CHECKING THE DESIGN OF A HIGHWAY BRIDGE

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

Roth R. Morris

1948

Checking the Design of a Highway Bridge

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

Roth R. Morris

Candidate for the Degree of

Bachelor of Science

June 1948

6/11/48
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Acknowledgement

My grateful thanks to the following gentlemen for their help and guidance in the preparation of this thesis.

Professor Chester L. Allen

School of Engineering---Michigan State College

Professor Leonard A. Robert

School of Engineering---Michigan State College

Mr. Harold Cooper

Michigan State Highway Department

Bibliography

Specifications for Highway Bridge Design

by American Association for State Highway Officials

Specifications for the Design of Highway Bridges

by Michigan State Highway Department

Reinforced Concrete Design

by Southerland and Reese

Reinforced Concrete Design Handbook

by American Concrete Institute

Outline of Procedure

I. T-beam design

   A. Dead load

      1. Maximum shear

      2. Maximum moment

   B. Live load

      1. Load distribution through fill (one lane)

      2. Maximum moment

   C. Maximum moment (one lane)

   D. Live load

      1. Load distribution through fill (multiple lanes)

      2. Maximum moment (two lanes)

   E. Maximum moment (two lanes)

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   G. Maximum moment (three lanes)

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INTRODUCTION

The purpose of this thesis is to check the design of a Michigan State highway bridge. Only the actual designed portions of the bridge will be considered and not the checking of a standard set up by the Michigan State Highway Department.

The structure design is completely of reinforced concrete, covered with thirteen feet of fill, a road slab, and railings. The superstructure is supported on reinforced concrete abutments, which in turn are supported by three rows of wood piles for each abutment. Borings taken at the site indicated that piles were required and due to clay, and non-supportable materials, the piles had to be driven to bed rock.

This bridge is located on Highway U. S. 41 over Carp River, approximately four miles west of Ishpeming Michigan, and was built in 1947. In considering the characteristics of Carp River, the Highway Department evidently saw fit to change the course of the river to meet a lesser cost of building the bridge.

T-BEAM DESIGN

The T-beam will be checked for the worst possible loading conditions and checked at points of maximum stress.

Dead load: (Using 10' lane loading) lbs.

beams-----------	(1) (22.5) (1.5) (4) (150)	20,250
slab------------	(10) (22.5) (.75) (150)	25,300
earth fill------	(10) (22.5) (13) (100)	292,500
road slab-------	(10) (22.5) (.834) (150)	28,200
Total Dead Load		366,250

Maximum dead load shear:

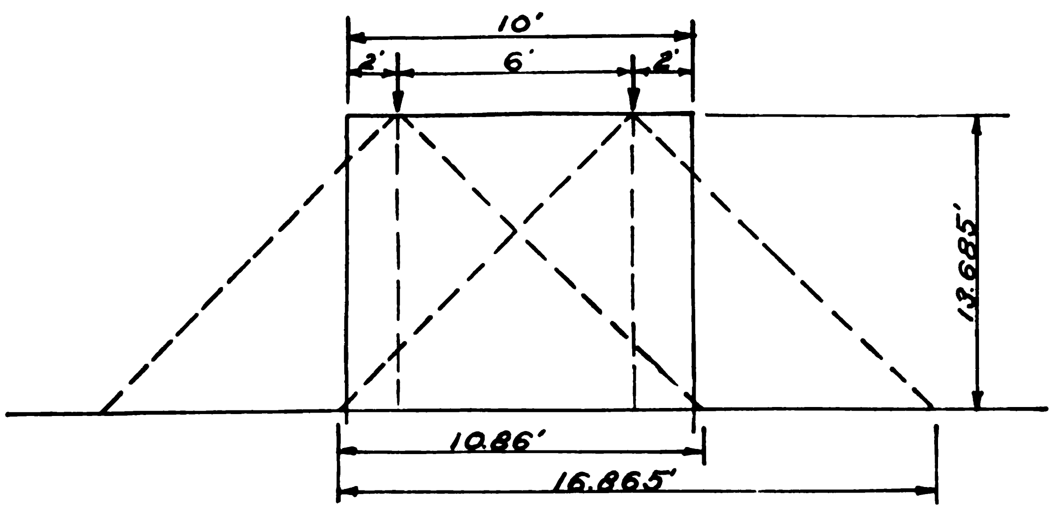
366,250 / 2 = 183,125 lbs.

Maximum dead load moment:

$$M = 1/8\ wl^2$$

$$M = 1/8(366,250/22.5)\ (22.5)^2 = 1035 \text{ ft. kips}$$

Live load: (Assume H20 S16 loading)

