Thesis for a B.S. Degree.

— C. T. Chenery —

Washington and Lee University,

June 1909.

Prof D. C. Humphreys
Dean Engineering School W. & L. U.
Lexington Va

Dear Sir -

I herewith hand you a thesis for a B.S. degree.

This thesis in accordance with your suggestion is a description of the field location and erection of a wooden trestle and steel Viaduct situated near Oak Vale W. Va on the Virginian Railway.

The Drawings submitted are copies of the Virginian plans for these structures though I have checked the designing of a typical trestle bent.

Very Respectfully Submitted
C. T. Cheney

Lexington Va
June 4, 1909.

— Five Mile Creek Viaduct —

Five Mile Creek Viaduct is situated at mile post 338.7 on the Virginian Railway, about one half a mile below the town of Oak Vale, West Virginia, and spans a stream known as Fibe Mile Creek.

The bridge is composed of twenty one bents of timber trestle work extending from station 587+65 to station 590+45 and of 387.5 feet of a deck plate girder viaduct.

The original intention of the company was to erect a steel viaduct from grade point to grade point but on account of having an excess of material to find room for because of heavy slides, the timber trestle approach was decided upon, the idea being to gradually fill in until the toe of the fill reached the masonry pedestals of the steel viaduct, the timber trestle being merely a temporary structure.

The bridge is on a one degree and thirty minute curve to the right and the grade is a −1.5% compensated or = 1.44% as the Virginian Railway considers a one degree curve equivalent to a four hundredths per cent grade and hence the proper compensation for a one degree and thirty minute curve is six hundredths.

This 1.5% compensated grade is the heaviest the company has east of its assembly yard at Princeton W.Va, and there is in all only about twenty five miles of it. twelve # miles of it being used in climbing from East River to the Princeton Summit and twelve in crossing the Alleghanies.

The first engineering work in connection with the bridge was the making up of a 'situation plan'. This was done by taking two foot contours with a wye level for a distance of fifty feet on both sides of the center line and then platting the center line and contours on a large scale. This map was sent to the designing engineer of the company at Norfolk Va. who finally decided on a timber approach trestle of twenty one bents, each bent having a span of fourteen feet, and on a deck plate girder construction for the rest of the way, this terminating in a concrete abutment on the east bank of the creek.

The timber for the trestle was to be yellow pine, Southern Timber Merchants association inspection, with the exception of the stringers which were to be of white oak.

The trestle varies in height from ten to fifty feet and is of varied construction from the low 'cripple bent' with its supports on different levels to the high double deck bent with its multitude of braces.

The crossties are carried by eight stringers each 8"x16" and the elevation of outer rail is provided for in the posts. The cap supporting the stringers is itself supported by two 12"x12" plum posts and two posts which batter 1 in 5. The diagonal bracing is of 3"x10" ~~stuff~~ timber and is fastened with 10" boat spikes.

The depth of the plate girder is 6'0½": ~~and~~ there are four girders of 30' span, 3 of 60' and two of forty five.
The thirty's and sixty's alternate until the creek is crossed and then two forty five's reach the abutment.
Five Mile Creek, as its name implies, extends about five miles back into the mountains and has a width at low water of about seventy feet. The Virginian Railway crosses it about seventy five feet in the air; on the west the hill slopes gradually to the waters edge but on the east a lime stone cliff rises abruptly to a hight of twenty five feet from within a few feet of the waters edge.
This limestone cliff was the only obstacle in the way of measuring and hence the actual field location was comparatively easy.
The stationing runs from west to east and the curve on which the bridge is located extends several hundred feet west of the bridge.
The first step in the location was to set a transit over the P.C. of the curve and actually locate by measurement and deflection the center of the West abutment.
A heavy oak hub was driven in and the point referenced by setting a transit over it and throwing out two lines of hubs, thus making the point over which the instrument was sitting the intersection of two lines and accurately determining its position. With this point fixed and using a Gurley transit whose every adjustment had been tested, a line tangent to the curve at this

point was turned and a point on this line distant about six hundred feet from the instrument was established and used for a foresight.

The tape used was of steel and one hundred feet long and a comparison was made with a standard tape before using it and as the thermometer read about 65°F no temperature correction was necessary.

The measurement was made on chords of 14' for the first 294 feet or until the first steel bent was reached and then on alternate spans of 30' and 60' until the last two bents and these were of 45' each.

Hubs were driven and tack points established in them at every bent and the tape measurement checked by using a level rod with a ~~tape~~ plumb bob attached to the target, ~~and a~~ a locke level being laid horizontally upon the rod in order to level it. The two measurements over the whole span of the bridge did not vary more than an eigth of an inch.

