DESIGN OF A FALSE CONCRETE
ARCH RAILROAD BRIDGE
AT EAST BOULEVARD, CLEVELAND, OHIO.

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THESIS FOR DEGREE OF C. E.

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JOHN GRIFFITH CAVANAGH

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The conditions which govern the design of structures used in the elimination of a series of grade crossings in cities are of various natures. The primary object in the design of any bridge is to provide a structure that will safely carry the traffic. The secondary object may depend upon local conditions, legal or municipal requirements, cost or results desired to be attained.

The City of Cleveland, desiring an entrance to a park, opened a street known as East Boulevard. In order to cross the tracks of The New York, Chicago and St. Louis ("Nickel Plate") Railroad, a bridge to carry the railroad traffic was built spanning the street. The street was depressed to allow the proper vertical clearance and the slopes graded to harmonize with the surrounding landscape.

In 1909 the City of Cleveland and the Village of East Cleveland passed ordinances granting The Cleveland Short Line Railway permission to construct a two track railroad across several streets.

A desirable location for the Cleveland Short Line Railway for about three miles through Cleveland and East

Cleveland was found to be adjacent and parallel to the tracks of the "Nickel Plate" Railroad.

No grade crossings were allowed in the construction of the Cleveland Short Line Railway, which made it necessary, in order to use the above mentioned location, to eliminate the grade crossings of the Nickel Plate Railroad through the zone where the tracks are adjacent.

When the grades of the respective railroads were established the elevation of the Cleveland Short Line Railway at East Boulevard was about three feet more than the elevation of the Nickel Plate Railroad at this point.

The City of Cleveland established the new street grade, which was only slightly changed from the old grade, and requested that a concrete arch bridge of an artistic design be built to carry the railroad traffic of the two railroads.

The difference in elevation of the railroad tracks and a horizontal plane at a given distance above the street surface fixed by the City ordinance for the under clearance of the bridge was great enough to permit the construction of a concrete arch under the Cleveland Short Line tracks but not under the Nickel Plate tracks.

After the design of the Cleveland Short Line arch was completed a design was made of a steel and concrete structure having the appearance of a concrete arch. This structure was placed adjacent to the concrete arch, to carry the Nickel Plate traffic, and consisted of a through plate girder bridge, with concrete floor slab and wing abutments and concrete fascia and soffit arches to conceal the steel.

The bridge was designed for Cooper's Class E-60 loading and according to The N. Y. C. & St. L. Railroad Company's specifications.

Width of street 54'feet

Angle between bridge and street, 90 degrees

Span center to center of supports, 58.3 feet

Distance center to center of tracks 16 feet

Track alignment 3° 5' curve

Design of Outside Girder.

Dead load to be carried by outside girder.

Estimated weight of steel in girder	37600 lbs.
" " " " " floor beams	27000 lbs.
" " " concrete and drainage gutter	130410 lbs.
" " " ballast	55680 lbs.
	250690 lbs.

(Note: Ballast is computed to top of tie and the weight of the track is neglected.)

Dead load end shear = 250690 ÷ 2 = 125345

Live load end shear (from tables for Cooper's Class E-60 loading for 58.3' span) 143610

Impact = live load $\left(\frac{300}{300+L}\right)$ (when L = loaded length of bridge in feet) 120230

Centrifugal force end shear (Eq. 6 Plate A) 16850

Centrifugal force impact 12130

Total end shear = 418165

The web is taken with a depth of 84 inches End shear 418165 divided by 13500 (shearing resistance of one square inch of web) = 30.9 square inches = net section of web necessary to resist the end shear.

The number of rivets necessary to resist 418165 lbs. in bearing on 1/2" web plate = 40. Use two rows of 7/8" rivets and assume web with thickness of 1/2". Then net section of web = 84 x 1/2 - 20 x 1/2 (rivet holes 1" in diameter) = 32 square inches.

Dead load bending moment = 1/8 w l^2 where l is length and w is load in pounds per foot. . . . 1826900

Live load bending moment (from tables for Cooper's Class E-60 loading) 1852000

Impact = $\left(\frac{300}{300+L}\right)$ live load bending moment 1550640

Centrifugal force bending moment (See Eq.7 Plate A) 208100

Centrifugal force impact 174500

5612140 foot lbs

5612140 foot pounds x 12 = 67345680 inch lbs.

6734580 inch lbs. $\div$ 84.2 effective depth of girder = 799830 lbs. tension in flange caused from load that tends to produce bending in a vertical plane.

799830 $\div$ 18000 (allowable value of 1 sq.in. in tension) = 44.44 square inches of flange necessary to resist the bending moment in a vertical plane.

