DESIGN OF A SINGLE SPAN REINFORCED CONCRETE ARCH HIGHWAY BRIDGE

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Gene Warren French

1952

This is to certify that the

thesis entitled

"Design of a Single Span Reinforced Concrete Arch Highway Bridge"

presented by

Gene Warren French

has been accepted towards fulfillment of the requirements for

M. S. **degree in** Civil Engineering

Richard J. Brain

Major professor

Date 7-15-52

O-169

DESIGN OF A SINGLE SPAN REINFORCED CONCRETE ARCH HIGHWAY BRIDGE

By
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A Thesis
Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Civil Engineering

1952

10-14-52 31

ACKNOWLEDGEMENT

The author wishes to express his sincere thanks to Dr. C.L. Shermer and Dr. R.H.J. Pian, under whose supervision this design was undertaken.

He is also greatly indebted to W.A. Bradley for his helpful suggestions and assistance.

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STATEMENT OF PROBLEM

The object of this paper was to design a highway bridge. The bridge was to be a three lane structure. It was to be constructed of reinforced concrete and is of the open spandrel hingless arch type. The span was to be two hundred and fifty feet and the location is imaginary. The abutements are on rock to eliminate settlement.

PROCEDURE

The proposed structure is shown on DS-1 with a cross section of the bridge shown on DS-2 which shows the location of the different sections that make up the structure. V.A. Cochrane's formulae, which can be found in the Concrete Engineers Handbook by Hool and Johnson, for open spandrel arches were used. These formulae are shown on DS-20 and the arch axis was plotted from these formulae and the tenative height of the spandrels shown on DS-3. The roadway was raised five feet above the height of the arch axis.

The loading used was the H-20-S16-44 according to the A.A.S.H.O. Specifications. This loading provides for a uniform load of 640#/linear foot of load lane plus a concentrated load of 18,000# for moment and 26,000# for shear. It also specifies that another concentrated load of 18,000# shall be placed in one other span in the series in such a position as to produce maximum negative moment. The lane loading as indicated in the specifications was for a load lane of 10 feet. In this bridge the load lane was 8 feet therefore the lane loading would be .8 of the specified loading or would be 512#/linear foot of load lane. The roadway is to be 32 feet in width with 2 four foot walks on either side plus a railing, the effect of which was not taken into consideration in this design. The srtingers are to be spaced 8 feet center to center with a span of 25 feet. Therefore the spacing of the floor beams was 25 feet center to center. Three thousand pound concrete was used throught out the design.

The slab of the bridge was designed according to the A.A.S.H.O. Specifications in section 3-3-2. A depth of the slab was assumed and then checked according to the above stated articles. This is shown on DS-4.

The first trial of the design of the stringers, DS-5, was begun by assuming the moment at the supports to be about half way between the fixed end moment and the simply supported moment due to the partially fixed end conditions. With this assumed moment, a beam was designed. With this beam and the loads from the roadway, a column was designed assuming that it was a short column and not fixed at the ends. This design is shown on DS-7. With these assumed sections spandrel "A" was checked by moment distribution assuming that the spandrel columns were fixed at the rib of the arch. In finding the stiffness ratio, it must be remembered that the mass moment of inertia resists rotation more effectively than the transformed moment of inertia and therefore the stiffness ratio is the mass moment of inertia divided by the length. The floor beam and spandrel column was then checked and found to be allowable at this point in the design. These computations are shown on DS-8.

The next step was to check by the maximum loading condition shown on DS-9 which was arrived at by trial and error with loading as was specified, the moments on the stringers and columns parallel to the roadway. This was done to check the assumed moment in the case of the stringers. The moment that was produced in the columns due to this loading is in addition to the moment produced at right angles to it by the floor beams. This analysis was done by the method of moment distribution, shown on DS-10. The stringers and columns were kept the same size throughout the structure for uniformity.

The stringer was then checked for this new moment and was found to be within the allowable. The column was then checked for the two moments acting on it and the section varied to meet the allowable stresses. This was done by the A.C.I. specifications.

With this new column section, the spandrel was redesigned. These computations are shown on DS-12. The floor beams and spandrel columns were to be of the same size throughout the structure so the column struts were so placed as to keep the relative stiffness the same. By placing the top column strut 5 feet below the floor beam, this was accomplished. The other struts were spaced at 25 foot intervals so as not to increase the stresses in the column to too great a degree. The relative stiffness of the struts to the column was so very small that they were assumed simply supported and could therefore take no moment induced from the column. The struts were kept at a minimum size as controled by the maximum case. The remaining spandrels were then designed by moment distribution as shown on DS-13 to 18. Some of the struts were tension struts and some were compression struts and they were designed accordingly.

The dead load of the superstructure that came down to the arch rib by the spandrels is shown on DS-19.

The first assumed section of the arch was determined by the study of arches already designed. This assumption was then checked by V.A. Cochrane's preliminary analysis formulae which can be found in <u>Design of Concrete Structures</u> by Urquhart and O'Rourke. The notations for these formulae are shown on DS-20. The formulae and notations are quite clearly defined and need no further explanation but the use of the average stresses to find the arch shortning stresses is a little difficult. By way of explanation for each combination of loading, the arch shortning thrusts and moments bear the same ratio to the thrusts and moments due to a fall of t degrees in temperature, as does the total average stress to the stress $t_c t_d E$. The application of these formulae along with the summaries found are shown on DS-21 to DS-25. The stresses that were computed were based on the assumption that the sections at the crown and springing acted as compression members with axial and bending stresses. The first assumed section was found to be too small so that the crown and springing sections were enlarged as was indicated. A second set of stresses were computed with these new sections in the same manner as was the first and the results seemed to indicate that a further analysis by an exact method was indicated.

Based upon a number of complete designs and investigations of a number of designs found in technical literature by Mr. Cochrane in order to determine what the thickness of the arch should be at various points in the haunch to give the same fiber stresses as at the crown and springing. These results can be found in the Concrete Engineers Handbook by Hool and Johnson. For this case the thickness at various points in the arch is shown on DS-28. The half arch shown on DS-29 was divided into ten dividions and the cross section data was tabulated and is shown on DS-30 and DS-31.

