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A Thesis Submitted

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THESIS

PREFACE.

The subject of crane construction relates to a branch of engineering devoted to a particular application of a class of machines which afford good general training and practice; for this reason the design of a 20 ton overhead electric traveling crane was chosen by the authors as a suitable subject for thesis work.

In preparing this volume, the writers have endeavored to approach not every detail in the design of an electric crane, but such that are of great importance, namely the design of the bridge and its other mechanical details, machinery for the drive, design of trolley frame, hoist and mechanism, driving machinery for the trolley with necessary shafts and gearing, and the selection of size and type of motors for driving trolley, bridge and hoisting.

Some references are made to such illustrations as are to the reader in this text, a list of which appears at the end of this volume.

We wish to express our thanks to Professor L. W. Wallace of the Michigan Agricultural College, who has materially assisted in securing valuable data and trade catalogs, and who has rendered many helpful suggestions. We also wish to express our appreciation to Mr. C. L. Collins of the General Electric Company, and Mr. L. A. Wills of the Crane Company, for their courtesy in supplying a number of valuable prints from which a list of some overall dimensions were obtained.

TABLE OF CONTENTS.

[illegible]

for

Type:	Three-[illegible].
Capacity:	[illegible] tons.
Span:	[illegible] feet.
Toilet:	[illegible] feet.
Loads:	
Trolley,	[illegible] lb./ft.
Wind,	[illegible] lb./ft.
Impact,	[illegible] lb./ft. to be stopped [illegible] within [illegible] feet.
Columns:	[illegible] inch [illegible] per unit.
Bent panel of trolley:	[illegible] ft. [illegible] in.
Bent base of trolley:	[illegible] ft. [illegible] in.
Base of trolley:	[illegible] ft. [illegible] in.

[illegible].

Frame:

[illegible] frame has the following [illegible] over the structural frame. [illegible] shown.

1. [illegible] is assumed to structural [illegible].

2. [illegible] frame [illegible] it can be [illegible].

3. [illegible] frame [illegible] of [illegible] and [illegible].

4. [illegible] frame.

5. [illegible] frame.

Live load	40,000 lbs.
Assumed weight of trolley	1',700 lbs.
Total	41,700 lbs.

Allowable fiber stress in cast iron is 2,000 lbs. per sq. in.

As the load hangs between the two sides of the frame it can be taken as acting one-half or twenty thousand pounds (20,000 lbs.) on each side as the total is forty thousand pounds (40,000 lbs.)

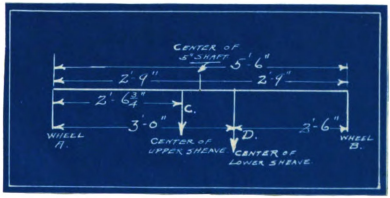

Fig. 1.

Taking moments about "B", see Figure 1, the reaction "A" is;

20,000 x 1'/3'6" = 9,091 pounds.

Bending under 6 inch shaft;

9,091 x 30 3/4 = 279,564 inch pounds; which is M_{b1};

Assuming that the bending moment due to the load is uniform;

M_{b2} = (1/2 =(1',700 lb)/2)/2 x 66 = 56,510 inch lbs.

$M_{b1} + M_{b2}$ = 279,564 + 56,510 = 336,074 inch pounds.

$I/y = 315,274/2,500 = 134.4$

By trial a suitable section is 1 unit.

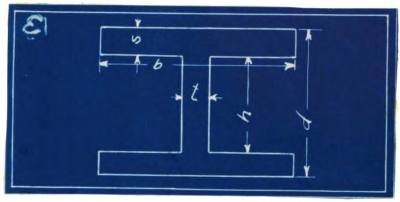

Fig. 2.

Section modulus, $S = I/y = bd^3 - h^3(b - t)/6d$.

Values assumed, $S = 1$ in., $t = 1$ in., $h = 10$ in., $b = 22$ in., $d = 24$ in.

Substituting:

$I/y = 10 \times (24)^3 - (22)^3 \times (10 - 1)/6 \times 24 = 1,[illegible].7$,

which indicates that the section is large enough when the values of the various parts are as assumed above.

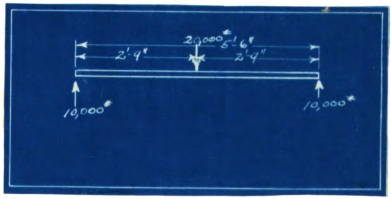

Fig. 3.

[illegible] [illegible], [illegible] [illegible] moment,

[illegible] [illegible] 3/4 = [illegible], [illegible] [illegible].

[illegible] [illegible]: 1/8 = [illegible] = [illegible], [illegible].

[illegible] [illegible], for [illegible] of [illegible] dia. 12", [illegible]. [illegible] 3/4 inch cover plate, slotted to allow for [illegible] [illegible].

[illegible] [illegible], for [illegible] of rivets in channel. 3/4".

[illegible] [illegible], number of rivets in [illegible] inches, [illegible] inches.

[illegible] [illegible] [illegible] [illegible]

[illegible]. [illegible], [illegible]. [illegible]. [illegible].

[illegible] [illegible] [illegible] [illegible].

[illegible]. [illegible]. [illegible] sq. in.

