STRUCTURAL DESIGN OF AN AUTO TRANSPORT

THESIS FOR DEGREE OF B. S.

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1938

SUPPLEMENTARY
MATERIAL
IN BACK OF BOOK

Structural Design Of An Auto Transport

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by

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Structural Design of an Auto Transport

The aim of this thesis is to check the design of the Auto Transport which is shown in the accompanying drawings. In checking this design, I have made use of the following facts:

1. The weight of each car is 3600#.

2. The center of gravity lies midway between the front and rear wheels and 2' above the ground.

3. Wheel-base is 120".

4. Gage distance of wheels is 4' - 9".

5. The distance between beads on the rim is 4 1/2 ".

6. The radius of the wheels when inflated is 14".

7. All joints are welded and I have considered the welded joint to be as safe as the metal welded.

8. Force due to impact will be used as 100%.

9. Allowable stress due to bending = 20,000 lbs./sq. in. Ten.
60,000 lbs./sq. in. Comp.

10. Allowable stress due to shear = 12,000 lbs./sq. in.

I have tried to pick the worst conditions that may arise and this is very evident from the fact that the force of impact is taken as 100%. Of course this is not true in all instances and these cases will be pointed out as they arise.

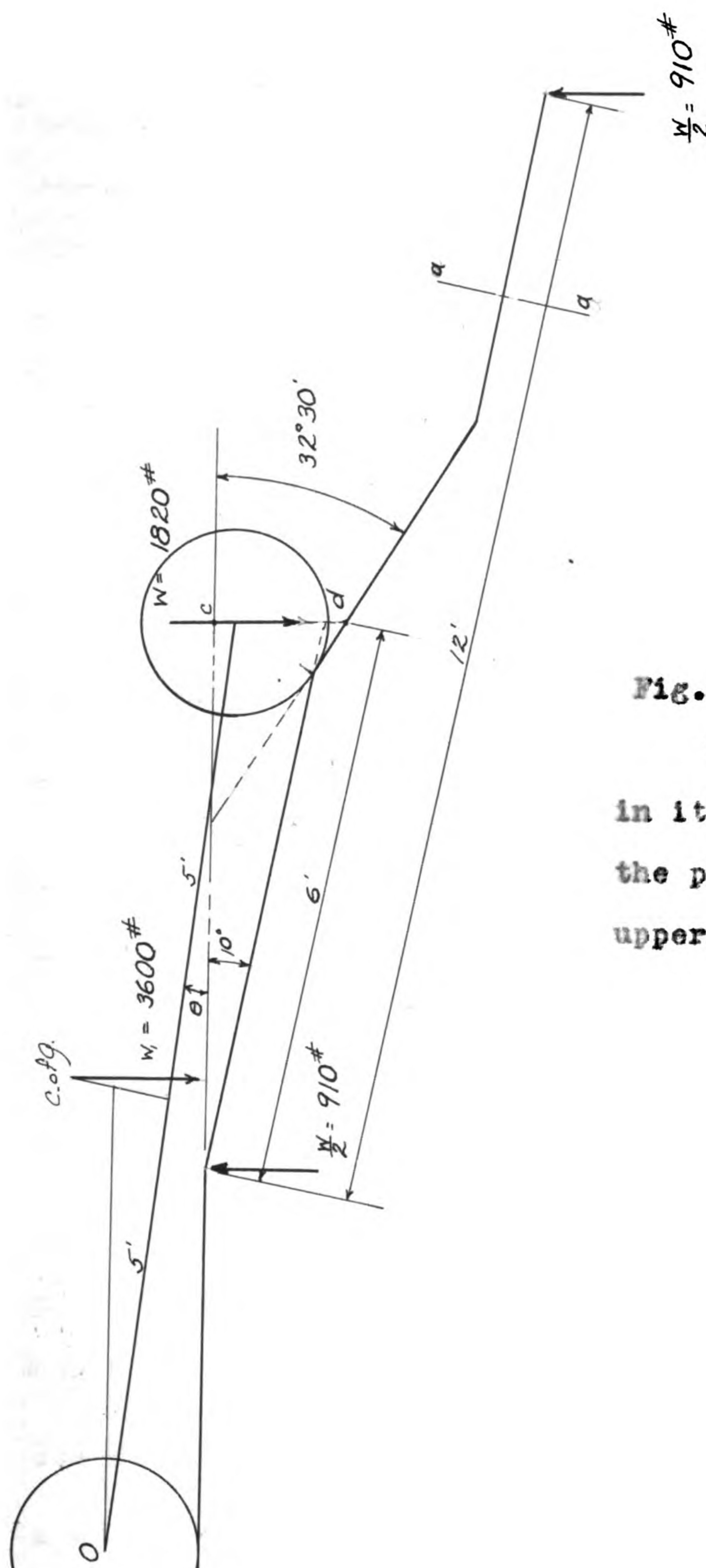


Fig. 1.

The runway AB is shown in its true position during the process of loading the upper deck.

Check Stresses In Member AB.

(a) Moment of inertia of cross-section a-a.

The one-half inch square bars are omitted in this computation because they do not take up any of the bending in the direction of the runway.

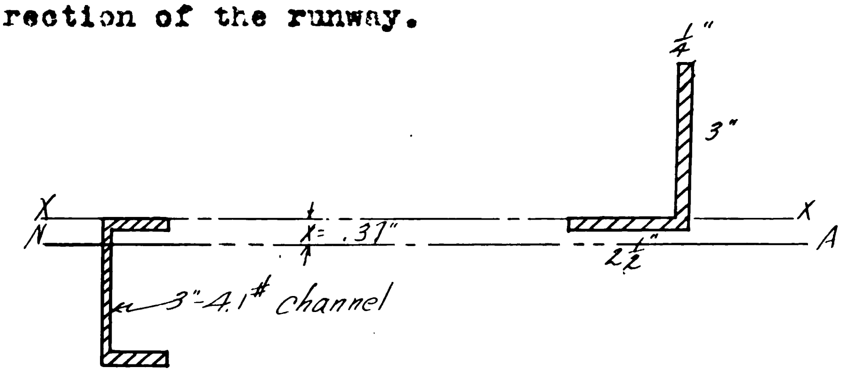


Fig. 2

$$x = \frac{1.19 \times 1.5 - 1.31 \times .66}{1.31 + 1.19} = .368 \text{ say } .37"$$

$$I = I_1 + I_2 = \left[1.6 + 1.19(1.13)^2\right] + \left[1.2 + 1.31(1.03)^2\right]$$

$$= 1.6 + 1.53 + 1.2 + 1.39$$

$$I = 5.72 \text{ "}^4$$

$$c = 3 + (.37 - .25) = 3.12"$$

(b) Stress due to bending moment.

