Thesis

Jas. Warren Bagley

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120 Span Steel Roof Truss

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Design of a 120-foot span steel truss for B.S. degree at Washington & Lee University, June 11, 1903

J.W. Bagley.

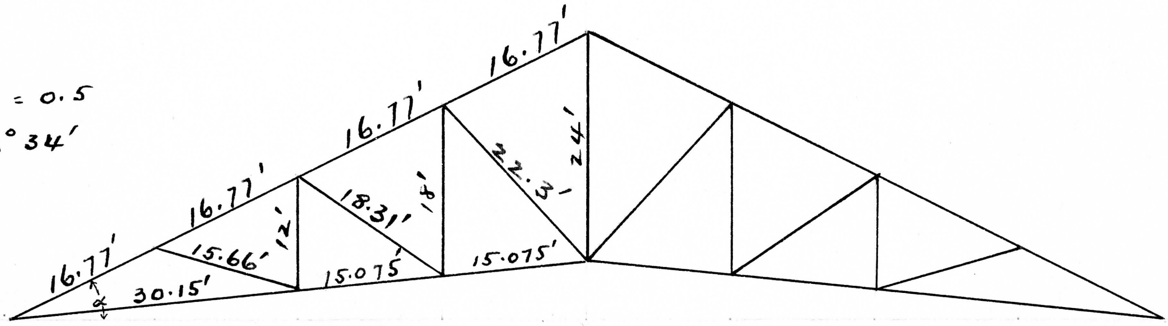
The form of the roof truss will be the straight chord with lower chord inclined as well as the upper one, having vertical ties and inclined struts. The span will be 120 feet; the distance between trusses 16 feet; the rise of upper peak 30 feet; the rise of lower peak 6 feet; and the upper chord will have eight panels, each being 16.77 feet long. The roof covering will consist of slate weighing 10 pounds per square foot, laid on sheathing 1 inch thick weighing 5 lbs per sq ft, supported by rafters spaced 2 feet center to center, these being carried in turn by purlins placed at the panel points of the trusses. All metal used in the construction will be medium steel unless otherwise specified and all wood northern yellow pine whose weight will be assumed at 36 lbs per cu. ft. The snow load will be taken at 10 lbs per sq. ft of horizontal area, which is the amount given for latitude of Baltimore by Merriman & Jacoby, and the wind load at 40 lbs per sq ft of vertical area as given by same authors.

The working unit stress for wood will be assumed at 1000 lbs this being equivalent to using a factor of safety of 8 (M & J). For the steel 16000 lbs will be taken as the working unit stress for tension and compression, and 7500 lbs for shear for rivets, etc, these being the regular numbers used by the Carnegie Steel company. In designing the pins I shall use 15000 lbs per sq in. Any deviations from these figures will be stated where occurring in the work.

The lengths of the various members of the truss are given below on the skeleton outline. They were computed and will be checked graphically.

$\tan \alpha = \frac{1}{2} = 0.5$

$\therefore \alpha = 26^\circ 34'$



Roof Covering

Sheets of slate 12 × 8 inches, or, of size approximating this, that can be obtained on the market, will be used. They shall be put on with sufficient lap to make the covering water-proof. It is not necessary to make computation for the sheathing since a thickness of 1 inch gives ample strength when the rafters are placed just 2 feet apart.

Rafters.

The rafters will be constructed of wood and the span is

16.77 feet - the distance between centers of purlins. The area supported by each one is hence $2 \times 16.77 = 33.54$ sq. ft. The weight of the slate then is $33.54 \times 10 = 335.4$ lbs; sheathing $33.54 \times 36 \div 12 = 110.62$ lbs; snow $10 \cos\alpha \times 33.54 = 10 \times 0.89441 \times 33.54 = 300$ lbs; and the normal wind pressure (see M + J Part II Page 47) $23.8 \times 33.54 = 798$ lbs. Adding about 1.5 pounds per sq. ft. for the assumed weight of rafter, the component of all the loads except the wind normal to the rafter is