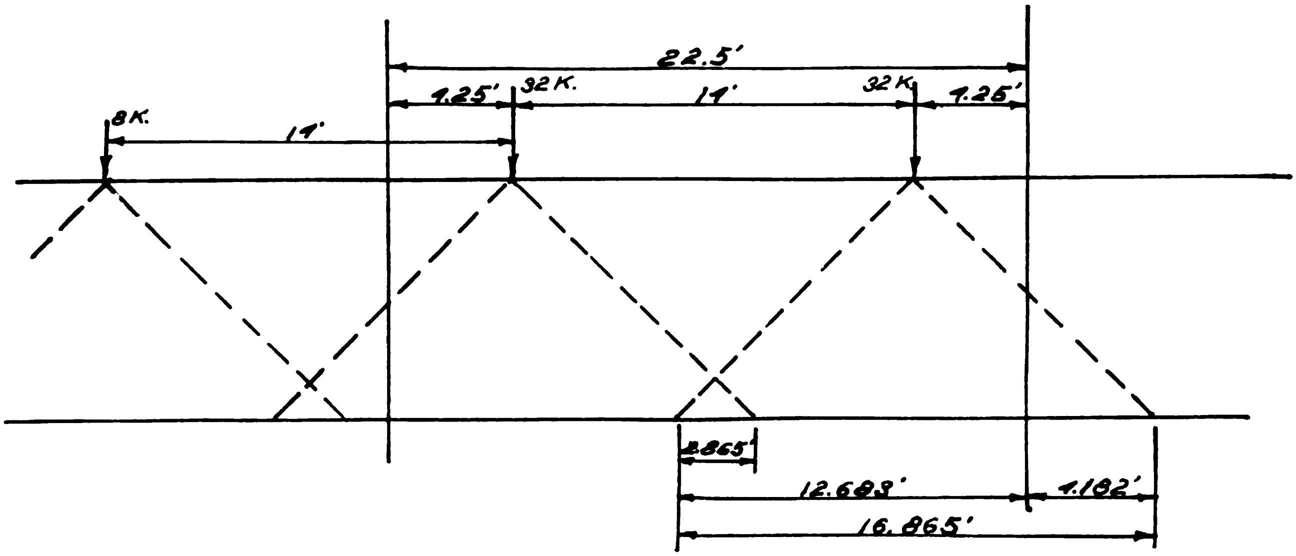


Load distribution diagram for

two rear wheels

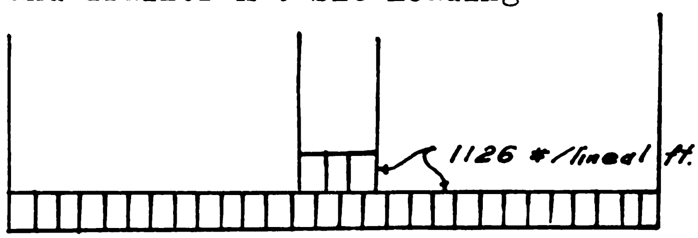
$$L = d + 3 = 13.865 + 3 = 16.865'$$

M.S.H.D. Art. 45



Load Distribution Diagram for

Truck and Trailer H20 S16 Loading



Load Distribution: (One lane)

For each wheel

$16{,}000/16.865^2 = 16{,}000/284.5 = 56.3$ lbs. per sq. ft.

Overlap for 10 ft. lane =

$(2)\ (56.3) = 112.6$ lbs. per sq. ft.

Uniform load

$(112.6)\ (10) = 1126$ lbs. per lineal ft.

Live Load Moment:

$$M = 1/8\ wl^2 + Pl/4$$

$$= 1/8\ (1126)\ (22.5)^2 + (1126)\ (2.865)\ (22.5)/4$$

$$= 89{,}300 \text{ ft. lbs.}$$

Total dead load and live load moment:

$89.3 + 1035 = 1124.3$ ft. kips

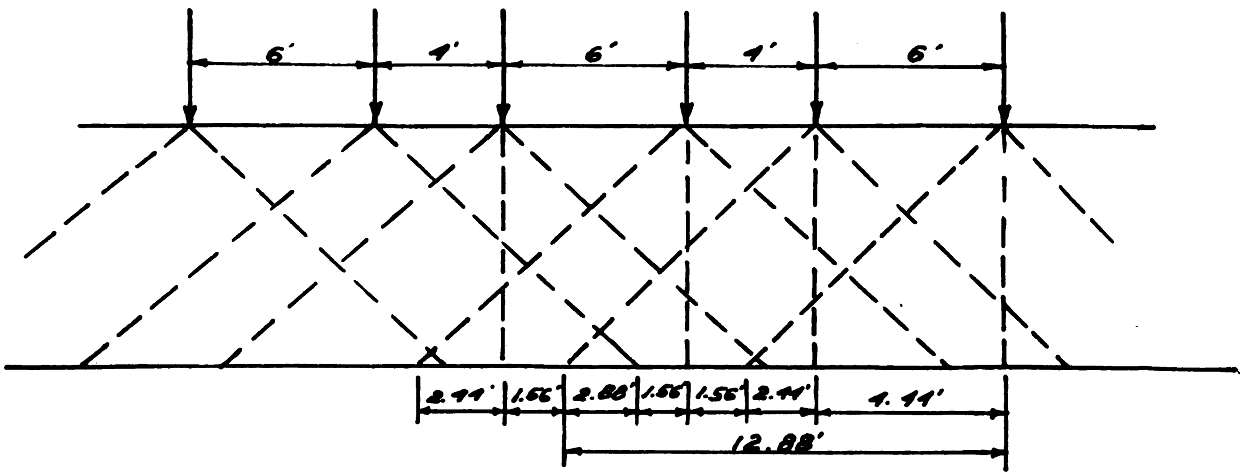
Maximum moment per beam for single lane loading:

$M' = cM/N$

M.S.H.D. Art. 43

$M' = 1124.3/10/5.66 = 636$ ft. kips

Allowable 733 ft. kips



Multiple lane loading distribution

diagram

From this diagram, three lanes will give the maximum loading regardless of any number of added lanes.

Load distribution: (two lanes)

Uniform load =

$(56.3)(3)(10) = 1689$ lbs./lineal ft.

Overlap load =

$(56.3)(4)(.88) = 198$ lbs./lineal ft.

Total 1887 lbs./lineal ft.

Live load moment:

$M = 1/8\ wl^2 + Pl/4$

$M = 1/8\ (1887)\ (22.5)^2 + (1887)\ (2.865)\ (22.5)/4$

$= 119{,}400 + 30{,}400$

$= 149.8$ ft. kips

Total $= 149.8 + 1035 = 1184.8$ ft. kips

$M' = cM/N$

$= 1184.8/10/5.66 = 670$ ft. kips

Allowable 733 ft. kips

Load distribution: (three lanes)

Uniform load =

(56.3) (3) (10) = 1689 lbs./lineal ft.

Overlap load =

(56.3) (4) (.88) = 198

(56.3) (4) (2.88) = 648

Total live load = 2535 lbs./lineal ft.

$M = 1/8\ wl^2 + Pl/4$

$= 1/8\ (2535)\ (225)^2 + (2535)\ (2.865)\ (22.5)/4$

$= 201$ ft. kips

Total $= 201 + 1035 = 1236$ ft. kips

$M' = cM/N$

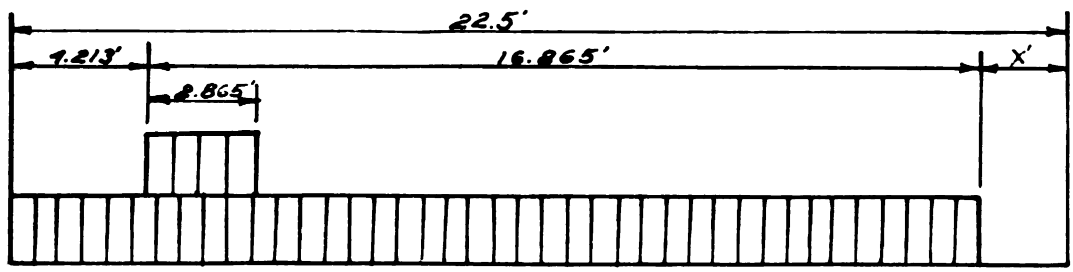
$= 1236/10/5.66\ (.90) = 630$ ft. kips

Allowable 733 ft. kips

A.A.S.H.O. 3.2.9

Improbable coincident maximum loading for three lanes is ninty percent. Therefore, the maximum loading condition for this bridge is for two lane loading, or 670 ft. kips.