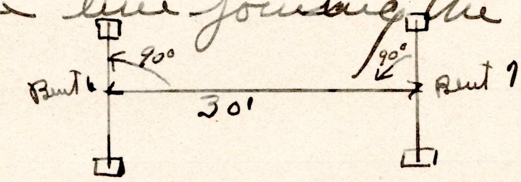
The transit work was checked by setting the transit over the line of undercoping of the east abutment, sighting on the initial hub, turning tangent at the point which the instrument was occupying and successively deflecting for each bent. In no case did the line miss the tack which had been previously set.

Having satisfied ourselves that the center line of the bridge was correctly located and the center line of the bents properly established, the next thing was the referencing of points and this was done in the customary manner of making of making the tack the intersection of two lines of hubs.

The bents of the trestle are located on radial lines and so the transit was set over the center of each bent and hubs driven on each side of the center line of the bridge on the radial lines produced far enough to be free from all disturbing influences.

The position of the radial lines was then checked by chaining the distance between radial lines on the inside of the curve, having first calculated the chord length on the shortened radius.

The steel towers supporting the viaduct are not built on radial lines, instead of this they are built on lines at right angles to the line joining the center of the tower bents, thus



This applies to all of the towers or bents 6 to 13 inclusive, bent 14 however is a star bent and built on radial lines and the line of undercoping of the abutment is parallel to this bent and makes an angle of 89°41' with the chord joining the center of bent 14 to the center of the line of undercoping.

Hubs on the lines of these bents were put out and checked before any excavation ~~was~~ for foundations was started.

A Bench Mark on a point of rock opposite bent no 1 was used as a starting point for levels and with a level in perfect adjustment and a rod that could be read to thousandths, levels were run from grade point to grade point, bench mark were ~~set~~ put in so frequently that the top of every pedestal could be seen ~~with~~ by making a single set up of the level. Check levels were then run and the mean of the two sets of elevations taken as correct.

Concrete pedestals support the whole structure, there being four under every timber bent and two under each steel bent. The two ~~two~~ center timber pedestals are 2'x2' in section at the top and batter 1 in 8 to the foundation. The pedestals under the batter posts are 3'x3' and have the same batter.

The two pedestals of the steel bent are both 4'x4' on top batter 1 in 2 for five feet ~~and~~ are 6.5'x6.5 at the springing line and have a footing course whose depth is naturally dependent on the depth of the foundation. The concrete is formed of sand, cement and crushed rock in the proportion of 1:3:6 except the footing course in which the concrete has the proportion 1:4:7½. "Nigger Heads" were used as fillers with the provision that they were not to exceed a cubic foot in volume, were not to be placed nearer than 4" to the face of the pedestal and were not to be within 12" of each other

After the alignment of the bents had been established and bench marks put in, foundations were staked out for the pedestals of the steel bents.
These pedestals were staked 8.5 by 8.5 to allow the contractors men sufficient room in excavating and elevations were taken at each of the four corners of the pit.
There was a layer of red clay varying in depth from five to nine feet overlying a hard lime stone strata and foundations were not accepted until this limestone strata had been fully uncovered and a rough approximately level bed gotten for the pedestal.
Steel bents eleven and twelve are under water and it was necessary to build a clay coffer dam in order to excavate for a foundation for them.
The up stream pedestals of these two bents were built with wedge shape projections as breakwaters and their bases were thoroughly riprapped to prevent damage from the stream.
Bent thirteen was built in the face of the vertical limestone cliff and most of the cliff had to be blown away before the steel braces could be put in place.
After the foundations had been excavated to solid rock the pits were accurately crosssectioned and the footing course of Class D concrete 1.4.7½ laid

This footing course filled the entire hole to within five feet of the top of the pedestals and after this concrete had set the forms of the ~~co~~ pedestals proper were put in position.
The forms were built the size of the pedestals, 4'x4' on top, five feet in heigth the sides battering 1 in 2 and pin points were established in the center of two opposite faces of the form. The form was leveled to approximately its proper heigth and then its position shifted until the two pin points in the center of the opposite faces of the form were in the line of ~~with~~ the bent; the distance from the center line of the viaduct to the inside face of the form tested and the elevation of the form so adjusted that the top of the pedestal should be built 0.01 higher than the specified elevation. This was done to allow for any shrinkage of the concrete as the pedestals hardened and contracted, for while it is a simple matter to chisel a pedestal down should it be too high yet is practically impossible to build a pedestal up should it be too low and the Virginian railway required that the elevation of the pedestals should not vary from their true height more than .003 of a foot.
The sand ~~from th~~ for the concrete was gotten from New River and hauled a distance of about seven miles as the sand in the neighborhood contained too much

loam.