[illegible] [illegible] 1 [illegible], 2 1/2 [illegible] 1/2 [illegible], [illegible] 1. [illegible] in. 1 = 3/4 [illegible] rivet in [illegible] for [illegible] lbs. in single shear.

10,[illegible] lbs. in single shear, therefore the number of rivets necessary is,

10,[illegible]/[illegible] = [illegible], use [illegible] rivets, if possible.

[illegible] [illegible] [illegible].

Value of bolts in shear, [illegible]. in. = 7,[illegible] lbs. 3/4 in. bolts are to be used for connecting [illegible] to frame and the value of one 3/4 inch bolt in shear is 3,315 pounds [illegible] [illegible] shear is 1[illegible] lbs. [illegible] number of bolts required is [illegible].

1[illegible]/[illegible], [illegible], [illegible] [illegible] [illegible], if possible.

[illegible] I H [illegible].

Horsepower of hoist motors, formula

H. P. = [illegible] load in tons x [illegible] speed per min. /[illegible].

Substituting:

H. P. = [illegible].

Select a General Electric, [illegible], [illegible] H. P., [illegible] volts, [illegible] R. P. M., [illegible] motor.

Trolley travel motor:

Minimum diameter of [illegible] from [illegible] steel trucks for trolley.

Formula (1).

D = 72 [illegible].

Where D is the diameter of the wheel in inches.

S is the tread of the wheel.

W is the total load on the wheel.

In the design [illegible] trolley carrying [illegible] the load [illegible].

The load on each wheel,

W = [illegible] + 1[illegible].7 [illegible] = 1[illegible] tons.

Substituting in formula (1),

D = 1[illegible] = [illegible] inches. [illegible].

[illegible].

Assuming the diameter of the axle journal [illegible] inches, the horsepower of the motor was calculated by use of the following formula ( ),

H. P. = [illegible] (([illegible] + [illegible] (f + ur) [illegible]) / [illegible])

[illegible]

[illegible] Friday, [illegible] trouble.

[illegible] the test.

[illegible] the [illegible] [illegible].

[illegible] [illegible] [illegible].

[illegible] [illegible] [illegible] [illegible].

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible].

[illegible] [illegible] [illegible] [illegible] [illegible] [

2 x 35 = 70 feet.

Number of turns of rope on each side of the drum,

70 x 12/26 x 3.1416 = 10.2, use 12 turns.

Thickness of drum under grooves, see Figure 4.

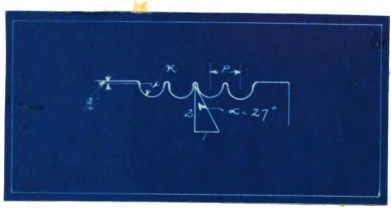

Fig. 4.

t = P/1.2 + 1/2 = 1.22 inches, use 1 7/8 inches.

Groove:

R = radius of the rope + 1/32 inch

= 3/8 + 1/32 = 13/32 inches.

Pitch of groove:

P = 1 1/8 x diameter of rope + 5/16 inches

= 1 1/8 x 3/8 + 5/16 = 1 5/32 inches.

Length of the drum:

Space allowed for winding two ropes	(12 x 1 5/32) =	17.75
" " between ropes on drum		6.00
" " on one end of the drum		6.00
" " on other end of the drum		6.00
Total length of the drum		42.75 in.

Area for the drum: Marshall p. 237. Formula (1).

$$h = \sqrt[3]{P \times 12/.0785 \times 3 \times 1 \times 2}$$

[illegible]

= 7.[illegible]

[illegible] = [illegible]

[illegible]

[illegible] of [illegible]:

[illegible]

[illegible]:

[illegible]

Hence [illegible], [illegible] to [illegible],

[illegible]

Three reductions are necessary [illegible] follows:
1 - [illegible]:1, 1 - [illegible]:1, 1 - [illegible]:1, [illegible]:1.

[illegible]

Assume [illegible] teeth on the pinion [illegible] [illegible] teeth on the gear.

Velocity of the [illegible] in [illegible] feet [illegible].

[illegible] feet [illegible].

Assuming that [illegible] feet [illegible] be in the velocity of the gear [illegible], and that the allowable fiber stress for steel [illegible] running at 100 feet or less per minute is 16,000 lbs. per sq. in. [illegible] for [illegible] teeth [illegible], [illegible].

Pull at [illegible] [illegible] [illegible] [illegible].

[illegible] pull on [illegible] in.

[illegible]

[illegible].

[illegible]

F_t = [illegible] pounds.

[illegible] pinion with [illegible] teeth.

From (4).

$p = \sqrt{[illegible]} \, / \, [illegible] (.154 - .912/n)$

Where n = number of teeth.

s = allowable working stress of material.

f = tooth face in inches.

p = circular pitch in inches.

a = f/p

Substituting in (4).

$p = \sqrt{[illegible]} \, / \, [illegible] \times 1[illegible] (.154 - .912/n)$

= 2.1.

Diam. pitch = 3.1416/2.1 = 1.[illegible], use 1.5.

Pitch diameter of gear = [illegible] /1.5 = [illegible] inches.

" " " pinion = [illegible] /1.5 = [illegible] inches.

Force on tooth is,

F_t = [illegible] = 17,97[illegible] pounds.

f = [illegible] = 17,97[illegible] / [illegible] .1 x .[illegible]7 = [illegible]

use [illegible] inches.