The maximum moment occurs when the rear wheel reaches the center of the span as shown in Fig. 1.

$$cd = 6 \times \sin 10^\circ = 1.04'$$

$$\theta = \arcsin \frac{1.04}{10} = 5^\circ\ 58'$$

$$\Sigma M_0 = 0$$

$$\frac{5}{\cos 5^\circ\ 58'}\ 3600 - 10\ W \cos 5^\circ\ 58 = 0$$

$$W = \frac{18,000}{10 \cos 5^\circ\ 58'} = 1820^{\#}$$

$M = 6 \cos 10^\circ \times 910 = 5390$ '#

$s = \frac{Mc}{I} = \frac{5390 \times 12 \times 263}{5.72} = 29{,}700$ lbs. / sq. in. Ten.

$s = 5390 \times 12 \times 312 / 5.72 = 35{,}300$ lbs. / sq. in. Comp.

The cars are in this position only when they are being loaded, and they are moved up so slowly that the force of impact would be very small that it may be neglected.

(c) Stress due to shear.

There is such a slight difference in the loads, which are transmitted by the wheels due to the difference in elevation, that they may be considered equal for check purposes only.

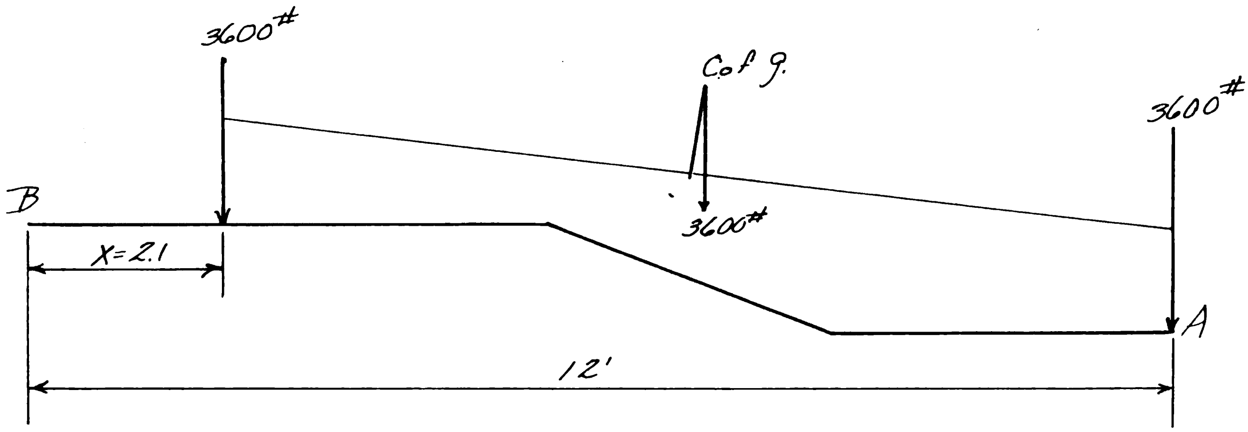


Fig. 3

$V_A = 1800 + \frac{2.1}{12} 1800 = 2150$#

$Q = 1.31 \times 1.03 + 1\ 3/8 \times 1/4 \times .24 + .12\ 3/16 \times .06$

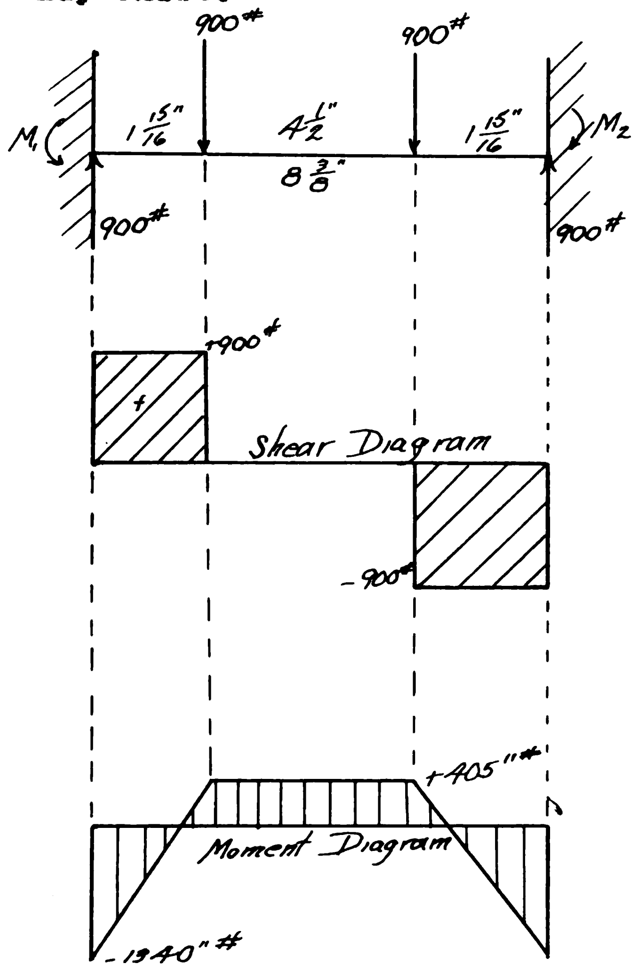
$= 1.35 + .08 + .0013 = 1.43$

$s = \frac{VQ}{Ib} = \frac{2150 \times 1.43}{5.72 \times 3/16} = 2870$ lbs. / sq. in.

The shearing stress is so low that I was safe in assumeing that each wheel carried the same load.

(d) Stresses due to the bending moment and the shear in the 1/2" square bars.

In checking the stesses on the bar, I have considered the tire to be flat, which is the worst possible case that may exist.



$$I_s = \frac{bh^3}{12} = \frac{\frac{1}{2} \times (\frac{1}{2})^3}{12}$$

$$I = 1/192"^4$$

$$M_2 = M_1 = \frac{Pab^2}{l^2} + \frac{Pa'b'^2}{l^2}$$

$$= P/L^2 \; (ab^2 + a'b'^2)$$

$$= \frac{900}{(8\ 3/8)^2} \left[1\ 15/16\ (6\ 7/16)^2 + 6\ 7/16\ (1\ 15/16)^2\right]$$

$$= 12.85\ (80.1 + 24.1) =$$

$$M_2 = 1340"\#$$

Fig. 4

$$M_{max} = 900 \times 1.938 - 1340 = 405"\#$$

$$s = \frac{Mc}{I} = \frac{405 \times \frac{1}{4}}{1/192} = 405 \times 48$$

$s = 19{,}400$ lbs. / sq. in. Ten. & Comp. O.K.

$$V_{max} = 900\#$$

$s = \frac{3V}{2bh} = \frac{3 \times 900}{2 \times \frac{1}{2} \times \frac{1}{2}} = 5400$ lbs. / sq. in. O.K.