This analysis was done by the least work method and the derivations of the formulae shown on DS-28 can be found in Reinforced Concrete Structures by Peabody. From these above mentioned formulae, influence lines were plotted from the tables computed. These influence lines were plotted in order to determine the affect the live loads will have with a variation in position. The position of the live load to give maximum forces at any given section can best be found by influence lines. The influence lines were also used in order to determine the stresses caused by the dead load of the superstructure which stresses are the values on DS-19 multiplied by the influence ordinate. In this particular arch the influence line shows how much of the span should be loaded with the designated live load in order to give either the maximum positive moment or the maximum negative moment.

An equlibrium polygon was construced by the dead load of the arch in order to find the resultant of this dead load. The dead load of each division was tabulated along with the sum of the moments about the center of each division and these values so computed used to find the stresses in the crown and springing sections according to the method set forth in section 402 in Reinforced Concrete Structures by Peabody. These computations are shown on DS-41 and DS-42.

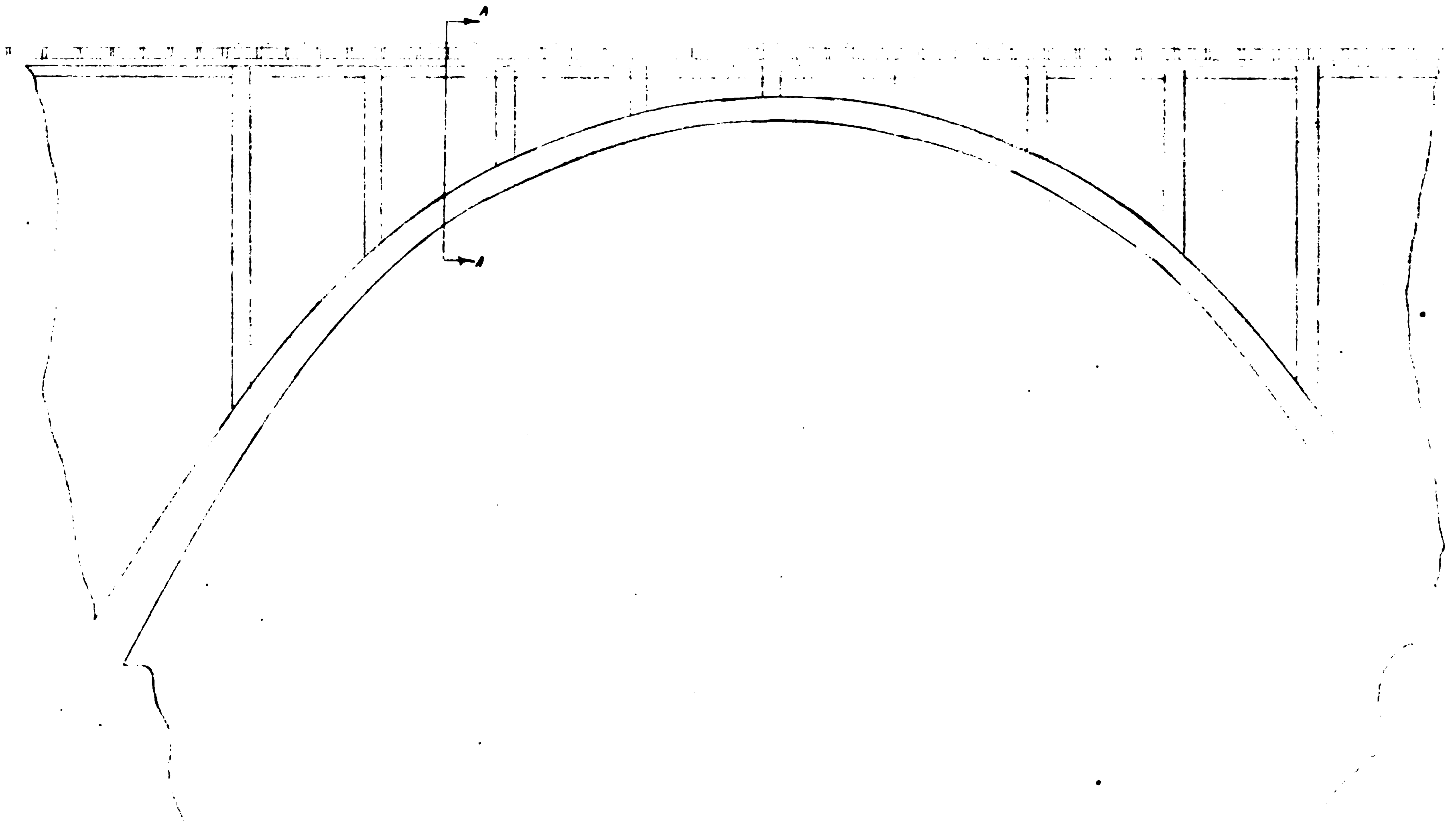
The arch shortning and temperature stresses were computed on DS-42. The section at the crown was computed for a temperature fall of 40 degrees and the section at the springing was computed for a rise of 30 degrees in order to give maximum stresses at these sections. The thrust and moment due to the arch shortning are always present and should be included in all summaries.

All the stresses were then summed up in the tables shown on DS-42 and DS-43. This process is self-explaitary and need no further explanation.