[illegible]

1[illegible] teeth on pinion and [illegible] teeth on gear.

Assume [illegible] inches [illegible] order

to get [illegible]

[illegible] .1416 / [illegible] x 12 = 1[illegible] ft. per min.

Allowable working stress of steel [illegible] speed at

this speed is about 1[illegible] lbs.

[illegible] moment of [illegible] is

[illegible] = [illegible] inch pounds.

[illegible] formula (4).

[illegible]

= [illegible].

[illegible] pitch = [illegible] = [illegible] inches.

[illegible] diameter of [illegible] = [illegible] = [illegible] inches.

" " " [illegible] = [illegible] = [illegible] inches.

[illegible] formula [illegible]

[illegible] of [illegible].

[illegible] = [illegible] lbs.

[illegible] = [illegible] = [illegible] lbs/in².

[illegible].

[illegible] inches.

[illegible] = [illegible] ft. per sec. [illegible] of [illegible].

[illegible] stress 7,000 lbs.

[illegible] moment on [illegible] is.

[illegible] = [illegible] inch pounds.

[illegible] moment on [illegible] is.

[illegible].

[illegible] tooth [illegible].

[illegible] is

[illegible] = [illegible]

[illegible] in.

[illegible]

[illegible] percent [illegible].

[illegible] Pitch = [illegible]

[illegible] = [illegible]

" " " = [illegible]

[illegible] of Face,

[illegible]

[illegible] = [illegible] . 77 = [illegible]

[illegible]

[illegible]

[illegible] of [illegible] in.

[illegible]

[illegible] = [illegible] . 7 = 7.7[illegible] = [illegible],

[illegible] to [illegible]: 1 - [illegible]:1, 1 - [illegible]:1.

[illegible]:

[illegible] in.

[illegible] in, [illegible]

[illegible]

[illegible] of [illegible] = 700 r. p. m. in.

[illegible]

[illegible]

[illegible]

[illegible]; [illegible]; [illegible]

[illegible] = [illegible]

[illegible]

" " " = [illegible]

[illegible]

[illegible]

221 x 16.66/2 = 1,841 inch lbs. Fig. 5.

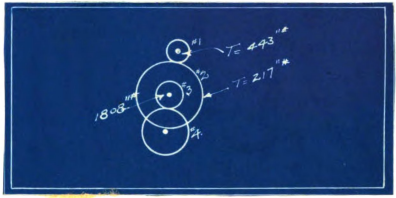

Fig. 5.

Use 6 as diam. pitch, with 22 teeth on the pinion, therefore the pitch diameter is 22/6 which is 3.66 inches.

1,841 x 2/3.66 = 1,005 lbs. on each tooth.

W = apfy, where a = 7,000; y = .093;

1005 = 7,000 x 3.1416 x f x .093/6

f = 1,005 x 6 x 1,000/7,000 x 3.1416 x 93 = 2.04 inches, use 3 inches.

Speed of pinion is,

760/5 = 152 rt. per min.

Diam. pitch is 6.

Pitch diameter of pinion = 22/6 = 3 2/3 inches.

" " " gear = 1.66 x 3 = 11 inches.

Face for pinion and gear is 3 inches wide.

SHAFTS FOR HOISTING MACHINERY.

Force acting on teeth on main drive gear = 12,275 lbs.

Load on drum = 20,000 lbs.

Taking moments about bearing "B", see figure 6.

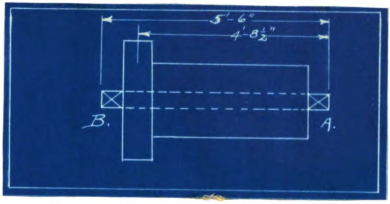

Fig. 6.

Vertical Reaction = 10,000 lbs.

Reaction due to both forces is,

15,275 x 56.5/66 = 13,075 lbs.

The resultant of these two forces, 13,075 lbs. and 10,000 lbs., from graphical solution resultant = 18,300 lbs., figuring that the pressure line is 15° involute. See fig. 7.

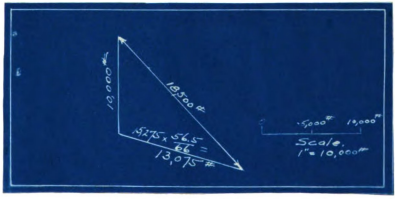

Fig. 7.

Calculations for shaft bearing only;

M_B = 18,300 x 9.625 = 178,060 inch pounds

Formula (5),

Diam. of shaft d = $\sqrt[3]{10.2 \times M_B/f_B}$

Where f_B = 12,000, from Kent p. 1071.

$$d = \sqrt[3]{13.2 \times 178,000/12,000} = 5.295 \text{ inches, use}$$

commercial size 5 1/2 inches.

Bearing surface for 5 1/2 inch shaft.

Use babbitt bearing, 400 lbs. per sq. in.

Projected area for bearing = 18,500/400 = 46.25 sq. in.

Length of bearing = 46.25/5.5 = 8.4 inches.

Shaft No. 2. see figure (7).

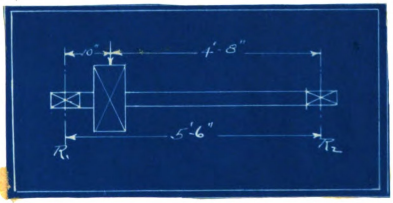

Fig. 8.