Check Stresses in Member BC.

(a) Moment of inertia of section b-b.

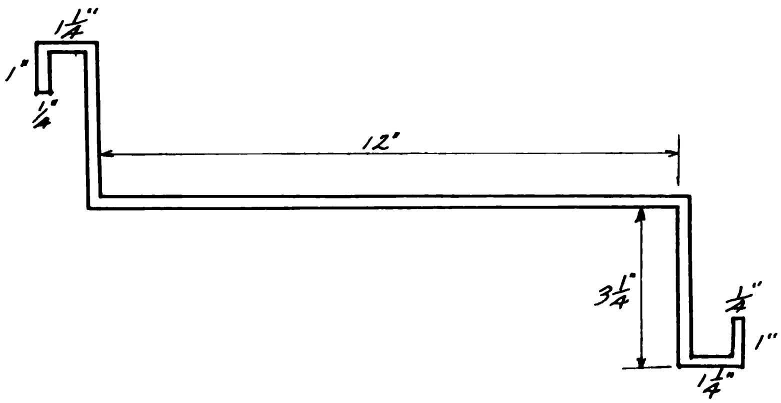


Fig. 5.

$$I = \frac{12 \times (\frac{1}{4})^3}{12} + 2\left[\frac{\frac{1}{4} \times (3\frac{1}{4})^3}{12} + \frac{1}{4} \times 3\frac{1}{4}\,(1\frac{11}{16})^2 + \frac{1 \times (\frac{1}{4})^3}{12} + \frac{1}{4} \times (3\frac{1}{4})^2 + \frac{\frac{1}{4} \times (\frac{3}{4})^3}{12} + \frac{1}{4} \times \frac{3}{4} \times (2\frac{3}{4})^2\right]$$

$$= .016 + 2\left[.855 + 2.310 + .001 + 2.645 + .009 + 1.419\right]$$

$$= .016 + 2 \times 7.24$$

$$I = 14.496 \text{ say } 14.50 \text{ "}^4$$

(b) Check the stresses.

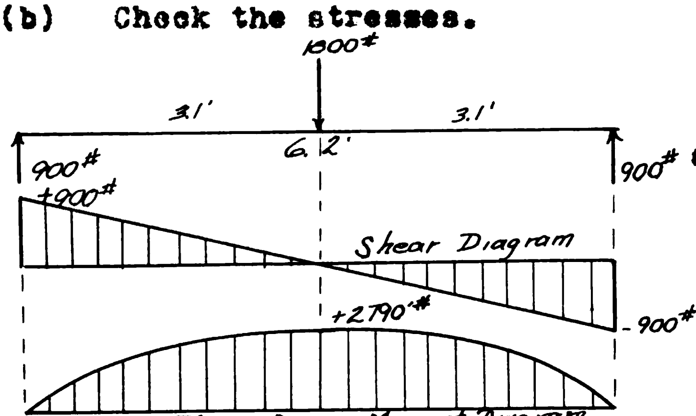


Fig. 6.

$M = 3.1 \times 900 = 2790'^{\#}$

$s = \frac{Mc}{I} = \frac{2790 \times 12 \times 3.375}{14.50}$

$s = 7,775$ lbs. / sq. in.

Ten. & Comp. O.K.

$V_{max} = 1900$ #

$Q = 3\frac{1}{4} \times \frac{1}{4} \times 1\frac{3}{4} + 1 \times \frac{1}{4} \times 3\frac{1}{4} + \frac{3}{4} \times \frac{1}{4} \times 2\frac{3}{4}$

$= 1.421 + .813 + .516$

$Q = 2.75$

$$s = \frac{VQ}{Ib} = \frac{1800 \times 2.75}{14.5 \times \frac{1}{4}} = \frac{7200 \times 2.75}{14.5}$$

$s = 1370$ lbs. / sq. in. O.K.

Check Stresses in Bottom Runway.

(a) Moment of Inertia of Fig. 7.

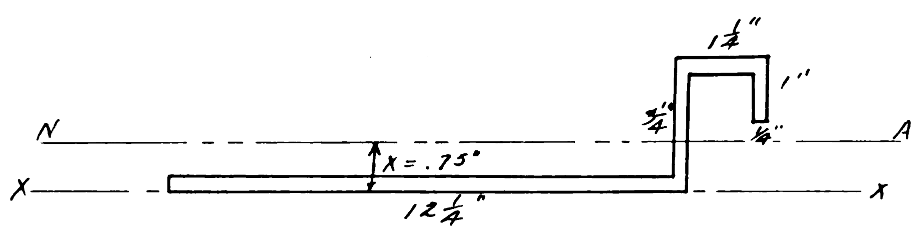


Fig. 7.

$$x = \frac{12 \times \frac{1}{4} \times 1/8 + 3\frac{1}{2} \times \frac{1}{4} \times 1\frac{3}{4} + \frac{3}{4} \times \frac{1}{4} \times 3\ 3/8 + 1 \times \frac{1}{4} \times 3}{3.00 + .875 + .188 + .250}$$

$$= \frac{.375 + 1.531 + .633 + .75}{4.313} = \frac{3.239}{4.313}$$

$x = .75"$

$$I = \frac{12 \times (\frac{1}{4})^3}{12} + 3\ (5/8)^2 + \frac{\frac{1}{4} \times (3\frac{1}{2})^3}{12} + .875\ (1)^2 + \frac{\frac{3}{4} \times (\frac{1}{4})^3}{12} +$$

$$.188 \times (2\ 5/8)^2 + \frac{\frac{1}{4} \times (1)^3}{12} + .25 \times (2\frac{1}{4})^2$$

$I = .016 + 1.172 + .893 + .875 + .001 + .519 + .021 + 1.015$

$I = 3.67"^4$

(b) Statical moment of inertia of Fig. 7.

$$Q = 3 \times 5/8 + \tfrac{3}{4} \times \tfrac{1}{4} \times 3/8 = 1.875 + .070$$

$$Q = 1.945$$

(c) Stresses due to bending moment and shear.

Maximum Bending Moment will occur with the wheel on the incline to the rear of the trailer as shown in Fig. 8.

