THE DESIGN OF A RAILROAD TRESTLE BRIDGE

Thesis for the Degree of B. S.
MICHIGAN STATE COLLEGE
Paul N. Gillett
1938

THESIS

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The Design of a Railroad Trestle Bridge

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

Paul N. Gillett

Candidate for the Degree of

Bachelor of Science

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THESIS

As a thesis for the Degree of Bachelor of Science in civil engineering, the writer selected the design of a wooden trestle bridge with a steel floor system. The design was based upon two factors: first, location of site, materials used, and loading and erection requirements as determined by the mythical "A & B Mining Co."; and second, design factors as determined from a survey of the location.

The writer is indebted to Mr. J. E. Meyer, sponsor of this thesis, and Professor C. L. Allen, of the Civil Engineering Department of Michigan State College, for valuable suggestions and assistance in the preparation of this design. He wishes also to acknowledge the assistance of Mr. Carl Haussman, of the H. G. Christman Co., Lansing, in making cost estimates, and of Messrs. W. M. Cade, R. W. Southwell, and F. M. Barron in the surveying work.

PRELIMINARY ASSUMPTIONS AND

CONSIDERATIONS

1. The alignment of the bridge shall be as shown by the two stakes "a" and "b" at the site. Stake "a" is at El. 276.83, which is the elevation of the top of rail at that point. The station no. of "a" is 51+05.00. Grade is -1.0 % from "a" to "b".
2. Previous explorations by borings show a mixture of sand and yellow clay for a depth of about 50 feet. Pile foundations are therefore feasible.
3. Materials: A large stock of steel beams (CB 242-24"x12"x18'-0") is available. The bridge is to be so designed as to utilize these beams. Seasoned and treated timber of sizes up to 12"x 12" and piles up to 14" dia. are locally available and cheap.
4. Loadings: The bridge shall be designed to safely carry two mining locomotives and their tenders followed by a train of ore cars. This condition approximates, on the safe side, a Cooper's E-40 loading.
5. Permanence: Due to the purpose of this railroad (feeder line for ore trains), permanence is a secondary consideration and low cost primary.
6. Construction: Will commence at "a" on south side of river and proceed towards "b". Equipment available will consist of one locomotive, one 10-ton crane with clam bucket and pile driver attachment, and such flat cars and other rolling stock as may be necessary. Materials will be brought in from the south on the completed portion of the track. Construction will be entirely by the forces of the A & B Mining Co.

DESIGN BASED ON PRELIMINARY CONDITIONS

Briefely, the requirements of this design are: a bridge using steel I-beams of the size available, and structural timber, for materials; a bridge of low first cost; and a bridge where permanence is a secondary consideration.

Two or three types are available which would probably fill the requirements: A wooden truss bridge of two or three spans, a framed timber trestle with steel I-beams as stringers, or a pile trestle with steel stringers. The truss is out of the question from an economical standpoint, since there would be a large expense involved in framing the members. Therefore, the type to be used appears to be a trestle of either the framed- or pile-bent type, since both of these are comparatively cheap to erect.

The wooden bridge is not as might be supposed, an obsolete structure. In 1936 the Atchison, Topeka & Santa Fe Railroad[1] built some 110.5 miles of new track, of which 5905 feet of the total of 6671 feet of bridging was composed of treated timber trestles. All tracking and structures were designed for modern high-speed passenger traffic. The use of timber trestles for work of this type seems to indicate that there is still a very definite place for this kind of bridge. It has been repeatedly shown[2] that a first class timber trestle can be erected, maintained, and replaced every 15 years -this being the estimated life of the structure- for less than the interest on the investment required to build a so-called permanent structure at the same location.

1. Engineering News-Record-April 22, 1937-P. 579

2. Holtman, D. "Wood Construction" McGraw-Hill Book Co., Inc.

THE SURVEY FOR DESIGN

The survey party consisted of Instrumentman, notekeeper, and rodman. First a point "a" was established and given a station no. of 51+05.00 and an elevation of 276.83. These values were assumed to have been given by a previous locating party, as was the location of point "b" on the north side of the river. To determine the station no. of "b" (that is, the distance "ab",) an auxiliary point "c" was set up and a simple triangulation carried through. This consisted of measuring each angle twice and the distance "ac" and "cb" twice each. From this information, the distance "ab" was computed from two sides, and a mean value of 272.91 was obtained.

Next, a topographic survey was made, locating the river banks and contours and the existing highway bridge. Sufficient levels were then taken to determine the profile of the center line of the proposed bridge. As a boat was not available, the following method was resorted to in obtaining the underwater contours: a weighted steel tape was lowered into the water at each panel point of the 10-panel highway bridge truss. The distance from bridge floor to water was established, and the distance from bridge floor to river bottom at each point recorded. The underwater contours were assumed to run parallel to the banks of the river for the 100 or so feet from the existing bridge to the proposed bridge site. This assumption may be considered as taking too much for granted, as temporary bars or depressions might be present at the point of soundings which would disappear entirely a few feet upstream. However, the riverbanks an both sides are fairly regular and there is no evidence to show that the river bottom is not a simple alluvial valley. Further, the depth to which the piles are to be driven is uncertain within several feet, and the underwater profile as shown is probably accurate to at least one foot.

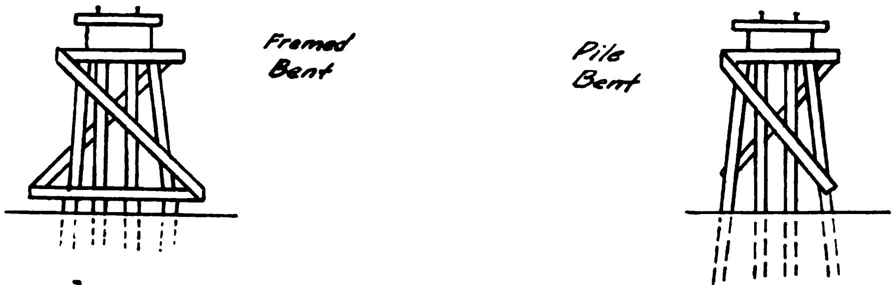
Six level shots were taken on the water surface, on both banks at distances of about 150 feet on either side of the center line. Elevations varied from an extreme upstream value of 265.05 to 265.53 on the downstream side. A mean of 265.2 was taken as the average water level.