Force acting at pitch line is 15,275 lbs.

Reaction R_1 is

15,275 x 56/66 = 12,900 lbs.

M = 12,900 x 10 = 129,000 inch pounds.

Calculations for bending and twisting, formula (6).

$$M_{B} = 0.35\, M_B + 0.65 \sqrt{M_B^2 + M_T^2}$$

$$M_{B} = 0.35 \times 129,000 + 0.65 \sqrt{(129,000)^2 + (78,000)^2}$$

= 143,[illegible] inch pounds.

Substituting in formula (5),

$$d = \sqrt[3]{13.2 \times 143,[illegible]/12,000}$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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a and b, see figure 9.

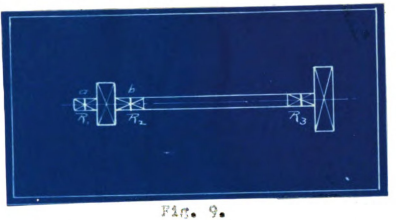


Fig. 9.

Now figuring from motor shaft to next shaft, twisting moment on the shaft is 19,260 inch pounds.

T = 63,000 x 5/500 = 4,410 inch pounds on the shaft, therefore on the pitch line of the pinion it would be,

4,410 x 2/5.5 = 1,605 lbs.

Then the reaction near the large gear is,

19,260 x 30.25/32.5 = 17,950 lbs.

Use bronze bearing allowing bearing pressure 800 lbs. to the sq. in., thus giving the length of the bearing,

17,950/3 x 800 = 7.5 inches.

As the frame was built 10 inches wide we deemed it advisable to make the bearings the same width, which gave us safe bearing area as no bearing exceeds that width.

Shaft of driving wheels.

Twisting moment on shaft is

443 x 15 x $(.92)^2$ = 5,534 lbs. acting on two wheels.

5534 / 2 = 2,767 lbs. acting on each wheel, = W_T .

As 13 inches was assumed as the distance from center of shaft bearing to center of shaft bearing the bending moment,

$M_y = WL/8 = 13,525 \times 10/8 = 16,733$ inch lbs.

Substituting in formula (6) the equivalent bending moment is,

$$M_{eq} = (0.35 \times 16,733) + \sqrt{(4707)^2 + (16,733)^2}$$

$$= 15,916 \text{ inch pounds.}$$

Substituting in formula (5), for diameter of shaft,

$$d = \sqrt[3]{10.2 \times 15,916 / 9,000} = 3.60 \text{ in., use } 3 \text{ in.}$$

Intermediate shaft.

Twisting moment on the shaft is 1,[illegible] inch pounds; Assume that the bending moment, which is not present, is equal to the twisting moment, or that the bending moment is equal to the twisting moment, 1,[illegible] inch pounds.

Substituting in formula (5), for diameter of shaft,

$$d = \sqrt[3]{10.2 \times 1,[illegible] / 9,000} = 1.27 \text{ in., use } 1.5 \text{ in.}$$

TROLLEY WHEEL.

The trolley wheel was designed according to proportions found in Kent, page 67.

Diameter assumed as 12 inches, with tread 2 1/4 inches, and a constant of 400 lbs. per sq. in., the relation is in the formula,

$W = c. b. D.$

W = total load wheel will stand.

b = tread in inches.

c = constant, between 300 and 900 lbs. per sq. in.

$W = 400 \times 2\ 1/4 \times 12 = 10,800$ lbs., this is more as the wheel load is figured is 1[illegible] lbs.

SHEAVES.

From investigation we found it advisable to use 21 inch lever sheave. In order to determine the size of the shaft it was necessary to find the maximum moment which is.

P x a = max. moment.

M_t = 20,000 x 2 1/2 = 50,000 inch pounds.

fz = 50,000

z = 50,000/10,000 = 5

= 3.1416 x d^3 / 32, Carbrin, page 153.

= 3.71 inches, use 4 inches.

The sheave wheels are to move on the shaft, and the shaft to be fastened. The bearing is to be steel on bronze, allow 1,100 lbs. per sq. in.

(20,000/1,100)/4 = 4.55 sq. in., which is sufficient. nor 1 was used.

Calculations for shear, crushing above hole for shaft.

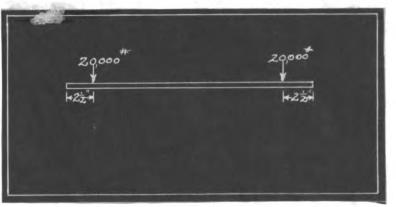


Fig. 15.

a = 20,000/10,000 = 2 sq. in.

t = 2 / 5 = .4 inches, thickness of the plate

necessary but 1 inch was used.

Sent for the [illegible] of shaft of [illegible] of plate.

Lever arm = 2 1/2 - 9/16 = 2 7/8 inches.

20,000 x 2 7/32 = 44,375 inch lbs. = M.

d = 44,375 / 10,000 = 4.44 inches

= 2.1415 = d³/32

d³ = 4.44 x 32 / .1415

d = 3.56 inches, so it is safe to reduce the shaft 1/2 inches in diameter through the plate.

[illegible] 3/4.