Maximum Live Load Shear:



$$M = 0$$

$$22.5\, V_1 = (15.433 + x)(188.7)(2.865)$$

$$\left(\frac{22.5 - x}{2} + x \right)(22.5 - x)(188.7)$$

$$V_1 = 24x + 462 - 8.38x^2$$

$$\frac{dV_1}{dV_1} = (24 - 16.76x)\,\frac{dx}{dV_1}$$

$$x = 24/16.76 = 1.432 \text{ ft.}$$

$$22.5\, V_1 = 16.865(188.7)\,(2.865) + 11.966\,(188.7)(21.068)$$

$$V_1 = 57020/22.5$$

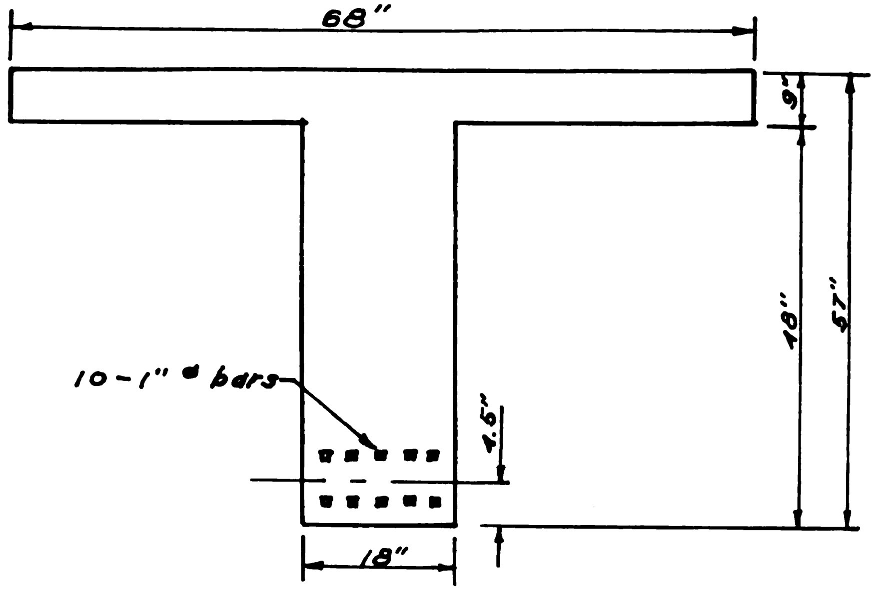
$$= 2530 \text{ lbs.}$$

Live load shear = 2530 lbs./ft. of abutment

Dead load shear = <u>18312</u> lbs./ft. of abutment

Total L.L. shear = 20,842 lbs./ft of abutment

Check T-beam for allowable stresses:



Allowable unit stress for Grade B concrete:

$n = 30{,}000/f_c' = 30{,}000/3{,}000 = 10$

$f_c = 1{,}200$ p.s.i.

$f_s = 18{,}000$ p.s.i.

$$kd = \frac{2nd\,As + bt^2}{2n\,As + 2bt}$$

A.A.S.H.O. 3.7.3

$$kd = \frac{(2)\,(10)\,(52.5)\,(10) + (68)\,(9)^2}{(2)\,(10)\,(10) + (2)\,(68)\,(9)}$$

$= 11.25$ in.

$$z = \frac{3kd - 2t}{2kd - t}\,\frac{(t)}{(3)}$$

$$z = \frac{(3)\,(11.25) - (2)\,(9)}{(2)\,(11.25) - 9}\;\frac{9}{3}$$

$= 3.64$ in.

$jd = d - z$

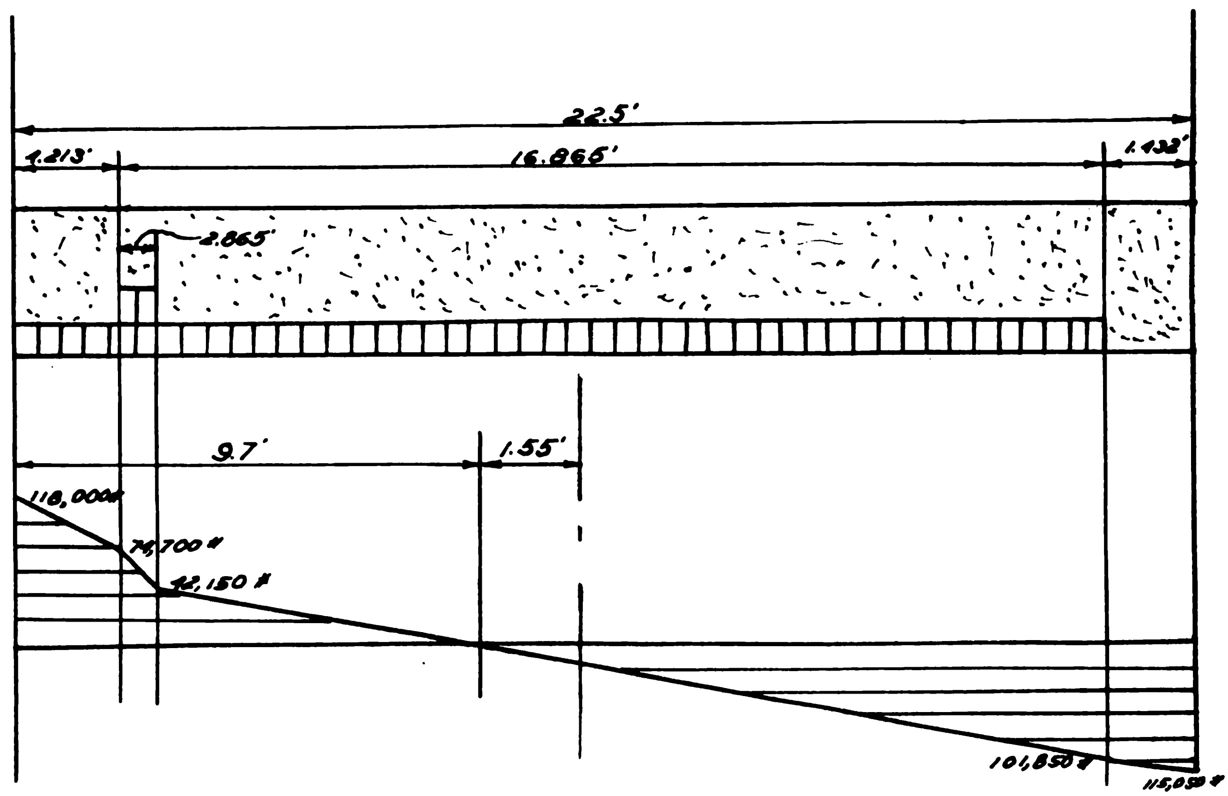
$= 52.5 - 3.64 = 48.86$ in.

$f_c = Mkd/bt\,(kd - 1/2\,t)jd$

$$= \frac{670{,}000\,(11.25)}{68\,(9)\,(11.25 - 9/2)\,48.86}$$

$=$ 380 p.s.i. Allowable 1200 p.s.i.