Investigations regarding high water were made, and muddy water lines were found on the piers of the existing bridge at about 266.5. These water lines were very likely made during the flood of February, 1938, which was probably a maximum 20-year flood. Another 1.5 feet were added to the 266.5, and a maximum value of 268.0 feet for high water was obtained. This is 3 feet below the lowest longitudinal steel in the floor system.

DESIGN BASED ON SURVEY

The distance between points "a" and "b" was found to be 272.91. It was not deemed advisable to start the bridge from a, since an earth fill would be more economical for a short distance. Also a large content of the present highway fill consists of large boulders, which would make pile driving difficult. Accordingly, sta. 51+54.00 was selected as the location of bent no. 1. Since the stringers are 18.0 ft. long, and allowing 0.10 ft. for expansion and clearance between stringers, bents will be located at intervals of 18.10 ft. There will be 12 spans, making the station no of bent no. 13 53+70.20.

It was previously stated that either the pile or framed bent would be used for this bridge. The two types of bent are shown in the accompanying sketch.



Good practice[1] in trestle work seems to indicate that pile bents are economical for heights up to about 15 feet, and framed bents for greater heights. Since the cost of obtaining and handling long piles is quite high, and increases with the length of pile used, a point is reached at which the additional cost of buying and erecting framed bents on a pile foundation is more than offset by the saving effected in not using long piles. In a study of about twenty designs of timber trestles,[2] 15 feet seemed to be the line of demarcation between pile and framed bents.

A study of the center line profile on the accompanying map shows that at the deepest point in the river, the bent must be about 7.5 feet above water and 2.5 feet from water surface to river bottom. Plainly, the trestle falls within the pile-bent classification.

It was not deemed expedient to conduct explorations by borings or by driving test piles, both of which methods should probably be used in actual practice. Foundation conditions were assumed, however, to be "a mixture of sand and yellow clay" for a depth of 50 feet below the

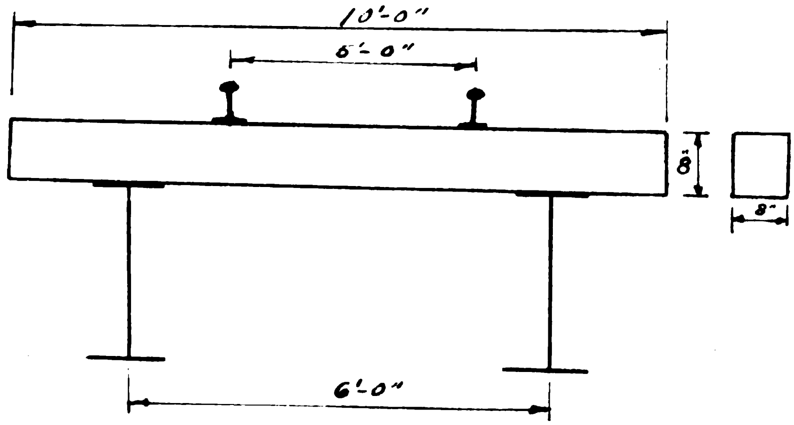
1. Foster, W.C. "A Treatise on Wooden Trestle Bridges"-Chapters 1,2,4.
2. Foster, W.C. Op.Cit. -Part 2.

ground surface. A reasonable penetration of piles in this ground can be expected to be about 15 feet. Adding on 10 feet to the cap and 2 feet for safety, a length of pile of 27 feet is obtained. In looking up prices on piling, the writer found no listings for piles less than 30 feet long. This seems to prove the advisability of using the pile bent in preference to the framed bent.

Computations for Design

1. Floor System

a. Ties



Live Load: Assume max. wheel load

distributed over 3 ties : $\frac{25}{3}$ = 8.340 K

Dead load : $\frac{150}{2}$ = wt. of rail per ft. = .075

Wt. of Tie (Assume 30#/') .300

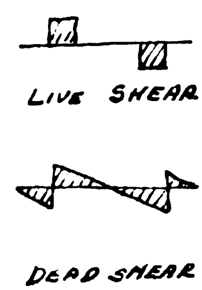
Max. live b.m. = 8340 · .5 = 4160 '#

Impact (100%) 4160

Dead. b.m. = 75 · .5 37.5

(Tie wt.) 150(3-2.5) 75

Total 8432.5



Bending moment: $S = \frac{Mc}{I}$ or $\frac{M}{S} = \frac{I}{c} = \frac{bd^2}{6}$

$d = \sqrt{\frac{6M}{Sb}} = \sqrt{\frac{8432.5 \cdot 6 \cdot 12}{8 \cdot 2000}} =$ 6.14

add on'l dap 1.00

7.14

Use an 8"x8"x10'-0" W.O. Tie

Bearing of Rail on Tie : Test for Tie Plate

Live load	4160#
Impact	4160
Rails	75
Total	8395#

Bearing stress: $\frac{8395}{6 \times 8} = 177$ #/□" – 375 #/□" allowed –

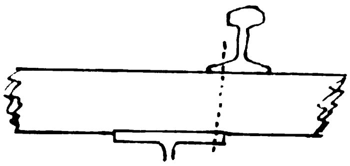
No Tie Pl. Req'd

Test for Shear Stress

Longitudinal Shear:

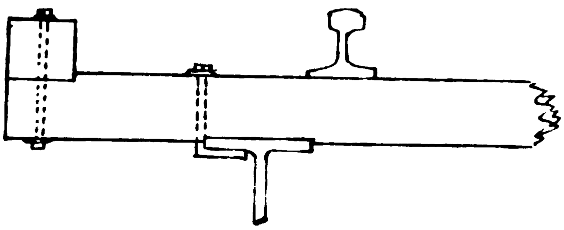
Live load	4160#
impact	4160
Rails	75
Tie	54
total	8449 = V

$$S_s = \frac{3}{2}\frac{V}{A} = \frac{3}{2} \cdot \frac{8449}{8 \cdot 8} = 198 \text{ \#/□"}$$