The lever sleeve is 1 inches in diameter at the shaft the same diameter as for the lever sleeve. The sleeve is to move on the shaft, and the shaft is to be fastened with a brass bushing. Refer to sheet number 4.

For lever [illegible] see sheet number 4.

[illegible].

The section of the lock was calculated from formula, from Kent, page 1114, formula (7),

P/F = 1 / (1 + y y₁ / k²), where

P = load.

F = area of section.

k² = square of the radius of gyration.

f = allowable fiber stress in lbs. per sq. in., 20,000 lbs. per sq. in., for [illegible] steel.

From tables, Kent page 1112, for [illegible] or [illegible] of d = 1/4, where P/F or f = 1.777, [illegible] = 1.1.

k² = (y + y₁)/(1 - f/E) = (1.1 + 1.1)/(1 - 1/4) = 11.2,

$$R = \frac{[illegible](11.[illegible] + [illegible] + 1.[illegible])}{18\,(11.[illegible] + 7.[illegible] + 1.[illegible])} = [illegible].1$$

$$x_1 = ([illegible] + [illegible] \times [illegible]) / ([illegible] + 1.1 \times [illegible]) = [illegible]$$

$$x_0 = [illegible] + [illegible] = [illegible]$$

$$P/f = 11.[illegible]/(1 + [illegible] \times [illegible]/[illegible].1) = 1.91.$$ which indicates that the above position is all right.

Work Sheet; Fr. [illegible] Bolts.

For calculating d_1 and d_2.

$$P = ([illegible]/4)(d_1^2 - d_2^2)\, f_s, \quad \text{formula (3)}$$

f_s = [illegible] lbs., pressure on the washer, then

$$.7[illegible]4\,(d_1^2 - d_2^2)\, d_s[illegible] = [illegible]$$

$(d_1^2 - d_2^2)$ = 11.1, assume d_2 equal to [illegible]/[illegible] inches.

$$d_1^2 - ([illegible]/[illegible])^2 = 11.1,$$

d_1 = [illegible].75, use [illegible] inches.

For $b_1 l_1$ assume b_1 as [illegible] inches, so that l_1 in the formula,

$$\pi/4 = ([illegible] \times b_1 l_1^2/[illegible])\, f_s, \quad \text{or } l = 1[illegible].1 \text{ in.}$$

f_s = 1[illegible],[illegible].

$$(b_1 l_1^2/[illegible]) = 1[illegible],000 \div [illegible],[illegible]0 = 1[illegible].17/4.$$

$$b_1 l_1^2 = 1[illegible],000 \times 1[illegible].1\,75 \times [illegible]/1[illegible],000 = [illegible].[illegible]$$

$$[illegible].3\, b_1^2 = [illegible].625.$$

b_1 = [illegible].[illegible] inches, use [illegible] inches.

For stress on the bolt; 7,[illegible] lbs. per sq. in., allowed in shear for bolts.

$$40,000/7,[illegible] = [illegible].54 \text{ sq. in. area of bottom of thread,}$$

[illegible] area at bottom of thread [illegible].[illegible]7 in.

[illegible] at least [illegible] [illegible] = [illegible]/[illegible] inches.

[illegible] = [illegible] 1/4 inches.

[illegible].

The maximum wheel load is approximately equal to the maximum wheel load, i.e., [illegible] pounds. The girder will be of the box type with [illegible] 1/4 inch web. [illegible] feet apart at the middle and 1' inches at the end.

The unit wheel load is,

[illegible] x 1/4 x 12 = [illegible] lbs. per sq. in., which is safe.

Assume the trolley wheel base as [illegible] inches. Position [illegible] will occur when wheel is at a distance a/2 from center of span. See figure 11.

Use formula (1) for bending moment.

$$M = (Pl/2)(1 - a/l)^2 + Gl/2 + \text{weight of girder} \times l/4$$

where M = maximum moment.

P = Total of live load in pounds.

l = length of the girder span in inches.

G = weight of the girder in pounds.

The trolley is to be built of two girders of the Kirchoffity type, so M will be 1/2 of the total live load.

Assume weight of trolley		12,700 lbs.
Wheel load	(2 wheel)	[illegible] "
Total load between girder		[illegible] "

Assume weight of girder [illegible] per lin. ft.

Assume weight of girder [illegible] pounds.

Then [illegible] for [illegible] (1),

$$M = \frac{[illegible]}{[illegible] \times 12} \left([illegible] - \frac{[illegible]}{2}\right) + [illegible] + [illegible]$$

V = [illegible] inch-pounds.

Approximation of [illegible] allowable [illegible] lbs. per sq. in. fiber stress.

M = [illegible] required [illegible] fiber stress [illegible], where d is the diameter of [illegible] rods.

d = [illegible] = [illegible] inches.

A = [illegible]/[illegible] x [illegible] = [illegible] sq. in.

Taking calculations so that 1/[illegible] of the web section is assumed as resistant bending.

1/8 x [illegible] = 1/[illegible] x [illegible] = 1/4 x 16 = 2.25 sq. in., and the allowed maximum fiber stress 10,000 lbs. per square inch.

1/8 web area	2.25 sq. in.
1 cover plate [illegible]	6.00 " "
2 angles [illegible]	6.72 " "
Total area	14.[illegible] " "

This stress is for 10,000 lbs. per sq. in. fiber stress, but the maximum stress will slightly exceed this so as we assumed the compressive stress to be [illegible],000 lbs. per sq. in.

