THESIS

DESIGN OF M. C. R. R. AND MOUNT HOPE AVENUE GRADE SEPARATION, LANSING, MICH.

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Railroads - Crossings

With Grade separation

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Civil engineering - Highway engineering

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THESIS

Presented for B. S. Degree

By

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Title

DESIGN OF

MICHIGAN CENTRAL RAILROAD AND MOUNT HOPE AVENUE

GRADE SEPARATION

LANSING, MICH.

THESIS

Grade separations have assumed an importance undreamed of a decade ago. The rapid change in the speed of the vehicular traffic due to the avent of the automobile, has increased accidents at an alarming rate.

Many of the accidents can be traced to the lack of grade separations. The public in its new idea of "Safety Always" has risen above looking at the cost of the project and are demanding safer crossings.

Since by a new state law there can be no more railroad crossings laid without constructing a grade separation it is just as necessary to build them over old crossings.

This particular grade separation that we are designing is located at the intersection of the Michigan Central Railroad and Mount Hope Avenue at Lansing, Michigan. Mount Hope Avenue runs East and West and the railroad North and South. Mount Hope is one of the main arteries leading from Lansing and on a traffic census there were in eight hours, 251 pedestrians, 183 vehicles and eight trains. The location on the city map in the holder at the back is indicated.

We first looked over the ground, taking pictures and getting the location and general contour of the ground in mind. At this time we also took traffic census to determine if grade separation was needed.

There are four possibilities in construction at a grade separation. They are as follows:

Change direction of the railroad; change the direction of highway; go over the railroad by means of a bridge; or to tunnel under. The first two are impractical except in rare instances. This being the case we decided to use a pass-over due to the profile of the ground which was advantageous to this design.

The next step was the final survey which consisted of taking cross sections and topography. The topography was checked over three times because our work did not agree with city maps. We checked every thing and found that the city maps were in error.

With this data and with the advice and aid of Professor's Vedder and Allen we designed the grade separation which computations follow ;

The overhead clearance necessary for a steam railroad is eighteen feet from the rail top to the lowest point of a bridge or other structure. In order to obtain the greatest necessary elevation for the design of the new grade of the highway it was needful to first design the bridge and get the depth from crown of roadway to under side of bridge. Altho the railroad at present has only a single track, the necessity of double tracking railroads is well recognized and in consequence of this fact the lateral clearance allowed was that needed for two tracks. The width required for two tracks is thirty three (33) feet, and as the abutments were to have no batter, this was taken as the span of the bridge. As the traffic rate is rather high and also as a protection against future congestion, the roadway over the bridge was designed twenty-four (24) feet wide.

The general form of the bridge as designed is as follows ; The roadway is carried by three floor slabs supported by two beams transverse to the highway and by two abutments. The two beams are supported by two longitudinal girders which also bear the weight of the side walks and railings.

The latter are attached by cantilever construction to the girders. The type of abutment adopted was the cantilever type.

Standard Notation.

A. Rectangular Beams.

f_s = tensile unit stress in steel.

f_c = compressive unit stress in concrete.

E_s = modulus of elasticity of steel.

E_c = modulus of elasticity of concrete.

$n = \frac{E_s}{E_c}$

M = moment of resistance, or bending moment.

A_s = area of steel.

b = breadth of beam.

d = depth of beam to center of steel.

K = ratio of depth of neutral axis to depth, d.

Z = depth below top to resultant of the compressive stresses.

j = ratio of lever arm of resisting couple to depth, d.

$j d = d - Z$ = arm of resisting couple.

p = steel ratio = $\frac{A_s}{b\,d}$

B. T - Beams.

b = width of flange.

b' = width of stem.

t = thickness of flange.

Standard Notation - continued.

C. Shear, Bond and Web Reinforcement.

V = total shear.

V ' = total shear producing stress in reinforcement.

v = shearing unit stress.

v = bond stress per unit area of bar.

o = circumference or perimeter of bar.

E v = sum of perimeters of all bars.

T = total stress in single reinforcing member.

s = horizontal spacing of reinforced members.

The notations have been made and approved by a committee consisting of the foremost engineers in the United States.

All formulae's are taken from Hool and Johnson a recognized authority on concrete design.