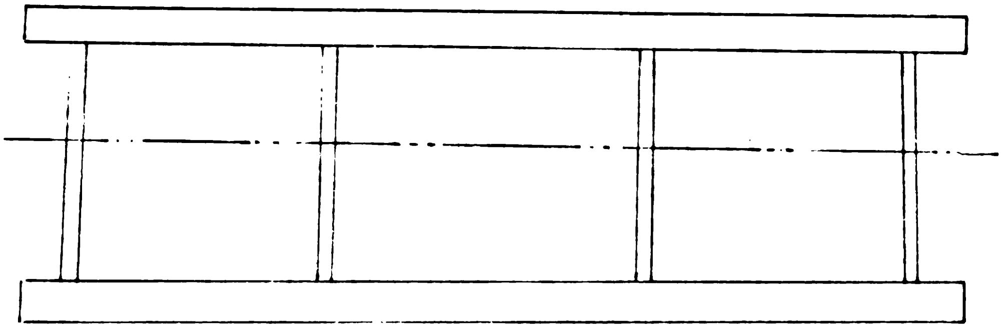
Allowable S_s = 125 #/□"; However, on account of overlap between rail and stringer flange, condition of shear will be considered satisfactory.

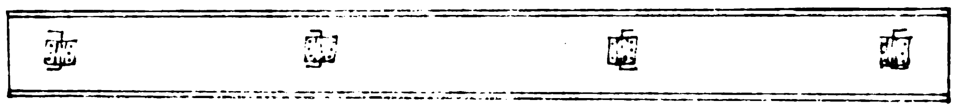
Guard Rail Details :

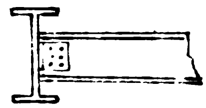


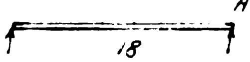
6"x8" Guard Rail – bolt every 3rd tie, staggered. Use 1"x16" Sq. hd. bolt and C.I. Washer. Secure tie to stringer with 1"x10" Ell bolt and washer. Bolt every second tie

b - design of Stringers









Max live shear & Impact - at end

Load ① at A = $\frac{479}{18}$ = 26.6

Load ② at A = $\frac{828 + 3 \cdot 90 - 26 \cdot 10}{18}$ = 46.6 - Max

Load ③ at A = $\frac{828 + 8 \cdot 90 - (229 + 50 \cdot 18)}{18}$ = 23.3

Alternate Load: $\frac{25(11+18)}{18}$ = 40.3 - Not max.

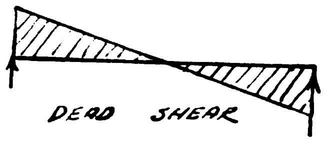
Impact : $\frac{46.6 \cdot 300}{300 + \frac{18^2}{100}}$ = 46.1

Total - 46.1 + 46.6 = 92.7 Kips

Dead Shear at end

Weight of Stringer: $W = \frac{K}{2}(12.5l+100) = \frac{.88}{2}(12.5 \cdot 18+100)$

$= 143^{\#/\prime}$

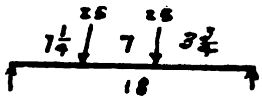


Rails & Fittings	$= 75$
Ties: $\left(\frac{8 \cdot 8}{12} \cdot 4.5^{\#} \cdot 5\right)$	$= 109.5$
Guard Rail $\left(\frac{6 \cdot 8}{12} \cdot 4.5\right)$	13.5
Total Uniform dead load:	$341.0^{\#/\prime}$

Dead Shear at end $\cdot\ 341 \cdot \frac{18}{2} = 3070^{\#}$

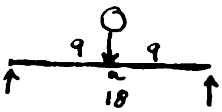
Max Live moment & Impact:

(1) Alternate Load:



$M: \frac{25(3.75+10.75)\cdot 7.25}{18} = 146.0$

(2) E-40 Load:



Load ② at A: $\frac{230+4 \cdot 50 \cdot 9}{18} - 18 = 128$

Load ③ at A: $\frac{[480+(4 \cdot 70)-220] \cdot 9}{18} - 100 = \underline{170\text{-MAX}}$

Load ④ at A: $\frac{\{830+4 \cdot 90-[120+(30 \cdot 11)]\} \cdot 9}{18} - 100 = 150$

Impact: $I = \frac{170 \cdot 300}{300+\frac{18^2}{100}} = 168.3$

Total Live moment $= 168.3 + 170$

$= 338.3$ Kip.ft.

Dead Moment:

$M = \frac{1}{8} w l^2 = \frac{1}{8} \cdot 341 \cdot 18^2 \qquad = 13.800$ kip ft.

Selection of Stringer:

$M = \frac{SI}{c}$; $\frac{M}{S} = \frac{I}{c}$ = Section Modulus = S

338300
13800
352100 = M

$S = \frac{352100 \cdot 12}{16000} = 264$

Properties of Beams on Hand:

Sec. index	Nom. size	Depth of Section	Wt. per foot	Area of Section	Flange width	Flange Thick.	I	$\frac{I}{c}$	r	web Thick.
CB242	24x12	24.31	120.0#	35.29□"	12.088"	0.930"	3635.3	299.1	10.15	0.556

Since the section modulus $\frac{I}{c}$ is greater than required, the beam is satisfactory from moment considerations.

Investigation for shear:

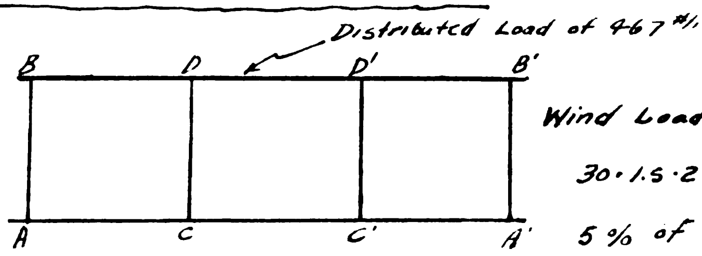
$S_v = \frac{V}{A} = \frac{95700}{.556 \cdot 24.31} = 7080$ #/□" — Allowable S_v = 10000 #/□"

Revision of Weights:

Actual stringer wt:
I - 120·18 = 2160
[- 40·12 = 480
[- 8·5.5 = 44
Rivets: 48·2 = 20
$\frac{2704}{18} = 150$ #/ft.

