THESIS

for

B. S. Degree

Design
of a
Steel Crescent Roof-Truss
span 80'

June 1, 1904

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A thesis being required of all candidates for the B. S. degree of W. L. U., I respectfully submit the following design of a crescent roof-truss. The subject was chosen in conference with Prof D. C. Humphreys, to whom this thesis is submitted.

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The truss chosen is of the crescent type, the rise of upper chord being 16 feet, and rise of lower chord being 4 feet. The panel points on upper chord are points on the arc of a circle of 58' radius; and the joints of lower chord are points on an arc of 202' radius. The upper chord is divided into 6 equal panel lengths. The truss is to have inclined struts and ties, with its right end placed on an expansion shoe as designed below. Trusses are to be placed 16' apart. The roof covering is to consist of iron shingles weighing 3 lbs. per sq. ft., laid on sheathing 1" thick, weighing 4 lbs. per sq. ft., supported by rafters spaced two feet center to center, and weighing 3 lbs. per sq. ft. in total, these being carried by purlins placed at the panel points of the truss. The purlins are to be trussed, and their planes will be in the direction of the radial line at the panel points.

The ties and struts are to be of

medium steel; the pins, rivets, shoe plates and rollers to be of material as specified by the American Bridge Co. in their standard specifications. The rafters and sheathing are to be of northern yellow pine, weight as above. The snow load is to be assumed at 10 lbs. per sq. ft. of horizontal area, and the wind pressure at 40 lbs. per sq. ft. of vertical area, these being the values given by Merriman & Jacoby.

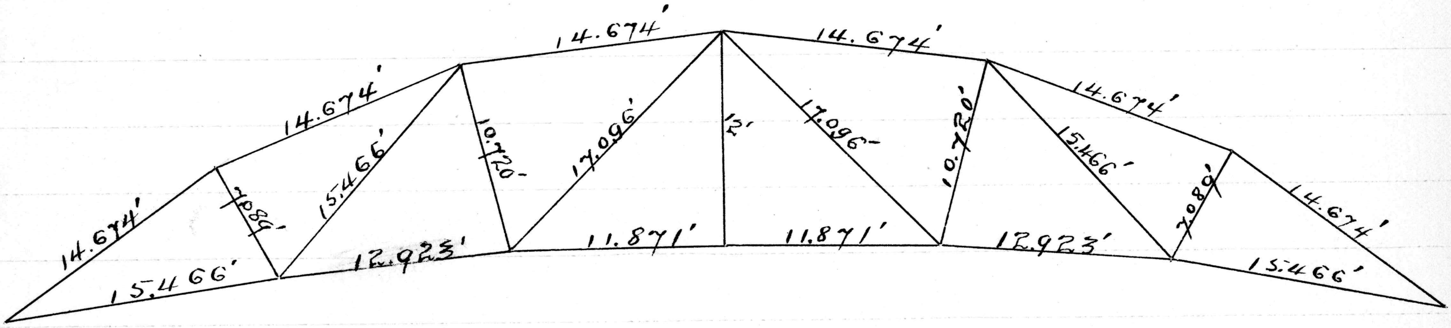
The allowable unit stresses shall be as follows.

For timber	in	compression ..	1000 $\frac{lbs}{ft^2}$
" steel	"	"	16000 $\frac{lbs}{ft^2}$
" "	"	tension	16000 $\frac{lbs}{ft}$
" rivets	"	shear	7500 $\frac{lbs}{ft^2}$
" pins	"	"	15000 $\frac{lbs}{ft^2}$

Lengths of Pieces

These were computed by the various trigonometric formulas necessary, and are given below on the truss outline.

These lengths will be altered later in the work owing to the introduction of plate at joints ~~in~~ ~~#8~~ on upper and lower chords



ROOF COVERING.

Iron shingles of standard size, details as per Amer. Bridge Co. specifications. These to be laid on sheathing 1" thick, which in turn rest on rafters spaced 2' center to center.