A rock crusher was put up between the first two steel bents and the rock crushed until it would pass through an inch and a half ring.

The rock used in the concrete was sandstone as there was a great abundance of this kind of rock of crushable size lying loose near the bed of the stream.

The cement used was shipped in in car load lots and a sample collected from at least ten per cent of the bags and shipped in a moisture proof box to the company's labrotary at Norfolk Va where the usual tests as to setting under water, fineness and compressive strength were made as well as a chemical analysis. These tests were made and judgment passed before any of the cement was used.

Wire netting was placed within six inches of the top of all pedestals and the specifications provided that reinforcing rods should be used when the foundation was not solid rock.

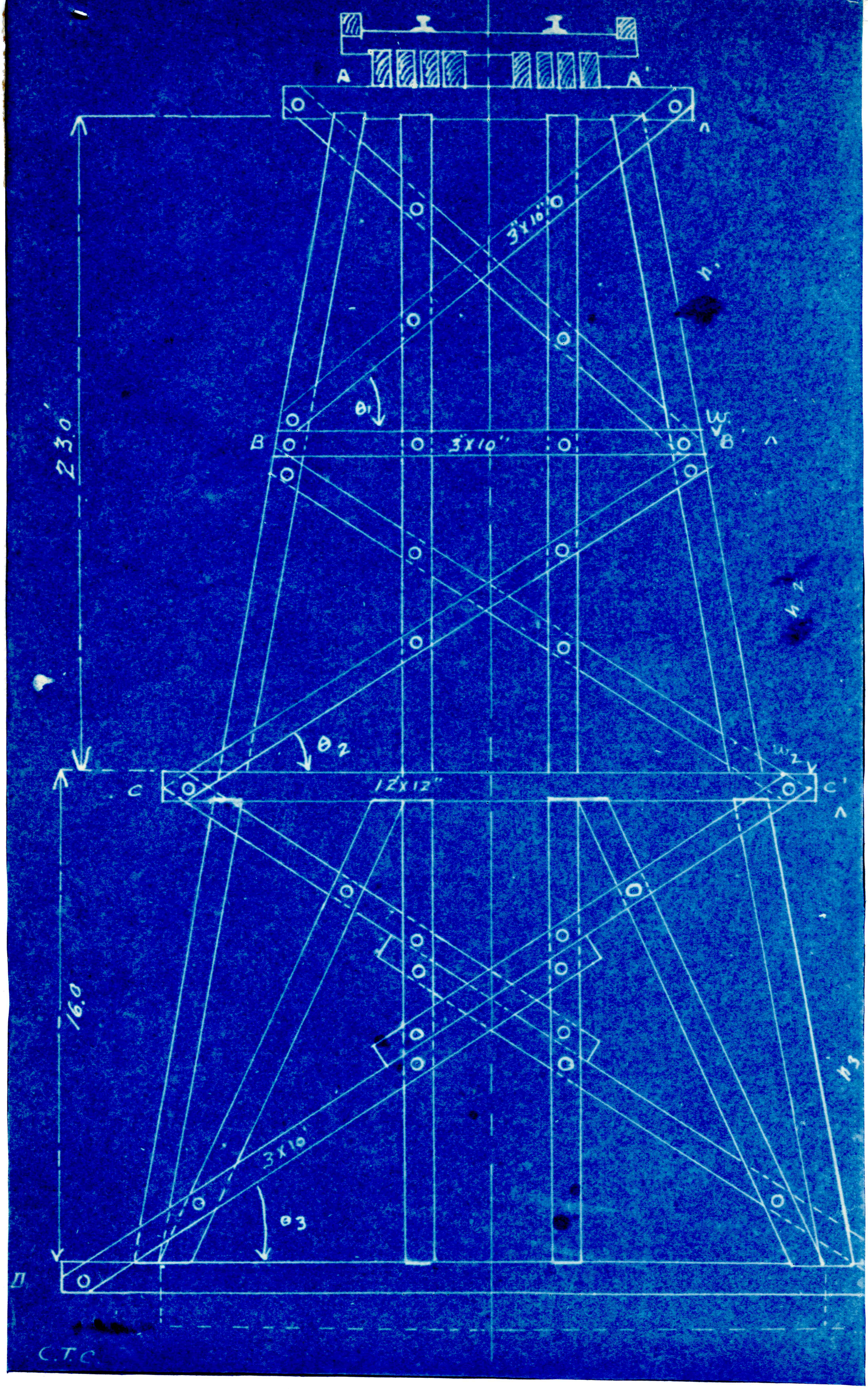
The abutment was the last thing to be built and as there was a long delay in deciding on the type of construction on the East bank of the creek, a fill had already been made to a depth of about ten feet over the ground which the abutment was to occupy.