Assumed Wt. of floor system = 341.0
Less assumed stringer wt. 143.0
198.0
Actual stringer wt.: 150.0
Revised Total : 348.0 #/

Provision for Lateral Loads:



Wind Load: (see AREA-1925-#32,33)

30 · 1.5 · 2 = 93.75 - Required to use 300 #/'

5 % of specified Live Load = 167 #/'

Total = 467 #/'

Assume CD and C'D' each takes $\frac{1}{3}$ of total Load = 2800# ea.

" AB " A'B' " " $\frac{1}{6}$ " " " = 1400# ea

Try a channel section - C-12-40 #/'

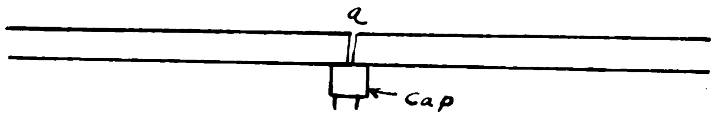
Compressive stress: = $15000 - 50\frac{l}{r} = 15000 - 50\left(\frac{5.95}{.75}\right) = 14604$ #/□"

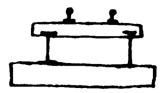
Allowable Load in each member: 14604 · 11.73 = 171,000# ~ ok.

Total Load to be resisted by anchor bolts: 8400# or 4200#

at each end. Use 4 lag screws - $\frac{3}{4}$ x 10"

2- Design of Bents





Max. Live shear & Impact on Cap:

	Average L		Average R	
Load (2) just right of A:	10	<	80	
" " " Left " "	30	<	60	
" (3) " right " "	30	<	60	
" " " Left " "	50	<	53	
" (4) " right " "	50	<	53	} a max.
" " " Left " "	60	>	33	
" (5) " right " "	60	>	33	
" " " Left " "	80	>	26	

Load (4) at a: $20 + \left(\frac{13+8+13}{18}\right) 20 + \frac{4}{18} . 13 = 60.8$

Impact: $I = \frac{300 \cdot 60.8}{300 + \frac{30^2}{100}} = 58.3$ Total Live shear = 119.1 K

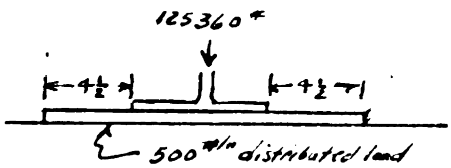
Dead Shear: (Wt. of floor system) = $348 \cdot 18$ = 6.26 K

Total load coming on cap from each stringer 125.36 K.

Bearing Value, Crosswise to grain (W.O. Cap.): $500^{\#}/\square''$

Width of bearing Pl. reqd = $\frac{125360}{500 \cdot 12} = 20.9''$ say 21"

Thickness of bearing Pl. reqd:



Max. moment = $\frac{1}{2} w l^2 = \frac{500}{2} . (4\frac{1}{2})^2 = 5050''^{\#}$

Resisting moment = $\frac{f I}{c} = 16000 \cdot \frac{1}{6} t^2$

$t = 1.37$ say $1\frac{1}{2}''$

Use bearing Pl. $12'' \times 21'' \times 1\frac{1}{2}''$

DESIGN OF PILES

The safe load a pile will support is dependent upon the method of driving. The are numerous formulas[1] expressing the relation between safe load, weight of hammer, height of fall, etc. Probably the best known and most used is the Engineering News formula, usually written in the form

$$L = \frac{2Wh}{s+1}$$

in which L is the safe load in pounds, W the weight of the hammer in pounds, h the fall of the hammer in feet, and s the distance in inches the pile moves under each of the last 5 blows of the hammer.

Assuming a 3000 lb. hammer with a fall of 15 feet and a set of $\frac{1}{2}$ in., we have

$$L = \frac{2 \times 3000 \times 15}{1 + \frac{1}{2}} = 60{,}000 \text{ lbs.}$$

The number of piles required under each cap will be 250,720 divided by 60,000, which equals 4.2. We therefore use 5 piles per bent.

Further investigation is necessary to determine if the individual piles are sufficiently strong acting as columns to bear their share of the load. The load on each pile is 250,720 divided by 5, or 50,144 lbs. The following formula, given by Foster,[2] is used for determining the allowable stress:

$$Q = \frac{1000}{1 + \frac{1}{550} \times \frac{L^2}{d^2}} \times f$$

In this formula, L is the unsupported length, d the least transverse

1. "Concrete Piles" booklet by the Portland Cement Assn. P. 18, 19, 22.
2. Foster, W.C. Op. Cit. P. 174, 175

dimension, and f is a factor depending upon the kind of wood. For short leaf yellow pine, f = 0.825. Assuming a 12 in. dia. pile with an unsupported length of 10 ft., the allowable stress Q is found to be 700 lbs. per sq. in. The total allowable load on each pile then equals the cross-sectional area x 700, or 78,800 lbs., which is amply strong.