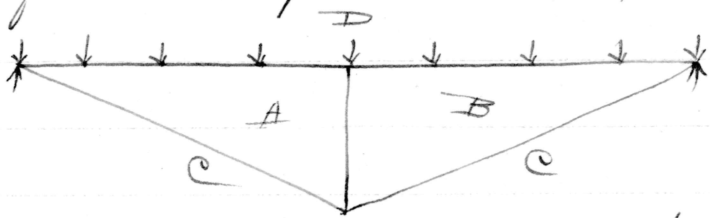
RAFTERS.

The span of these will be the distance between purlins; and they will be constructed of wood.

Area roof supported by one rafter = 29.584 ft^2
Total wt. of roof " (vert) " " " = 295.84 lbs
" " " snow " (") " " " = 146.7 "
" wind pressure " (normal) " " " = 920. "
" normal pressure " " " " = 1360 "
Normal component of roof + snow = 440 "
Bending moment = $\frac{1}{8} WL$ = 30039 lbs-in.
But $M = \frac{SI}{C} = \frac{1000 \times bd^2}{6}$, let b = 2"
$\therefore$ $333.33 d^2 = 30039$ or d = 9½ inches.
Therefore size of rafter will be taken as 2" X 10".

PURLINS

To be constructed of two angles for the upper member, and to be in the shape of a simple truss; as,



Total dead load on each = 2368 lbs.
" wind " " " = 7104 "
" " " " = 9472 "

Stresses found graphically as follows

AD = -10900 lbs　　AB = -9472 lbs
BD = -10900 lbs　　AC = +11900 lbs.
BC = +11900 lbs

The upper member is also a beam under concentrated loads placed 2' apart, but practically uniform.

$M = \frac{1}{8} W L = \frac{1}{8} \times 9472 \times 8 = 9472$ lbs.

By Cambria pocket book, 2 angles 5" X 3" X 7/16" with short legs along upper chord, will fill the requirements. The angles will be placed back to back. Strut AB will consist of 1 angle 2" X 1½" X 3/8", this satisfying Rankine's

formula for columns (M+ ~~J~~. Mech. of Mat. p121)
Ties AC + BC will each consist of 1 bar.
stress = + 11900 lbs. ∴ area req. = $\frac{11900}{16000}$ = .75 in²
Use 1 rect. bar 1½" × ½" for each; diam of head of eye = 4½" by Cambria specifications.
By Cambria Steel Co., pins for Purlins will be 2" in diam. to support mom. = 11900 lbs.
All connections and joints are to be made as shown in drawing.

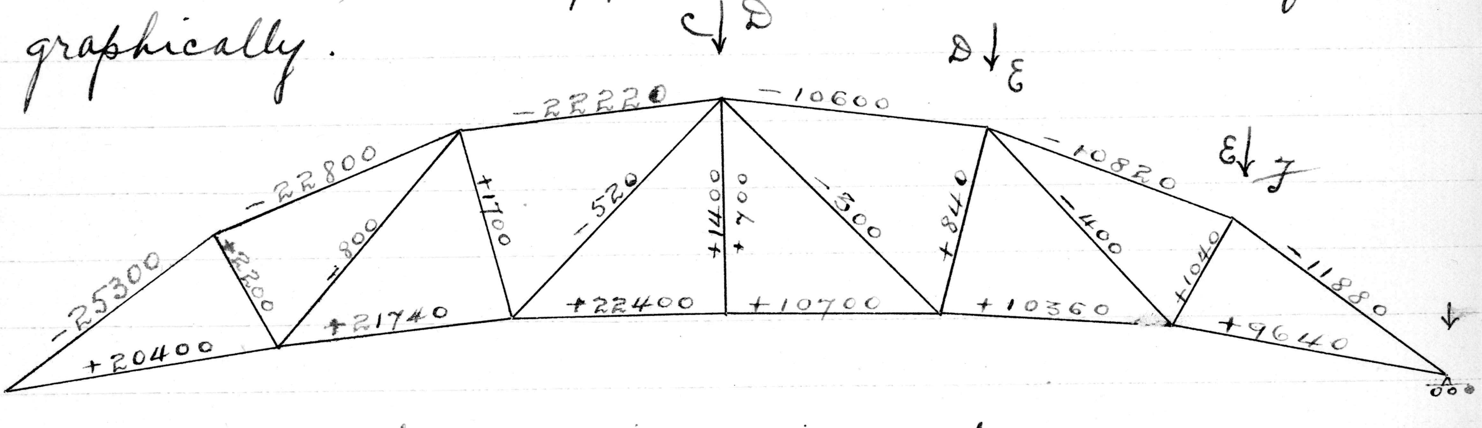
Dead Load.