The centrifugal force tends to cause a bending moment in a horizontal plane which equals the bending moment in the vertical plane x $\frac{s}{h}$ (Plate A)

s = 192 inches
h = 107 inches

Live load bending moment equals

2081000 x $\frac{192}{107}$ = 370400

Impact = 310120
680520 foot lbs. x 12 = 8166240 inch lbs.

8166240 $\div$ 192 = 42532 lbs. tension in lower flange

42532 $\div$ 18000 = 2.36 sq. inches of flange area necessary to resist bending in horizontal plane due to the centrifugal force.

44.44+2.36 = 46.8 sq. inches of flange area necessary to resist the bending moment.

2 angles 6"x6"x7/8" = 19.48 sq.in. - 3.50 sq.in for rivet holes	=	15.98
1 plate 3/4"x16" = 12.00 sq.in. - 1.50 sq. in. for rivet holes	=	10.50 full length
1 plate 3/4"x16" = 12.00 sq.in. - 1.50 sq.in. for rivet holes	=	10.50x40'6"
1 plate 3/4"x16" = 12.00 sq.in. - 1.50 sq.in. for rivet holes	=	10.50x29'0"
		47.48 net area

Design of Inside Girder.

Dead load to be carried by inside girder.

Estimated weight of steel in girder	60700 lbs.
Estimated weight of steel in floor beams	54000 lbs.
Estimated weight of concrete floor	240340 lbs.
Estimated weight of ballast	111360 lbs.
	466400 lbs.

(Note: Ballast is computed to top of tie and the weight of the track is neglected.)

Dead load end shear = 466400 ÷ 2 =	233200 lbs.
Live load end shear (from tables for Cooper's Class E-60 loading)	287220 lbs.
Live load impact = end shear $\left(\frac{300}{300 \quad L}\right)$ =	206800 lbs.
	727220 lbs.

(Note: Maximum impact occurs when both tracks are loaded and L = 2 x 58.3 = 116.6)

There is no end shear caused by centrifugal force as the maximum end shear occurs when both tracks are loaded and vertical reactions due to centrifugal force are balanced.

End shear 727220 ÷ 13500 (shearing value of 1 sq. inch of web) = 53.87 square inches of web required to resist the end shear.

With web 13/16" in thickness and 84" wide the gross area is 68.25 square inches. The strength of one 7/8" rivet to resist 13500 lbs. per square inch in double shear is 16240 lbs.

727220 ÷ 16240 = 45

Number of rivets necessary to carry 3/4 of the end shear from the web to the end stiffeners as allowed by specifications is 34.

If two rows of rivets are used the area to be deducted from the gross section of the web is 17 x 13/16 (rivet holes 1" in diameter) = 13.75

68.25 - 13.75 = 54.50 square inches net section of web.

Dead load bending moment = $1/8\ w\ l^2$ =	3398890
Live load bending moment (from tables)=	3704000
Impact $\left(\frac{300}{300+L}\right)$ live load bending moment =	2666880
	9769770 foot lbs.

9769770 x 12 = 117237240 inch lbs.

117237240 ÷ 84.93 (effective depth of girder) = 1380398 lbs. tension in flange caused from load that tends to produce bending in a vertical plane.

1380398 ÷ 18000 (allowable value of 1 sq. in. in tension) = 76.7 square inches of flange necessary to resist the bending moment in a vertical plane.

The centrifugal force tends to cause a bending moment in a horizontal plane $M_F = \frac{Mw}{5}$ Eq. 8 Plate A = 740800

Impact = $\left(\frac{300}{300\ \ L}\right)$ L L B M =	533370
	1274170 foot lbs.

1274170 x 12 = 15290040 inch pounds.

15290040 ÷ 192 = 79635 lbs. tension in lower flange.

79635 ÷ 18000 = 4.42 sq. inches of flange area necessary to resist the bending moment in a horizontal plane.

$76.7 + 4.42 = 81.12$ square inches of flange necessary.

2 angles 8"x8"x1-1/8"	= 33.46 sq.in. area - 6.75 for rivet holes	= 26.71
1 plate 13/16"x20"	= 16.25 sq.in. area - 1.62 for rivet holes	= 14.63 full length
1 plate 3/4" x 20"	= 15.00 sq.in. area - 1.50 for rivet holes	= 13.50x44'0"
1 plate 3/4" x 20"	= 15.00 sq.in. area - 1.50 for rivet holes	= 13.50x35'6"
1 plate 3/4" x 20"	= 15.00 sq.in. area - 1.50 for rivet holes	= 13.50x25'6"
		81.94 net area

Length of cover plates determined by formula

$$l' = l\sqrt{\frac{a + a' + a''}{A}}$$

where l is total length of span, a, a', a", are areas of cover plates from outside towards flange angles, and A is total area of flange.