The abutment (see accompanying plans) was to be about 30' wide at the springing line and had a side wall on the lower side at right angles to the line of under coping extending about 30' back along line.
The abutment is 26.18' high from the springing line to the top of the backwall. The faces batter 1 in 12 and both the abutment proper and the slope wall are built in steps
In excavating for a foundation a pocket of clay was encountered first and then a ~~stra~~ seam of rotten shale.
This shale was not acceptable as a foundation and the excavation was continued until a firmer shale was gotten at a distance of forty feet below subgrade.
A derrick with a sixty foot boom was erected and a hoisting engine put in place on top of the limestone cliff on the east bank of the creek. This was done both in order to handle excavated material and to put concrete in place as a Smith Concrete mixer had been erected on the creek bank.
Steam for running both boiler and hoisting engine was gotten from a boiler which one of the sub-contractors had installed on the creek bank to furnish steam to his shovel which was working in a rock cut just east of the viaduct.
The footing of the abutment was built of class A concrete (1,4,7½), the body of class B (1,3,6) and the bridge seat of class C (1,1,2). in all there was about 550 cu. yds. of concrete in it and an inspector saw every yard placed.

The completion of the abutment marked the close of the field work as a force of carpenters under the companys supervision erected the trestle on the masonry as built and the bridge companys erecting gang put the steel work in place without assistance from the ~~[illegible]~~ engineering department.

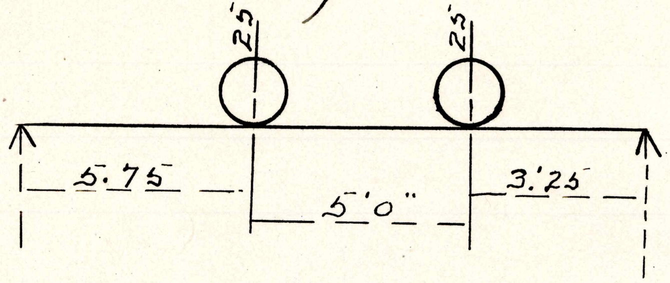
Respectfully submitted
C. T. Cheney

Lexington Va
May 24, 1909.


A
A'
3"X10"
B
3"X10"
B'
W1
θ1
23.0'
θ2
C
12"X12"
C'
W2
16.0'
3"X10"
θ3
D
C.T.C.

– Design of stringers –

The span is fourteen feet, the stringers are to be white Oak 8"×16" in section and their number necessary to support one rail is required.
Coopers Class E 50 loading is used.



The section of absolute bending moment is as far from the left end as the center of gravity of the loads is from the right end. Hence the position of the loads is as shown.

$$R = \frac{50000 \times 5.75}{14} = 20500$$

$$M = 20500 \times 5.75 = 117900 \text{ lbs. ft.}$$

$$M = s\frac{I}{c} \quad \therefore \quad m = 117900 \quad \frac{I}{c} = \frac{1}{6}bd^2 \quad d = 16$$

assuming a factor of safety of 10 s for timber = 1000.

Hence

$$12 \times 117900 = \frac{1000\, b\, (16)^2}{6}$$

$$\therefore b = 33.4''$$

Therefore 4 stringers 8"×16" will support the load with a factor of safety of approximately 10.

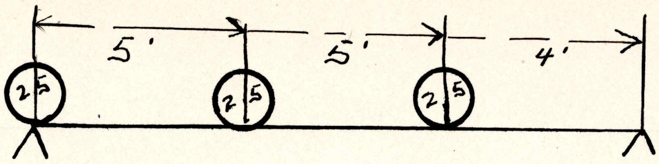
To Determine the Inclination of Batter Posts.

Height of Base of Rail above pedestal = 43.13'
Hence live wind load acts at a height of 50' above pedestal. This wind load is taken at 40 lbs per square foot and hence the live wind load is $40 \times 10 \times 14 = 5600$ lbs. The wind load on the bent is estimated at 150 lbs acting at 41.7' above the pedestal.
The weight of the bent is estimated at 20000 lbs and of the train load at 70000. Hence.

$$5600 \times 50 + 150 \times 41.7 = (70000 + 20000)\,x$$
$$x = 4.4$$

The length of the plum post is ~~hence~~ 37'
Hence for safety the posts should batter
~~3 14.4~~ $\frac{4.4}{37} = .12'$ in one foot or the batter should be 1' in 8'.
The posts are designed to batter 1' in 5' and hence are safe.