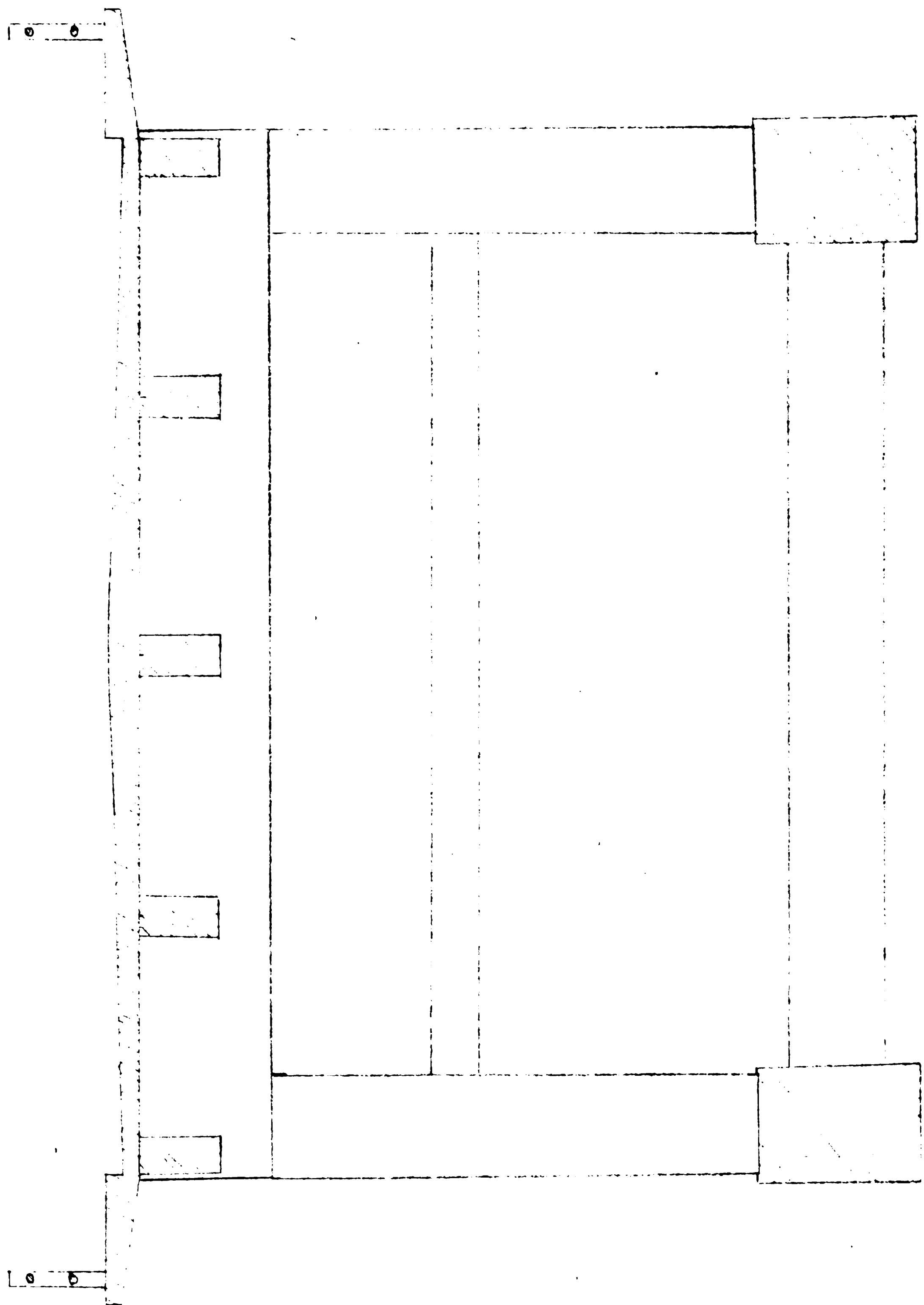
The actual stresses were then computed assuming that the arch acts as a column with an axial load and bending moment. The allowable stresses of dead and live loads will vary with the eccentricity. The allowable stress may be increased 25 percent when the temperature stresses are included along with the dead load, live load, and arch shortning stresses.

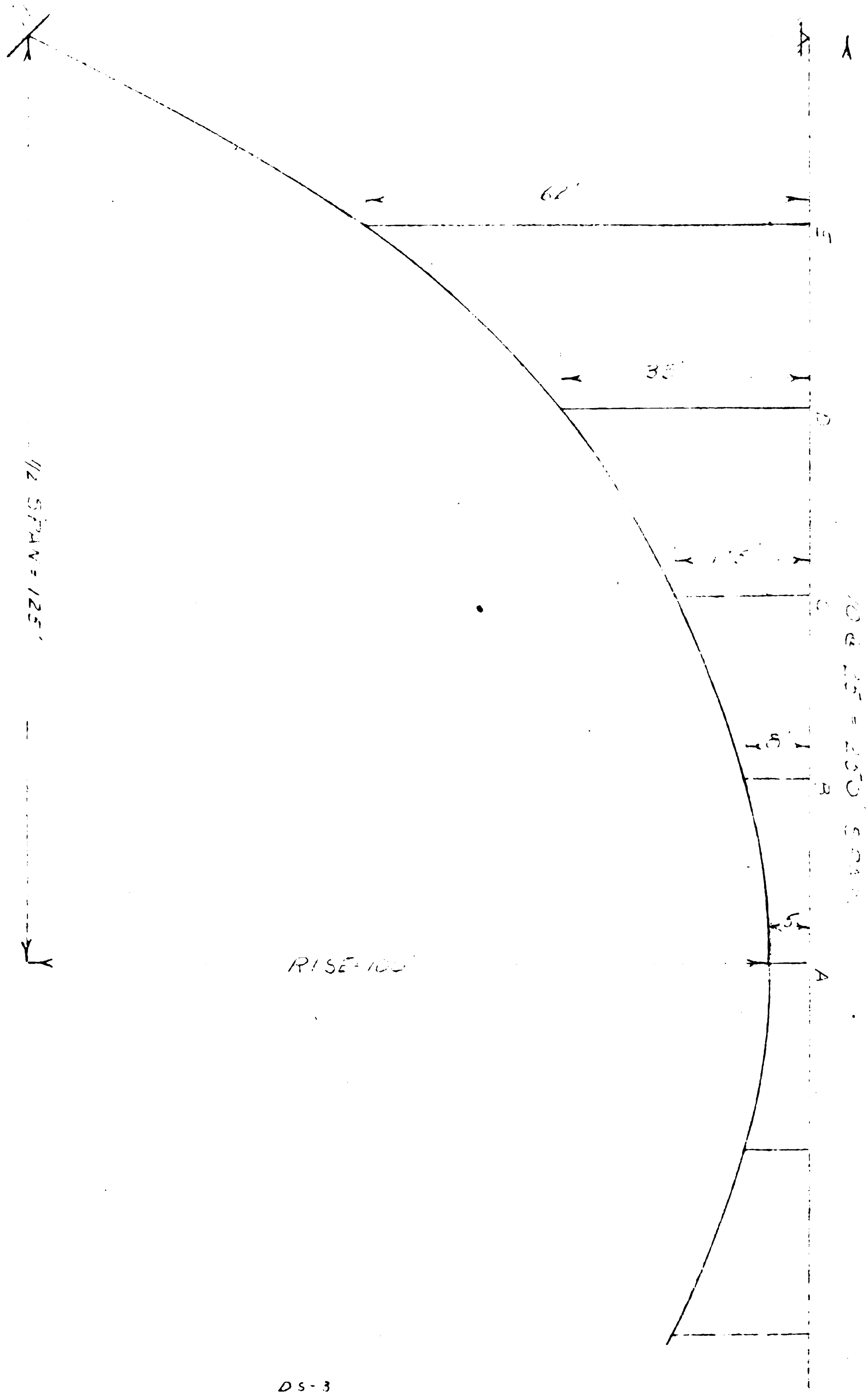
The rib struts were then designed assuming that the arch rib took one half of the maximum moment found on DS-16 and the other half was taken by the strut. The rib strut were located at the base of each spandrel and were kept the same size for uniformity.