With this above trial section take the [illegible] for the final at the [illegible].

d = [illegible] = [illegible] = [illegible] inches.

A = [illegible] / [illegible] = [illegible] = [illegible] sq. in., based on [illegible] lbs. per sq. in. fiber stress.

[illegible] x [illegible] = [illegible] sq. in. based on [illegible] lbs. per sq. in., fiber stress.

Thus area is [illegible].

[illegible]	[illegible]	[illegible] in.
2 [illegible] 1" x [illegible]	[illegible] "	"
2 angles [illegible] x 3/8" [illegible]	[illegible] "	"
[illegible]	[illegible] "	"

[illegible]

[illegible] of Inertia.

[illegible]

	Area.	Moment.
1" x 3/8" plate	6.75 x .187 =	1.266
Upper angles [illegible]	[illegible] x 1.31 =	[illegible]
24" [illegible] plate	17.[illegible] x [illegible] =	[illegible]
Lower angles [illegible]	6.75 x 17.[illegible] =	[illegible]
1" x 9/16" plate	[illegible] x [illegible] =	[illegible]
	[illegible] in.	[illegible]

[illegible] for rivet holes, 11/16 in. holes.

2 x (11/16 x 11 [illegible]) = [illegible]	[illegible]
2 x (11/16 x 12/16) = [illegible]	[illegible]
Total [illegible]	[illegible] in.

Moment = [illegible] x [illegible] = [illegible]

	Area.	Moment.
Section	[illegible]	[illegible]
Rivet holes	[illegible]	[illegible]
Net	[illegible] in.	[illegible]

Center of gravity is,

x = [illegible] / [illegible] = [illegible] inches.

[illegible] OF [illegible].

Upper flange plate:

$bd^3 / 12$ (negligible)

$Ah^2 = 6.75(17.54 - .1875)^2$ = 2,[illegible].57

Flange angles:

2 angles at [illegible]

$Ah^2 = 5.72\ (17.54 - 1.515)^2$ = 1,466.15

Web plates:

$bd^3 / 12 = .5 \times .25 \times [illegible]^3 / 12$ = 2,255.43

$Ah^2 = .5 \times [illegible] \times 1.214^2$ = 62.51

Lower flange angles:

2 angles at [illegible]

$Ah^2 = [illegible].72 \times 19.7^2$ = 2,219.37

Lower flange plate:

$bd^3 / 12$ (negligible)

$Ah^2 = 5.625 \times 21^2$ = 2,[illegible].62

I = 19,562.15

Rivet holes (neglecting Ah^2 values only).

Lower flange only in tension.

$4 \times .6875 \times [illegible]^2 = 1,133.[illegible]$

Net I is,

19,562.51 - 1,[illegible] = 8,271.61, [illegible] neither not considered in the allowance for rivets.

The extreme fiber stress in compression [illegible] will be,

$M = P_2 l/4$; $P_2 = M\ e/I$

$P_2 = 8,[illegible] \times 17.54 / 8,271.61 = [illegible]$ lbs. [illegible] stress for [illegible].

[illegible] tension.

P_t = [illegible] x [illegible] = [illegible] lbs.

which checks for tension.

[illegible].

Total load on the trolley [illegible] pounds is distributed over four wheels.

Load on each wheel is,

[illegible] / 4 = [illegible] lbs.

Refer to sheet number [illegible], (attached in back cover).

Figure 1, Scale 1 inch = 10,000 lbs., W = 16,[illegible] lbs.

Figure 2, the scale of linear dimension is 1 inch = 10 ft.

Figure 3, the scale is 1 inch = 16,[illegible] x [illegible] = [illegible] ft.lbs.

In the lower part of figure 1, the bending moment due to the uniform load of the girder is [illegible] lbs. per lin. ft.

[illegible] x [illegible] = [illegible] inch pounds for one girder.

Middle ordinate is in

[illegible] / 16,[illegible].

M = [illegible] = [illegible] x [illegible] = [illegible]

[illegible] = [illegible] / 16,[illegible] = [illegible] ft.

[illegible] to the scale, 1 inch = 1[illegible] ft.

Moments corrected by 16 %.

4/10 moment = [illegible] x 1.[illegible] = [illegible]

3/10 " = [illegible] x 1.06 = [illegible]

2/10 " = [illegible] x 1.06 = [illegible]

1/10 " = [illegible] x [illegible] = [illegible]

Depth of web:

4/10 moment = [illegible] / [illegible] x [illegible] = [illegible] inches.

3/10 upon = 3,935,7[illegible]/9,000 x 14.37 = [illegible] inches.

2/10 " = 2,[illegible]/9,000 x 14.37 = [illegible] "

1/10 " = 1,[illegible]/9,000 x 14.37 = 11.[illegible] "

1/10 of the upon is decisive for shear along.