Design of Bridge.

M.S.H. (Mich. State Highway) Specifications.-

M in a continuous slab $= \frac{wl^2}{12}$

M in a simple beam $= \frac{wl^2}{8}$

Minimum slab thickness = 1/30 of the span.

Loading for sidewalks = 100# / sq. ft.

Impact = 25% of the live load.

A 20 ton truck gives a load of 140 # per sq. ft. on the area actually occupied and as this is a short span 140 # will be taken as the live load.

Slab Design.

span = 11' = 1 — Use # 2000 concrete

live load = 140 # — f s = 16000 / sq. in.

25% Impact = 35 # — f c = 650 / sq. in.

Dead load : Consists of 12" packed gravel = 120 #

Total load = 140 + 35 + 120 = 295 #

Assume that slab is 8" thick.

Then unit weight or "w" = $295 \quad \frac{8 \times 150}{12} = 395$ # / ft.

From specifications $M = \frac{wl^2}{12}$

and "b" = 12" (assume a section one foot wide) and

"K" = 107.4 (from tables on page 355 Hool and Johnson).

$b\, d^2 = \frac{M}{K}$

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{wl^2}{12 \times 12 \times 107.4}} = \sqrt{\frac{395 \times 11^2}{12 \times 107.4}} = 5.9$ "

Since it is necessary for fire protection to add a certain amount to the beam (table on page 300 Hool and Johnson) $1\frac{1}{4}$" additional was added and D = 7.15" say 7"

our new w = $295 + \frac{7}{12} \times 150 = 382.5$ # / ft.

$d = \sqrt{\frac{382.5 \times 11^2}{12 \times 107.4}} = 5.75$ and D = 7.0 " (which is O.K. because we assumed an 8" thickness and 395 # / ft and both figured results are under this).

Then the area of steel must be found.

A s = p b d = .0077 x 12 x 5.75 = x531 in.^{2} or A s = x55

Use $\frac{1}{2}$ bars spaced $5\frac{1}{2}$" longitudinally

Use $\frac{1}{4}$ bars spaced 18" transversely for shrinkage and temperate cracks.

(The size and spacing of the rods is found on page 357 of Hool and Johnson).

Testing for shear is necessary to see if slab is strong enough to take all shear.

$v = \frac{V}{b\,j\,d} = \frac{382.5 \times 5.5}{12 \times .874 \times 5.75} = 34.9$ # which is O.K.

allowable 40 #

In appendix B Hool and Johnson it says " For slabs with horizontal bars only and without web reinforcement, 2% of the compressive strength may be allowed". Since we are using a 2000 # concrete it would be .02 x 2000 = 40 #

It is now necessary to see if the bond is great enough between the steel and concrete so that they will not pull apart.

$$u = \frac{V}{\Sigma o\, jd} = \frac{382.5 \times 5.5}{436 \times .874 \times 5.75} = 96\ \#$$

too large for straight bars but can be made safe with hooking the ends.

In Appendix B (page 846 Hool and Johnson) under the title BOND . "The bond stress between concrete and plain reinforcing bars may be assumed at 4% of the compressive strength of the concrete". "But by hooking them or deforming 5% of compressive strength may be allowed".

.04 x 2000 = 80 # so it is too large (96#) for plain bars but with hooks on .05 x 2000 = 100 # hooks make it safe.

Design of T - Beam.

$$b = \begin{cases} \frac{1}{4} \text{ span length} = 11 \times 12 = 33'' \\ 12 \times \text{slab}, t, = 84'' \quad \text{Use } b = 33'' \end{cases}$$

$$M = \frac{wl^2}{8} \qquad W = 11 \times 382.5 = 4208\ \#\ /\ \text{lin. ft.}$$

$$l = 24'$$

$$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{4208 \times 24^2 \times 12}{8 \times 107.4 \times 33}} = 10.15'' \quad D = 11.55''$$

SAY 12" = D

$$Kd = \frac{2nd\, A_s + b\, t^2}{2n\, A_s + 2\, b\, t} = \frac{2 \times 15 \times 10.25 \times 2.75 + 33 \times 49}{30 \times 2.73 + 2 \times 33 \times 7} = 4.22''$$

Case I because the neutral axis comes in the flange.

