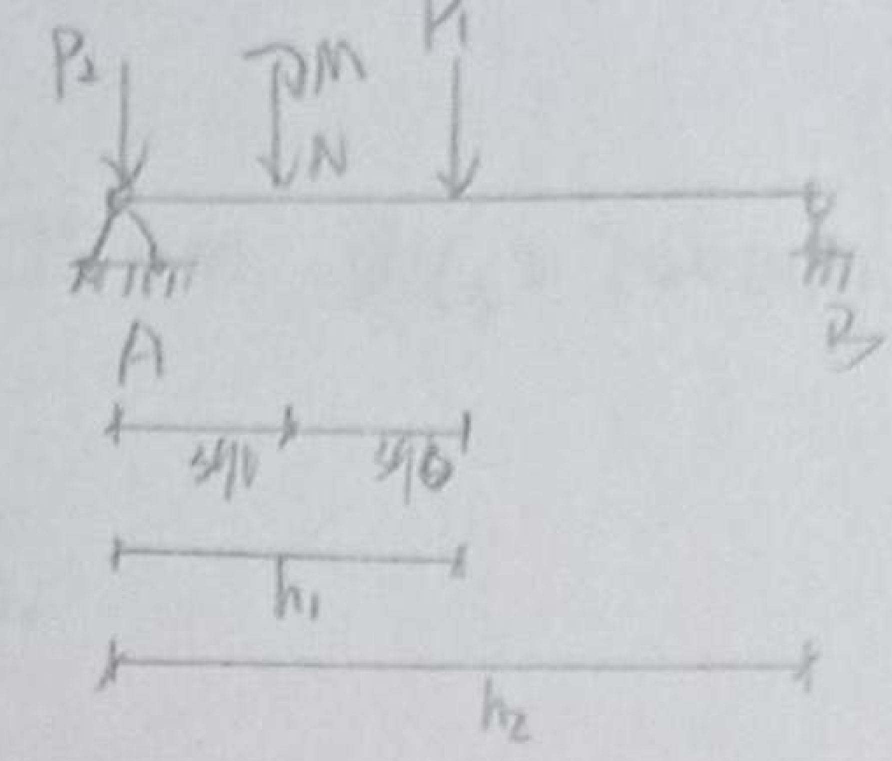
2.1 肩梁计算　　　　　　　　邓淑俊　2009001024.

解：①内力计算.

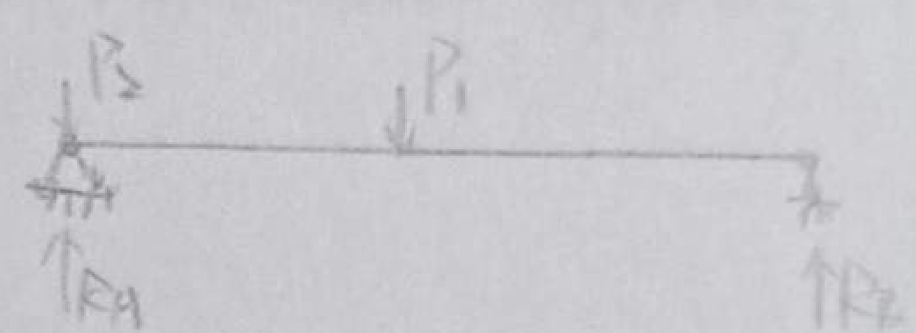


$h_1 = 400+400-\frac{1}{2}\times 20-\frac{1}{2}\times \cancel{14}^{20} = \cancel{783}^{780}\ mm.$

$h_2 = 2000-\frac{1}{2}\times 20 = 1990\ mm.$

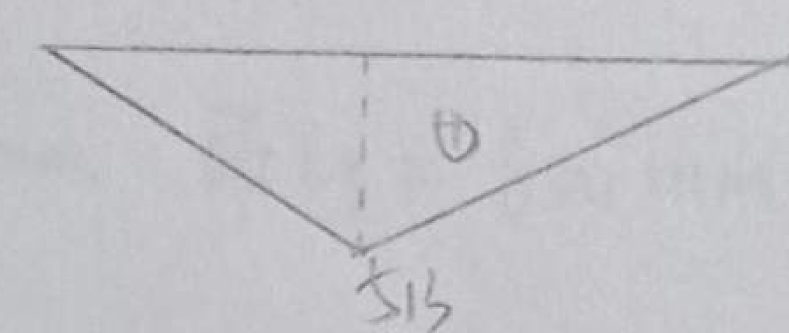
$\Rightarrow P_1 = \frac{N}{2}+\frac{M}{h_1} = \frac{500}{2}+\frac{650}{0.783} = 1080.1\ KN.$ （$h_1=780$时，$P_1=1083.3\ KN$，$P_2=-583.3\ KN$，由于相差无几，故后续仍按$h_1=783mm$时内力计算，误差忽略不计）