To determine the wt. of the truss, the formula given by M.+J. Book II for a wrought iron truss, since the wt. of a steel truss will not depart far from this. Then $W = \frac{3}{4} al (1 + \frac{1}{10} l)$ in which a = dist. between trusses + l = span
Therefore $W = \frac{3}{4} \times 16 \times 80 (1 + \frac{1}{10} \cdot 80) = 8640$ lbs.
giving a dead apex load of 144 lbs, and for each support 720 lbs.
The dead load due to roof covering is the wt. of the shingles, sheathing, ~~#~~ rafters and purlins, the total being assumed at 14 lbs. per sq. ft. Then each truss will

support the wt. of 8' of roof covering on each side. Therefore 6 (panel length) x 14.67 x x 16 x 14 = 19868 lbs., giving an apex load of 3311 lbs., and 1655 lbs. at each support. Total dead apex load then equals 4750 lbs., and for each support 2375 lbs. Stresses were found graphically and are given below in blue ink on truss outline.

Snow Load.

This was assumed at 10 lbs. per sq. ft. of horizontal area. Each apex supports half the load in the adjacent panels. The apex loads are as follows: CD = 2350 lbs., DE = 2280 lbs + EF = 2050 lbs., & at supports 958 lbs. Stresses found graphically.



Wind stresses given in red ———

Dead load stresses given in blue ———

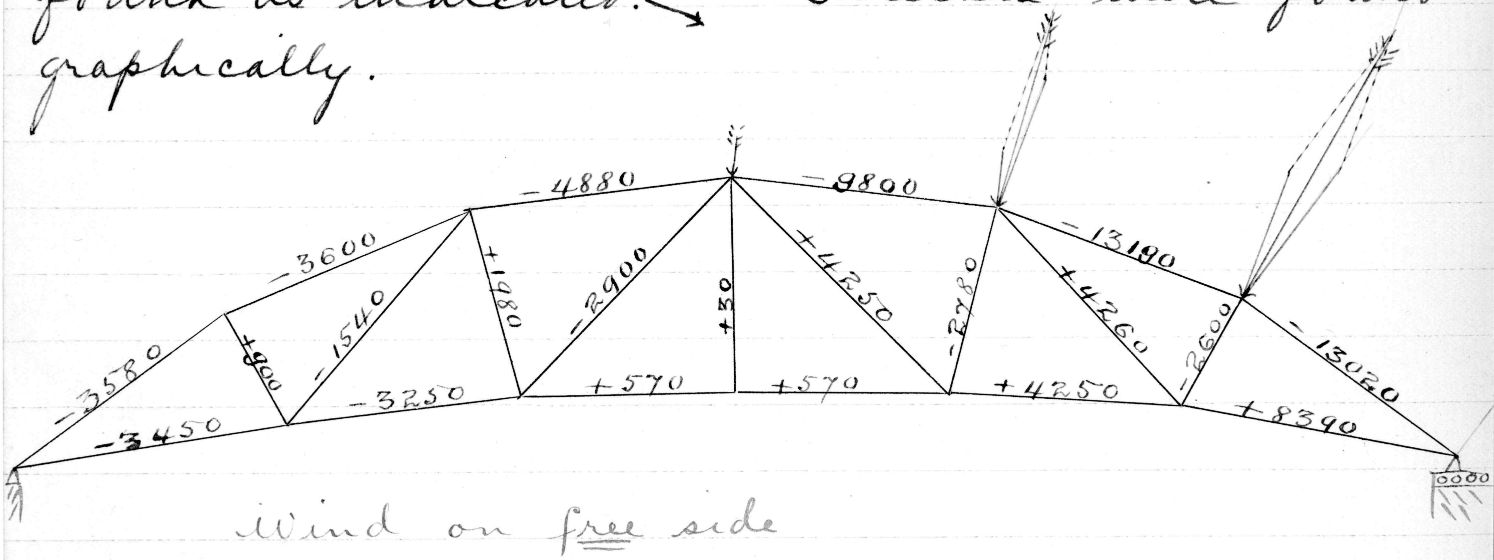
Wind Loads

Wind on Free Side.

The wind pressure was assumed at 40 lbs per sq. ft. of vertical area. A table giving pressures for various angles of inclination were used.

	Pressure	Load	
1st Panel	31.1 $\frac{lbs}{ft^2}$	7360 lbs	= 31.1 X 14.67 X 16
2nd "	20 $\frac{lbs}{ft^2}$	4733 "	= 20 X 14.67 X 16
3rd "	7.1 $\frac{lb}{ft^2}$	1680 "	= 7.1 X 14.67 X 16

The apex load is the resultant of those parts of adjacent panel loads acting at the apex, and were found as indicated. → Stresses were found graphically.

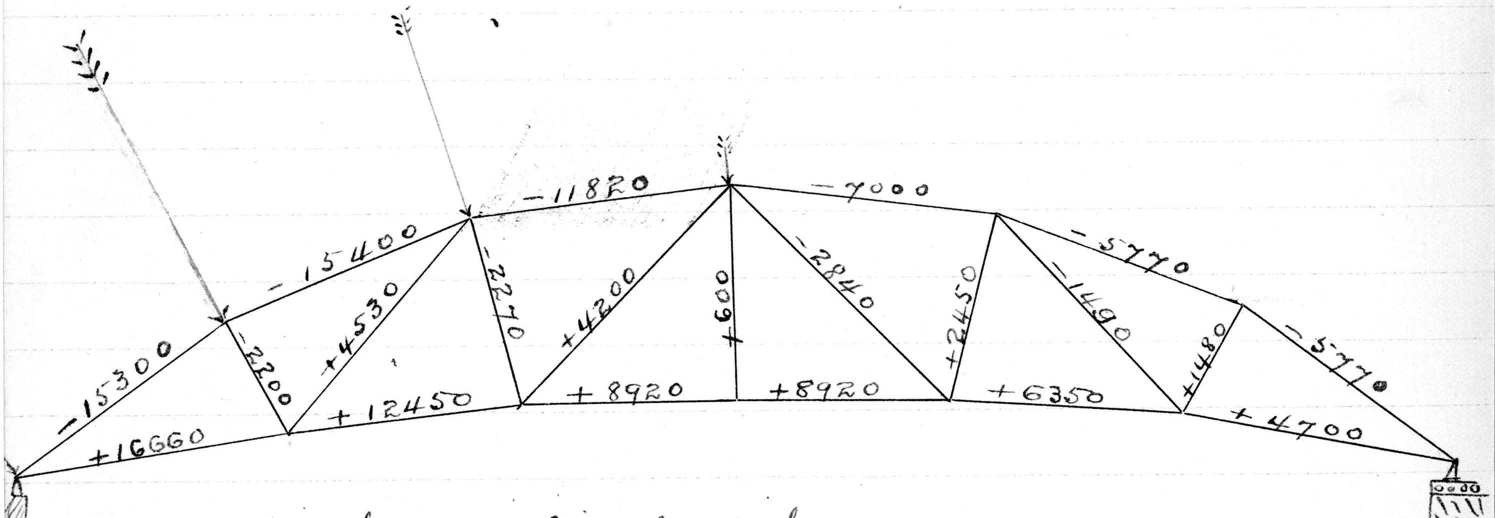


Wind on free side

Stresses given in pounds.