$A_s = pbd = .0077 \times 33 \times 10.5 = 2.67 \text{ in}^2$

Use 7 - 5/8" bars $A_s = 2.73 \text{ in}^2$ (p. 357 H & J).

$b' \text{ needed} = \left[3(n-1)+4\right] d = \left[3(7-1)+4\right] 5/8 = 13.75$

$W = 4208 \frac{(12-7)\,13.75 \times 150}{144} = 4279\ \#$

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{4279 \times 24^2 \times 12}{8 \times 107.4 \times 33}} = 10.25 \qquad D = 11.75$

This is O.K. because assumed D was 12" .

$v = \frac{V}{bjd} = \frac{4279 \times 12}{13.75 \times .874 \times 10.25} = 417$

Stirrups are necessary because shrinkage is liable to part.

Use 5/8" W - Stirrups $A_s = 1.227$ Hook them.

$S = 3/4 \times \frac{1.227 \times 16000 \times .874 \times 10.25}{4279 \times 12} = 5.14$

space stirrups 5 feet apart.

<u>Side Walk Slab.</u>

L.L = 100 # / ft ^{2} l = 6 '

Suppose slab t = 5¾" including 2" finish and 1" steel protection.

$W = 100 + \frac{5.75 \times 150}{12} = 172\ \# / \text{ft.}$

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{172 \times 36 \times 12}{12 \times 107.4 \times 8}} = 2.70 \quad \text{O.K.}$

$A_s = pbd = .0077 \times 12 \times 2.75 = .25$

Use ¼" bars spaced 3" transversley.

Use ¼" bars spaced 18" longitudinally.

The railing used is an approved design of the United States Office of Public roads.

Steel necessary in railing to furnish support for outer edge of sidewalk and its own weight.

$b = 8''$

$W = 172 \times 3 + \frac{8 \times 48 \times 150}{144} = 916$

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{916 \times 11^2 \times 12}{8 \times 12 \times 107.4}} = 11.4''$

$A_s = p\,b\,d = .0077 \times 8 \times 11.4 = .70$

Use $3 - \frac{1}{2}''$ rods $A_s = .75$

<u>Design of Cantilever Beam</u> - to support sidewalk and railing.

Let $d = 10{,}25''$

$b\,d^2 = \frac{M}{K}$ or $b = \frac{M}{d^2 K}$ Say $b = 6\frac{7}{8}'' = 6.875''$

$W = \frac{6.875 \times (11.75 - 3.75) \times 150}{144} = 57.3\ \#/\text{lin. ft.}$

$M = \left[916 \times 11 \times 6\text{-}1/3 + \frac{57.3 \times 6.66^2}{2}\right] \times 12 = 780{,}000\ \text{in.}\ \#$

$b = \frac{780{,}000}{10.25^2 \times 107.4} = 6.87''$

$A_s = p\,b\,d = .0077 \times 6.87 \times 10.25 = .543$

Use $3 - \frac{1}{2}''$ rods.

$v = \frac{V}{bjd} = \frac{916 \times 11 + 57.3 \times 6}{6.87 \times .874 \times 10.25} = 53\ \#/\text{in.}^2$

<u>Stirrups are necessary.</u>

Using $5/16''$ ° U stirrups with hooks $A_s = .1534$

$S = \frac{3}{2}\frac{A_s f_s j d}{V} = \frac{3}{2} \times \frac{.1534 \times 16000 \times .874 \times 10.25}{10450} = 3.16''$

Space stirrups $3\frac{1}{4}''$.

Girder Design.

M of concentrated loads = $(916 \times 11 + 57.3 \times 6 + 4279 \times 12) \times \frac{16.5}{5.5} = 186000$ ft. / b

Say Girder is 20" x 50"

$W = 172 \times 3 + \frac{20 \times 50 \times 150}{144} = 1556$ # / ft.

M due to distributed load $= \frac{wl^2}{8} = \frac{1556 \times 33^2}{8} = 212000$ ft. #

Total M = 186000 + 212000 = 398000 ft. / b.

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{398000 \times 12}{20 \times 107.4}} = 47.5"$ D = 50" O.K. because this size is equal to the assumed size.