$P_2 = \frac{N}{2}-\frac{M}{h_1} = \frac{500}{2}-\frac{650}{0.783} = -580.1\ KN$（受拉）



$R_B = \frac{h_1}{h_2}P_1 = \frac{783}{1990}\times 1080.1 = 425\ KN.$

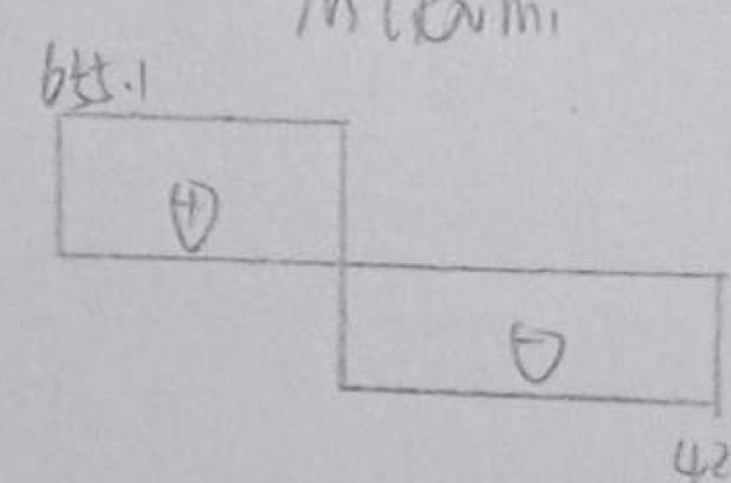
$R_A = P_1+P_2-R_B = 1080.1-580.1-425 = 75\ KN.$



M (KN·m)

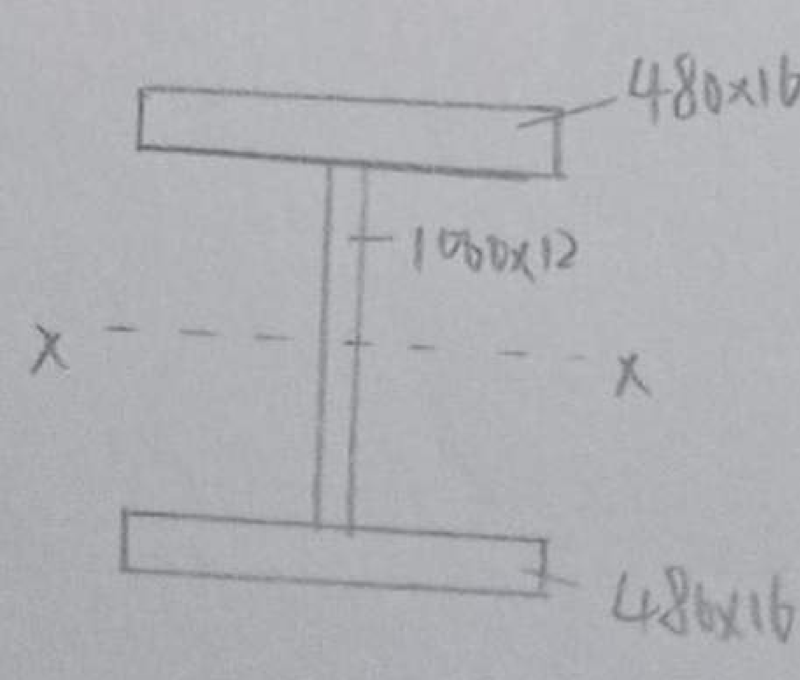
$M_{max} = R_B(h_2-h_1) = 425\times(1.99-0.783) = 513\ KN\cdot m.$

$V_{max} = 655.1\ KN.$



V (KN)

② 截面特征计算.



$I_x = \frac{1}{12}\times 12\times 1000^3+2\times 480\times 16\times 508^2 = 4.96\times 10^9\ mm^4.$

$W_x = \frac{I_x}{500+16} = \frac{4.96\times 10^9}{516} = 9.61\times 10^6\ mm^3.$

$\frac{b}{t} = \frac{480-12}{2\times 16} = 14.625 > 13\varepsilon_k = 13$，但 $\frac{b}{t} \le 15\varepsilon_k = 15$，即翼缘全部有效.

同理，依《钢结构设计标准》表3.5.1，对腹板 $\frac{h_0}{t_w} = \frac{1000}{12} = 83.3 \le 124\varepsilon_k = 124$，即腹板也全部有效.