Flange area is,

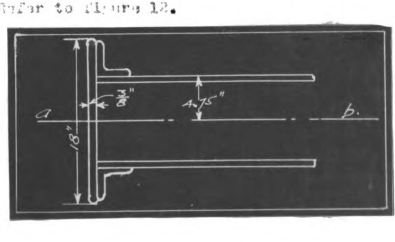
Angles 4"x 4"x 3/8"	4.72 sq. in.
Plate 18" x 3/8"	6.75 " "
4/5 of 1/[illegible] plate	1.90 " "
Area	14.37 " "

Before the section is finally accepted, it should be examined for the lateral bending that may come upon it due to suddenly stopping the fully loaded crane, if the brake operating upon the bridge shaft will exert a retarding force sufficient to stop the crane in 10 feet.

Weight in pounds:

Bridge	30,000
Trolley	13,700
Motor	1,200
Live Load	40,000
Total	4,900

The moment of inertia of the upper flange must now be found. Refer to figure 12.



Inertia about axis m.

[illegible] = [illegible] = 1[illegible]

[illegible] = [illegible] = [illegible]

[illegible] = [illegible] = [illegible]

[illegible] = 1[illegible] x 1/2 x [illegible] = 17[illegible]

[illegible] = [illegible]

Inertia energy of the trolley,

[illegible] = ([illegible]) ([illegible])^2 = 11,[illegible] ft. lbs.

Inertia energy of the trolley and live load,

[illegible] = ([illegible])([illegible])^2 = [illegible] ft. lbs.

Total rotarding force for one girder train,

[illegible] x 1[illegible] = [illegible] lbs.

Total rotarding force for one girder, trolley and load,

[illegible] x 1[illegible] = 1,[illegible] lbs.

[illegible] = [illegible] + [illegible]

= [illegible] x [illegible] + 1[illegible] x [illegible] x 1/[illegible] =

= 1[illegible] foot pounds.

[illegible] = p I/e; p = [illegible]/I;

[illegible] = [illegible] = [illegible] lbs., which must be added to extreme fiber.

The fiber stress in the upper flange will be,

[illegible] + [illegible] = [illegible] lbs., for the worst conditions possible [illegible] will be [illegible].

[illegible]

The [illegible] are [illegible] only for [illegible] strength. The [illegible] given in [illegible] section [illegible] foot number 7. [illegible] (see [illegible] No. 7).

[illegible] for both [illegible] and lower lo[illegible].

S_1 = total vertical [illegible] over one inch of flange length [illegible] shear load is distributed over the [illegible] length. ([illegible])

S_1 = [illegible] / [illegible] rd.

V = vertical [illegible] shear in [illegible].

h = vertical distance between [illegible] rivets in the upper and lower flanges.

S_2 = Shear of flange force per inch of [illegible].

If S = the resultant [illegible] shear upon rivet in one inch of [illegible].

$S = \sqrt{S_1^2 + S_2^2}$ [illegible] rivet spacing is,

p = direct value / S, or [illegible] in the pitch of rivets [illegible] horizontally.

Trolley steel construction is,

$(4,200 + 16,700)/4 = 16,900$ pounds.

5/16 in.:

$S_1 = 12,400 / [illegible] = 172.2$, say 17.

$S_2 = 16,900 / 17 = 1[illegible]$.

$S = \sqrt{172^2 + [illegible]^2} = [illegible]$.

Using 5/8 inch rivets would make pitch of rivets,

$5,000 / 5[illegible] = 9.5$ inches.

The limit is 5 inches (according to specifications, not more than 16 times the thickness of plate [illegible] over 7,500 lbs. per sq. in.

3/16 in.:

$S_2 = 20,500 / [illegible] = [illegible]$; $S_1 = 7$.

[illegible]

[illegible] = [illegible] / [illegible] = [illegible].

[illegible] = [illegible] / [illegible] = [illegible]. [illegible] = [illegible].

[illegible]:

[illegible] = [illegible] / [illegible] = [illegible]; [illegible] = [illegible].

[illegible] = [illegible] / [illegible] = [illegible] = [illegible].

[illegible] / [illegible] = [illegible] of inch pitch, [illegible] / [illegible] inch pitch.

[illegible].

Area [illegible] shear / [illegible] stress in tension.

[illegible] / [illegible] = [illegible] sq. in.

[illegible] and [illegible], [illegible] sq. in.

[illegible] + [illegible] = [illegible];

[illegible] / [illegible] = [illegible] sq. in. or [illegible]. ([illegible])

[illegible] = [illegible] / [illegible] [illegible].

[illegible] = [illegible] ([illegible]), [illegible] ([illegible]), [illegible].

[illegible] = [illegible] [illegible] of [illegible]

[illegible].

[illegible] = [illegible] in.

[illegible] = [illegible] sq. in.

[illegible] ([illegible]),

[illegible] = ([illegible] / [illegible]) ([illegible] - [illegible]) / [illegible] = [illegible] lbs.

[illegible].

[illegible] volume of [illegible] / [illegible] inch [illegible]

plate, [illegible], [illegible] cu. in., is

[illegible] = [illegible].

[illegible] of rivets is.

[illegible] / [illegible] = [illegible] / [illegible] = [illegible].

([illegible])

END STIFFENERS.

End stiffeners to be same as web stiffeners.

Distance apart is equal to depth of the section at end.

Rivet spacing is the same as for the web stiffener.

REACTIONS.