$A_s = p\,b\,d = .0077 \times 20 \times 47.5 = 7.31$

Use 5 - 1¼" rods $A_s = 7.81$

The Joint Committee recommends that the lateral spacing of parallel bars should not be less than 3 diameter C - C and that the distance from the side of the beam to the center of the nearest bar should not be less than 2 diameter.

Testing : $b = [3(n-1)+4]\,d = (3 \times 4 + 4)\,1\tfrac{1}{4} = 20"$

O.K. because this is equal to the assumed size.

$v = \frac{V}{bjd} = \frac{1556 \times 16.5 \times 61800}{20 \times .874 \times 47.5} = 105.5$ # / in. ^{2}

Stirrups are necessary because the allowable unit shear is 40 # .

Using ½" Round hooked W - stirrups $A_s = 4 \times .1963 = .786$

$s = \frac{3}{2}\,\frac{A_s f_s j d}{V} = \frac{3}{2} \times \frac{.786 \times 16000 \times .874 \times 47.5}{87500} = 8.95"$

Space stirrups $8\frac{7}{8}"$

Girder Design - continued.

Point where no more stirrups are needed.

$$x = \frac{l}{2}\left(1 - \frac{v}{V}\right) = 16.5\left(1 - \frac{40}{105.5}\right) = 10.25' \text{ from end.}$$

From a point 10' - 3" from the end space stirrups 24" to take care of shrinkage cracks due to temperature changes.

Abutment Design.

In this climate the depth to which a footing must go to be safe from frost action is usually taken as four and one half ($4\frac{1}{2}$) feet. This makes the total height of the abutment $18 + 4\frac{1}{2} = 22\frac{1}{2}$ feet.

As an expansion joint separates the bridge from one of the abutments, the abutment must be designed to resist the earth pressure and to sustain the weight of the bridge, the bridge furnishing no bracing for the two abutments.

Use a factor of limitation "f" of 2 and let "K" , the proportion which the length of the toe bears to the breadth of the base "b" , equal 1/3 . Take the unit weight of the fill "w" to be 120 # / ft. The angle of friction of the fill is 30 ° . With these assumptions the abutment was designed according to Hool and Johnson formulae's pages 583-596 .
C_d is a constant depending on the material of the fill and may be read from Diag. 7 page 588.

Lateral unit pressure of earth $= W' = C_d W = .333 \times 120$
$= 40$ # / ft.

$$\frac{b}{h} = C\sqrt{f w'} = .074 \sqrt{2 \times 40} = .662$$

$b = .662 \times 22.5 = 14.9'$ Say $15'$

From the right hand side of Dig. 6 page 587 Hool and Johnson it is found that for $f = 2$ and $K = 1/3$ the resultant will strike the base at a point $.50 \times 15$ or $7.5'$ from the toe which will make the structure safe from overturning due to earth pressure and cause an evenly distributed pressure over the base.

Abutment design - continued.

Stem.

Say that the base is 18" thick.

h ' is the height of the abutment wall from the top of the base.

$h' = h - 18" = 21'$

$$M \text{ of stem} = \frac{w' h'^2}{2} \times \frac{h'}{3} = \frac{40 \times 21^3}{6} = 61700 \text{ ft. \#}$$

$$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{61700 \times 12}{12 \times 107.4}} = 24" \qquad D = 26.5"$$

$$A_s = p\,b\,d = .0077 \times 12 \times 24 = 2.22$$

Use $\frac{7}{8}$" rods spaced 4" $A_s = 2.30$

As the greatest bearing on the abutment is beneath a girder, the necessary thickness of the abutment wall will equal the girder shear divided by the allowable unit stress and by the width of the girder $= \frac{87500}{650 \times 20} = 6.73"$

Taper the abutment wall to 18" at top.

The safe bearing capacity of the soil is 8000 # / ft.^{2}

The allowable punching shear is 120 # / in.^{2}

The concentrated load of the girders becomes evenly distributed over the base as the stress is transmitted down through the wall.

Distributed weight of girder and bridge =

$$\frac{87500}{24} + 4279 = 7779 \text{ \# / ft.}$$

Weight of wall per lin. ft $= \frac{9 \times 26.5 \times 21.5 \times 150}{12} = 60500$ #

Abutment Design - continued.