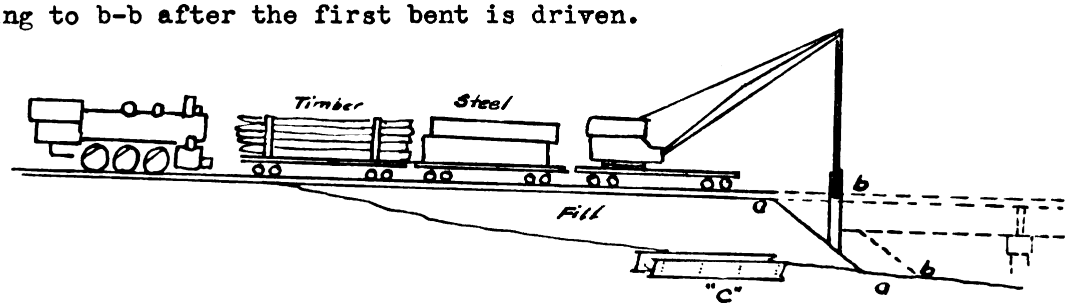
The Forest Products Laboratory[1], which has done considerable research in timber structures, recommends that "for short columns having an unsupported length (in inches) not greater than ten times the least transverse dimension (in inches), the working stress S_s equals the allowable compressive stress S. For short leaf yellow pine, S = 880 lbs. per sq. in, In the previous computation, a unit stress of 700 lbs. per sq. in. was used.

For both Foster's formula and the rule of the Forest Products Laboratory, the column is assumed to have hinged ends. In the pile under consideration, the lower end is fixed, and a degree of stability is furnished by the sway bracing. A column with one end fixed and one end hinged is at least twice as resistant as a column with both ends hinged. Therefore, it is considered that the piles as designed are amply safe.

1. Timoshenko & Mac Cullough "Elements of Strength of Materials" P. 274 et seq.

ERECTION PROCEEDURE

Construction will start from the south side of the river and work north. Fill will be placed and track laid to the point a-a in the sketch. Work should be arranged so that a day's work will end at this point, thus clearing the tracks for the bridge equipment the following day. Sufficient fill material should be left at this time to complete the filling to b-b after the first bent is driven.



The work train will be made up as shown in the sketch. Proceedure will be as follows: First, the engineer will give the location of bent no. 1. During this time the crane will unload stringers from first car and place them on the ground at "c". The crane will then take off the piles and other timbers from the second car and place conveniently in front of crane. At this time the pile leads and driver will be attached to the crane boom, and driving will begin, driving vertical piling first. While driving is in progress, a crew of 2 men will be fastening ties and guard rails to stringers at "c".

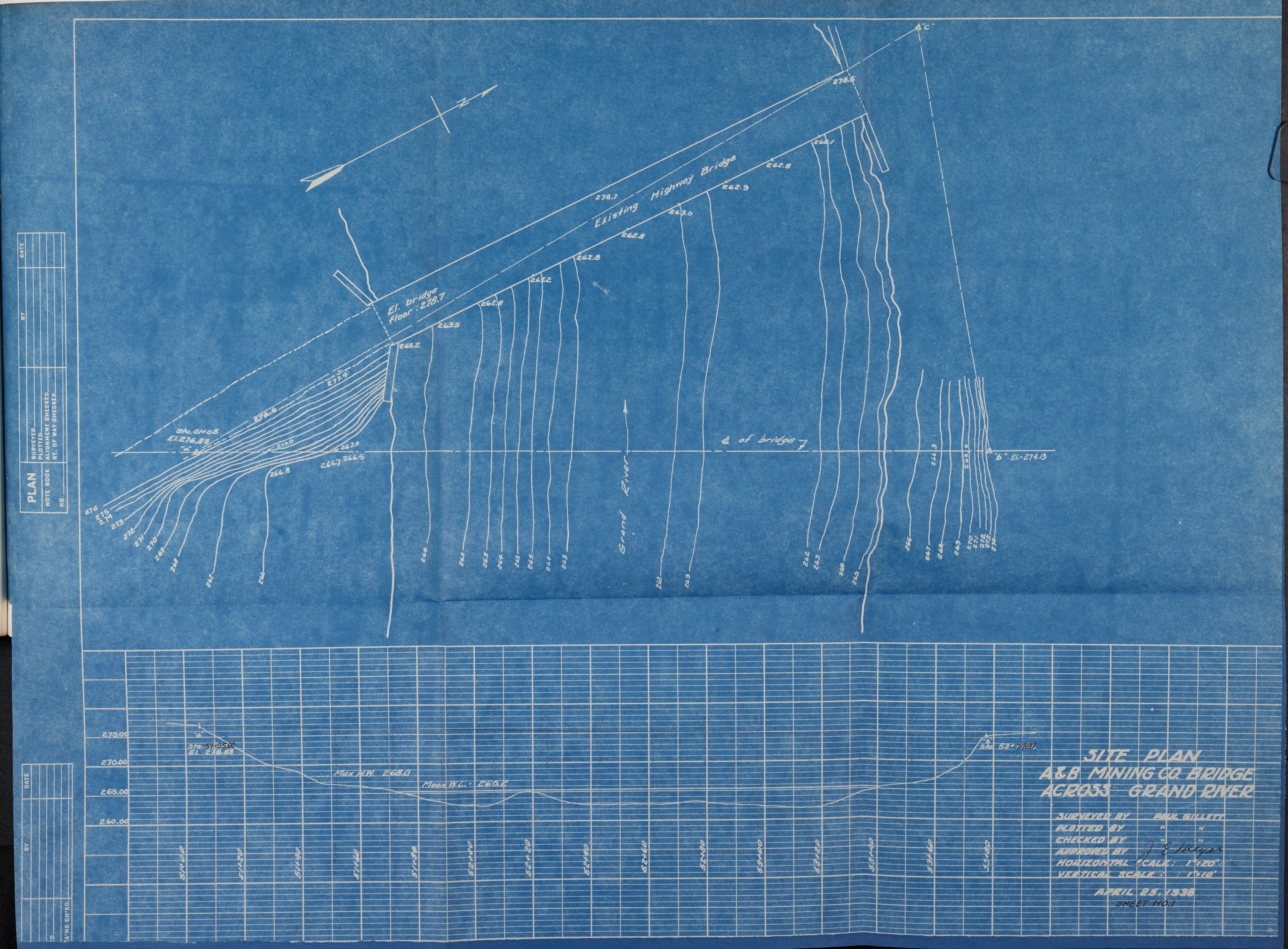
When piles have been driven to refusal, or until a pile sinks $\frac{1}{2}$ in. under each of 5 successive blows, the elevation of cutoff (see sheet no.2) will be given by the engineer, and the pile sawed at that elevation. The cap and sway bracing will then be fastened to the piles, and the 3" x 12" planks nailed on in back. The remainder of the fill to b-b will now be placed, and track built out to bent no. 1. Bent no, 2 will be constructed in the same fashion, except that there will be no planks on the back of the bent.