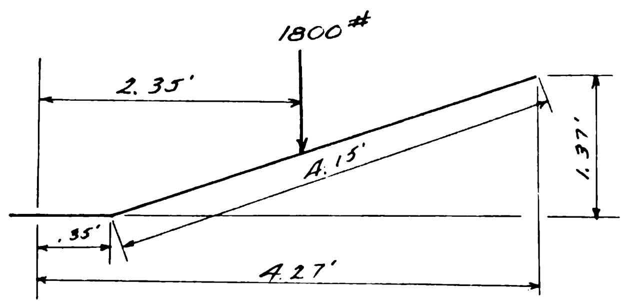


Fig. 8.

$$M_{max} = 2.135 \times 1800 = 3{,}840'^{\#}$$

$$V_{max} = 1800^{\#}$$

$$s = \frac{Mc}{I} = \frac{3840 \times 12 \times 0.75}{3.67} = 9420 \text{ lbs. / sq. in. Ten O.K.}$$

$$s = \frac{3840 \times 12 \times 2.75}{3.67} = 39{,}500 \text{ lbs. / sq. in. Comp. O.K.}$$

$$s = \frac{VQ}{Ib} = \frac{1800 \times 1.945}{3.67 \times \frac{1}{4}} = 3{,}820 \text{ lbs. / sq. in. O.K.}$$

Stresses In The 5 Inch Channel On The Bottom Deck.

(a) Moment of inertia of Fig. 9.

$I_{2-2} = .20''^4$ (from handbook)

(b) Statical moment of inertia of Fig. 9.

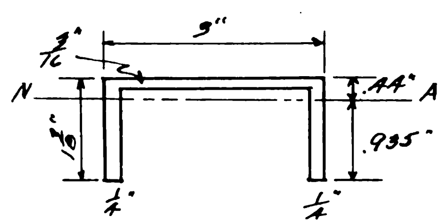
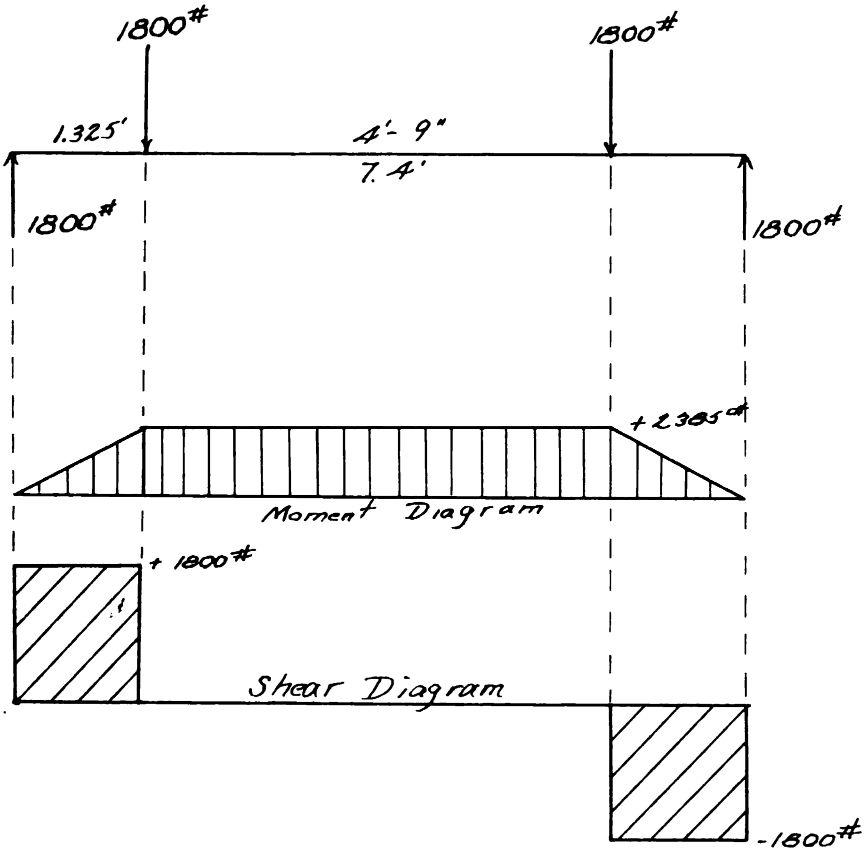


Fig. 9.



$M = 1800 \times 1.325$

$= 2385\ '\#$

Fig. 10.

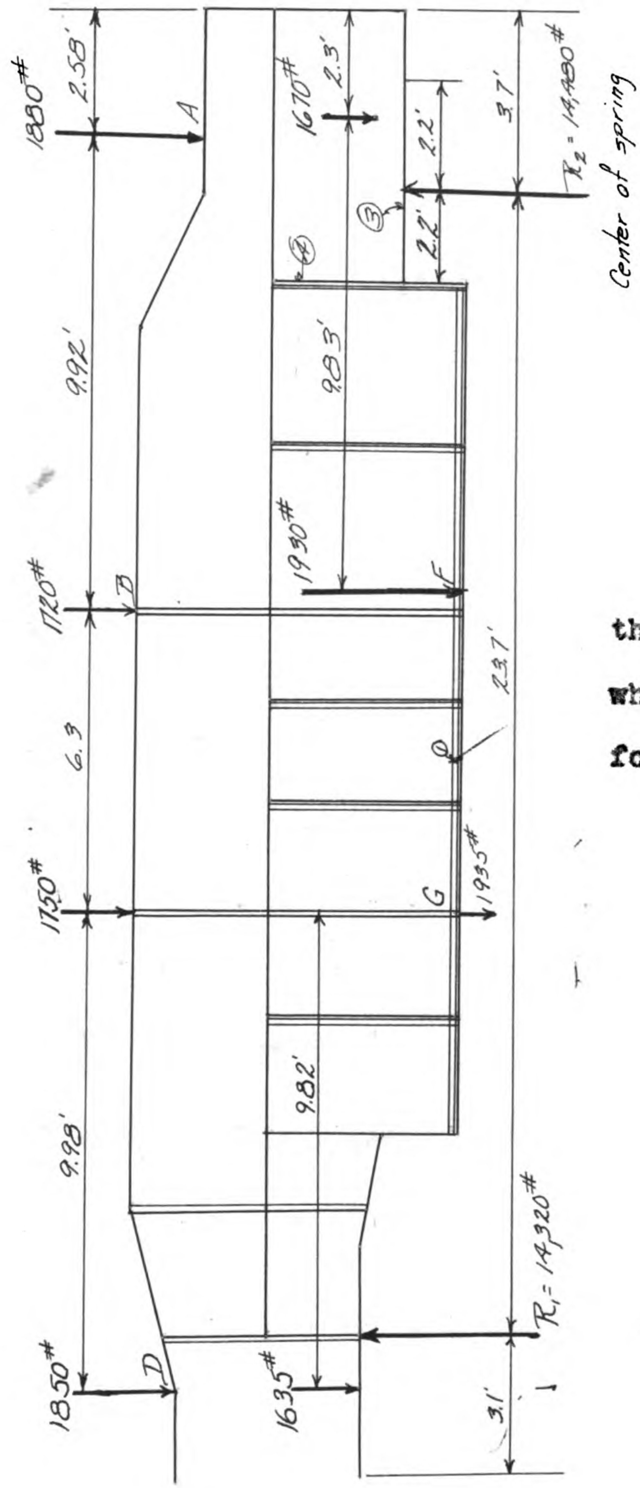
$Q = 2\left[1/12 \times \tfrac{1}{4} \times (.935)^2\right] + .935/4 \times .935/2\,]$