② 强度验算

1° 上翼缘的边缘最大正应力

$$\sigma_{max} = \frac{M}{\gamma_x W_x} = \frac{513\times10^6}{1.0\times9.61\times10^6} = 53.4\,N/mm^2 \le f = 215\,N/mm^2 \quad (t = 16mm \le 16mm)$$

2° 腹板中最大剪应力

$$\tau_{max} = \frac{V_{max}}{h_0 t_w} = \frac{655.1\times10^3}{1000\times12} = 54.6\,N/mm^2 \le f_v = 125\,N/mm^2.$$

3° 腹板计算高度边缘局部压应力.

$a = 500mm,\ h_R = 0,\ h_y = 16mm. \Rightarrow l_z = a + 5h_y + 2h_R = 500 + 5\times16 + 2\times0 = 580\,mm.$

$\psi = 1.0,\ D_{max} = 1.5\alpha R_{max} = 1.5\times1.05\times1600 = 2520\,KN.$ (α为动力系数取1.05), $t_w = 30mm$.

$$\Rightarrow \sigma_c = \frac{\psi F}{l_z t_w} = \frac{1.0\times2520\times10^3}{580\times30} = 144.83\,N/mm^2 \le f = 205\,N/mm^2 \quad (t_w = 30mm > 16mm)$$

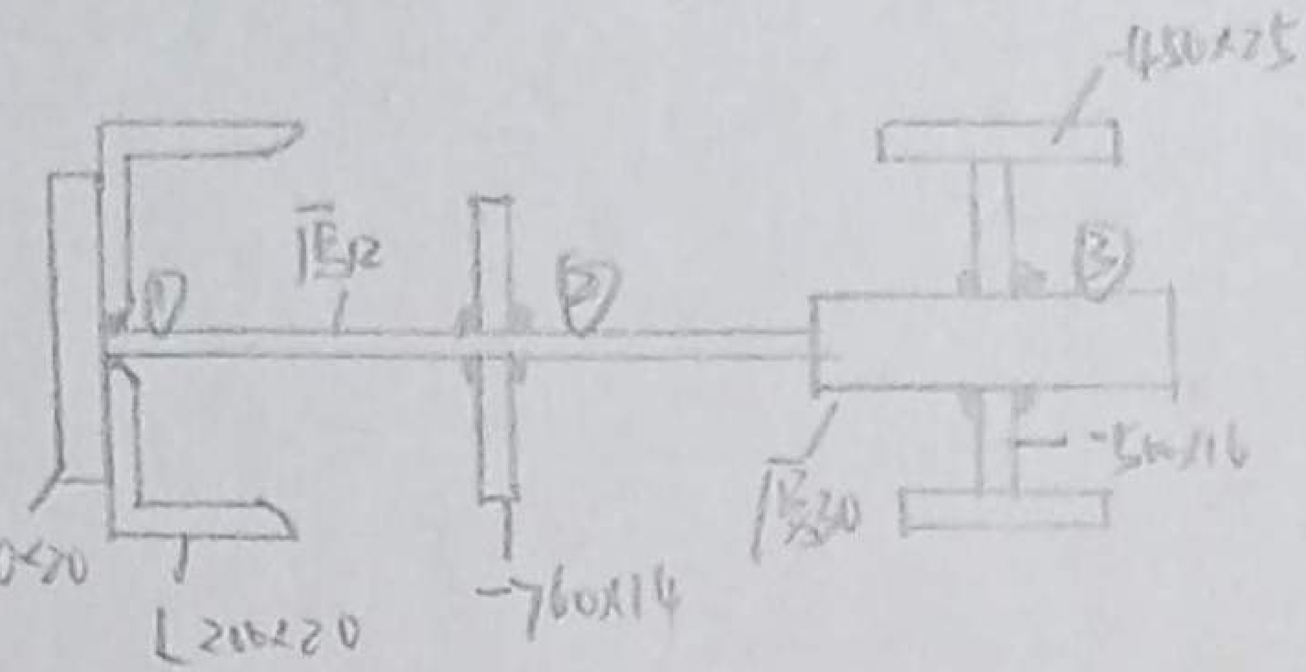
4° P_1作用处截面腹板和翼缘交接处的折算应力.

$$\sigma = \frac{M}{I_x}y = \frac{513\times10^6\times500}{4.96\times10^9} = 51.7\,N/mm^2.$$

$$\tau = \frac{VS_x^*}{I_x t_w} = \frac{655.1\times10^3\times480\times16\times508}{4.96\times10^9\times12} = 42.94\,N/mm^2.$$

$$\Rightarrow \sqrt{\sigma^2 + 3\tau^2} = \sqrt{51.7^2 + 3\times42.94^2} = 90.58\,N/mm^2 \le f = 215\,N/mm^2.$$

(四)焊缝设计



连接处焊缝如下图中①、②、③处所示.

对①处焊缝，其承受 $V = 655.1KN$.