III Design of Plum Post –



The above loading is for greatest vertical shear ~~in~~ at the support.

$$V = R = \frac{25 \times 4 + 25 \times 9 + 25 \times 14}{14} = 48.21^{\text{KIP}}$$

Estimated Dead Load = 2800 lbs

Therefore P = 48210 + 2800 = 51000

Plum post built is 12" x 12" x 23

$$\frac{P}{A} = \frac{S}{1 + \frac{1}{3000}\left(\frac{l}{r}\right)^2}$$; P = 51000 . A = 144 in l = 23
r = 0.5

$$51000 = \frac{144 S}{1 + \frac{1}{3000}\left(\frac{23}{.5}\right)}$$ ∴ S = 600 lbs/in²

Ult Strength lumber = 8000 lbs/in²

Hence Factor of Safety = $\frac{8000}{600}$ = 13.3.

Design of Batter Posts E A C - C D - A'C' - C'D'

(see sketch)

This on the supposition that Plum Posts do not act.

$\theta = 11°20'$. $\tan\theta = 0.20$ $\cos\theta = .98$. θ = angle of inclination of Posts.

$P = 51000^{lbs}$ $W_1 = 3000^{lbs}$ $W_2 = 6000^{lbs}$

Hence Stress from Vertical Loads in
$AB = A'B' = -P\sec\theta = -52000^{lbs}$
$BC = B'C' = -(W_1 + P)\sec\theta = 55000$
$CD = C'D' = -(W_1 + W_2 + P)\sec\theta = 58000$

Stress from Wind Loads. $H = 7400^{lbs}$ effective W.P.

$h = 9$ = ht of H above cap. $h_1 = 11.5'$ $h_2 = 11.5' = h_3 = 15'$

$b = 9.17$ $b_1 = 12.77'$ $b_2 = 17.37$ b_3 23.73

$A'B' = -H \frac{h + h_1}{b_1} \sec\theta = -12000^{lbs}$

$B'C' = \qquad = -13900^{lbs}$

$C'D' = \qquad = -15000^{lbs}$

as originally designed C'D' = 10" x 12" 15'

Hence max stress for Batter Post C'D' =

$58000 + 15000 = 73000$ lbs

For CD, $l = 15'$ $r = 0.5$ $a = 120^{in^2}$

Then $\frac{P}{A} = \frac{S}{1 + \frac{1}{3000}\left(\frac{l}{r}\right)^2} \doteq$

$\therefore 73000 = \frac{120\,S}{1 + \frac{1}{3000}\left(\frac{15}{.5}\right)}$ $\therefore S = 1340$.

$F.S. = \frac{8000}{1340} = 6.0$.

This 1340 is the greatest stress that could occur in the batter post and then it could occur only on the supposition that the plumb post fail and with the failure of the plump post the ~~ho:~~ diagonal strut.

– Design of Horizontal Strut – BB'

Stress in strut from Vertical Load – W_2 =

$BB' = -W_2 \tan\theta = -3000 \times 0.2 = -600$ lbs

from Wind Loads $BB' = -H + 2H \frac{h+h_1}{b_1} \tan\theta = -2700$

Max stress = $-2700 + (-600) = -3300$

Strut as built is 3" x 10" x 12.77'

Hence $P = 3300$ $A = 30$ $L = 12.77$ $r = 2.9"$

$$3300 = \frac{30S}{1 + \frac{1}{3000}\left(\frac{13}{.25}\right)^2}$$

$\therefore S = 210$ lbs

$$F.S. = \frac{8000}{210} = 38.$$

The struts AA', CC' and DD' are 12" x 12" in section and are designed as sills or Caps.

Design of X Braces. Diagonals

Under symmetrical loads the diagonal bracing does not act. Under wind loads however the max stress is in the upper webbing and is found as follows

$$BA' = +H\left(\frac{h+h_1}{b_1} - \frac{h}{b}\right)\sec\theta_1 = 7800.$$

This bracing is designed as 3"×10" and for tension only.

Hence $P = 7800$, $A = 30''$

$$S = \frac{P}{A} = \frac{7800}{30} = 260$$

Hence $F.S. = \frac{8000}{260} = 31.$

Respectfully Submitted.

C T Cheney