$Q = 2\,[.018 + .109] = .254$

$s = \frac{My}{I} = \frac{2385 \times 12 \times .935}{.20} = 13{,}410$ lbs. / sq. in. Ten.

$s = \frac{VQ}{Ib} = \frac{1800 \times .254}{.20 \times \frac{1}{2}} = 4{,}570$ lbs. / sq. in. O.K.

$s = \frac{2385 \times 12 \times .44}{.20} = 6{,}330$ lbs. / sq. in. Comp. O.K.



This drawing shows the position of the cars when they are loaded for transportation.

Fig. 11.

Find The Wheel Loads

(a) Find wheel loads A and B.

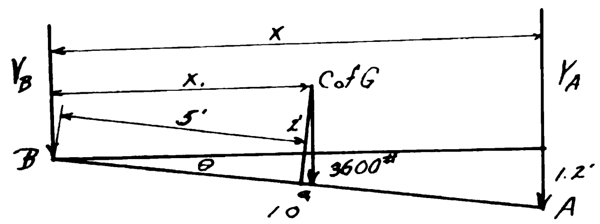


Fig. 12.

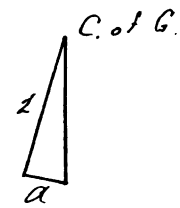


Fig. 12a.

$\theta = \arcsin 1.2/10 = 6\ \ 53'$

$$x = \frac{1.2}{\tan \theta} = 9.92'$$

$x_1 : 5.242 = 9.92 : 10$

$$x_1 = \frac{5.242 \times 9.92}{10} = 5.18'$$

$2 : a = 9.92 : 1.2$

$$a = \frac{2 \times 1.2}{9.92} = .242$$

$\Sigma M_B = 0$

$3600 \times 5.18 - 9.92 V_A = 0$

$$V_A = \frac{3600 \times 5.18}{9.92} = 1880^{\#}$$

$\Sigma F_y = 0$

$V_B = 3600 - 1880 = 1720^{\#}$

(b) Find wheel loads C and D.

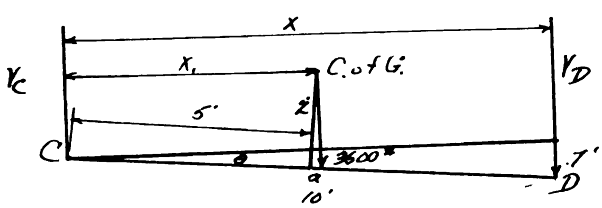


Fig. 13.

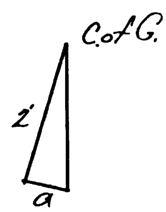


Fig. A.

$\theta = \arcsin .7/10 = 4\ \ 1'$

$2 : a = 9.98 : .7$

$$x = \frac{1.2}{\tan\theta} = 9.98'$$

$$a = \frac{.7 \times 2}{9.98} = .14$$

$$x_1 = \frac{5.14 \times 9.98}{10} = 5.13'$$

$$\Sigma M_C = 0$$

$$5.13 \times 3600 - 9.98\, V_D = 0$$

$$V_D = \frac{5.13 \times 3600}{9.98} = 1850^{\#}$$

$$\Sigma F_y = 0$$

$$V_C = 3600 - 1850 = 1750^{\#}$$

(c) Find wheel loads E and F.

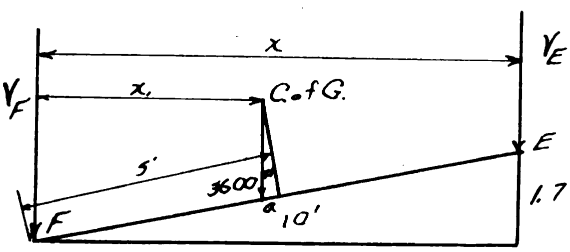


Fig. 14.

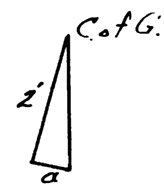


Fig. 14A.

$$\theta = \arcsin 1.7/10 = 9^\circ\ 47'$$

$$2 : a = 9.82 : 1.7$$

$$x = \frac{1.7}{\tan\theta} = 9.83'$$

$$a = \frac{2 \times 1.7}{9.83} = .35'$$

$$x_1 = \frac{4.65 \times 9.83}{10} = 4.57'$$

$$\Sigma M_F = 0$$

$$4.57 \times 3600 - 9.83\, V_E = 0$$

$$V_E = 1670^{\#}$$

$$\Sigma F_y = 0$$

$$V_F = 3600 - 1670 = 1930^{\#}$$

(d) Find wheel loads G and H.

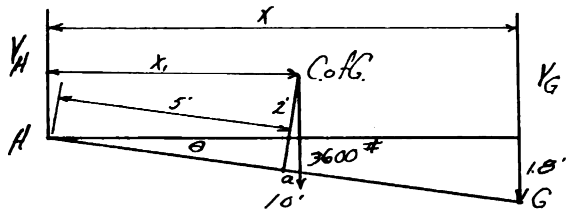


Fig. 15

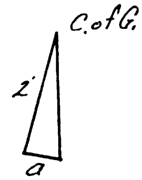


Fig. 15A.