SKETCH OF PROPOSED BRIDGE



SECTION A-A





DS-3

SLAB DESIGN FROM A.A.S.H.O. 3.3.2.

$E = .175S + 3.2$

$E = .175(6.67) + 3.2$

$E = 4.37$

% L.L.M FOR IMPACT MOMENT

$\% = \frac{50}{L+125} \times 100 = \frac{50 \times 100}{132} > 30\%$ ∴ USE 30% L.L.M

ASSUME 8" SLAB

$L.L.M = \pm \frac{.2P}{E} S = \pm \frac{.2(12,000)(6.67)}{4.37} = 3660$ #FT

IMPACT MOM $= .30(3660) =$ 1098 #FT

$D.L.M = \frac{(100)(6.67)^2}{10} =$ 455 #FT

TOTAL M = 5213 #FT

$d = \left(\frac{M}{Kb}\right)^{1/2} = \left(\frac{5213 \times 12}{248 \times 12}\right)^{1/2} = 4.6"$ ∴ USE 8" SLAB

MAIN REINFORCEMENT

$A_s = \frac{M}{f_s j d} = \frac{5213 \times 12}{16,000 \times .87 \times 4.6} = 0.98$ □"/FT

∴ USE #5 @ 3 3/4" c/c TOP & BOTTOM

DISTRIBUTION STEEL

$\% A_s = \frac{100}{\sqrt{S}} = \frac{100}{6.67^{1/2}} = 38.7\% A_s$

∴ DIST $A_s = .387 \times 0.98 = .38$ □"/FT

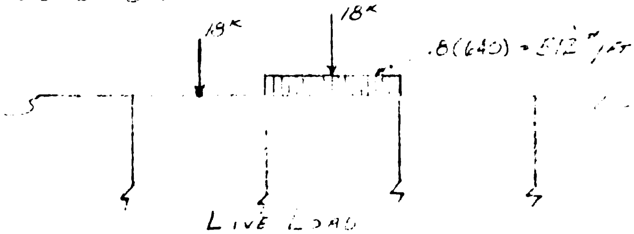
∴ USE #4 @ 6" c/c IN BOTTOM

THE DISTRIBUTION STEEL IS PLACED NORMAL TO MAIN REINFORCEMENT

DESIGN OF STRINGERS

ASSUME NEG. MOM. @ SUPPORTS = $\frac{wL^2}{11}$ & $\frac{PL}{8}$

USE LOADING AS INDICATED IN A.A.S.H.O. 3.2.6



ASSUME D.L. = 1400#/FT

b = 16" t = 36"

IMPACT = $\frac{50}{25+125}$ > 30% ∴ USE 30%

L.L. M = $\frac{512(25)^2}{11}$ + 2$\left[\frac{18,000(25)}{8}\right]$ = 141,600 #FT

I.M. M. = .3(141,600) = 42,480 #FT

DL M. = $\frac{1400(25)^2}{11}$ = 79,500 #FT

TOTAL MOM = 263,580 #FT OR 3,160,000 IN#

$d = \left(\frac{3,160,000}{248 \times 16}\right)^{1/2}$ = 29" ∴ ASSUMPTION TOO HIGH

2ND. ASSUMPTION

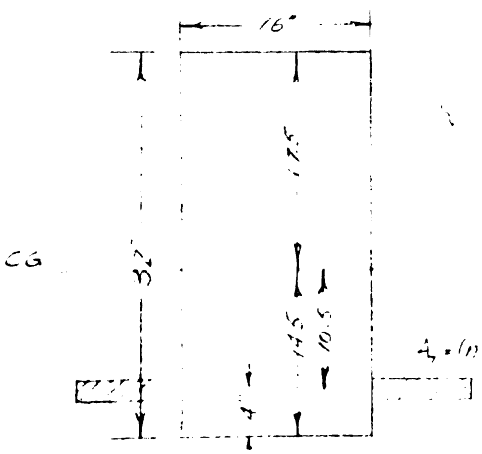
t = 32" b = 16" DL w = 1334 #/FT

DL M = $\frac{1334(25)^2}{11}$ = 75,795 #/FT

∴ TOTAL MOM = 3,118,500 #-IN

$A_s = \frac{3,118,500}{16,000(.857)(28)}$ = 8.12 IN²

$d = \left(\frac{3,118,500}{248 \times 16}\right)^{1/2}$ = 28" ∴ ASSUMPTION O.K.



$A_s(n-1)A_s$ = 73.08

$\bar{x} = \frac{16(32)(16) + 73.08(4)}{16(32) + 73.08}$

$\bar{x}$ = 14.5" FROM BOTTOM OF BEAM.

$I_{CG} = \frac{1}{3}(16)(14.5)^3 + \frac{1}{3}(16)(17.5)^3 + 73.08(10.5)^2$

I_{CG} = 52,999 IN.^{4}

ASSUME COLUMN 30" x 30" p = .06 d' = 2"

$V = (65,800 + 65,800 + 1,200)\,.6 = 114,000^{\#}$

$N = 114,000 + 65,800 = 179,800^{\#}$

$M = 114,000(15) + 6,820,000 = 8,530,000^{\#}$ IN.

