F. E. L. Beal

Beal. Foster Eh.

Design for Howe Truss Bridge

To the Faculty of the Mass. Inst. Technology.

The problem hereby submitted for your approval, is one that occurs upon the line of the proposed Bangor and Winterport Rail-road, in the town of Hampden in Maine. The stream to be crossed is of no considerable size itself, but is situated at the bottom of a ravine nearly one hundred feet in depth and four hundred in width, (see profile) and as the grade of the road at this point corresponds very nearly with the natural surface of the ground, it becomes entirely out of the question to fill it up as it would not only involve a large expenditure of material, but it would have to be brought from a considerable distance.

Under these circumstances a bridge of considerable span was deemed the most feasible method of crossing, and as timber is the cheapest suitable material in that section the Howe Truss was fixed upon as the best adapted to the purpose. Owing to the great width of the ravine a total span of two hundred and eight feet, very nearly the maximum used in any single span bridge of this class, was adopted, and even this involves very high and expensive abutments. The abutments used are of the class known as T-shaped, the foundation of the "tail" corresponding very nearly with the natural surface of the ground. An elevation of the abutments and their position is shown on the profile, and a plan of one of them is annexed. Another and perhaps better plan would be to omit the "tail" altogether, and introduce trestle work behind the abutments. This would involve an additional outlay for timber, but would be a great saving in masonry, and would probably be the cheapest method.

The timber selected for the bridge was Spruce, as being the most easily procured, and well adapted to the purpose. The details of construction are as follows:-

The clear span of 198 feet, is divided into 18 panels of 11 feet each, and having at each end a pier panel of 5 feet.

The height of the trusses was determined by the equation $\frac{h_0}{l} = \frac{n''f'}{4m'E}\frac{l}{v_1}$, in which $l = 198$, $n'' = \frac{5}{12}$, $f' = 10000$, $m' = \frac{1}{2}$ $E = 1800000$ and $\frac{l}{v_1} = 1000$. 10 was taken as a factor of safety. The result gave 22.8 feet, 23 feet was therefore taken as the height from centre to centre of the chords. The fixed load upon the bridge was estimated at 1500 lbs. per linear foot including the weight of the track. The rolling load was assumed at 2000 lbs. per foot, making a total load of 3500 lbs. per foot, or 1750 lbs. per foot per truss, or 19250 lbs. per panel per truss, of which the fixed part $w = 8250$ lbs, and the rolling portion $w' = 11000$ lbs. The greatest strain upon the bottom chord was then calculated by the formula $H_n = \frac{(w+w')l}{k} \frac{n(N-n)}{2N}$ which gave 372864 lbs.

Assuming the tensile strength of spruce timber at 12000 lbs. per sq. inch of sectional area, and taking 10 for a factor of safety, we find that it requires a section of 310.6 sq. inches area in the bottom chord to resist this strain. Assuming the depth of the chord at 15 inches, this gives 20.7 inches for the width, but for safety we call it 22 inches.

In the same manner having

calculated the greatest strain upon the top chord, we take the resistance of the timber to crushing at 6000 lbs. per sq. inch, and find the proper depth of the chord to be 14 inches, its width being already determined by that of the bottom chord. In this case however we use a factor of safety only half as large as that taken in the other for the reason that joints do not form an element of weakness in timber when subjected to a strain of compression.

From this it follows that the total height of the truss is 24 ft. 2½ inches.

The strains upon the different divisions of the chords are as follows:

Compression upon Top Chord			Tension upon Bottom Chord		
On panel	A	= 0	On panel	a	78255 lbs.
" "	B	78255 lbs.	" "	b	147304 "
" "	C	147304 "	" "	c	207147 "
" "	D	207147 "	" "	d	257783 "
" "	E	257783 "	" "	e	299212 "
" "	F	299212 "	" "	f	331435 "
" "	G	331435 "	" "	g	354451 "
" "	H	354451 "	" "	h	368261 "
" "	I	368261 "	" "	i	372864 "

The tensions upon the truss bolts was calculated for the middle sett by the formula $V = w + \frac{w'}{4}\left(\frac{N}{2}+1\right)$ and for the others by the formula $V_n = w\left(\frac{N+1}{2} - n\right) + w'\frac{(N-n)(N-n+1)}{2N}$. The following are the results, together with the number and diameters of the bolts required in each sett, the tensile strength of wrought iron being taken at 60000 lbs. per sq. inch, and 6 being taken as a factor of safety.

9th, or middle sett	35750.	3 bolts	each	1¼	inches	in	diam.
8 "	45986.	3 "	"	1⅜	"	"	"
7 "	60958.	3 "	"	1¾	"	"	"
6 "	76542.	3 "	"	1⅞	"	"	"
5 "	92736.	3 "	"	2	"	"	"
4 "	109542.	4 "	"	1⅞	"	"	"
3 "	126958.	4 "	"	2	"	"	"
2 "	144986.	4 "	"	2¼	"	"	"
1 "	163625.	4 "	"	2½	"	"	"

The compression upon the main braces or those which slope from the top towards the ends of the bridge were computed by the formula $T_n = \frac{ws}{k}\left(\frac{N+1}{2} - n\right) + \frac{w's}{k}\frac{(N-n)(N-n+1)}{2N}$ in which $s = \sqrt{k^2 + \frac{l^2}{N^2}} = 25.5$ nearly.

The results are the following together with the number and dimensions of the braces, the dimension parallel to the length of the bridge being assumed and the other calculated.

				assumed dimension			
No. 1	181410	2	Braces	10	×	8	inches
" 2	160746	2	"	10	×	7	"
" 3	140758	2	"	9	×	7	"
" 4	121448	2	"	9	×	6	"
" 5	102816	2	"	8	×	6	"
" 6	84862	2	"	8	×	5	"
" 7	67584	2	"	7	×	5	"
" 8	50984	2	"	7	×	5	"
" 9	35063	2	"	7	×	4	"

The compression upon the counter braces or those which slope from above toward the centre of the bridge was calculated by the formula $t_n = -\frac{w s}{k}\left(\frac{N-1}{2} - n\right) + \frac{w' s}{k} \frac{n(n+1)}{2N}$. This gives a positive result for the four middle panels only, but for the sake of giving additional stiffness to the trusses, the counter braces are introduced throughout. It is the practice of some builders to neglect the negative part of the above formula, and thereby obtain a positive result for every panel. The result of this is to give a counter-brace to every panel as we have done but the reason is based upon a false supposition.

The strains and dimensions of the counter braces are as follows:-

No. 7	5251	1	Brace	6 x 4	same for the
" 8	15818	1	"	7 x 5	[other panels.

To stiffen the bridge laterally diagonal braces are introduced at both bottom and top, with iron tie-rods at bottom, and timber ties at top. The road-way rests upon timber cross sleepers, 6 inches in width, by 10 inches in depth, and placed at a little less than 3 feet apart. The width of the bridge is 18 ft. from outside to outside of chords. The only principle governing the determination of this beyond that of having sufficient width for the road-way was simply to secure a good proportion between the height and width. The timber in the chords may be conveniently distributed into four pieces each 5½ inches in width. The amount and distribution of the timber in the other parts have already been shown.

The formulæ used for the above computations are those of Professor Rankine and are essentially the same as those in ordinary use, and which are demonstrable upon well known mathematical principles.

No calculation has been applied to determine the lateral stability of the bridge as the amount of material introduced for other reasons is amply sufficient to resist all forces acting in that direction. The method of splicing the chords and other more minute details of construction are not considered here, falling rather within the province of the builder than the engineer.

W. E. L. Beal.