M.S.H.D. Table 1



Shear diagram

Computations for shear diagram:

V = 20,842 (5.66) = 118,000 lbs.

4.213 (10,287) = 43,300

2.865 (10,287) = 29,500

2.865 (1067) = 3,050

14 (10,287) = 144,000

1.432 (9220) = 13,200

Total = 233,050 lbs.

118,000	144,000	115,050
43,300	42,150	118,000
74,700	101,850	233,050
32,550	13,200	
42,150	115,050	

x/101,850 = 14/144,000

x = 9.9 ft.

Stirrups: (M.S.H.D. 51)

Maximum v' = 135 — 60 = 75 p.s.i.

S = 11.25 — 1.55 = 9.7 ft.

d = 52.5 in.

fv = 18,000 p.s.i.

fc' = 3,000 p.s.i.

1/2 in. round U-stirrups used

From diagram 17 (Reinforced Concrete Design Hand Book) for fv = 18,000 and 1/2 in. round U-stirrups:

Avfv = 7,200

Maximum 1/s = (max. v') b/Avfv

= 75 (18)/72,000

= .187

N = number of stirrups = 6S (max. 1/s)

= 6 (9.7) (.187) = 10.9 stirrups

Index = 1.5S/max.(1/s)

= 1.5 (9.7)/.187

= 80 use 76

Spacing from diagram 17

4 at 6 in.

3 at 8 in.

5 at 12 in.

11 used in plans

As the stirrups take all the diagonal tension, it is not necessary to check the bent up bars. However, the bent up bars do take some of the tension, therefore, less stirrups are needed.

ABUTMENT DESIGN

Loading: (Office practice M.S.H.D.)

Superstructure dead load:

Total concrete = 205 cu. yds.

205 (27) 150 = 830,000 lbs.

830,000/2 (1/98.5) = 4,220 lbs./ft. of abutment

Dead load above superstructure:

Earth fill = 10 (24) 100 = 24,000 lbs.

24,000/2 = 12,000 lbs./ft. of abutment

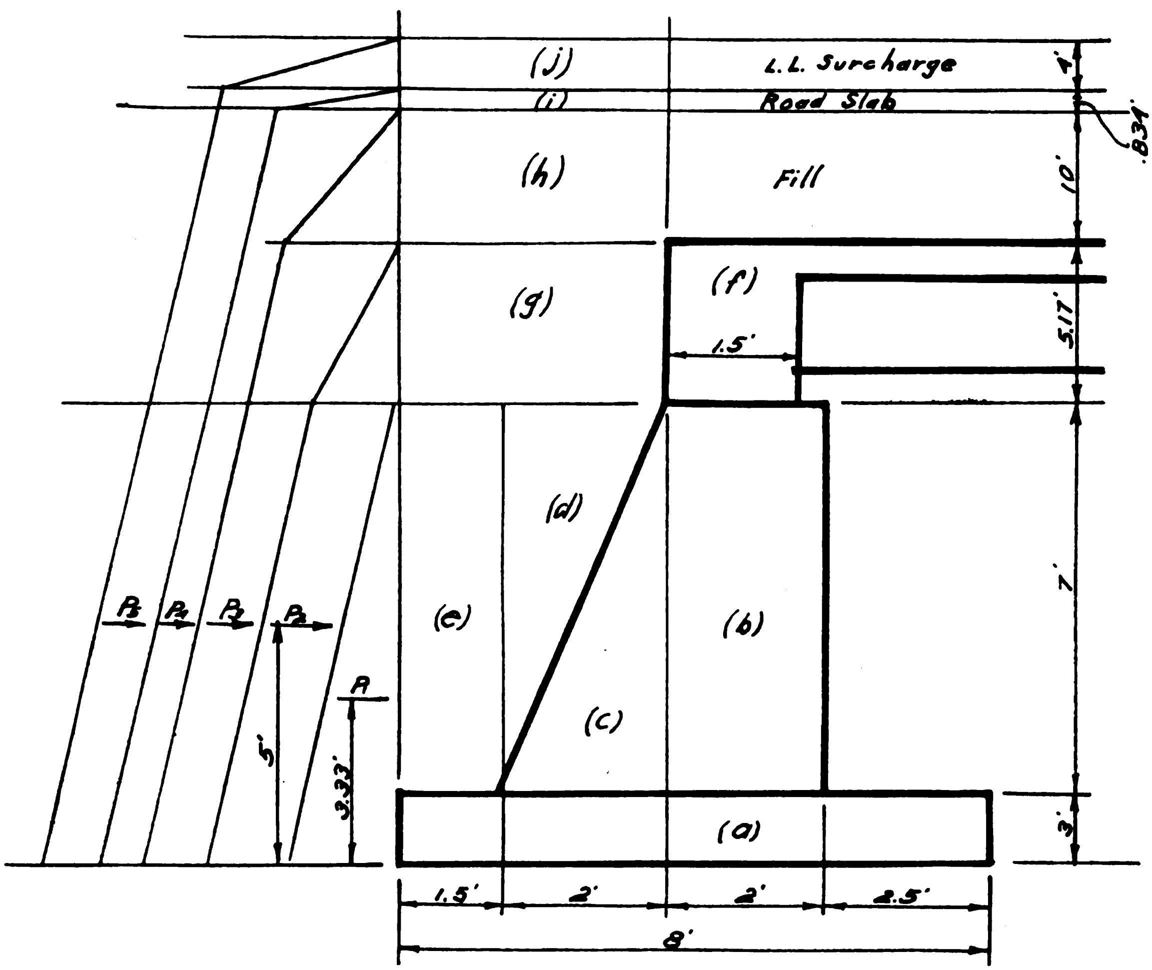
Concrete road slab

$\frac{.834 (24) 150}{2}$ = 1,500 lbs./ft. of abutment

Live load = 2,530 lbs./ft. of abutment

Live load surcharge = 4 (100)

= 400 lbs./ft. of abutment



(j)
L.L. Surcharge
(i)
Road Slab
(h)
Fill
(g)
(f)
1.5'
(d)
(e)
(b)
(c)
(a)
P5
P4
P3
P2
P1
5'
3.33'
4'
.834'
10'
5.17'
7'
3'
1.5'
2'
2'
2.5'
8'

Rankine's method:

$p = cwh \qquad c = 1/3$ (Rankine coeff.) (Office Practice)

$p1 = 1/3\ (100)\ (10) = 333$ lbs./ft.^{2}

$p2 = 1/3\ (100)\ (5.17) = 172$

$p3 = 1/3\ (100)\ (10) = 333$

$p4 = 1/3\ (150)\ (.834) = 42$

$p5 = 1/3\ (100)\ (4) = 133$

Overturning		Thrust		Moment
P1 = 333 (10/2)	=	1666 (3.33)	=	5,550
P2 = 172 (10)	=	1720 (5)	=	8,600
P3 = 333 (10)	=	3333 (5)	=	16,665
P4 = 42 (10)	=	420 (5)	=	2,100
			$M_{O1} = M_{O3} =$	32,915
P5 = 133 (10)	=	1333 (5)	=	6,665
			$M_{O2} =$	39,580 ft. lbs.

