 3\left(\frac{\tau}{K_q\sigma_y}\right)^2 = \underline{0.71} \ (\leq 1, \text{OK})$

Thus, these new loads can be safely carried.