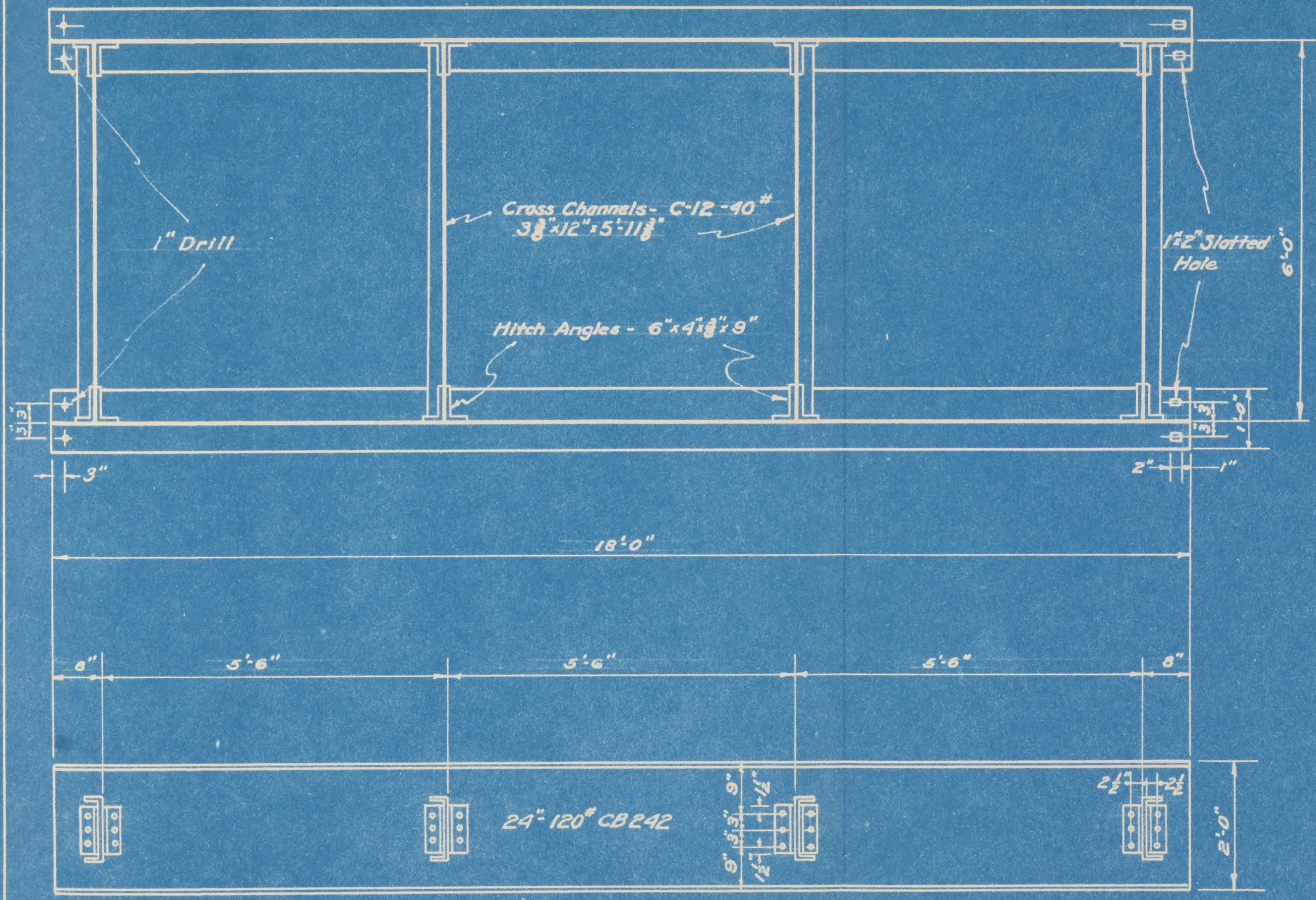
After bent no. 2 has been erected, the pile leads will be removed from the crane and the stringer lifted out over the bents and lowered into place. This done, and the stringers fastened down by lag screws, track will be laid out to bent no. 2.

The same proceedure will be followed in building the remaining bents. The locomotive will bring in new timber and steel as erection proceeds.