Stability		Weight		Moment
(a) 3 (11) 150	=	4950 (5.5)	=	27,200
(b) 2 (7) 150	=	2100 (2.25)	=	4,730
(c) 2/2 (7) 150	=	1050 (5.16)	=	5,410
(d) 2/2 (7) 100	=	700 (5.83)	=	4,080
(e) 1.5 (7) (100)	=	1050 (7.25)	=	7,610
(g) 5.17 (3.5) 100	=	1800 (6.25)	=	11,250
(h) 10 (3.5) 100	=	3500 (6.25)	=	21,900
(i) .834 (3.5)150	=	440 (6.25)	=	2,730
W1	=	15,590 lbs.	M_{s1} =	84,910 ft. lbs.
(f) D. L. superstructure		4220		
Earth fill		12000		
Road slab		1500		
Total D.L.		17,720 (3.75)	=	66,500
W1	=	33,310	Ms4 =	151, 410
(j) L. L. surcharge		1400 (6.25)	=	8,750

W2 = 34,710 lbs. Ms2 = 160,160

L. L. = $\underline{2,530}$ (3.75) = $\underline{9,500}$

W3 = 35,840 Ms3 = 160,910

Case I: No superstructure load or L. L. surcharge

Ms1 = 84,910

Mo1 = $\underline{32,915}$ R1 = $\frac{51,995}{15,590}$ = 3.33 ft.

M1 = 51,995

Case II: Superstructure D. L. and L. L. surcharge

Ms2 = 160,160

Mo2 = $\underline{39,580}$ R2 = $\frac{120,580}{34,710}$ = 3.62 ft.

M2 = 120,580

Case III: = Superst. D. L. and L. L. No L. L. surcharge

Ms3 = 160,910

Mo3 = $\underline{32,915}$ R3 = $\frac{127,995}{35,840}$ = 3.57 ft.

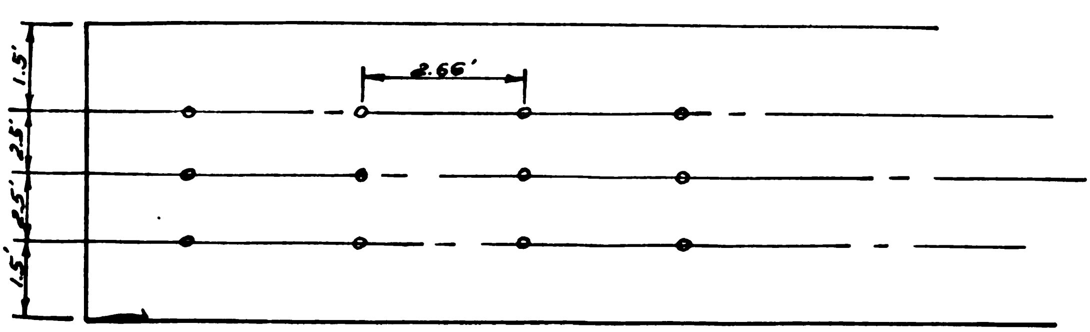
M3 = 127,995

Ca

Case IV: Superst. D.L. No L. L. or horizontal earth thrust

R4 = $\frac{160,160}{34,710}$ = 4.62 ft.

ABUTMENT DESIGN (PILES)



Piles: (Main Wall)

Maximum abutment load W3 = 35,840 lbs./ft.

Piles / ft. = $\frac{35,840}{40,000}$ = 897

Bearing capacity of Piles = 20 Ton = 40,000 lbs.

1/.897 = L/6

L = 6.7 ft.

L/2 = 3.35 ft.

This spacing assumes C.G. of piles and location of the resultant are coincident. This condition rarely exists, therefore, reduce spacing. From plans L/2 has been reduced from 3.35 ft. to 2.66 ft.

C.G. of Piles: (L= 5.33 ft.)

Back = 6.5 (2) = 13

Middle = 4 (2) = 8

Front = 1.5 (2) = 3

Total = 24

24/6piles = 4 ft. resultant

I (Moment of inertia) = Ad^2

Back = $2\ (2.5)^2$ = 12.5

Middle = $2\ (0)^2$ = 0

Front = $2\ (2.5)^2$ = 12.5

I = 25

Load on Pile = $\frac{P}{A} \pm \frac{Mc}{I}$

Case II.

$$\frac{34,710\ (5.33)}{6} \pm \frac{34,710\ (5.33)\ (2.5)\ (.38)}{25}$$

30,800 + 7,040 = 37,840 lbs. (front row)

30,800 — 7,040 = 23,760 lbs. (back row)

Case III.

$$\frac{35,840\ (5.33)}{6} \pm \frac{35,840\ (5.33)\ (2.5)\ (.42)}{25}$$

3

31,850 + 8030 = 39,880 lbs. (front row)

31,850 — 8030 = 8,030 lbs. (back row)

Case IV.

$$\frac{33,310\ (5.33)}{6} \pm \frac{33,310\ (5.33)\ (2.5)\ (.62)}{25}$$

29,600 + 11,000 = 40,600 lbs. (back row)

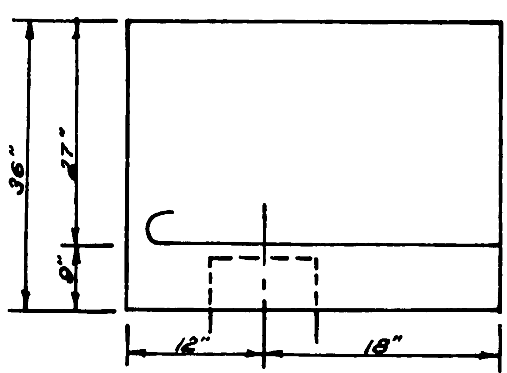
29,600 — 11,000 = 18,600 lbs. (front row)

ABUTMENT DESIGN

Reinforcement: (Main Wall)

M.S.H.D. office practice uses a minimum of 3/4 in. round bars at 2 ft. centers.

Toe Toe: Case III. (AASHO. 3.7.3)



Pile load = 39,880 lbs. (spacing 2.66 ft.)

Load/ft. of wall = $\frac{39,880}{2.66}$ = 14,950 lbs.