$$(110.62 + 300 + 335.4 + 33.54 \times 1.5) \cos 26°34' = 712 \text{ lbs.}$$

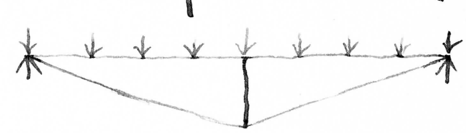
The bending moment in the rafter is $\frac{1}{8} \times 712 \times 16.77 \times 12 = 17900$ lbs-inches. Taking the width of the rafter at 2 in. the resisting moment is $1000 \times 2 \times d^2 \div 6 = 333.3\, d^2$. Equating these two moments we have

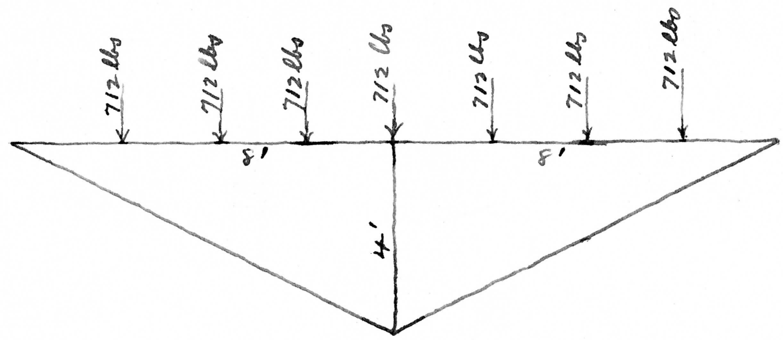
$$333.3 d^2 = 17900 \qquad \therefore d = 7.33 \text{ inch}$$

Since the sizes run only in even numbers generally the size 2×8 inches will be used and this allows for the compression due to the longitudinal component of the vertical loads.

The Purlins

The purlins will be constructed of two medium steel angles for the upper member, two angles for a strut and two tie rods, forming a simple truss as shown in free hand sketch. This will be shown in drawing of truss.





The stresses in the members as obtained both graphically and by computation are: upper chords, each 4950 lbs; vertical strut, 2492 lbs; and ties, each 5600 lbs.

The upper chord must also be investigated as a beam of length 8 feet. The maximum bending moment is found to be 7130 ft lbs, or the loading is equivalent to 7130 lbs uniformly distributed over the length 8 feet. or 7130 ÷ 2000 = 3.565 tons. Now two angles will be placed together and the size that will carry a load of 3.565 ÷ 2 = 1.7825 tons safely is what is wanted. From the Pocket Companion page 84 the size which comes nearest filling the requirements is an angle $4\frac{1}{2}'' \times 3'' \times \frac{13}{16}''$, the loading being given at 1.81 tons. This size will hence be used since the area is far in excess of that required by a stress of 4950 lbs.

The size of the angles used in the vertical will be determined by Rankines formula for columns, (See M & J Mechanics of Materials pages 121 & 125), one end being considered fixed.

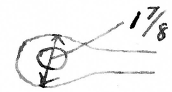
We will try size 1″ × 1″ × $\frac{1}{8}$″ first. We have

$$S = \frac{2500}{0.48}\left(1 + \frac{1.78}{25000} \times \frac{48^2}{(0.31)^2}\right) = 14150 \text{ lbs}$$

This agrees close enough and is on the safe side and hence will be used.

The strut will be joined to the upper chord by a 5/8″ plate and riveted as shown in drawing. The sizes of the rivets were found by use of the Pocket companion. Both upper chords and the strut will have a rivet at their middle with a ring between the angles to stiffen them. The sizes of these are shown in drawing.