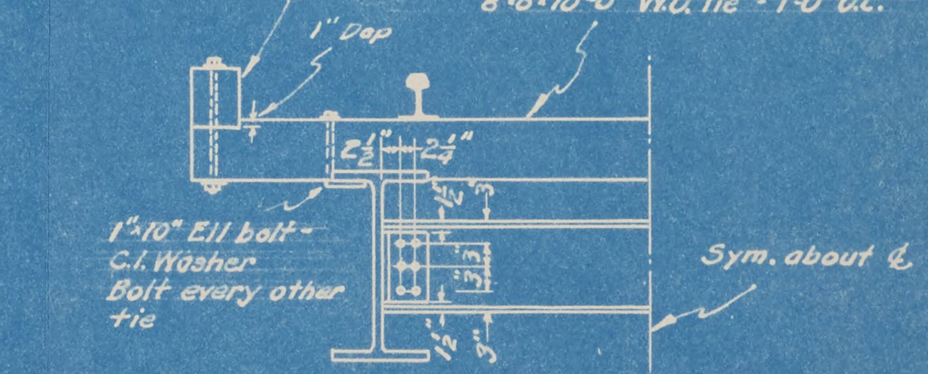
COST ESTIMATE

Preliminary engineering:		
Engineer's salary - 78 hrs. at $2.00	$156.00	
Assistants' wages - 12 hrs. at $0.50	6.00	
Drafting equipment	.50	$162.50
Wood materials and labor:		
Piling - 13 bents of 5 ea. - 12" dia. x 27' long- S.L.Y.P. at $0.20 per ft.		351.00
Labor at $0.20 per ft.		260.00
Cap - 13 bents - each cap 12"x12"x13'-0" - W.O. at $80 BM		162.00
Sway bracing - 3"x10"x14'-0" -pine-2 ea. on 11 bents at $38 BM		29.00
Ties - 216 of 8"x8"x10'-0" - W.O. at $47 BM		55.50
Guard Rails - 6"x8"x216' - pine at $38 BM		65.70
Bank bent - 6 of 3"x12"x18' Old Timbers		
Labor at $15 per BM		90.50
Iron and Steel materials and labor:		
Stringers - On hand		
Cross channels	11,502 lbs.	
Hitch angles	1,770	
Drift bolts	215	
Lag screws	75	
Bolts and rivets	2,140	
Bearing plates	2,780	
	18,500 lbs at $8.00 per 100 lb.	1,480.00
Labor at 5% of steel cost		74.00
	Total cost	2,703.20

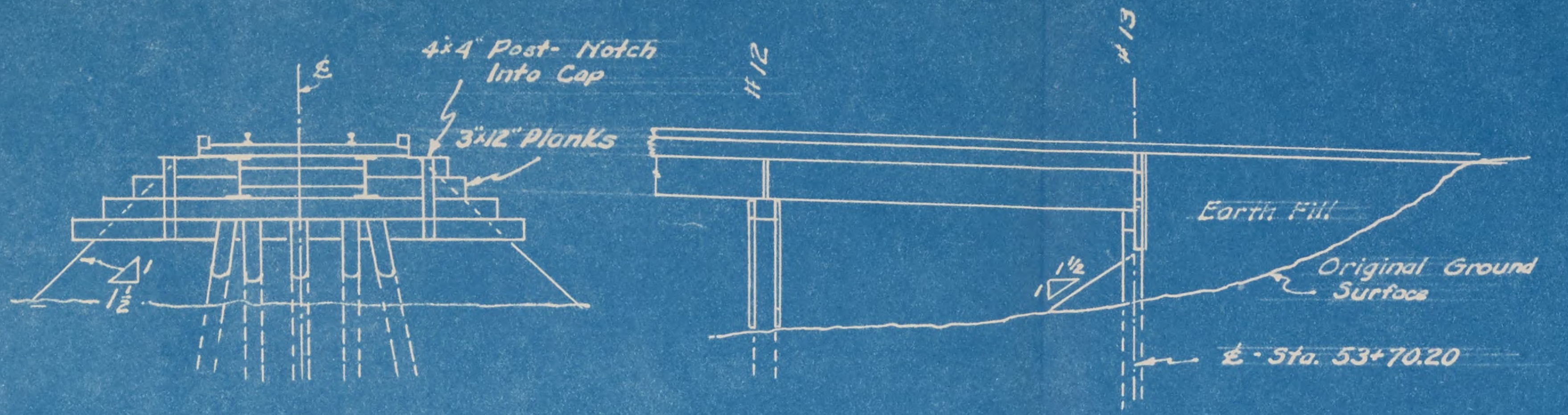

PLAN
SURVEYED
PLOTTED
ALIGNMENT CHECKED
RT. OF WAY CHECKED
NOTE BOOK
NO.
BY
DATE
Existing Highway Bridge
El. bridge floor: 278.7
Grand River
℄ of bridge
Sta. 51+05
El. 276.83
"b" El. 274.13
Max. H.W. 268.0
Mean W.L. 265.2
Sta. 53+77.91
275.00
270.00
265.00
260.00
SITE PLAN
A&B MINING CO. BRIDGE
ACROSS GRAND RIVER
SURVEYED BY PAUL GILLETT
PLOTTED BY " "
CHECKED BY " "
APPROVED BY J. E. Meyer
HORIZONTAL SCALE: 1"=20'
VERTICAL SCALE: 1"=10'
APRIL 25, 1938
SHEET NO. 1



NOTE
Use ⅞" rivets throughout.
Assemble stringer complete in shop.
12 Stringer Units req'd.

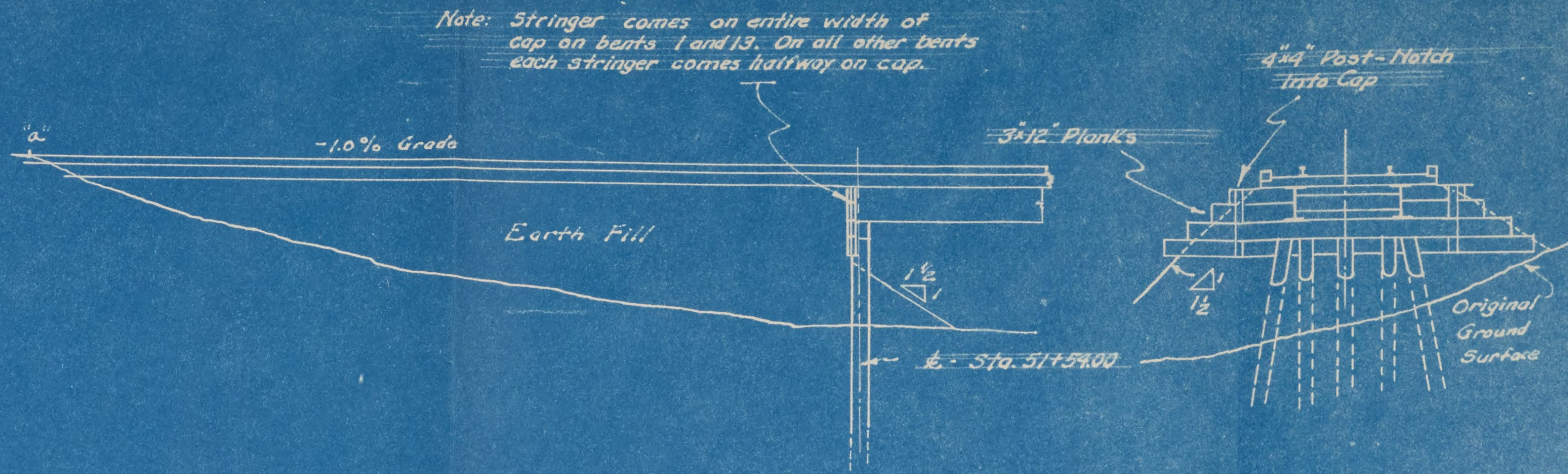


A & B MINING CO.	
RAILROAD TRESTLE BRIDGE	
ACROSS GRAND RIVER	
FLOOR SYSTEM DETAILS	
DESIGNED BY P.G.	SCALE : 1" = 2'-0"
DRAWN BY P.G.	DATE : 5-5-38
APPROVED BY J. E. Meyer	SHEET NO 2