Wind on Fixed side.

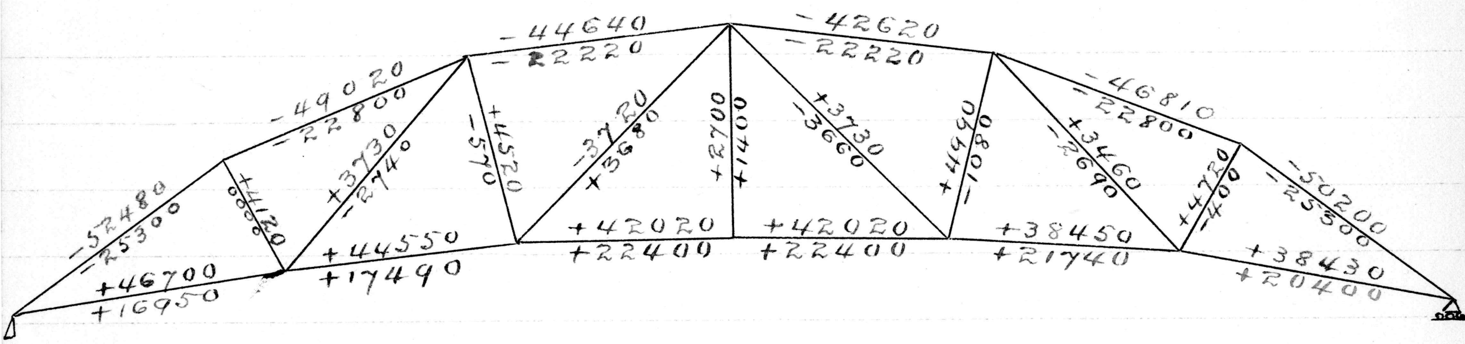
The method of procedure in this is the same as for wind on free side of truss. Resultant apex load the same as above. The stresses were all found graphically.



Wind on fixed side

Final Maximum and Minimum Stresses

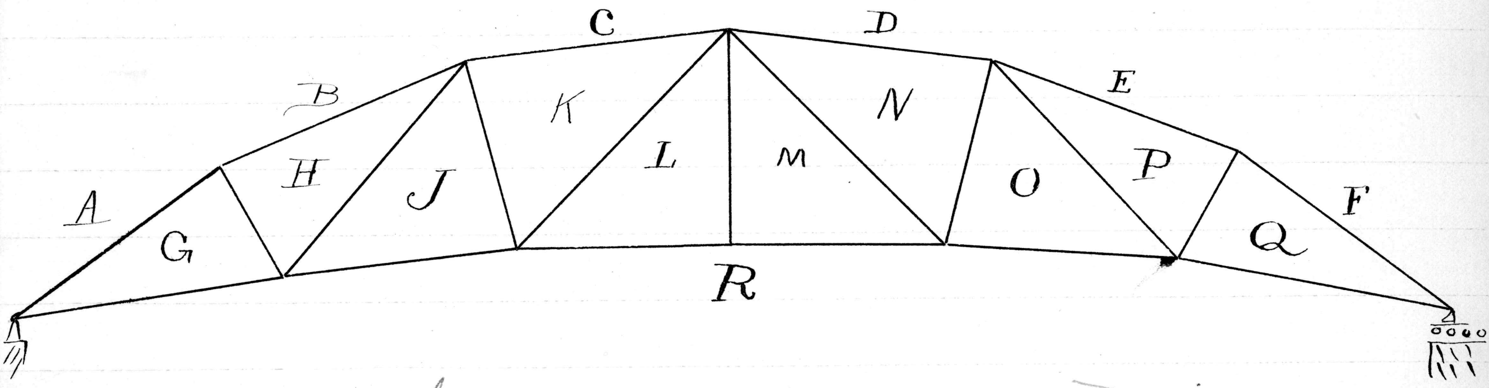
These are found by summing the stresses due to wind, snow, and dead loads, always taking such combinations of stresses as to produce the greatest possible stress. These are given below on the truss outline for convenience - the maximums being given in blue and minimums in red ink to distinguish them better.