The area required for the tie is $\frac{5600}{16000} = 0.35$□″ and hence a rod 5/8″□ will be used. The size of the rivet to be put in end of strut as determined from Pocket Companion will be 3/4″, while that of those to hold ties and go through upper chord will be 7/8″. The eye bars at end of ties will a width of $\frac{1}{2}$″ inch on each side of rivet or the total width across head will be



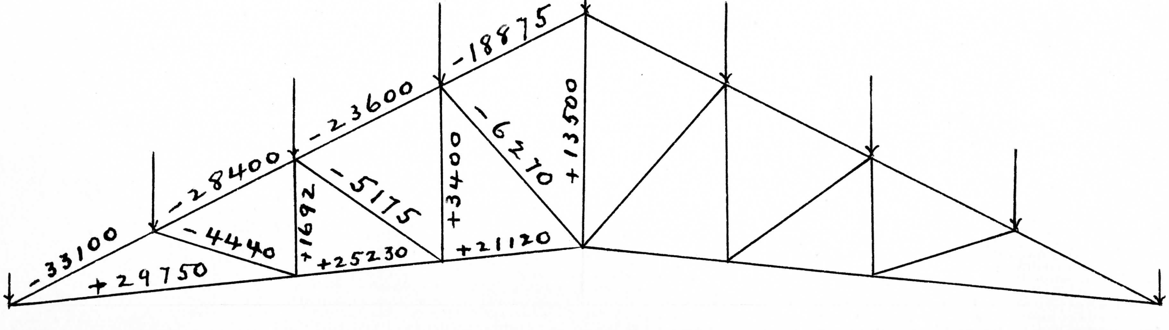
1 7/8″, which gives an excess of 50% of area over that of the bar as required by Carnegie Steel Co.

Dead Load Stresses

Since no formula for weight of a steel truss is available, that for wrought iron, viz., $W = \frac{3}{4} al(1 + \frac{1}{10} l)$ given on page 35 Part II of M + J's. Roofs + Bridges will be used, in which a is the distance between trusses in feet, l the length of span and W the weight of the truss in pounds.

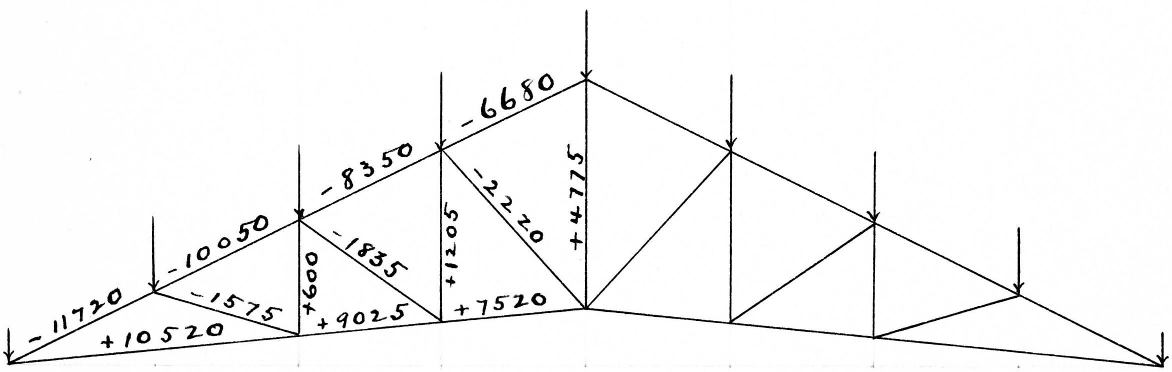
Then $W = \frac{3}{4} \times 16 \times 120 \left(1 + \frac{120}{10}\right) = 18720$. This gives a load of 2340 lbs at every apex of the truss except the end ones, which are 1170 lbs each. The area of the roof covering supported by one apex of the truss is $16.77 \times 16 = 268.32\ ft^2$. For the weight of the covering supported at each apex we have then $268.32 \times 13 = 3388$ lbs, that of eight rafters each 2 x 8 inches in cross section and 16.77 ft long, $\frac{1}{6} \times \frac{2}{3} \times 16.77 \times 36 \times 8 = 804$ lbs and that of one purlin $15 \times 16 = 240$ lbs. The total apex dead load is hence $2340 + 3388 + 804 + 240 = 6772$ lbs.