$\theta = \arcsin 1.8/10 = 10\ 22'$

$2 : a = 9.82 : 1.8$

$x = \dfrac{1.8}{\tan\theta} = 9.82'$

$a = \dfrac{2 \times 1.8}{9.82} = .37'$

$x_1 = \dfrac{5.37 \times 9.82}{10} = 5.275'$

$\Sigma M_H = 0$

$5.275 \times 3600 - 9.82\ V_G = 0$

$V_G = 1935^{\#}$

$\Sigma F_y = 0$

$V_H = 3600 - 1935 = 1665^{\#}$

(e) Calculations for reactions R_1 and R_2.

$\Sigma M_{R_2} = 0$

$$- 1.4 \times 1670 - 1.12 \times 1880 + 8.8 \times 1720 + 8.43 \times 1930 + 15.1(1935 + 1750) + 25.08 \times 1850 + 24.92 \times 1635 - 23.7\ R_1 \times \tfrac{1}{2} = 0$$

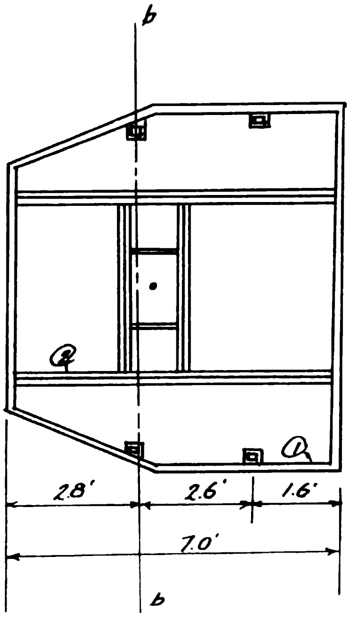
$$23.7\ R_1/2 = -2340 - 2110 + 15,150 + 16,280 + 55,700 + 46,400 + 40,750 = 169,830$$

$\tfrac{1}{2}R_1 = 7,160^{\#}$

$R_1 = \underline{14,320^{\#}}$

$\Sigma F_y = 0$

$R_2 = 4 \times 72,00 - 14,320 = \underline{14,480^{\#}}$



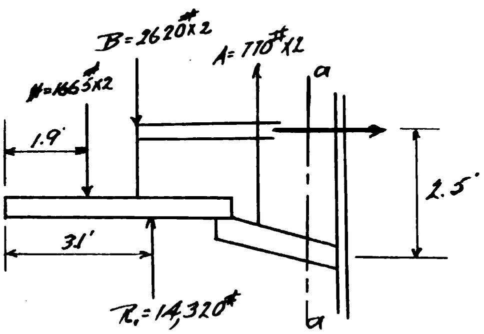


Fig. 16.

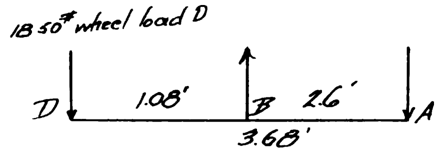


Fig. 16A.

$\Sigma M_A = 0$

$2.6\ B = 3.68 \times 1850$

$B = 2620^{\#}$

$\Sigma F_y = 0$

$A = 2620 - 1850 = 770^{\#}$

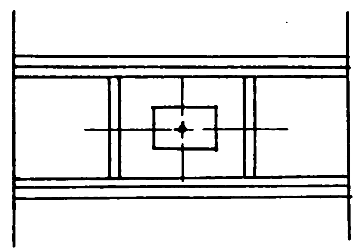


Fig. 17.

The stresses, due to bending, in the bars of Fig. 17 will be considered safe because the size of the plate on the truck, upon which it rests, is not known.

The maximum shear on the bars of Fig. 17 are one fourth of the reaction R_1 which is equal to $14320/4 = 3{,}580^{\#}$.

$s = \dfrac{3580 \times 1.3}{3.2 \times 3/8} = 3{,}880$ lbs./sq. in. O.K.

$Q = 2\ (1\ 3/8)^2 \times \frac{1}{4} + (1\ 3/8)^2 \times 3/16 \times \frac{1}{2} = 1.3$

Check stress in bar ● of Fig. 16.

Take moments about 0 of the portion to the left of section a-a of Fig. 16.

$\Sigma M_o = 0$

$1.6 \times 770 \times 2 + 14320 \times 3.9 - 4.2 \times 2620 \times 2 - 5.1 \times 1665 \times 2 - 2.5\,P = 0$

$1.25\,P = 1.6 \times 770 + 7160 \times 3.9 - 4.2 \times 2620$

$P = 985 + 22350 - 8800$

$P = 14{,}535^{\#}$

$A = 2\,(1.95) + 4 \times 1.19 = 8.66$ sq. in.

$s = \dfrac{P}{A} = \dfrac{14535}{8.66} = 1{,}680$ lbs./sq. in. Ten. O.K.

The tenile dtress just found is resisted by 4 - 3"- 4.1# channels and 2 - 5" - 6.7# channels.

Check the stresses in bar ◉ of Fig.16

In order to get the maximum shear and bending moment, wheel load H of Fig. 12 will be 7' from the front of the trailer. In moving the wheels loads G and H back 5.1 feet, the reaction R_1 will be reduced but for check purposes it will be considered to be the same in both cases. This assumption is on the safe side.

See Fig. 18 on the next page.