由 $h_f \geq 1.5\sqrt{t_{厚}} = 1.5\times\sqrt{20} = 6.7mm$，且 $h_f \leq 1.2t_{薄} = 1.2\times 20 = 24mm$. 取 $h_f = 7mm$.

$\Rightarrow h_e = 0.7h_f = 4.9mm$，$f_f^w = 160 N/mm^2$.

$\Rightarrow \Sigma l_w = \dfrac{V}{h_e f_f^w} = \dfrac{655.1\times10^3}{4.9\times160} = 835.6 mm$. 则 $l_{w1} = \dfrac{\Sigma l_w}{2} = 417.8 mm$.

$\Rightarrow l_1 = l_w + 2h_f = 431.8 mm$. 取 $l_1 = 500mm$. 此时 $l_{w1} = l_1 - 2h_f = 486 mm > 60h_f = 420mm$.

故需再验算. $f_f^{w'} = \alpha_f f_f^w$. $\alpha_f = 1.5 - \dfrac{l_w}{120h_f} = 1.5 - \dfrac{486}{120\times7} = 0.92$.

$\Rightarrow \sigma = \dfrac{V}{h_e\Sigma l_n} = \dfrac{655.1\times10^3}{4.9\times486\times2} = 137.5 N/mm^2 < \alpha_f f_f^w = 0.92\times160 = 147.2 N/mm^2$，可行。

对②处焊缝，其承受 $P_1 = 1080.1 KN$.

$h_f \geq 1.5\sqrt{t_{厚}} = 1.5\times\sqrt{14} = 5.6mm$. $h_f \leq 1.2t_{薄} = 1.2\times12 = 14.4 mm$. 取 $h_f = 7mm$.

$h_e = 0.7h_f = 4.9mm$. $\Rightarrow \Sigma l_w = \dfrac{P_1}{h_e f_f^w} = \dfrac{1080.1\times10^3}{4.9\times160} = 1377.7 mm$.

共4条焊缝，$\Rightarrow l_{w2} = \dfrac{\Sigma l_w}{4} = 344.425 mm$. $l_2 = l_w + 2h_f = 358.425 mm$. 取 $l_2 = 400 mm$.

$l_{w2} = l_2 - 2h_f = 386 mm < 60h_f = 420mm$，不需重新验算。

对③处焊缝，其需传递 D_{max} 和 $V = 425KN$. 即 $N = D_{max} + V = 2520 + 425 = 2945KN$.

$h_f \geq 1.5\sqrt{t_{max}} = 1.5\times\sqrt{30} = 8.2mm$, $h_f \leq 1.2t_{min} = 1.2\times 16 = 19.2mm$. 取 $h_f = 10mm$

$\Rightarrow h_e = 0.7h_f = 7mm$. $\Rightarrow \sum l_w = \dfrac{N}{h_e f_f^w} = \dfrac{2945\times 10^3}{7\times 160} = 2629.5mm$.

$l_{w3} = \dfrac{\sum l_w}{4} = 657.375mm$. $\Rightarrow l_3 = l_w + 2h_f = 677.375mm$. 取 $l_3 = 700mm$.

$l_w = 700 - 2h_f = 680mm > 60h_f = 600mm$. 故需重新验算。

$\alpha_f = 1.5 - \dfrac{l_w}{120h_f} = 1.5 - \dfrac{680}{120\times 10} = 0.933$.

则 $\sigma = \dfrac{N}{h_e \sum l_w} = \dfrac{2945\times 10^3}{7\times 680\times 4} = 154.7N/mm^2 > \alpha_f f_f^w = 148.8N/mm^2$. 再取 $h_f = 12mm$.

$h_e = 0.7h_f = 8.4mm$. $\Rightarrow \sum l_w = \dfrac{N}{h_e f_f^w} = 2191.2mm$.

$\Rightarrow l_{w3} = \dfrac{\sum l_w}{4} = 547.8mm$ $\Rightarrow l_3 = l_{w3} + 2h_f = 571.8mm$. 取 $l_3 = 600mm$.

$l_{w3} = l_3 - 2h_f = 576mm \leq 60h_f = 720mm$. 可行。

综上此肩梁截面强度满足要求，连接焊缝已设计。

2.2 吊车梁计算-1

解：

①内力计算

验算吊车梁强度时，考虑两台并列吊车满载时的作用，验算吊车梁疲劳强度时只考虑一台起重量最大的吊车的荷载标准值作用。

(1) 两台吊车荷载作用下的内力

(a) 竖向轮压作用

编写python程序得梁的绝对最大弯矩 $M_{k.max}$ 和剪力 $V_{k.max}$（位于支座内边缘），（源码附于后面）

$$M_{k.max} = 3138.95 kN\cdot m. \qquad V_{k.max} = 1281.64 kN.$$

(b) 横向水平作用

每个轮压处的水平荷载：

吊车是重级工作制吊车，取 $T_k = \alpha_1 P_{max.k} = 0.1\times 324 = 32.4 kN.$

其作用位置与竖向轮压相同，因此，横向水平作用下产生 M_{ky} 和支座处剪力 H_k。

$$M_{ky} = 0.1M_{k.max} = 313.895 kN\cdot m. \qquad H_k = 0.1V_{k.max} = 128.164 kN.$$