The stresses due to this dead load were now found graphically and are given below in pounds on the skeleton outline



Snow Load

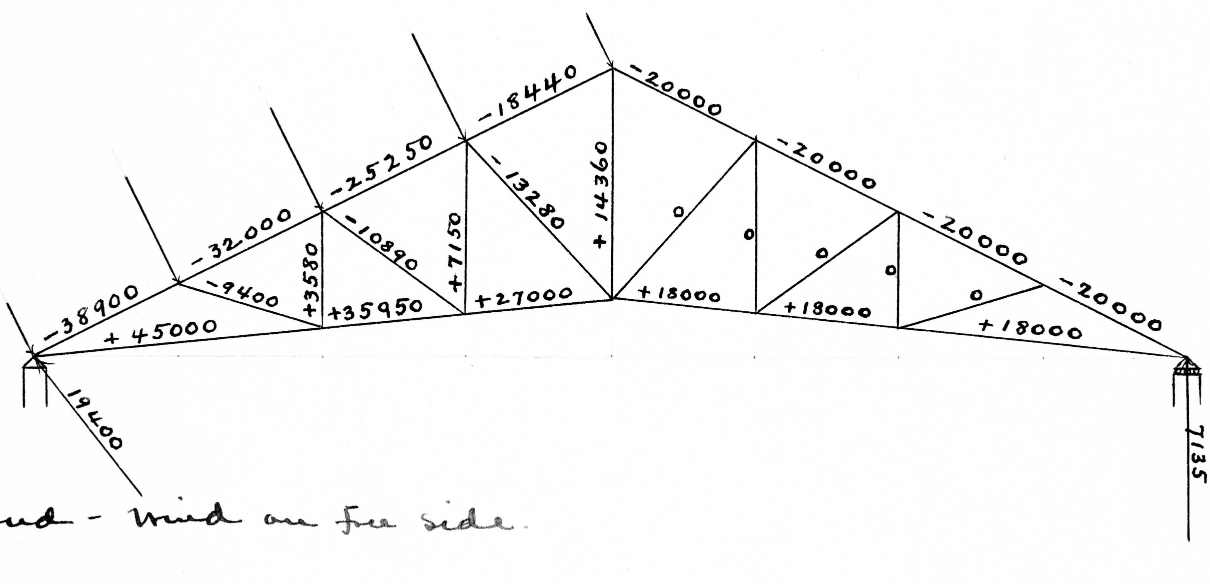
The snow apex load is 16.77 × 0.894 × 16 × 10 = 2400 lbs. The stresses due to this load were now found from the dead load diagram by multiplying the dead load stresses by the ratio of the snow apex load to the dead apex load. They are given below on the skeleton outline in pounds.