Amount of punching shear = $60500 + 7779 - \frac{24}{12} \times 1 \times 8000$

$= 52279.$

Thickness of base needed for punching shear = $\frac{52279}{2 \times 12 \times 120} = 18"$

The unit pressure on the base due to weight of fill and wall = $\frac{10 \times 1 \times 22.5 \times 120}{15} = 1800$ # / ft.

The bearing capacity of the soil, as can be seen from previous figures, will take care of all the load due to the bridge so no moment need be figured for this load.

M to be designed for at the toe = $\frac{wl^2}{2} = \frac{1800 \times 25}{2} = 22500$ ft. #

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{22500 \times 12}{12 \times 107.4}} = 14.5"$

A s = p b d = .0077 x 14.5 x 12 = 1.34

Use 3/4" rods spaced 5" A s = 1.35

The M at the heel.

Overturning M of stem = 61700 ft. lb.

Resisting M of toe = 39200 ft. lb.

M taken by heel = 39200 ft. lb.

$d = \sqrt{\frac{M}{bK}} = \sqrt{\frac{39200 \times 12}{12 \times 107.4}} = 19.1"$

A s = p b d = .0077 x 19.1 x 12 = 1.76

Use $\frac{7}{8}$" rods spaced 5" A s = 1.84

Design of Grade.

After the bridge had been designed and the greatest elevation necessary for the centerline of the road found, the new grade of the highway was designed. The grade was designed on the profile sheet (which may be found in the pocket at the back) . In choosing the maximum grade to be used several authorities were consulted and the concensus of opinion was that a grade of 4½% , while slightly more costly, was the maximum that could be used and still have a roadbed give its proper wear and service. In other words the longer life of the road more than makes up for the extra cost of the fill. Bearing this in mind the grade was designed with smooth curves at the breaking points and with a slope of 4½% .

The cross section adopted (shown in typical cross-section in pocket at the back) was largely copied from the standard cross section used by the Michigan State Highway Dept, but due to the large amount of traffic at this point and allowing for future expansion of the city the M.S.H. cross section was slightly enlarged upon including the depth of road metal. In order to avoid any unnecessary fill it was decided to run the sidewalk along what would ordinarily be the shoulder of the road, separating the sidewalk from the roadway by a standard 6" x 20" curb projecting 6" above the road surface. This curb protects the sidewalk from the water draining off of the roadway and also gives protection to the pedestrians. The water collected from the roadway is drained through curb catch basins into sewers at Donora street and Bailey street at the east and west ends respectively.

Design of Grade - continued.

It was decided that as there was a sidewalk on the south side of the road only, there would be no sidewalk placed at present on the north side of the street. A curb was placed on the north side however and enough fill put in place to support a sidewalk if that becomes necessary.

The cross sections taken in the final survey were plotted for every fifty (50) foot station and over these the new cross sections were plotted at the proper grade elevation. The area between the new and old cross sections was measured by means of a planimeter and the amount of fill and excavation found by the "average end areas" method.

The estimate of cost was accomplished by figuring the amount of fill and the distance it must be hauled, by computing the cubic yardage of concrete and the number of pounds of steel, and mutiplying these values by the unit costs of each. These unit costs were taken from the current Engineering News Record.

Cost Estimate.

By the "average end areas" the amount of fill was found to be 12,542.8 cu.yd. The amount of gravel necessary is 222.1 cu.yd. of 75% pebble and 208 cu.yd. of 60% gravel. The amount of concrete to be used in the bridge is 227.9 cu.yd. and the weight of steel is 40584.7#.

12542.8	cu.	yd.	Fill	at $.73	-----------	$9157.03
222.1	"	"	75% Gravel	at $1.80	-------	400.00
208.0	"	"	60% "	at $1.50	-------	312.00
227.9	"	"	Concrete including form work	at $15.00	--	3418.50
40584.7#			Steel in place	at $.05	---------	2029.24
				Total		$15316.77

[redacted] In Pocket. : 3 Suppls.

Tracing - Crossections

" - General Plan of Bridge

" - " " " Work

[redacted]

KW
2/19/14