(2) 一台吊车荷载作用下内力

(a) 竖向轮压作用

见源码，即得 $M_{k.max} = 2060.54 kN\cdot m.$ $V_{k.max} = 911.84 kN.$

根据以上计算，汇总内力如下表所示，其中1.1为动力系数（A7级吊车）。吊车梁自重以5%的活荷载标准值计入。

吊车台数	荷载	M_{kmax} (kN·m)	M_{max} (kN·m)	M_{ky} (kN·m)	M_y (kN·m)	V_{kmax} (kN)	V (kN)
两台	吊车	3138.95	$1.1\times1.5\times3138.95 = 5179.27$	313.895	$1.5\times313.895 = 470.8$	1281.64	$1.1\times1.5\times1281.64 = 2114.7$
	自重	$0.05\times3138.95 = 156.95$	$1.3\times156.95 = 204.04$			$0.05\times1281.64 = 64.1$	$1.3\times64.1 = 83.33$
	Σ	3295.9	5383.31			1345.74	2198.03
一台	吊车	2060.54				911.84	

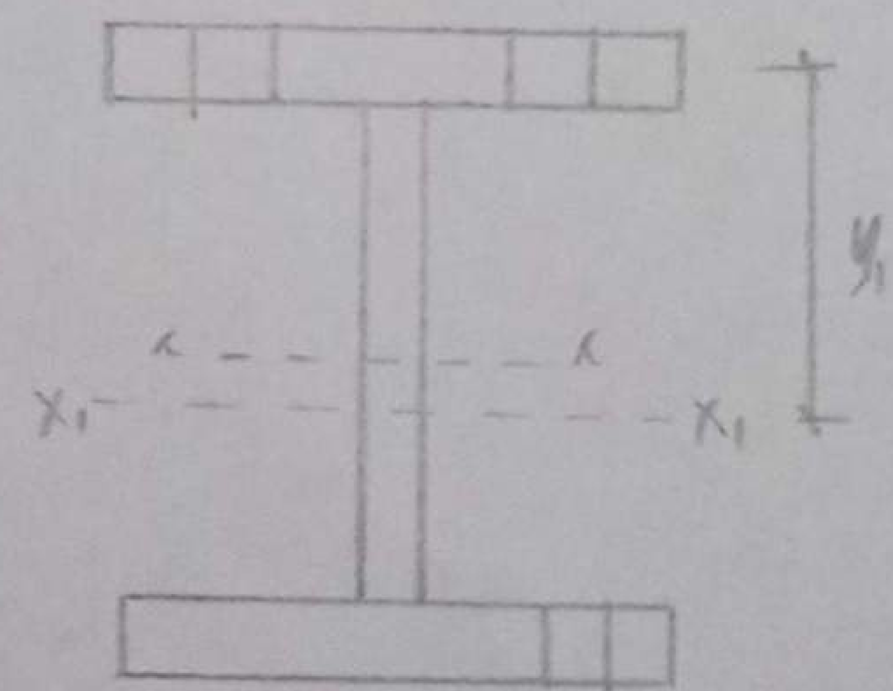
②截面的特性计算.

(1)吊车梁

毛截面惯性矩：$I_x = \frac{1}{12}\times14\times1600^3 + 2\times24\times500\times(800+12)^2 = 2.06\times10^{10}\ mm^4$.

净截面面积：$A_{n1} = (500-22\times2)\times24 + (500-22)\times24 + 1600\times14 = 10944 + 11472 + 22400$

$= 44816\ mm^2$.



净截面形心位置 $y_1 = \frac{11472\times1624 + 22400\times812}{44816} = 821.6mm$.

净截面惯性矩 $I_{nx1} = \frac{1}{12}\times14\times1600^3 + 22400\times9.6^2 + 10944\times821.6^2$

$+ 11472\times(1624-821.6)^2 = 1.955\times10^{10}\ mm^4$.

上翼缘左侧外边缘净截面模量 $W_{nx1} = \frac{I_{nx}}{y_1+\frac{t}{2}} = \frac{1.955\times10^{10}}{821.6+12} = 2.35\times10^7\ mm^3$.