$\Sigma M_A = 0$

$6.85\,V_B = 3580(2.25 + 3.55) = 20{,}750$

$V_B = 3030^{\#}$

$V_A = 7160 - 3030 = 4{,}130^{\#}$

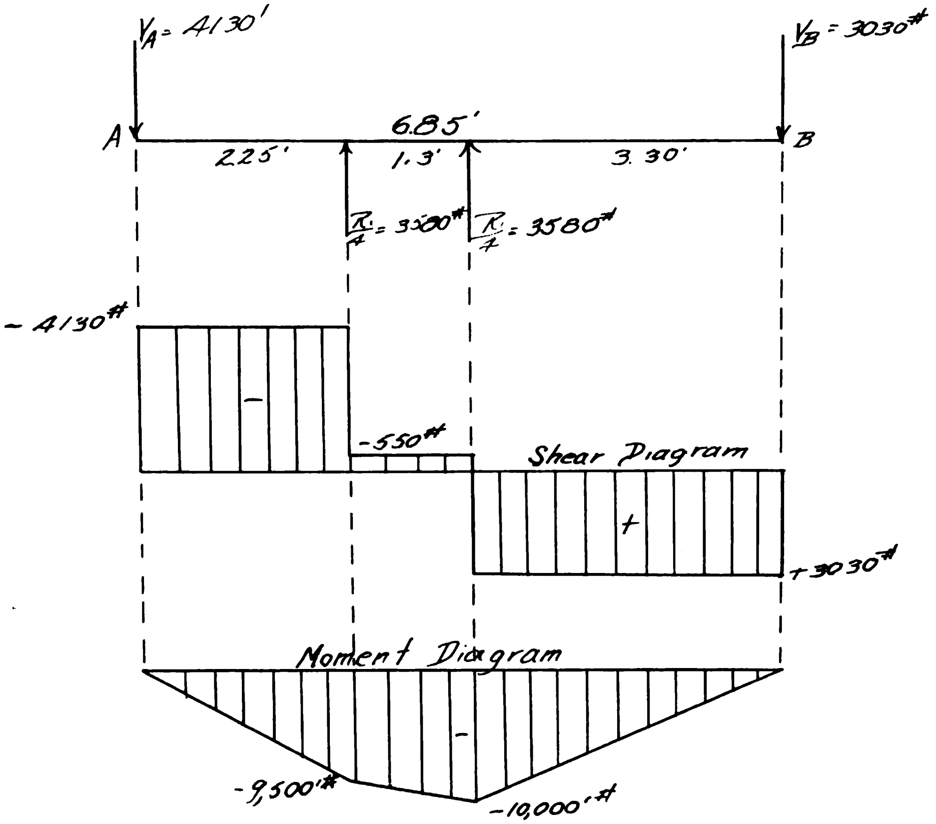


Fig. 18.

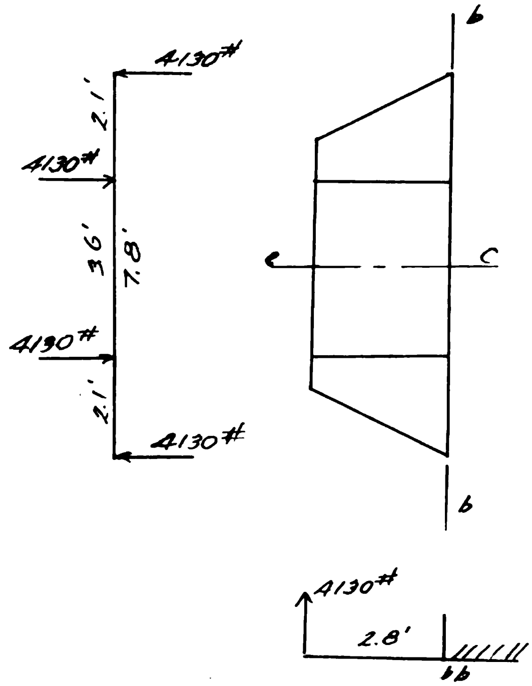
$$M_{max} = 3030 \times 3.3 = -10{,}000'\#$$

$$s = \frac{10000 \times 1\tfrac{1}{2}}{3.2} = \underline{4{,}690} \text{ lbs./sq. in.} \quad \text{Ten and Comp.} \quad \text{O.K.}$$

$$V\ max = 4{,}130^{\#}$$

$$s = \frac{4130 \times 1.3}{3.2 \times 3/8} = \underline{4{,}475} \text{ lbs./sq. in.} \quad \text{O.K.}$$

The portion to the left of section b-b of Fig. 16 forms a cantilever and it is the next member to be checked. Bending occurs about b-b and about the center line C.-L. I am only concerned with the one that will produce the maximum bending moment.



$M_{C.L.} = 2.1 \times 4130$

$= 8670'^{\#}$

$M_{b-b} = 2.8 \times 4130$

$M_{max} = M_{b-b} = 12,000'^{\#}$

$V_{max} = 4,130^{\#}$

Fig. 19.

$s = \dfrac{12000 \times 2.5}{7.4} =$ 4,650 lbs./sq. in. Ten and Comp.

$s = \dfrac{4130 \times 1.7}{7.4 \times 3/16} =$ 5,070 lbs./sq. in. <u>O.K.</u>

Check $1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{4}$" angles for tensile stress.

The maximum stress will occur when the front wheels of the car are just above the 5" channel at point ① of Fig. 11.

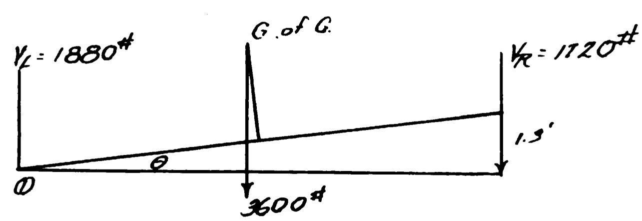


Fig. 20.

The loads of Fig. 20 are so close to the loads of Fig.

12 that I have assumed them to be the same. Therefor the maximum load will be 1880# on the channel. This load is to be split up between the two angles as follows:

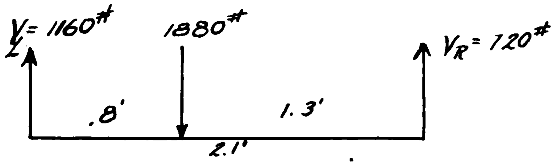


Fig. 21.

V_L = 1.3 x 1880/2.1 = 1160#

V_R = 1880 - 1160 = 720#

$s = \frac{V_L}{A} = \frac{1160}{.56} =$ 2,080 lbs./sq. in. O.K.

Check stresses in $3\frac{1}{2}$ x $3\frac{1}{2}$ x $\frac{1}{4}$" angle I-J of Fig. 11.

The maximum bending moment will occur in panel 2 of Fig. 11.

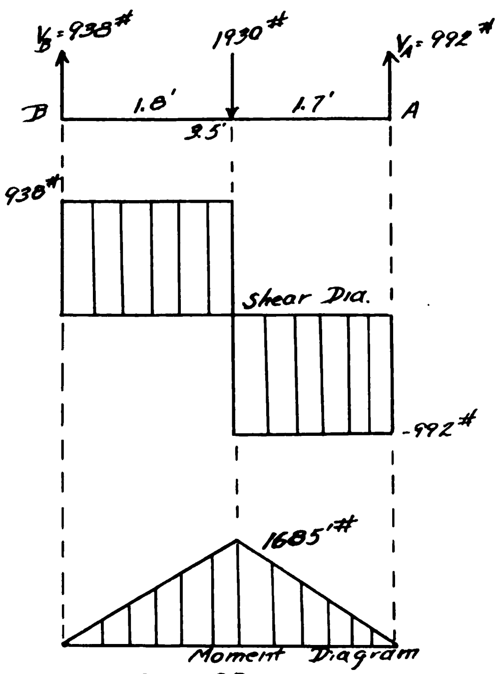


Fig. 22.