$e = \frac{M}{N} = \frac{8,530,000}{179,800} = 47.7''$

$\frac{e}{t} = \frac{47.7}{30} = 1.59$ ∴ CASE III.

$\frac{t}{e} = \frac{1}{1.59} = .628$

$\frac{d'}{t} = \frac{2}{30} = 0.067$

FROM TABLES:

$C_2 = 3.0$ $\not k = 0.46$

ACTUAL $f_c = \frac{8,530,000(3.0)}{30^3} = 945$ psi.

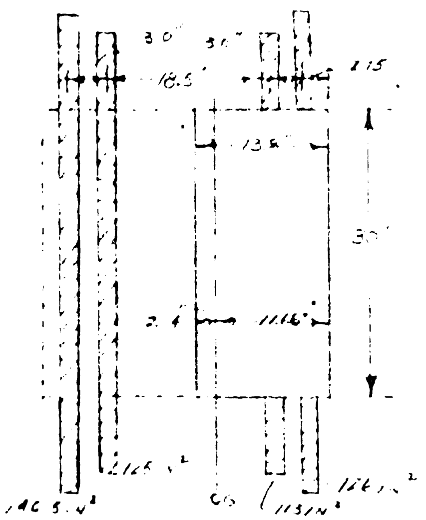
$f_a = .8\left[0.225(3000) + \frac{16,000(.06)}{1+(11-1)(.06)}\right] = 850$ psi

FROM TABLES:

$D = 4.16$ $\frac{Dd}{t} = 2.61$ $\frac{f_a}{f_c} = .258$

$\frac{f_a}{f_c} = .417$ ∴ ALLOWABLE $f_c = 1250$ psi. ∴ SAFE

$A_s = 900(.06) = 54$ in.^{2} USE 34 # 11 BARS



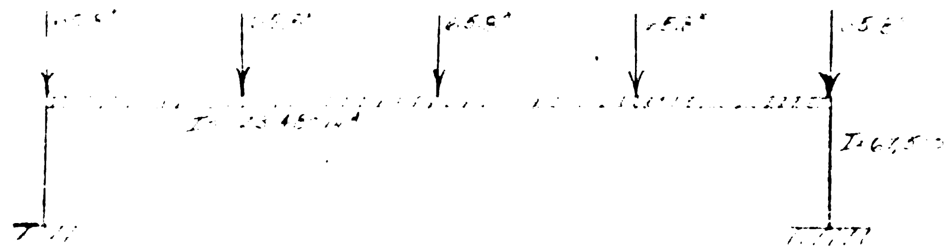
$\bar{x} = \frac{2.4 \times 30 [6.3] + 126(2.15) + 113(5.15) + 126(24.15) + 140.5(20.25)}{140.5 + 126 + 113 + 126 + 414}$

$\bar{x} = 11.66''$

$I_{cg} = \frac{1}{3}(30)(2.4)^3 + \frac{1}{3}(11.66)^3(30) + 126(9.31)^2 + 113(5.1)^2 + 126(12.49)^2 + 140.5(\ldots)^2$

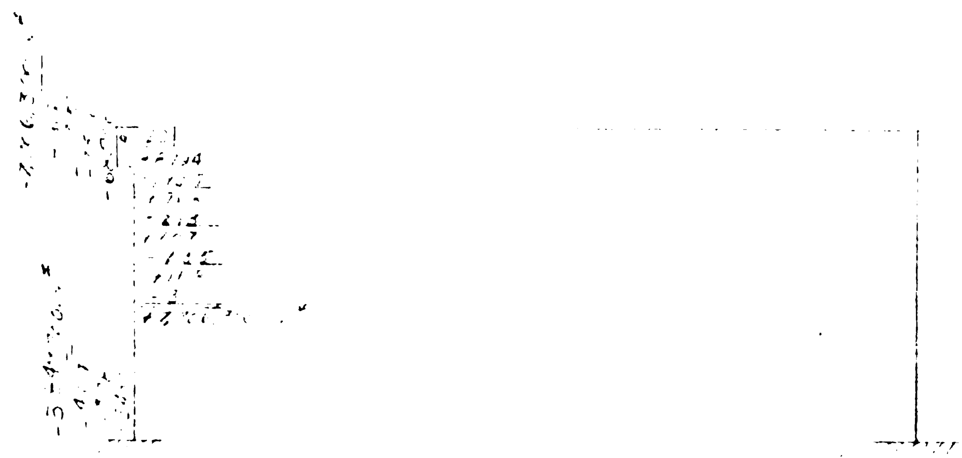
$I_{cg} = 83,558$ in.^{4}

[illegible]



[illegible]

$M'_1 = 8,773,550$ in-#



Check Section [illegible]

[illegible] $= 32.4''$ [illegible] $= 42$ [illegible] ∴ Section O.K.