Less weight of concrete

2.5 (3) 150 = 1,150

13,800 lbs./ft.

Moment = 14,950 (1) — 1,150 (1.25) = 13,512

Shear = 13,800 lbs.

$$As = M/fsjd$$

$$= \frac{13,512\ (12)}{18,000\ (.867)\ 27} = .385\ in^2$$

Use 3/4 in. round at 1 ft. centers

$$As = .44\ in.^2 \qquad \Sigma o = 2.4\ in.$$

$$p = \frac{.44}{12\ (27)} = .00136$$

$$k = \sqrt{2pn + (pn)^2} - pn$$

$$= .1519$$

$$j = 1 - k/3 = .949$$

$$fs = \frac{13,512\ (12)}{.44\ (.949)\ (27)} = 14,400\ p.s.i.$$

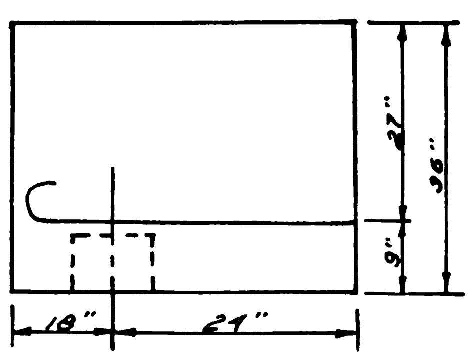
$$fc = \frac{14,400\ (.152)}{8.48} = 258\ p.s.i.$$

$$v = \frac{13,800}{12\ (.949)\ 27} = 45\ p.s.i.$$

$$u = \frac{13,800}{2.4\ (.949)\ 27} = 225\ p.s.i.$$

Special anchorage provided.

Heel: Case IV.



Pile load = 40,600 lbs. (spacing 2.66 ft.)

Load/ft. of wall = 40,600/2.66 = 14,100 lbs.

Less flange and dead loads above

3 (2.5) 150 = 1125

(a) = 700

(c) = 1050

(d) = 1800

(h) = 3500

(i) = <u>440</u>

Total = 8615 lbs.

Total pile load = 5,485 lbs.

Moment = 14,100 (24) — 8615 (21)

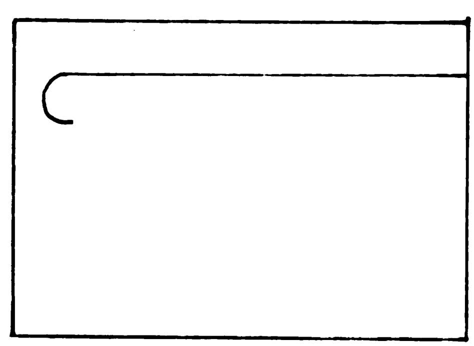
= 101,000 in. lbs.

Shear = 5,485 lbs.

As the values of moment and shear are much less than those of Case III. it is safe to assume all stresses are within the allowable for Case IV.

Reinforcement: (Main Wall)

Heel: Case II. (Top steel)



Pile load = 23,760 lbs.

Load/ft. of wall = 23,760/2.66 = 8950 lbs.

Less <u>8615</u>

Shear 345 lbs.

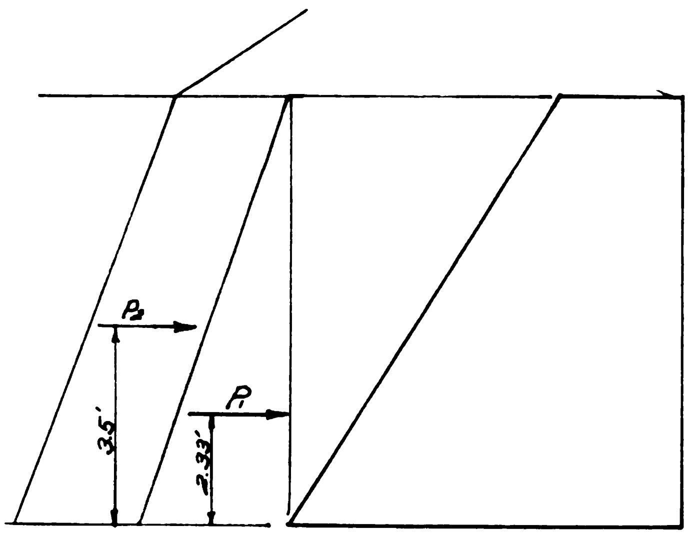
Moment = 8,950 (24) — 8615 (21)

= 34,000 in. lbs. upward

no top steel needed.

ABUTMENT DESIGN

Reinforcement: (Wall)



$p_1 = 1/3 \ (100) \ 7 = 233\#/ft^2$

$P_1 = 7/2 \ (233) = 1166\#$

$p_1 = 233$

$p_2 = 172$

$p_3 = 333$

$p_4 = 42$

$p_5 = 133$

P_1			= 1166	X	2.33	=	2510'#
P_2	= 172	(7)	= 1204	X	3.5	=	4220
P_3	= 333	(7)	= 2331	X	3.5	=	8150
P_4	= 42	(7)	= 294	X	3.5	=	1030
P_5	= 133	(7)	= 931	X	3.5	=	3260
Shear			=5,836#		Mom.	=	19,170'#

At base

$$As = \frac{19{,}170 \times 12}{18{,}000\ (.876)\ 45} = .328\ in^2\ /ft.$$

$$As = \frac{19{,}170 \times 12}{18{,}000\ (.887)\ 33} - = .447\ in^2\ /ft.$$

Area used $\frac{130\ \text{bars}}{130\ \text{ft.}}$ = 1-3/4" bar/ft.