The wheel loads will be the same as in Fig. 14.

3.5 V_B = 1.7 x 1930

V_B = 938#

V_A = 1930 - 938 = 992#

M_c = 1.7 x 992 = 1,685'#

$$s = \frac{1685 \times 12 \times 1.11}{1.8} = 12,450 \text{ lbs./sq. in. Ten.}$$

$$s = \frac{1685 \times 12 \times 2.39}{1.8} = 26,800 \text{ lbs./sq. in. Comp.} \quad \underline{\text{O.K.}}$$

The maximum shear will occur when the car is in the same position as in Fig. 20. Therefor the maximum shear will be 1160 # (Fig. 21).

$$Q = (2.39)^2 \times \tfrac{1}{4} \times \tfrac{1}{2} = .715$$

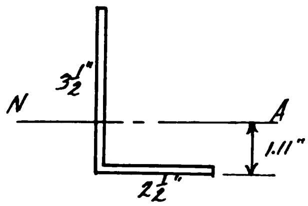


Fig. 23.

$$s = \frac{1160 \times .715}{1.8 \times \frac{1}{4}} = 1,850 \text{ lbs./sq. in.} \quad \underline{\text{O.K.}}$$

Check stresses in Member 3 of Fig. 11.

The reaction R_2 is split up into two components as shown in Fig. 24.

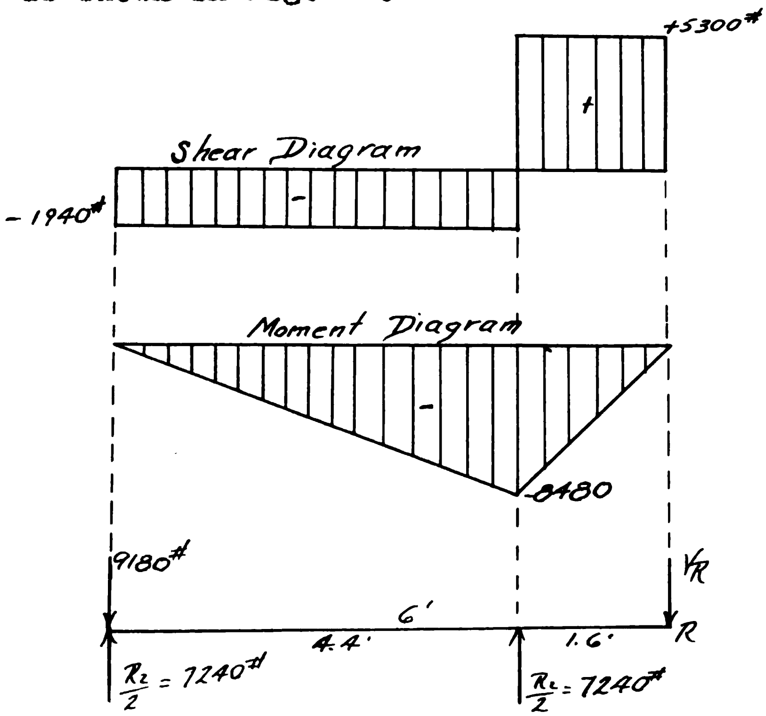


Fig. 24.

$\Sigma M_L = 0$

$6\ V_R = 4.4 \times 7240$

$V_R = 5300^{\#}$ Max.

$V_L = 14,480 - 5300 = 9,180^{\#}$

$M_{max} = 5300 \times 1.6 = 8,480'^{\#}$

$s = \dfrac{8480 \times 1\frac{1}{2}}{3.2} = 3,980$ lbs./sq. in. Ten and Comp. O.K.

$s = \dfrac{5300 \times 1.3}{3.2 \times 3/8} = 5,740$ lbs./sq. in. O.K.

Check bar 4 of Fig. 11 for compression.

$s = \dfrac{P}{A} = \dfrac{9180}{1.44} = 6,375$ lbs./sq. in. O.K.

Check for the stresses in the $2\frac{1}{2} \times 2\frac{1}{2}$" columns.

Failure will occur by buckling or lateral bending rather than by direct compression. I shall check the column at the rear of the trailer which is the most stressed member.

Moment of inertia of cross-section of column.

$I_{1-1} = \dfrac{d^4 - d_1^4}{12} = \dfrac{(2\frac{1}{2})^4 - (2)^4}{12}$

$I_{1-1} = \dfrac{39.1 - 16}{12} = 1.93''^4$

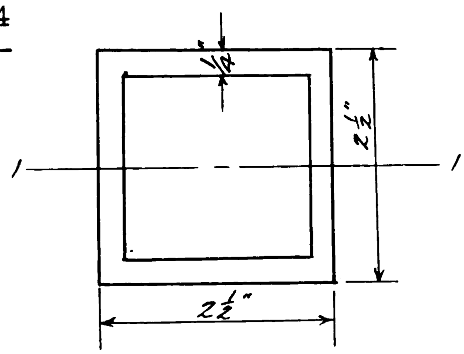


Fig. 25.

$P = 2150^{\#}$

$e = .3'$ or $1.2''$

$\delta = e\,(\sec \sqrt{P/EI}\; l - 1)$

$= 1.2(\sec \sqrt{2150/30 \times 10^6 \times 1.93} \times 7.1 \times 12 - 1)$

$= 1.2\,(\sec .52 - 1)$

$= 1.2\,(\sec 29 - 48' - 1)$

$\delta = 1.2 \times 1.01 = 1.212''$

$M = 2150\,(1.21 + 1.2) = 5180''^{\#}$

$s = \dfrac{5180 \times 1\frac{1}{4}}{1.93} = 3{,}350$ lbs./sq. in. O.K.

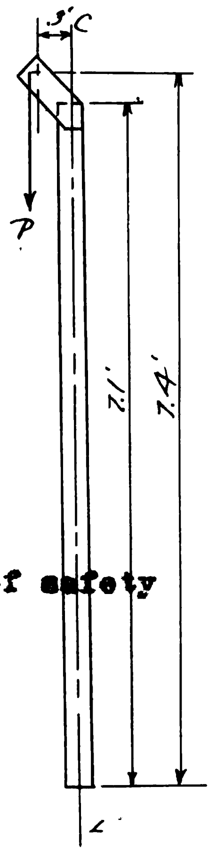


Fig. 26.

This concludes the check of the design. The results of my computations show that the trailer is safe, and has a fairly high factor of safety in most cases. The size of certain members may be made smaller upon further investigation, but will not be considered here due to the lack of time.

Pocket has: 2 Plans

[redacted] [redacted] [redacted]