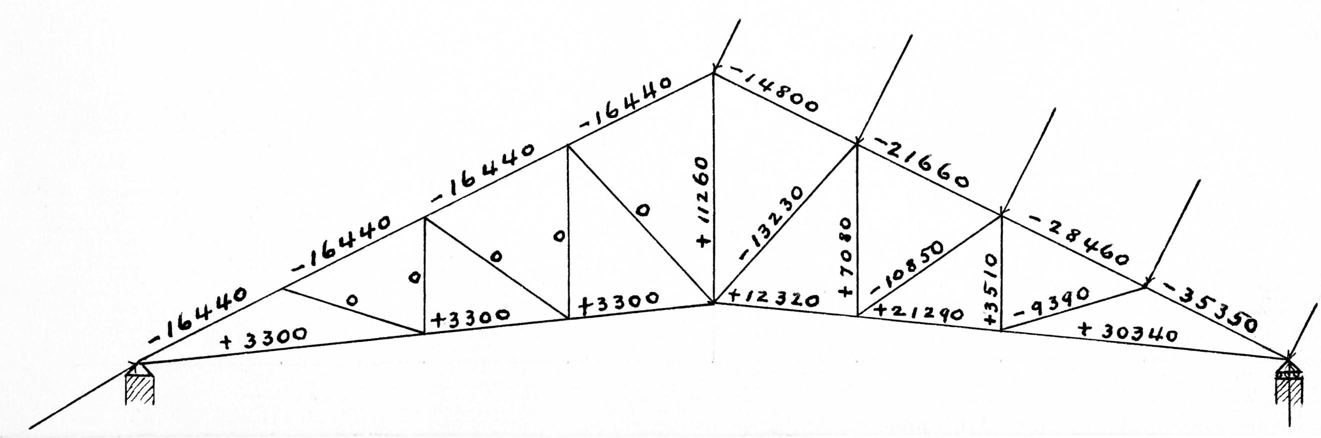
Wind Load

The wind load on each apex is 23.8 × 16.77 × 16 = 6380 lbs. The stresses due to this load acting on the fixed side were first found and then those due to it acting on the free side. These stresses we found graphically and are given below on the skeleton outlines.

First - wind on fixed side.

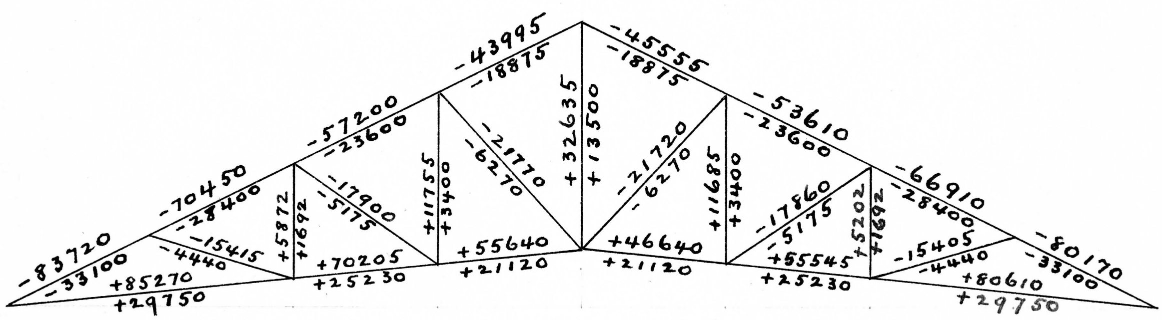


Second - wind on free side.

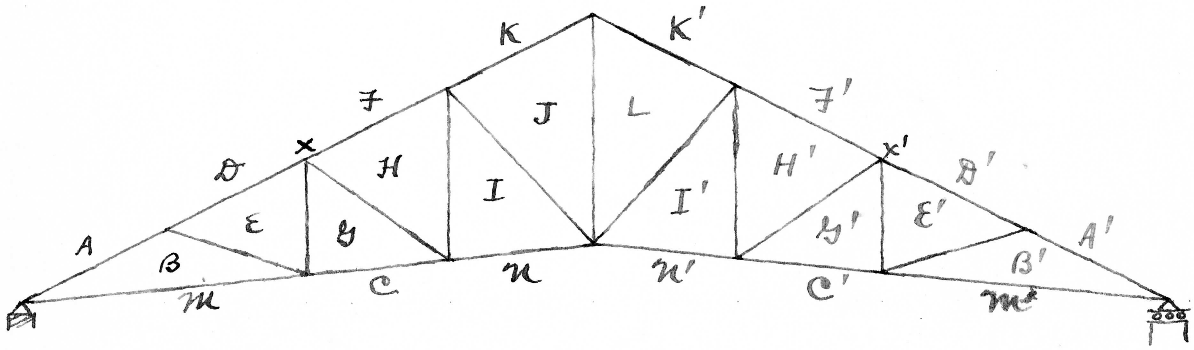


Final Maximum & Minimum Stresses.

These final maximum and minimum stresses were found by tabulating the dead, snow and wind load for each side and summing. They are put on the skeleton outline in order to be most easily read and understood. The maximums are given just above their members and the minimums just below.



Truss Members



The members AB & DE and likewise A'B' & D'E' will be made the same size straight through and also FH, KJ, F'H' & K'L will be made the same size.

Members AB, DE, A'B' & D'E'.