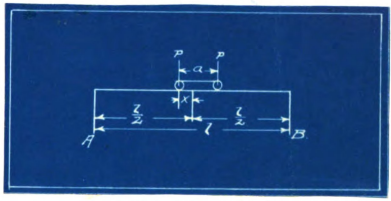


Fig. 13.

$$A = P\,(1 + 2x/l - a/l)$$

$$B = P\,(1 - 2x/l + a/l)$$

Substituting;

$$A = 12{,}429\ (1 + 2 \times 1.375/50 - 9.5/50) = 12{,}627 \text{ lbs.}$$

$$B = 12{,}429\ (1 - 2 \times 1.375/50 + 9.5/50) = 14{,}163 \quad "$$

Reaction due to dead load,

$$15{,}000 / 2 = 7{,}500 \text{ lbs.}$$

Total reactions;

$$A = 12{,}627 + 7{,}500 = 20{,}127 \text{ lbs.}$$

$$B = 14{,}163 + 7{,}500 = 21{,}663 \quad " \quad \text{(Same p. 11)}$$

BENDING THEM.

See figure 14.

$$M = Pa + Wl^2/8$$

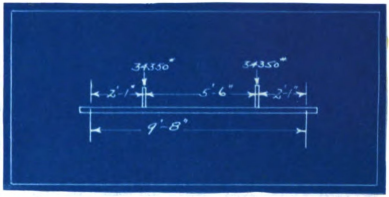


Fig. 14.

M = 34,350 x 2 1/2 x 12 + 35 x 10 x 10 x 12/8

= 863,000 inch pounds.

M = S I/c;

I/c = 863,000 / 10,000 = 86.4

From Cambria, page 163, select 2 channels, 15 inch, 40 pounds.

Maximum wheel load, the following weights were assumed.

Weight of trolley	13,700 #	= W_T
Load	40,000 #	= L
Weight of Bridge	30,000 #	= W_B

Maximum wheel load is,

W_B / 4 + (W_T + L) / 2

Substituting;

30,000/4 + (13,700 + 40,000)/2 = 34,350 lbs.

SPLIT SECTION.

Use 1/2 inch plate on the inside of the girder and 3/8 inch on the outside. Shear at split section from shear

diagram is 22,800 lbs.

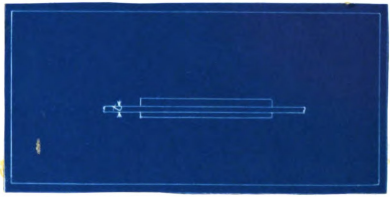


Fig. 15.

t = thickness of plate.

P = compression load.

p = pitch of the rivets in one row, using 5/8 inch rivets.

Shear on rivets:

$P = 1/4 \times 3.1416 \times (5/8)^2 \times 20,000 = 6,136$ lbs. per rivet.

Number of rivets;

22,800 / 6,136 = 3.6 rivets, use 4 rivets.

Compression on rivets;

$P = 2 \times 1/4 \times 5/8 \times 20,000 = 6,250$ #.

Number of rivets;

22,800 / 6,250 = approx. 3.6, use 4 rivets.

Tension in plate;

$P = 1/4\ (4 - 5/8)\ 12,000 = 8,750$ #.

[illegible] I [illegible] POWER [illegible] DRIVE.

Power [illegible] motor for hoisting drum.

$$\text{I. P.} = \frac{(W_1 + W_2 + L)(f + gr)\ [illegible] \times 1.5}{R \times 33{,}000}$$

Substituting, [illegible] we get,

$$\frac{1.5\,(2{,}000 + 1{,}710 + 40{,}000)(.02 + .01 \times 2)\ [illegible]}{1 \times 33{,}000}$$

$$\text{I. P.} = 15.5$$

Select a [illegible] 1 [illegible] H.P. I. P. motor, [illegible] R.P.M.,

[illegible] I. P. I.

The [illegible] of [illegible] is [illegible].

The [illegible] speed is [illegible] ft. per min.

$$\text{I. P.} = \frac{\text{[illegible] speed in ft. per min.}}{\text{[illegible] in ft. per min.}}$$

[illegible]:

[illegible] / 2 × 3.1[illegible] = 47.7, [illegible] I. P. I.

[illegible], motor to [illegible] shaft.

[illegible] / [illegible] = 11.[illegible], [illegible] 11 : 1.

1- [illegible]:1; 1 - [illegible]:1;

The [illegible] must be [illegible] for the torque due to the [illegible] or the torque due to the [illegible] motor. [illegible] torque [illegible] is the larger.

For the [illegible] motor, the torque is,

$$T = 63{,}000 \times \text{H. P.} / n,$$

$$= 6{,}300 \times 21 / 1{,}1 = 2{,}[illegible] \text{ lb.}$$

Kinetic energy in crane (crane [illegible], [illegible] lbs. and full [illegible]).

$$W/2g = (2{,}700 \times (\text{[illegible]}/60)^2)/2.4 = 32{,}5[illegible] \text{ ft. lbs.}$$

[illegible] Zones [illegible] of the [illegible] [illegible] is [illegible] by [illegible] potential [illegible] [illegible] [illegible]

[illegible]

[illegible]

[illegible] Textbook, by [illegible], [illegible]

[illegible], [illegible], [illegible], [illegible], by [illegible], [illegible]

[illegible] Textbook, by [illegible], [illegible]

Elementary [illegible], by [illegible], [illegible]

[illegible] Textbook, by [illegible] and [illegible].

[illegible] Textbook, by [illegible], [illegible]