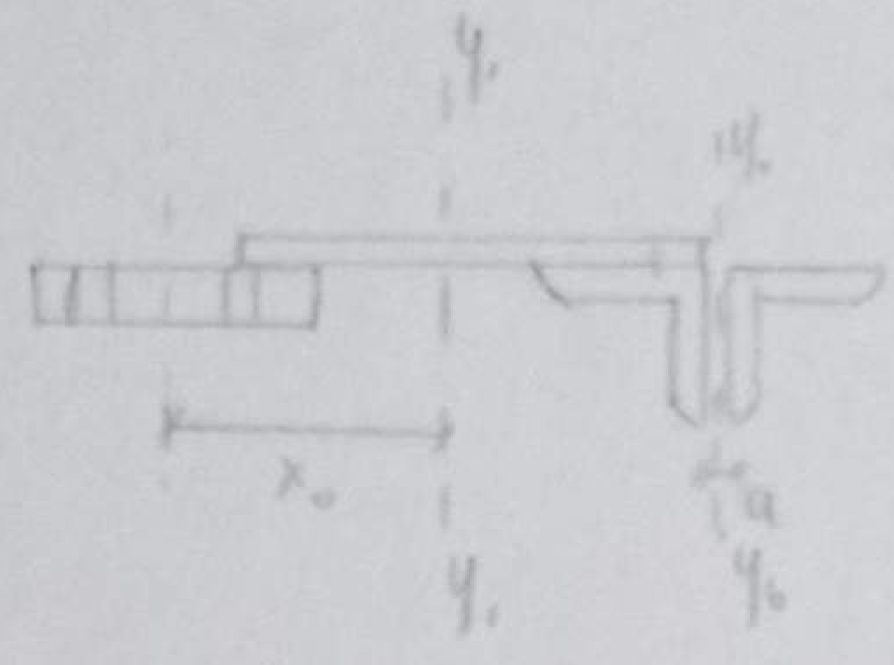
半毛截面对x轴的惯性矩：$S_x = 500\times24\times812 + 800\times14\times400 = 1.42\times10^7\ mm^3$.

(2)制动梁

净截面面积：$A_{n2} = 24\times(500-22\times2) + 860\times8 + 1930\times2 = 10944 + 6880 + 3860$

$= 21684\ mm^2$.

截面形心至吊车梁腹板中心线之间的距离



$$x_0=\frac{6880\times(430+200)+3860\times1100}{21684}=395.7\,mm$$

不妨取 $a=10mm$.

$I_{y0}=A\cdot i_{y0}^2$

净截面惯性矩 $I_{ny1}=\frac{1}{12}\times24\times500^3-2\times24\times22\times120^2+10944\times395.7^2+\frac{1}{12}\times8\times860^3+6880\times(630-395.7)^2+3860\times452^2$

$+3860\times(1100-395.7)^2=\cancel{7.43}\ 4.67\times10^9\ mm^4.$

对 y_1-y_1 轴的净截面模量（吊车梁上翼缘左侧边缘）

$$W_{ny1}=\frac{I_{ny1}}{x+250}=\frac{4.67\times10^9}{395.7+250}=7.23\times10^6\ mm^3.$$

③截面验算.

(1)强度验算.

上翼缘最大正应力 $\sigma_{max}=\frac{M_x}{W_{nx1}}+\frac{M_y}{W_{ny1}}=\frac{5383.31\times10^6}{2.35\times10^7}+\frac{470.8\times10^6}{7.23\times10^6}=229.1+65.1=294.2\ N/mm^2$

$\le f=295\ N/mm^2$ ($t=24mm>16mm$)

腹板最大剪应力. $\tau_{max}=\frac{VS}{I_x t_w}=\frac{2198.03\times10^3\times1.42\times10^7}{2.06\times10^{10}\times14}=108.24\ N/mm^2\le f_v=175\ N/mm^2.$

腹板边缘局部压应力

$\sigma_c=\frac{\psi F}{l_z t_w}$. $l_z=a+2h_R+5h_y$. $a=50mm$. $h_R=150mm, h_y=24mm$.

$l_z=50+2\times150+5\times24=470mm$. A7为重级工作制吊车, 取 $\psi=1.35$.

$\Rightarrow\sigma_c=\frac{1.35\times1.1\times1.5\times324\times10^3}{470\times14}=109.7\ N/mm^2\le f=305\ N/mm^2$ ($t=14mm\le16mm$).

(2)疲劳验算.

下翼缘因高强螺栓连接下弦水平支撑处的主体金属.

$$\Delta\sigma = \frac{M_x}{I_{nx1}}y = \frac{206.54\times10^6}{1.955\times10^{10}}\times(1624-821.6+12) = 85.84\ N/mm^2.$$

按疲劳计算的构件和连接分类，此处为Z2类，查书表2-11. $\Rightarrow [\Delta\sigma]_{2\times10^6} = 144\ N/mm^2$.