$V =$ [illegible] $+ 13,992 = 145,502$#

$N =$ [illegible] $+ 65,800 = 211,302$#

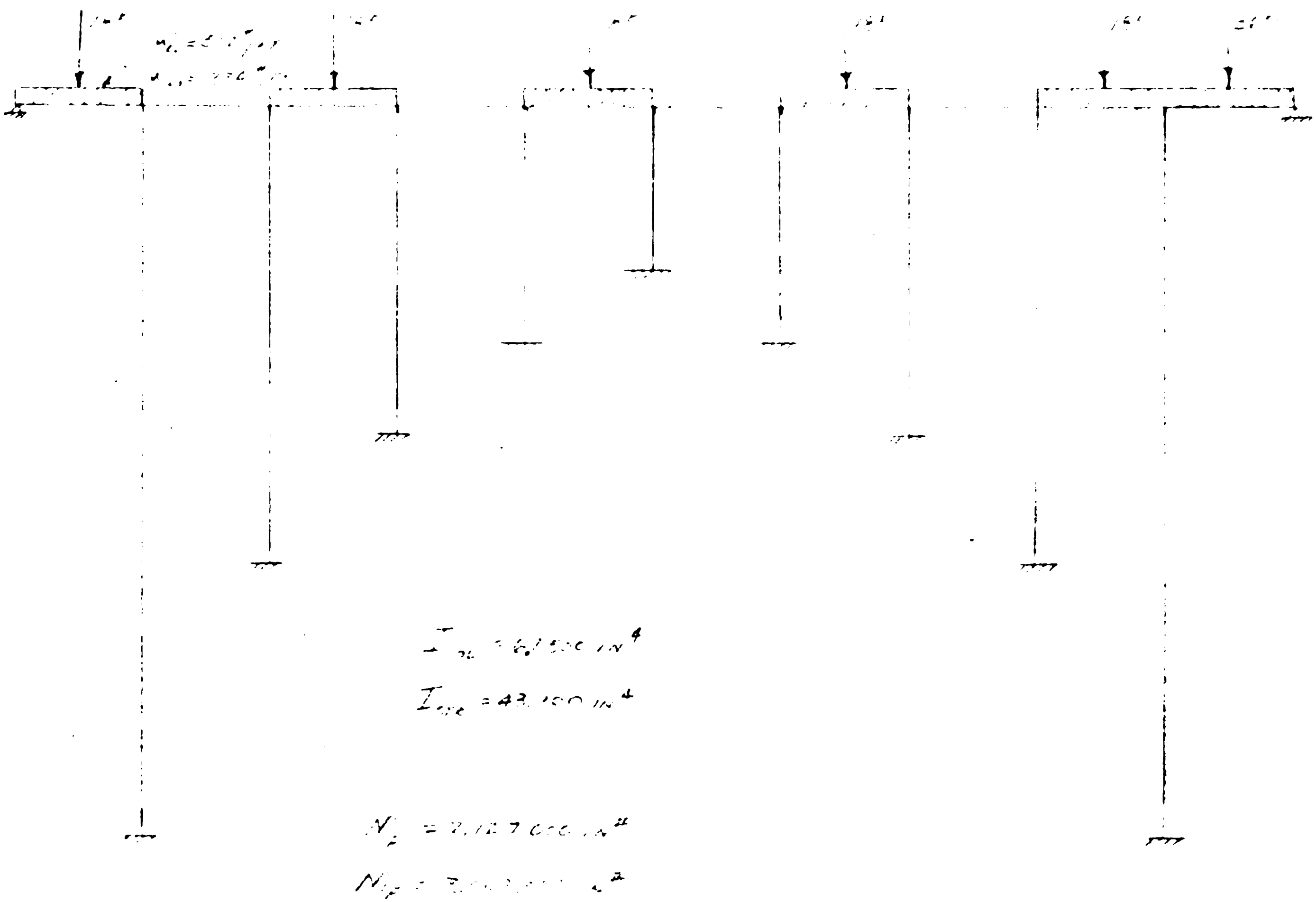
$M' = 145,502$ [illegible] [illegible] in-#

[illegible]

[illegible]

[illegible]

∴ Section O.K.