These will be constructed of two angles whose size will be determined by Rankine's formula for columns with both ends fixed.

We will try size 6" × 4" × 3/8" first. We have

$$S = \frac{83720}{7.22}\left(1 + \frac{(201.24)^2}{25000 \times 1.93^2}\right) = 16650$$

and since S should result equal to 16000, this is close enough and that size will be used.

To stiffen these members two plates each 8" × 3/8" will be put on top so as to make the distance between the two and that between each and the end nearest to each equal, i.e., so as to divide the length into about three equal parts. 7/8" rivets will be used to fasten these to the angles.

These stiffening plates of the same size will also be used on all the other upper chord members.

<u>Members FH, KJ, F'H' & K'L.</u>

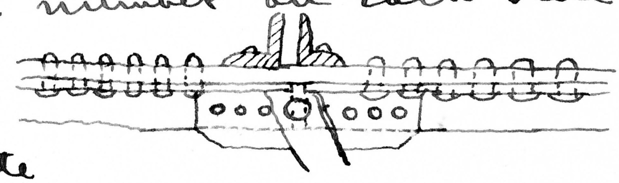
These will likewise be constructed of two angles. Try size 5"×3½"×3/8". We have

$$S = \frac{57200}{6.1}\left(1 + \frac{(201.24)^2}{26000 \times 2.56}\right) = 15400$$

The resulting value of S is close enough and hence this size will be used.

<u>The Splices on Upper Chord.</u>

The upper chord members will be spliced where they join at the panel points x and x'. The area required is 7.22 □". The splices will consist of one plate 7" wide by 7/8" thick for the top as cover plate and two plates on the ~~web~~ outside, each 5" wide by ¼" thick giving an area of a little over 8 □". The purlins will rest on these cover plates and be ~~riveted~~ to them. In order then to raise the ~~raise the~~ other purlins to the same height 7/8" plates must be used at every panel point. 7/8" rivets will be used in these upper plates and the number required for each plate must be sufficiently strong to support 3/4 of the stress, or 52830 lbs. From Pocket companion the number required is twelve on each side of purlin i.e. six through each flange of upper chord. 7/8" will also be used in the other splice plates and the number on each side of joint for each is three.



The length of the upper plate will be 34" and the length of the web plates twelve inches

<u>Member BM</u>

This will be constructed of two bars. The required area is $\frac{85270}{16000} = 5.33\square''$. Each will be made of flat bars 3" × 15/16". The eyebars will then be nearly 8" in diameter at head since pin will be $3\frac{1}{8}$".

<u>Members BE & B'E'.</u>

These will be constructed of two angles whose size is 3" × $2\frac{1}{2}$" × $\frac{1}{4}$" as determined by Rankine's formula, one end being free. The struts will be connected to the pin at the lower end by a plate which will lap 8 inches and go between the two angles. Its thickness will be 15/16" and 7/8" rivets will be used. The stress requires 3 rivets and they will be placed 3 inches apart. (See American Bridge Co's Standards page 224).

Ties E G & E' G'.

These will be constructed of one bar. The required area is 5872 ÷ 16000 = 0.367 □". The size 2" × 3/16" giving an area of 0.375 □" will be used. Diameter of head of eye bar will be about 7 inches.

Member G C.

This will be constructed of two bars each 2 3/4" × 13/16" giving an area of 4.46 □", the required area being 70205 ÷ 16000 = 4.4 □". Diameter of head of eyebar will be nearly 8 inches.

Members H G & H' G'.

These will be constructed of two angles whose size as determined by Rankine's formula will be each 4" × 3" × 5/16". These will be connected to the pins at their lower ends by 11/16" plates. On each side of these plates and between the angles will also be put a 1/4" filling plate. The plates will be connected to the angles with 4 - 7/8" rivets. The lap will hence be 11 inches.

Members H I & H' I'.

These will be constructed of one bar 3" × 1/4" giving an area of 0.75 □". Required area is 11755 ÷ 16000 = 0.736 □". Diameter of head of eye bar = 8" about.