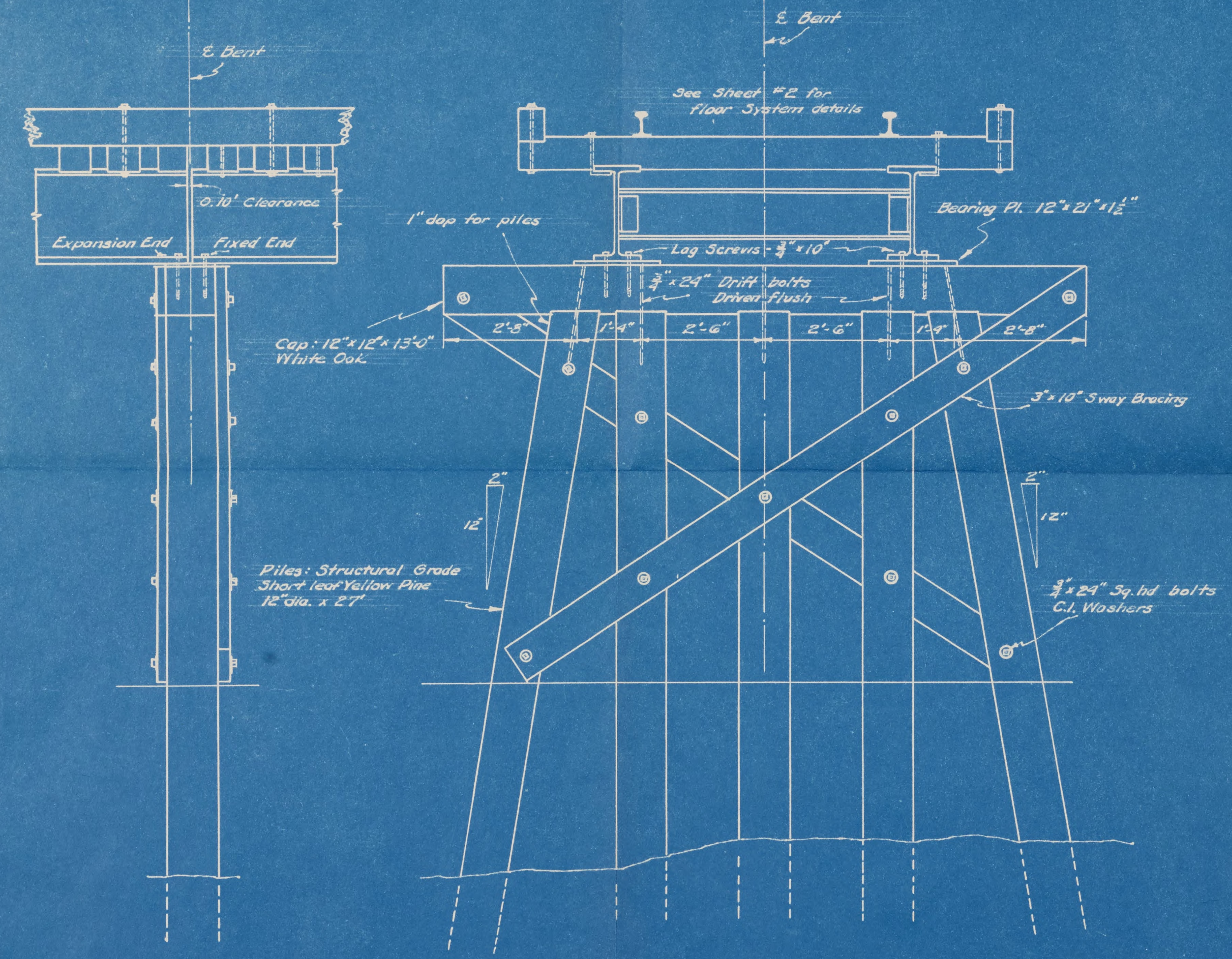
BENT NO. 13

A Typical bent except for notched cap and absence of sway bracing
Scale: 1/8" = 1'-0"



BENT NO. 1

A Typical bent except for notched cap and absence of sway bracing
Scale: 1/8" = 1'-0"



TYPICAL BENT

BENTS NO. 2 TO 12-Inc.
SCALE: 1" = 2'-0"

SCHEDULE OF BENTS

Bent No.	Sta. No.	El. of Rail	El. of Cap	El. of Pile Cutoff	Remarks
1	51+54.00	276.83	273.60	272.68	No Sway Bracing
2	71.60	276.65	273.42	272.50	
3	89.70	276.47	273.24	272.32	
4	52+07.80	276.29	273.06	272.14	
5	25.90	276.11	272.88	271.96	
6	44.00	275.93	272.70	271.78	
7	62.10	275.75	272.52	271.60	
8	80.20	275.57	272.34	271.42	
9	98.30	275.39	272.16	271.24	
10	53+16.40	275.21	271.98	271.16	
11	34.50	275.03	271.80	270.88	
12	52.60	274.94	271.71	270.79	
13	70.20	274.77	271.54	270.62	No Sway Bracing

A & B MINING CO.
RAILROAD TRESTLE BRIDGE
ACROSS GRAND RIVER
DETAILS OF BENTS

DESIGNED BY: P.G.	SCALE: AS SHOWN
DRAWN BY: P.G.	DATE - 5-5-38
APPROVED BY: J.E. Meyer	SHEET NO. 3

ROOM USE ONLY