Design of Floor Beams.

The floor beams are spaced 16" apart.

The dead load supported by the floor beams per lineal foot of bridge is approximately 8000 lbs.

The dead load end shear on one floor beam

$$= \frac{8000}{2} \times \frac{16}{12} = \qquad 5333$$

The live load end shear is computed from the special loading of 72000 lbs. distributed uniformly over an area of five feet longitudinally and ten feet transversely (from specifications)

Live load end shear $= \frac{72000}{2} \times \frac{1}{5} \times \frac{16}{12} = \qquad 9600$

Impact $= \qquad 9600$

$\qquad 24533$

Dead load bending moment = $1/8\ wl^2$ = 21333

Live load bending moment = 9600 x 8 - 9600x2-1/2= 52800

Impact 52800

126933 foot lbs

126933 x 12 = 1523200 inch lbs.

1523200 ÷ 18000 (allowable stress in tension) = 84.62 required.

A 15 inch 65 lb. I beam has a section modulus of 84.8

Concrete Fascia Arch.

A concrete fascia arch reinforced with a steel truss is placed in front of the outside girder. The fascia arch has contours, copings and panels exactly like the face of the concrete arch between street lines.

The face of the wings of the abutments and the fascia arch form a continuous surface that has the appearance of a concrete structure exactly like the face of the concrete arch.

The steel fascia truss is designed as a simple arch truss to carry the weight of the steel and concrete in the arch. The panel loads are computed from the amount of material in the arch considering the weight of concrete as 150 lbs. per cubic foot and the weight of steel as 490 lbs. per cubic foot. The stresses and size of shapes are as shown on the strain sheet.

Design of Grillages.

The bearing value of concrete (from specifications) is 500 lbs. per square inch.

The end shear of the outside girder is 418165 pounds.

418165 ÷ 500 = 836.33 square inches bearing area of concrete necessary to support load at one end of outside girder.

A 15 inch 42 lb. I beam has a flange 5-1/2 inches wide.

Four I beams have an area of 4 x 5-1/2 = 22 square inches per lineal inch of beam.

836 ÷ 22 = 38 inches = length of four 15" - 42 lb. I beams necessary to distribute the load carried by one end of the outside girder to the concrete abutment.

The end shear of the inside girder is 727220 lbs.

727220 ÷ 500 = 1454 sq. inches bearing area of concrete necessary to support load at one end of inside girder.

1454 ÷ 22 = 66.1"

5' - 7" = length of four 15" - 42 lbs. I beams necessary to distribute the load carried by one end of the middle girder to the concrete abutment.

Method of Grouping Rivets for Floor Beam Connections.

Minimum rivet pitch for flanges $p = \frac{sd}{V}$

Where s = least value of rivet to resist shear or bearing,

d = distance between center of rivet lines,

V = vertical reaction at support.

For inside girder.

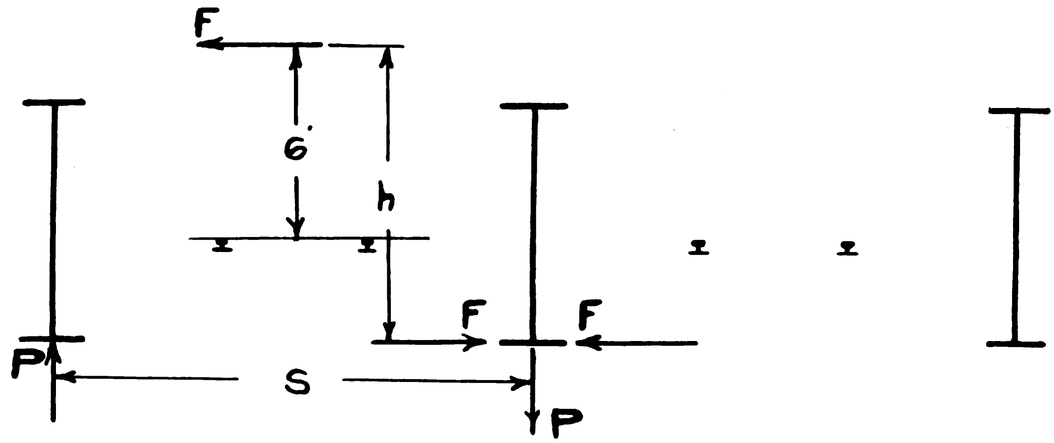
$$p = \frac{16240 \times 75}{727220} = 1.67 \text{ inches}$$

Two rows of rivets with 3 inch spacing are sufficient to transmit the stress from the flange to the web.