Members I N & G'C'

Required area is $\frac{55640}{16000} = 3.48^{\square''}$. These will be constructed of two bars each $2\frac{1}{2} \times \frac{3}{4}'' = 3.76^{\square''}$. Diameter of eye bar head = 7" about.

Member J L

Required area is $32635 \div 16000 = 2.04^{\square''}$. This will be constructed of 1 bar $2\frac{3}{4}'' \times \frac{3}{4}'' = 2.06^{\square''}$. Diameter of head of eye bar = $7\frac{1}{2}''$ about.

Member I'N'

Required area is $46640 \div 16000 = 2.91^{\square''}$. To be constructed of 2 bars each $2\frac{1}{2}'' \times \frac{5}{8}'' = 3.12^{\square''}$. Diameter of head of eye bar = $7\frac{1}{4}''$ about.

Members JI & LI'

These to be constructed of two angles whose size by Rankine's formula will be $4\frac{1}{2}'' \times 3'' \times \frac{3}{8}''$. They are to be connected to the pins at their lower ends by 1" plates running between the angles, and connected to the angles ~~by~~ 4 - $\frac{7}{8}''$ rivets. The lap will hence be 11 inches.

Member B'M'

Required area is $80610 \div 16000 = 5.04^{\square''}$. To be constructed of 2 bars each $3'' \times \frac{7}{8}'' = 5.26^{\square''}$. Diameter of head of eye bar about 8 inches.

The Pins.

The pins will be made the same size all the way through in order to secure uniformity. The size is determined by the member B M. The thickness of the two bars of B M is $1\frac{7}{8}$". A compression of $85270 \div 1\frac{7}{8} = 45477$ lbs will be made, and hence require a diameter of pin $= \frac{45477}{15000} = 3.03$ or say $3\frac{1}{8}$". Since I found this thickness to be ample sufficient for all bearing shearing and moments it will be used.

Strut stiffeners.

In order to stiffen the struts plates $9" \times \frac{3}{8}"$ will be put 2 feet from each end and riveted with three $\frac{3}{4}$" rivets.

Shoe-Plates

These will be constructed of 1 filling plate $\frac{1}{4}$" thick, two angles $5" \times 4" \times \frac{3}{8}"$, one cover plate between the angles and the channels $\frac{1}{4}$" thick, two Channels each standard 8" taken from Pocket Companion, one $\frac{1}{4}$" bearing plate; and on one side rollers will be put directly under this bearing plate as shown in sketch on next page. There will be 4 rollers each 4" in diameter and $5\frac{1}{2}$" long as determined by formula given in American Bridge Co's Specifications. The angles will not necessarily have to receive any of the load since the upper chords will bear close against the

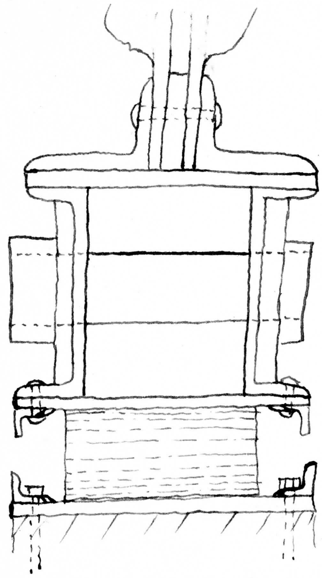


plate. I investigated the plate as a beam and found its thickness in excess of that required. In order to giving bearing area enough for pins two $1\frac{1}{8}$" plates must be riveted to the web of the channels as shown.

Summary

In working up this roof truss I have used the following books for reference: Merriman & Jacoby's Roofs & Trusses Parts I, II & III, Merriman's Mechanics of Materials, The Carnegie Steel Co's Pocket Companion, Kidder's Architects' & Builders' Pocket Book, L. De C. Berg's Safe Building and The American Bridge Co's Standards Books. In getting up the thesis in shape to hand in I have left out many of the details that would only have made the work lengthy without being of special value.

Respectively Submitted

J W Bagley