Area 3/4" bar = $44 in^2$

$$p = \frac{As}{bd} = \frac{.44}{12\ (45)} = .000815$$

$k = .136$

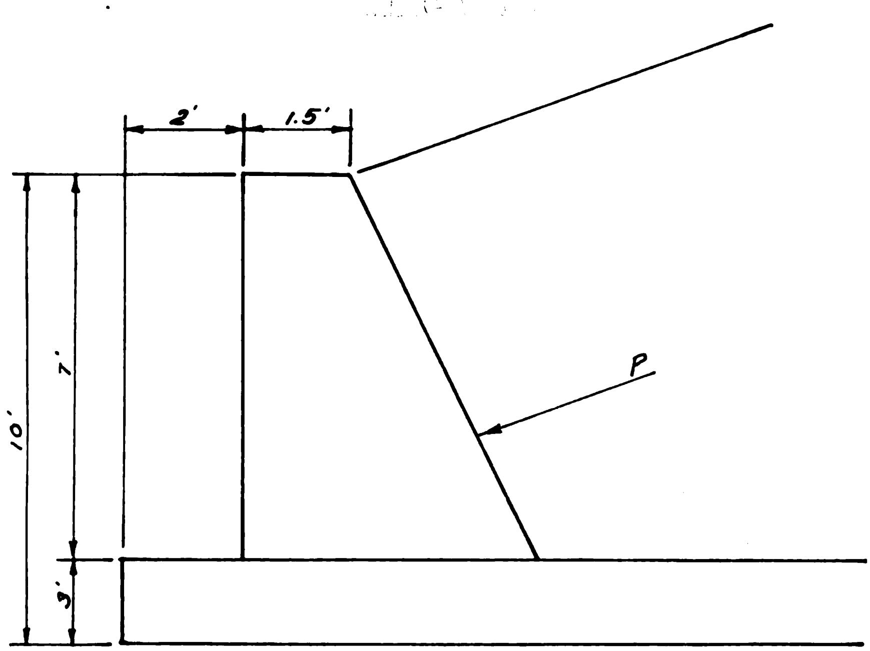
$j = .955$

$$fs = \frac{19{,}170 \times 12}{.44\ (.955)\ 45} = 12{,}300\ \#/in^2$$

$$fc = \frac{12{,}300 \times .136}{8.64} = 194\ \#/in^2$$

$$v = \frac{5836}{12 \times .955 \times 45} = 11.9\ \#/in^2$$

$$u = 5836 = 56.5\ \#/in^2$$



$P = c\ w\ h\ (h/2)$

$= 1/3\ (100)\ (7)\ (7/2)$

$= 816\ \#$

$P_h = 816 \times 2/\sqrt{5} = 730\ \#$

$M_o = 730 \times 7/3 = 1700$ ft. lbs.

$$A_s = \frac{1700 \times 12}{18{,}000 \times .867 \times 45} = .029 \text{ sq. in.}$$

1-3/4" bar area .44 sq. in. is sufficient.

SPECIFICATIONS

American Association for State Highway Officials

3.2.1.— Loads.

Structures shall be proportioned for the following loads and forces.

(a) Dead load.

(b) Live load.

(c) Impact

(d) Wind load

(e) Other forces when they exist, as follows:

Longitudinal force, centrifugal force, thermal forces, earth pressure, buoyancy, shrinkage stresses, rib shortening, erection stresses, ice and current pressure, and earthquake stresses.

Upon the stress sheets a diagram or notation of the assumed live loads shall be shown and the stresses due to the various loads shall be shown separately.

3.2.2.— Dead Load.

The dead load shall consist of the weight of the structure complete, including the roadway, sidewalks, and car tracks, pipes, conduits, cables and other public utility services.

The following weights are to be used in computing the dead load:

	weight per cu. ft. (lbs)
Steel or cast steel	490
Cast iron	450
Aluminum alloys	175

	weight per cu. ft. (lbs.)
Timber (treated or untreated)	50
Concrete, plain or reinforced	150
Compacted sand, earth, gravel or ballast	120
Loose sand, earth and gravel	100
Macadam or gravel, rolled	140
Pavement, other than wood block	150

3.2.3.— Live Load.

The live load shall consist of the weight of the applied moving load of vehicles, cars and pedestrians.

3.2.5.— Highway Loadings.

(a) General

The highway live loadings on the roadway of bridges or incidental structures shall consist of standard trucks or of lane loads which are equivalent to truck trains. Two systems of loading are provided, the H loadings and the H-S loadings, the corresponding H-S loadings being heavier than the H loadings.

(f) For truck highways, or for other highways which carry, or which may carry, heavy truck traffic, the minimum live load shall be the H 15 - S 12 designated herein.

3.2.6.— Traffic Lanes:

The lone loadings or standard trucks shall be assumed to occupy traffic lanes, each having a width of 10 feet corresponding to the standard truck clearance width. Within the curb-to-curb width of the roadway the traffic lanes shall be assumed to occupy and position which will produce the maxumum stress, but which will not involve ov rlapping of adjacent lanes, nor place the center of the lane less than 5 feet from the roadway face of the curb.

3.2.7.— The wheel spacing, weight distribution, and clearance of the stand rd H and H-S trucks shall be as shown in figs.1 and 2 and corresponding lane loads shall be as shown in figs. 3 and 4 .

Each lane loading shall consist of a uniform load per linear foot of traffic lane combined with a single concentrated load (or two concentrated loads in the case of continous spans,) H loading, so placed on the span as to produce maximum stress. The concentrated load shall be considered as uniformly distributed a cross the lane on a line normal to the center line of the lane. For the computations of moments and shears, different concentrated loads shall be used as indicated. The lighter concentrated loads shall be used when the stresses are primarily bending stresses and the h eavier cincentrated loads shall be used when the stresses are primarily shearing stresses.

3.2.8.— Application of Loadings.

(a) Traffic Lane Units.

In computing stresses, each 10-foot traffic lane loading, or single standard truck loading shall be considered as a unit, occupying 10 feet of width. Fractional lane widths or fractional trucks shall not be considered.

(b) Number and Position, Traffic Lane Units

The number and position of loaded lanes, whether lane loading or truck loading, shall be such as to produce maximum stresses, subject to the reduction specified in article 3.2.9.

(d) Loading for maximum stress

The type of loading, whether lane loading or truck loading, to be used, and whether the spans be single or continuous, shall be the loading which produces the maximum stress. The moment and shear tables given in Appendix A show which loading controls for simple spans. The axle spacing for H-S trucks shall be varied between the specified limits to produce maximum stresses.

3.2.9.— Reduction in Load Intensity

Where maximum stresses are produced in any member by loading any number of traffic lanes simultaneously, the following percentages of the resultant live load stresses shall be used in view of improbable coincident maximum loading:

One or two lanes	100%
Three lanes	90%
Four lanes or more	75%

The position and number of loaded lanes used shall be such as to produce maximum stresses in all cases.

The reduction in intensity of floor beam loads shall be such as to produce maximum stresses in all cases, using the width of roadway which must be loaded to produce maximum stresses in the floor beam.

3.2.12.— Impact

Impact shall not be applied to items in group B.

Group B

(a) Substructures, including abutments, retaining walls, piers, piling and other parts of structures subject to static loads.

(b) Foundation pressure.

(c) Timber structures.

3.2.13.— Longitudinal Forces:

Provision shall be made for the effect of a longitudinal force of 5% of the live load in all lanes, using lane loads, with concentrated foad for moment, and no impact. The reductions in load intensity of article 3.2.9. shall apply. This force shall be considered as acting four feet above the floor. The force assumed is based on all traffic headed in the same direction.

3.2.19.— Earth Pressure

Structures designed to retain fills shall be proportioned to withstand pressure as given by Rankine's formula: provided, however, that no structure shall be designed for less than an equivalent fluid pressure of 30 lbs./cu. ft.