吊车荷载系数查表2-12，得 $\alpha_f = 0.8$.

$\Rightarrow \alpha_f\Delta\sigma = 0.8\times85.84 = 68.672\ N/mm^2 \le [\Delta\sigma]_{(2\times10^6)} = 144\ N/mm^2$，满足要求。

受拉翼缘对接焊缝处：

$$\Delta\sigma = \frac{M_x}{I_{nx1}}y = \frac{206.54\times10^6}{1.955\times10^{10}}\times(1624-821.6-12) = 83.31\ N/mm^2.$$

同理，查书附录8-1(a). 由于题目未给出具体分类，此处按最不利取为Z5类.

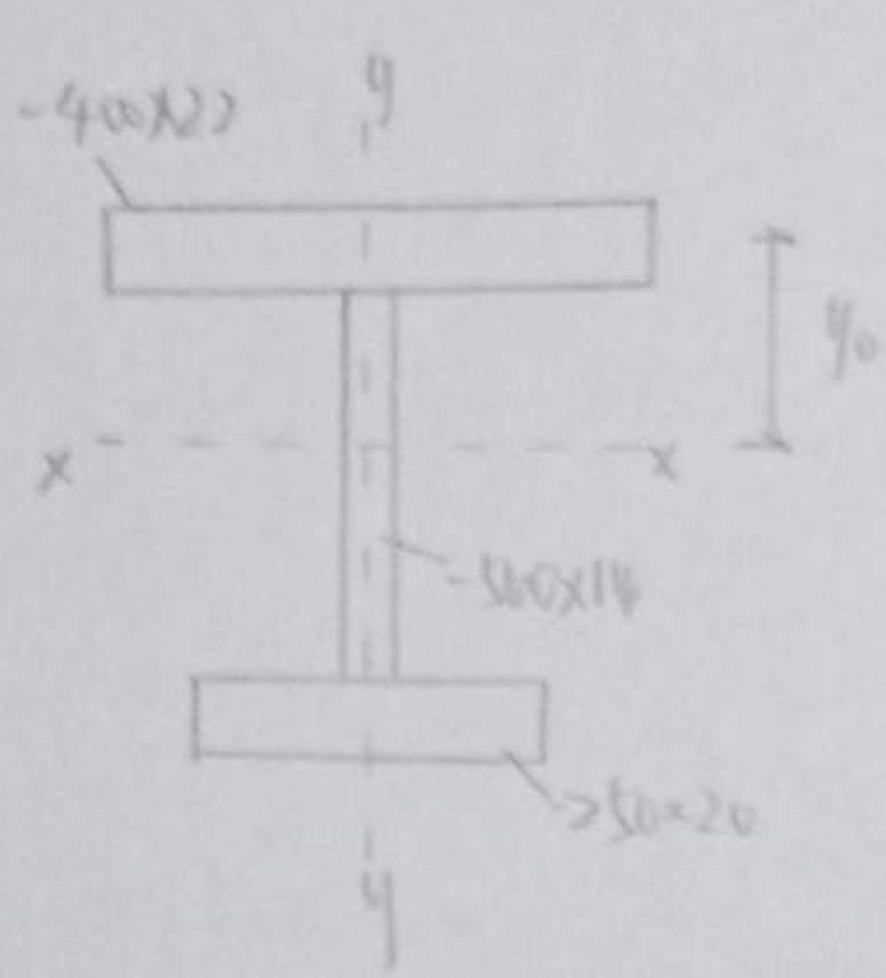
$\Rightarrow [\Delta\sigma]_{2\times10^6} = 100\ N/mm^2$.，且 $\alpha_f = 0.8$

$\Rightarrow \alpha_f\Delta\sigma = 0.8\times83.31 = 66.648\ N/mm^2 \le [\Delta\sigma]_{2\times10^6} = 100\ N/mm^2$. 满足要求.

综上，该吊车梁截面强度和疲劳强度均满足要求。

2-3. 吊车梁设计-2

解：①截面特征计算



$$y_0=\frac{500\times14\times261+250\times20\times521}{250\times20+500\times14+400\times22}=213\ mm.$$

$$\Rightarrow I_x=400\times22\times213^2+\frac{1}{12}\times14\times500^3+14\times500\times(261-213)^2+250\times20\times(521-213)^2=1.036\times10^9\ mm^4.$$

上翼缘右侧外边缘

$$W_{nx_1}=\frac{I_x}{y_0+\frac{t}{2}}=\frac{1.036\times10^9}{213+11}=4.625\times10^6\ mm^3.$$

下翼缘外边缘

$$W_{nx_2}=\frac{I_x}{521-y_0+10}=\frac{1.036\times10^9}{521-213+10}=3.26\times10^9\ mm^3.$$