Maximum stresses given in blue ———

Minimum stresses given in red ———

Designing of members.



Since the stresses of symmetrically placed members in this truss are not far different, the larger stress in the members in question will be used for both, and both are made the same size.

AG & FQ.

max = − 52480 ; min = − 25300

To be constructed of two angles each whose size must satisfy Rankine's formula for a column with both ends fixed.

$S = \frac{P}{A}\left(1 + q\frac{l^2}{r^2}\right)$ in which P is the total stress, A = assumed area ; q = cons. = $\frac{1}{25000}$ for steel column with both ends fixed.

l = length of column in inches,

r = radius of gyration (least).

An approximate area is first found

by dividing the stress by the allowable working unit stress, which is 16000 lbs/in² in this case. But the area thus found will always be too small for compression members. Therefore with this guide I made repeated trials and found that 2 angles 5" × 3½" • 8.7# satisfies formula for

$S = \frac{522 \times 80}{2 \times 2.56}\left(1 + \frac{315 \times 1}{25000 \times 2.57}\right) = 15370$ which is

below the allowable stress and on safe side. In these calculations a factor of safety of about 10 is allowed.

<u>BH & EP.</u>

Max = − 49020   min = − 22800

Use two angles • 5" × 3" • 8.2#, this size is on the safe side since S = 13300

<u>CK & DN</u>

Max = − 44640   min = − 22220

Use 2 angles • 5" × 3" • 8.2#

dimensions satisfy formula and give S = 15000 lbs, a safe value

GH & PQ

max = + 4720 min = − 400

Use 1 angle 1" x 1" @ 1.2# which gives an area of .34 in², in excess of that required. An angle is used on account of the minimum in compression.

HJ & OP

max = + 3730 min = − 2740

Use 1 angle 2½" x 2" @ 2.8# which stands the comp. and holds the tension.

JK & NO

max = + 4990 min = − 1080

Use 1 angle 1" x 1" @ 1.2# by Rankine's formula.

KL & MN

Max = + 3730 min = − 3660

If designed to hold the compression it will satisfy tension also. Therefore by Rankine's formula. use

1 angle @ 2¾" x 1½" @ 2.6#

Special angle − Cambria form A 128.

I M

Max = +2700   min = 1400

Tension only.

∴ area req. $= \frac{2700}{16000} = 0.17\ in^2$

Use rectangle $1'' \times \frac{3}{16}''$ of area $= .188\ in^2$

RG & RQ.

Tension only   Max. = + 46700 lbs.

area req. $= \frac{46700}{16000} = 2.92\ in^2$

Use 2 rect. bars $2'' \times \frac{3}{4}''$, giving an area of $3.00\ in^2$.

RJ & RO.

Tension only.   Max. = 44550 lbs

area req. $= \frac{44550}{16000} = 2.78$

Use 2 bars $2'' \times \frac{3}{4}''$.

RL & RM

Tension only.   Max = 42020 lbs.

area req. $= \frac{42020}{16000} = 2.63\ in^2$

Use 2 bars $2'' \times \frac{11}{16}''$.

Joints

On upper chord

A cover plate and two side plates will be used at each of these. To secure uniformity, the greatest existing stress will be satisfied, and that size plates used for all.