= 61,500 in⁴
= 43,100 in⁴
= 2,127,000 in²

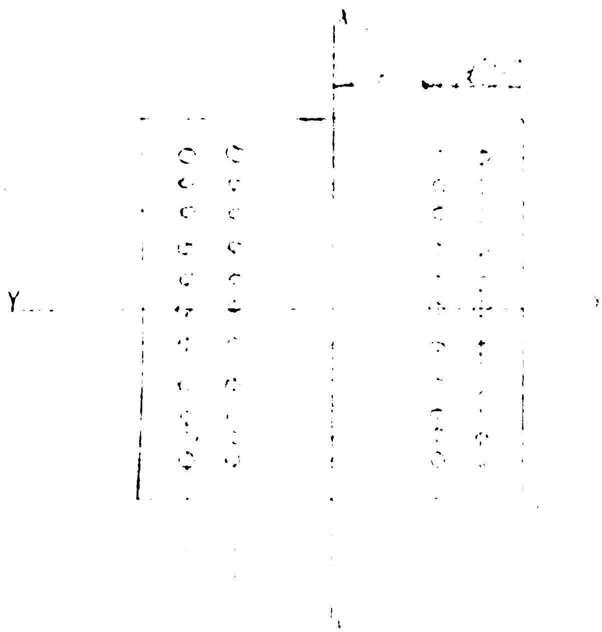
CHECK OF STRESSES IN COLUMNS

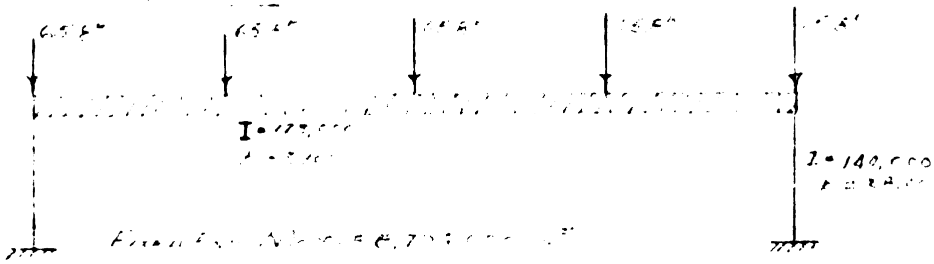
ACCORDING TO A.A.S.H.O. 3.2.2

ACTUAL f =

VERY CONCRETE

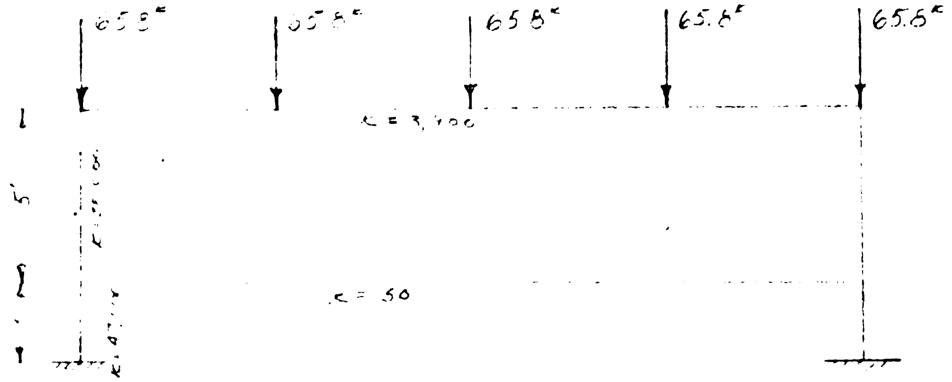
BARS





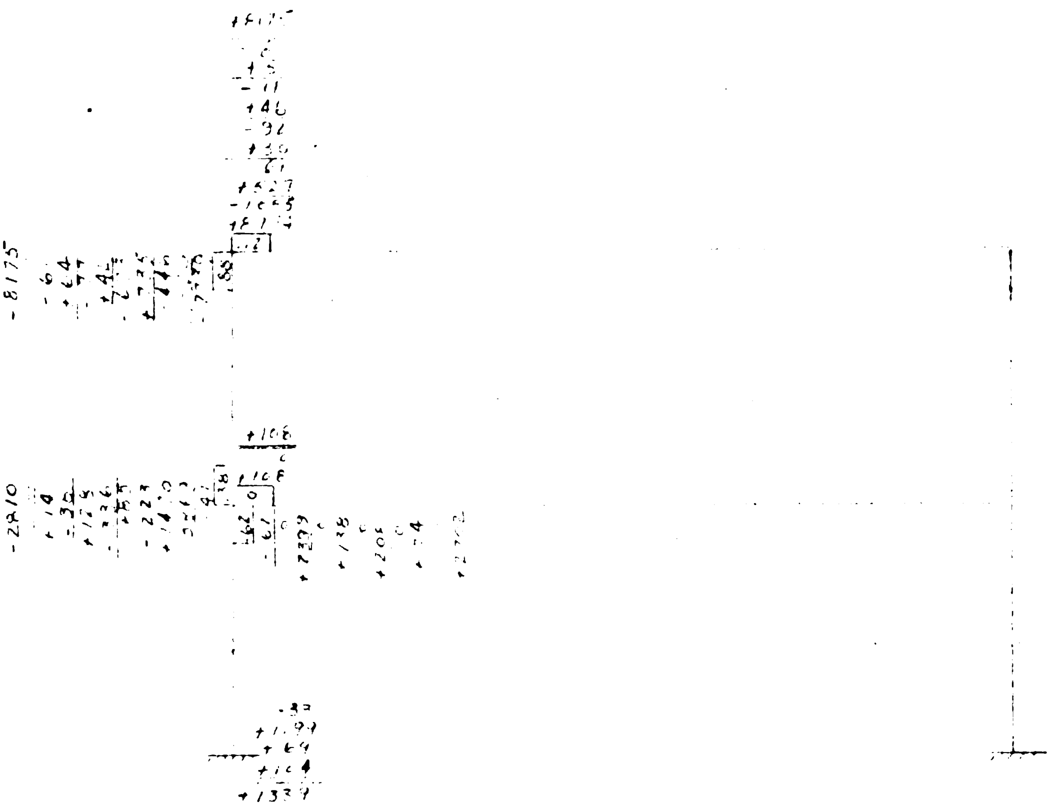
SECTION O.K.

DESIGN OF [illegible] B



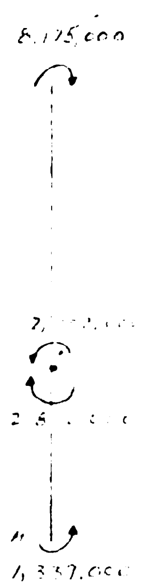
ASSUME [illegible] STRUT TO BE 7" x 14"

ASSUME CROSS STRUT [illegible] SELECTED & DESIGN AS COMPRESSION MEMBER.



NEG. STRESS $= \frac{wL^2}{8} = \frac{24.4 \times 112}{144} \times 32^2 \times \frac{12}{8} = 155,000$ IN#

$A_s = \frac{155,000}{16000 \times .875 \times 11.5} = .96$ IN² FOR DEADLOAD



$\Sigma M_A = 0$

$+8,175,000 + 2,702,[illegible] - 2,6[illegible] + 1,339,000 - 36P = 0$

$P = 192,[illegible]$# TENSION

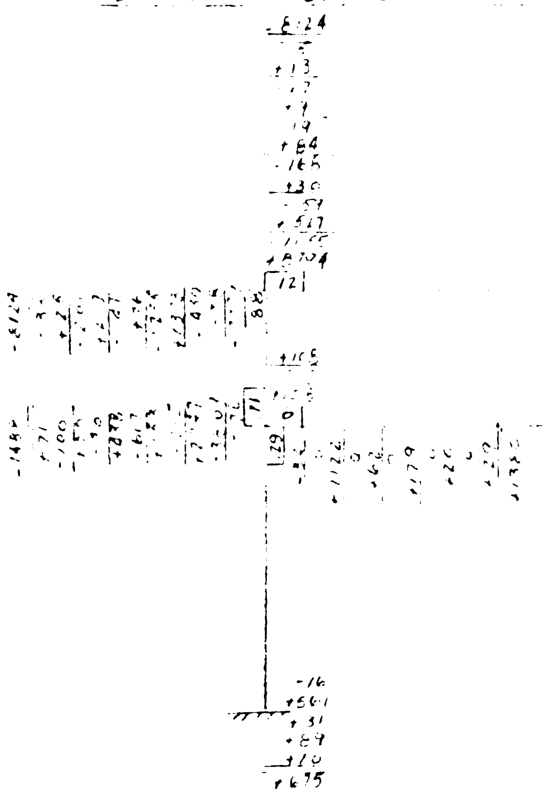
$A_s = \frac{192,[illegible]}{16,000} = 12.06$

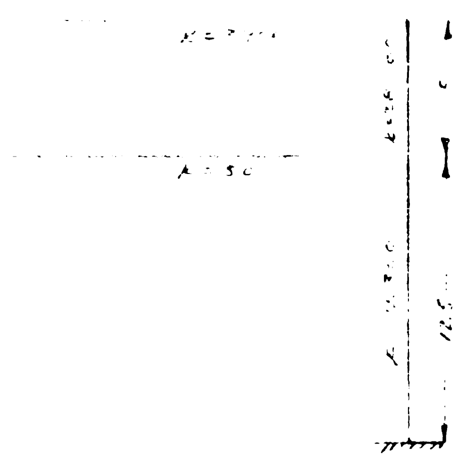
TOTAL $A_s = 12.06 + .96 = 13.02$

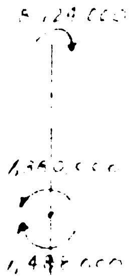
USE 9 #11 BARS

PROVIDE HOOKS OF SUCH LENGTH AS TO [illegible] 21,000# TENSION.