When highway traffic can come within a distance from the top of the structure equal to one/half its height, the pressure shall have added to it a live load surcharge pressure equal to not less than two feet of earth.

Where an adequately designed reinforced concrete approach slab supported at one end by the bridge is provided, no live load surcharge need be considered.

3.7.2.— Standard Notations.

(a) Rectangular beams

f_s = tensile unit stress in longitudinal reinforcement

f_c = compressive unit stress in extreme fiber of concrete

E_s = Modulus of elasticity of steel

E_c = Modulus of elasticity of concrete

n = E_s/E_c

M = bending moment

A_s = effective cross-sectional area

b = width of beam

d = effective depth

k = ratio of depth of N.A. to effective depth d

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

jd = d — z = arm of resisting couple

p = ratio of effective area of tension reinforcement to effective area of concrete in beam = A_s/bd

(b) T—beams

b = width of flange

b' = width of stem

t = thickness of flange

(c) Beams reinforced by compression

z = Depth from compression surface of beam to resultant of compressive stresses.

(d) Shear, Bond and Web Reinforcement

V = total shear

V' = external shear on any section after deducting that carried by concrete

v = shearing unit stress

u = bond stress per unit of area of surface of bar

o = perimeter of bar

$_o$ = sum of perimeters of bars in one set

A_v = total area of web reinforcement in tension within a distance, a, of the total area of all bars bent up in any one plane.

f_v = tensile unit stress in web reinforcement

3.7.3.— Design Formulas

(a) Rectangular beams

Position of neutral axis

$$k = \sqrt{2pn + (pn)^2} - pn$$

Arm of resisting couple = $1 - k/3$

Compressive unit stress in extreme fiber of concrete

$$f_c = 2M/jkbd^2 = 2pf_s/k$$

tensile unit stress in longitudinal reinforcement

$$f_s = M/Asjd = M/pjbd^2$$

(b) Flexure of reinforced concrete T-beams

Computations of flexure in reinforced concrete T-beams shall be based on the following formulas:

For neutral axis in the flange, use the formulas for rectangular beams and slabs.

For neutral axis below the flange, the following formulas neglect the compression in the stem:

$$kd = \frac{2ndAs + bt^2}{2nAs + 2bt}$$

$$jd = d - z$$

$$z = \frac{3kd - 2t}{2kd - t}\left(\frac{t}{3}\right)$$

$f_c = Mkd/bt(kd - 1/2t)jd$

$f_s = M/A_s jd$

(c) Shear, Bond and Web Reinforcement

Diagonal tension and shear in reinforced concrete beams shall be calculated by the following formulas:

$v = V/bjd$

$f_v = V's/A_v jd$

$u = V/\Sigma_o jd$

3.7.4.— Span Lengths

For the analysis of all rigid frames, the span lengths shall be taken as the distance between the centers of bearings at the top of the footings.

4.5.1.— Bar Reinforcement

All bars shall be of the deformed type unless otherwise specified.

SPECIFICATIONS

Michigan State Highway Department

10 Classification of Bridges:

Bridges carring highway traffic shall be classified as follows:

Class AA Bridges for specially heavy traffic units in cities and other locations where passage of such loads is frequent.

29 Dead Load:

The dead load shall consist of the actual weight of all materials and construction comprising the completed structure and wupported thereby.

The following weights of materials may be used in estimating dead load:

Material	Weight in lbs. per cubic ft.
Concrete (plain or reinforced)	150
Loose sand and earth	100

31 Roadway Live Loads:

Class AA Bridges --------H20 Loading

43 Longitudinal Beams ---Stringers:

The bending moment carried by each interior beam or stringer shall be taken not less than that determined by the following formulae:

M= Bending moment for one traffic lane.

N = Width of Traffic Lane (not to exceed 10 ft.) devided by spacing of beams.

C = Coefficient = 1 for concrete.

M' = Bending moment on one beam or stringer.

45 Distribution of Concentrated Loads Through Fill:

Concentrated loads on concrete pavement may be assumed as uniformly distributed over an area below the pavement which lateral and longitudinal dimensions are given by the following formula:

$L = d + 3$ where

L = Lateral or longitudinal distribution in ft.

d = Depth of fill below pavement to plane of distribution.

When the areas thus determined for adjacent concentrated loads overlap, the pressured on overlapping portions shall be taken as the combined pressure from each such load.

51 Allowable Unit Stress in lbs. per sq. in. Shear:

Without special anchorage of longitudinal steel

$v_c = 0.02 f'c$

57 Requirements for T-beams:

(a) In T-beam construction, the slab shall be built as an integral part of the beam and care shall be taken to secure effective and adequate bond and shear resistance at the junction of beam and slab.

(b) The effective flange width to be used in the design of symmetrical T-beams shall not exceed one-fourth the span length of the beam, and its overhanging width on either side of the web shall not exceed eight times the thickness of the slab nor one-half the distance to the next beam.

(c) For beams having a flange on one side only, the effective over-hanging flange width shall not excees one-twelfth of the span length of the beam, nor six times the thickness of the slab, nor one-half the clear distance to the next beam.

(d) Where the principal slab reinforcement if parallel to the beams, transverse reinforcement for negative bending moments, shall be provided in the top of the slab in the amount of not less than 0.3% of the sectional area of the slab, and shall extend across the beam into the slab not less than two-thirds of the width of the effective overhang.

(e) The flange of the slab shall not be considered as effective in computing the shear and diagonal tension resistance of T-beams.

Table I

Allowable Unit Stresses (in lbs. per sq. in.) for various strengths of Concrete where $n = \frac{30,000}{f'c}$

$f'c = 3,000$

$n = 10$

Flexure:	
Extreme unit stress in compression	1200
Shear:	
Beams with properly designed web reinforcement	
Without special anchorage longitudinal steel, v =	180
With special anchorage longitudinal steel, v =	270
Footings with special anchorage	90
Bond:	
In beams and slabs and one way footings deformed bars M =	150

Note: Where special anchorage is provided these values may be doubled.

Summary and Conclusions

The specific summaries have been covered in detail at the conclusion of each section by the comparison of actual stress values with the allowable values included in the specifications. Throughout the analysis of this bridge, it is apparent that all the requirements of the specifications are well within the allowable limits. In many cases the Michigan State Highway Department has set up standards whereby more steel has been added than is really necessary for safety.

As the purpose of this thesis is to check the designed portions of the bridge, there has been no detail concerning the standards set up by the Michigan State Highway Department, for beauty or the necessary requirements, other than those which actually prove the bridge stable and safe. Results show that the T-beams, abutments, and pilings have been designed by analysis, while the rest of the bridge has been designed to meet standard specifications.

[redacted]