For a space of 16 inches, which is the distance from center to center of floor beams, the number of rivets necessary to transmit the stress from the flange to the web is $16 \div 1.67 = 10$ rivets.

Near the ends of the girder where the greatest number of flange rivets are required the rivets are grouped in three rows so spaced to allow three rivets in each row between the floor beam connection angles. The object of this arrangement is to provide sufficient number of rivets between floor beam connections to transmit the flange stress to the web so it will not be necessary for the rivets in the floor beam connections to act as flange rivets.

Method of Determining Centrifugal Force Stresses.



From the specifications the centrifugal force due to the curvature of the track shall be considered for curves from 2 degrees to 10 degrees as 10 percent of the live load and acting at a point 6 feet above the top of rail.

W = total load on one girder with one track loaded

$F = 2 \times 10\%$ of $W = \frac{W}{5}$ Eq. (1) With two tracks loaded.

$Fh = PS$ Eq. (2)

$P = \frac{Fh}{S}$ Eq. (3)

P = Summation of $p_1 \; p_2 \; p_3 \ldots$ Eq. (4) p = floor beam reactio

$$\frac{R_P}{R_w} = \frac{\frac{W}{5}\;\frac{h}{S}}{W} \qquad \text{Eq. (5)}$$

$$R_P = \frac{R_w}{5}\;\frac{h}{S} \qquad \text{Eq. (6)}$$

Likewise $M_P = \frac{M_w}{5}\;\frac{h}{S}$ Eq. (7)

$\frac{M_P}{\text{Effective depth of girder}}$ = flange stress.

$M_F = \frac{M_w}{5}$ on lower flange only. Eq. (8)

Flange stress is $\frac{M_F}{S} = \frac{M_w}{5S}$ Eq. (9)

h = approximately 9 ft. for E. Boulevard

Plate A

The floor beams are attached to the girders with the lower flanges of the floor beams placed at the same elevation as the lower flanges of the girders. The object of this arrangement which makes it necessary to dip the floor beams is to secure sufficient space for the floor slab and ballast with the limited difference in elevation of the track and the under clearance of the bridge.

The height of the abutments is fixed at such an elevation that the lower flanges of the girders and floor beams are slightly above the intrados of the concrete arch at the crown.

Below the floor system of the steel bridge and making a continuous surface with the intrados of the concrete arch is supported a plastered surface. The plaster has a thickness of 2 inches and is attached to Style 5A wire mesh. At the middle of the bridge the wire mesh is attached directly to the floor beams. From the fifth to the eighth floor beam from the center of the bridge channels varying from about 3" to 8" in width are attached below the beams. The wire mesh is attached to the lower edge of the channels. Between the eighth floor beam and the face of the abutments the channels to which the wire mesh is attached are supported by 8" - 18 lb. I beams. The I beams are curved to the exact shape of the intrados of the concrete arch. The lower ends of the I beams are supported in recesses in the abutments at the elevation of the springing line of the concrete arch.

The floor beams are imbedded in concrete reinforced with Style 5A wire mesh which forms a slab with its lower surface 2" below the bottom flanges of the floor beams and its upper surface 6" above the top flanges of the floor beams at the center of the track. The top of the concrete floor slab slopes downward from the center of the track towards the girders to carry the water to a 4" tile drain which is located parallel to the girders and as near the girders as the gusset plates will permit. From the tile towards the girders the concrete slab slopes upward to the upper flanges of the girders. This prevents water coming in contact with any of the steel work of the bridge excepting the upper flanges of the girders. The tile drain is carried over the backwall of the bridge and through the abutment to a sewer. A slot 2" x 2" in the top of the backwall extending the full length of the backwall is filled with waterproofing. The upper surface of the floor slab is made of a rich mixture and is well reinforced which is the only provision considered necessary to take care of the drainage between the tracks.

Between the outside girder and the fascia girder a gutter made of concrete plastered to wire cloth and supported by rods and brackets fastened to the stiffeners of the outside girder is provided to take care of the drainage.

The concrete abutments which act as a support for the superstructure as well as a retaining wall to support the fill were designed so that the thickness at any point is equal to or greater than one half of the vertical distance between that point and the bridge seat.

The length of the wings of the abutments are the same as those of the concrete arch whose length is one and one half the vertical distance between the ground surface and the subgrade of the railroad fill. This is to provide for a one and one half slope from the railroad subgrade to the street surface.

The wings of the abutments and the concrete fascia girder are provided with copings, bays and panels exactly the same as those of the concrete arch.