Area req = 3.78"□

Use 1 plate bent on top as cover, 7" wide × 1/2" thick × 18" in length. Two side plates each 8" × 1/8" × 32" long. These must be riveted on with a sufficient number of rivets to carry all the stress, no allowance being made for friction. Using 7500 lbs/in as the shearing unit stress, I found the number of 7/8" rivets required at end of each angle to be 13, putting 7 on top and 6 on side plate as shown in drawing. The Purlins will rest on the upper plate, with details of arrangement as below.

Instead of putting pins in these spliced joints, a plate 3/8" thick will be riveted between the angles of upper chord and the web members riveted to these.

The length of these plates must be made sufficient to hold the necessary number of rivets.

The upper chord members will be stiffened by two plates 6" x 3/8" and fastened by 2 - 7/8" rivets on each side. These plates to be placed at approximately equal distances from each other and from the joints adjacent.

Joints RGHJ & PORQ.

Use pin of diam. = 2 7/8" since largest stress = 46700, and thickness of bars = 1.5" ∴ resulting comp = $\frac{46700}{1.5}$ = 31133 lbs. and allowing an extreme fiber stress of 15000 lbs/in the size required will be as above.

Diam. head of eye bar GR = 5 1/2"

Use same head for all others on lower chord.

Angles GH & PQ to be connected to pin by 1/2" plates with lap of 8", held by 6 - 3/8" rivets.

Angles HJ & OP to be connected by 3/4" plate of lap 10" and fastened to plate by 5 - 3/4" rivets.

The size of rivets to use for an angle is taken from Cambria Co. specifications, in which the maximum sizes are given for various angles.

Joints JKIR & MNOR.

Use pin of diam = 2 7/8"
all eye bar heads = 5 1/2" diam
Angles JK & NO to be connected to pin just as GH & OP above.
For KI & MM, use 3/4" plate, lap - 10 inches riveted to plate ~~by~~ with 4 - 3/4" rivets. Detail of plate given in drawing.

Joint IMR.

Eye bars for lower chord given above.
Use same diam. head for IM and use 2 7/8" pin.

The web members will be riveted to plates at upper chord joints with exactly the same size and number of rivets as used for lower joints.
To fasten LM to plate at apex, use 6 - 3/8" rivets.

SHOE.

The right end of the truss is to be placed on rollers to allow for expansion and contractions due to temperature changes, also to allow for spread under maximum loads.

The angles of the upper chord will bear directly on a plate of 1/4" thickness, and will be held to it by an angle (1"×1"×1/4") on each side. These small angles will be riveted to the plate at the ends, and to the large angles between them by 3/8" rivets, the number required being that just to hold the pieces together since no stress is on them.

The 1/4" plate will rest directly on 4-4" rollers, and these in turn will rest on a lower plate of thickness 1/4". The rollers will be allowed about 1" for play under loads.

Small angles, size 1"×1"×1/4", will be riveted to the plates above and below, at the ends and on the outside along the rollers.

The number and diameter of the rollers was assumed. Then to

find the required length.
$500\sqrt{d}$ = allowable unit stress per unit length of rollers.
$\therefore S = 500\sqrt{4} = 1000$ lbs/in

The total reactions of the free end are
For wind on Fixed side = 2670 lbs
" " " Free " = 9400 lbs
" Dead Load = 14254 lbs
" Snow " = 6487 lbs.

giving a maximum of 30141 lbs. to be held by 4 rollers. Then each roller bears 7535 lbs.

Then length $= \frac{7535}{1000} = 7.535''$
Therefore 8" rollers will be used.

Respectfully Submitted

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Summary.

Reference Books

Merriman's Mechanics of Materials

Merriman & Jacoby - Roofs & Bridges I, II & III

Building Construction; I, III & IV.

American Bridge Co. Specifications.

Cambria Steel Co. Pocket Book for sizes of pieces, and steel parts of truss