横向水平荷载仅由上翼缘承担，故只计算上翼缘绕y轴的惯性抵抗矩：

$$W_{ny}=\frac{1}{6}bh^2=\frac{1}{6}\times22\times400^2=5.87\times10^5\ mm^3.$$

②强度验算

对上翼缘右侧边缘：

$$\sigma=\frac{M_x}{W_{nx1}}+\frac{M_y}{W_{ny}}=\frac{300\times10^6}{4.625\times10^6}+\frac{100\times10^6}{5.87\times10^5}=235.24N/mm^2>f=205N/mm^2.\ (t=22mm>16mm)$$

对下翼缘：

$$\sigma=\frac{M_x}{W_{nx2}}=\frac{300\times10^6}{3.26\times10^6}=92.02N/mm^2\le f=205N/mm^2\quad(t=20mm>16mm)$$

强度验算不满足要求。

② 整体稳定验算.

$$\frac{M_x}{\varphi_b W_x} + \frac{M_y}{W_y} \le f.$$

其中 $\varphi_b = \beta_b \cdot \frac{4320}{\lambda_y^2} \cdot \frac{Ah}{W_x} \cdot \left[\sqrt{1+\left(\frac{\lambda_y t_1}{4.4h}\right)^2} + \eta_b\right]\varepsilon_k^2$,

查表附录得 $\xi = \frac{l_1 t_1}{b_1 h} = \frac{6000\times22}{400\times542} = 0.609$. $\Rightarrow \beta_b = 0.73+0.18\xi = 0.73+0.18\times0.609 = 0.84$.

整体截面对y轴的惯性矩:

$I_{y1} = \frac{1}{12}\times22\times400^3 + \frac{1}{12}\times20\times250^3 = 1.43\times10^8\ mm^4$. $A = 400\times22+500\times14+250\times20 = 20800\ mm^2$.

$i_y = \sqrt{\frac{I_{y1}}{A}} = \sqrt{\frac{1.43\times10^8}{20800}} = 82.92\ mm$. $\lambda_y = \frac{l_{0y}}{i_y} = \frac{6000}{82.92} = 72.36$.

$\eta_b = 0.8(2\alpha_b-1)$. $\alpha_b = \frac{I_1}{I_1+I_2}$, $I_1 = \frac{1}{12}\times22\times400^3 = 1.17\times10^8\ mm^4$. $I_2 = \frac{1}{12}\times20\times250^3 = 2.6\times10^7\ mm^4$.

$\Rightarrow \alpha_b = 0.818$, $\eta_b = 0.8(2\alpha_b-1) = 0.8\times(2\times0.818-1) = 0.5088$.

$\Rightarrow \varphi_b = 0.84\times\frac{4320}{72.36^2}\times\frac{20800\times542}{4.625\times10^6}\times\left[\sqrt{1+\left(\frac{72.36\times22}{4.4\times542}\right)^2}+0.5088\right]\times1^2 = 2.91 > 0.6$

$\Rightarrow \varphi_b' = 1.07 - \frac{0.282}{\varphi_b} = 1.07 - \frac{0.282}{2.91} = 0.973$

$\Rightarrow \frac{M_x}{\varphi_b W_x} + \frac{M_y}{W_y} = \frac{300\times10^6}{0.973\times4.625\times10^6} + \frac{100\times10^6}{587\times10^3} = 237\ N/mm^2 > f = 205\ N/mm^2$.

整体稳定不满足.

③ 刚度验算.

$M_{kx} = \frac{M}{\gamma\gamma_G} = \frac{300}{1.05\times1.5} = 190.5\ kN\cdot m$. $E = 206\ GPa$.

$\Rightarrow v = \frac{M_{kx} l^2}{10EI_x} = \frac{190.5\times10^6\times6000^2}{10\times206\times10^3\times1.036\times10^9} = 3.21\ mm \le [v] = \frac{l}{900} = \frac{6000}{900} = 6.67\ mm$.

满足要求。

④疲劳验算

受拉翼缘与腹板连接焊缝处：

$$\Delta\sigma = \frac{M_{kx}}{I_x}y = \frac{190.5\times10^6}{1.036\times10^9}\times(511-213) = 54.79\ N/mm^2.$$

查表2-12，得 $\alpha_f = 0.5$．查出附录8得4，按最不利取为之5类．即 $[\Delta\sigma]_{2\times10^6} = 100\ N/mm^2$.

$\Rightarrow \alpha_f\Delta\sigma = 27.395\ N/mm^2 \le [\Delta\sigma]_{2\times10^6} = 100\ N/mm^2$.

疲劳强度满足要求。

综上，此吊车梁强度及局部稳定性不满足要求。