The body concrete of the abutments is a 1:3:6 mixture. The exposed colored surfaces are a 1:2:4 mixture.

In deciding upon the general color scheme and texture of the exposed surfaces, the original plan was that the surfaces should be dull pink in color and that it should show in the texture of the aggregate three grades, rough or pebbled in the panels, bush-hammered from the springing line of the arch to the sidewalk, and polished or ground for the other surfaces. This plan was later modified by bushhammering all surfaces except the panels and rubbing to a finish all bushhammered areas except copings, belt course, abutment below the springing line of the arch and the raised semicircles over the bays in the wings.

A few small samples of the proposed surfaces were cast in order to determine the amount of coloring matter necessary and the proper selection and grading of the aggregate to obtain the desired result. The proper color was obtained when eighteen pounds of ferric oxide, sold under the name "Princess Metallic Dry", was added to two bags of cement. At all times during the construction of the bridge this proportion was rigidly adhered to. The ferric oxide was thoroughly mixed dry with the cement in a box rotating on a rod through its diagonally opposite corners, giving the effect of a cube mixer.

Aggregate in the facing was made by crushing red granite rubble to pass a one inch ring. Screenings from the crusher were passed over a number 4 and number 8 screen.

Aggregates were mixed as follows:-

For bushed and rubbed surfaces except in coping, belt course, raised semicircles over bays in the wings and fascia girder:-

3 barrows river sand

2 barrows # 3 stone (1" ring)

1 barrow washed gravel

2 bags colored cement

making a 1:2:4 mixture.

In copings, belt course and raised semicircles over the bays in the wings and fascia girder:-

1 part colored cement

3 parts river sand

3 parts washed gravel

For pebbled surfaces in the panels:-

1 part colored cement

1 part granite sand passing a # 8 screen, run as grout into 4" of granite crushed to pass a 1" screen. The granite was held against the forms by # 20 chicken wire, 1" mesh.

For polished or ground surface as originally planned:-

1 part colored cement

2 parts granite screenings retained on a # 8 screen

Bushhammered surfaces on the abutments between the springing line and the sidewalk contain the last

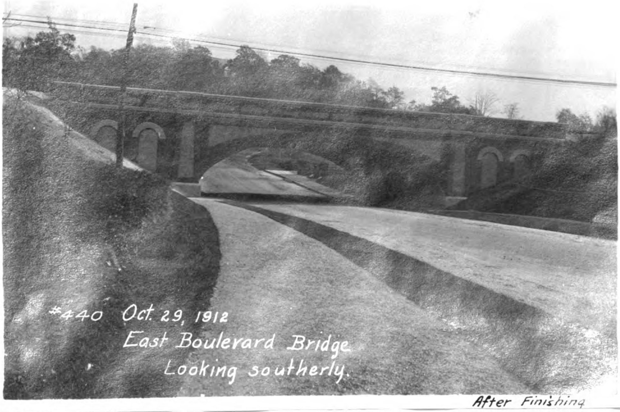
mentioned proportions.

The expensive colored aggregates were used only in the facing mixture, a veneer about two inches thick except in panels as noted above.

After the concrete had become thoroughly hard, the embedding mortar was tooled from between the particles of granite in the panels. All other areas were full bushed except the false arch under the girders. Hammer head points on the panels and 25 point bush hammers on the full bushed surfaces were the tools used. Power was furnished by an air compressor mounted and housed on a flat car.

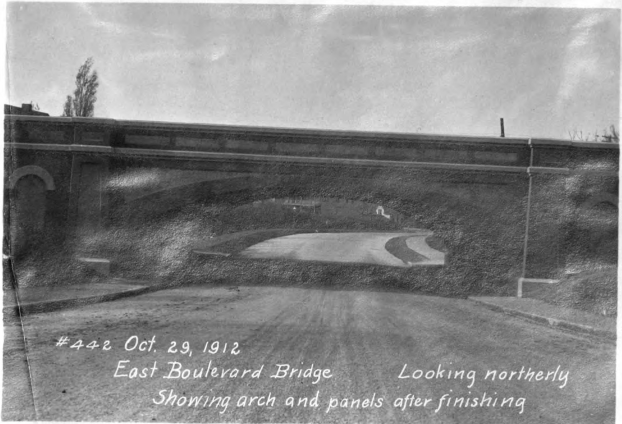
The results sought and obtained from the design and construction of the false arch are:- a structure that safely carries the railroad traffic, is not noisy, is as near in accordance with municipal requirements as possible, and has a pleasing appearance that does not mar the beauty of the surrounding landscape.

Before Finishing



After Finishing

Before Finishing



After Finishing

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