DESIGN OF SPANDREL "C"







$\Sigma M'_A = 0$

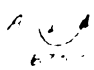
$P = \dfrac{8{,}129{,}000 + \ldots\ 1{,}488{,}000 + 675{,}000}{12 \times 12.5}$

$P = 50{,}380$# TENSION

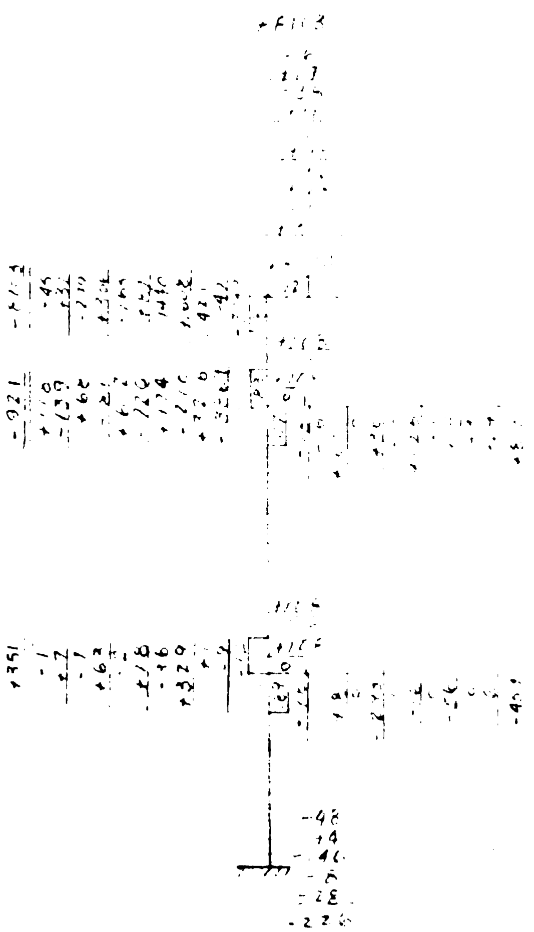
$A_s = \dfrac{50{,}380}{16{,}000} = 3.15\ in^2$

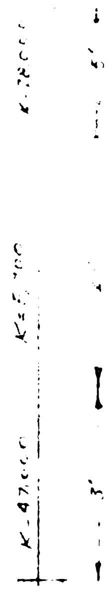
TOTAL $A_s = 3.15 + .95 = 4.10\ in^2$ USE 4 #5 BARS

[illegible] FOR 17,500# TENSION

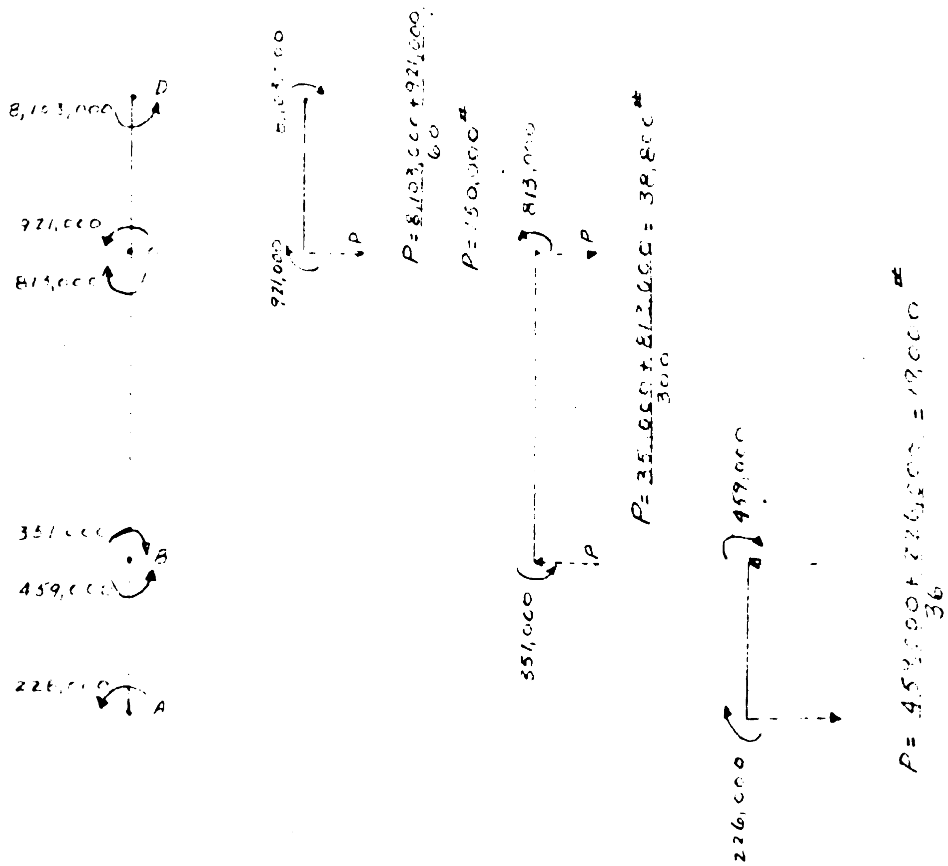


[illegible] D[illegible]





STANDPIPE "D" CONT.



@ POINT C $P = 188,800^{\#}$ TENSION [illegible]

$A_s = \frac{188,800}{[illegible]}$ [illegible] IN^2

TOTAL $A_s = 11.70 + .95 = 12.65\ IN^2$ USE 10 #10 BARS

PROVIDE HOOK FOR $18,680^{\#}$ TENSION

@ POINT B $P = 57,800$ COMPRESSION

$N = A(0.18 f_c' + 0.32 f_s P_g)$

$57,800 = 98(540 + 16,000 P_g)$

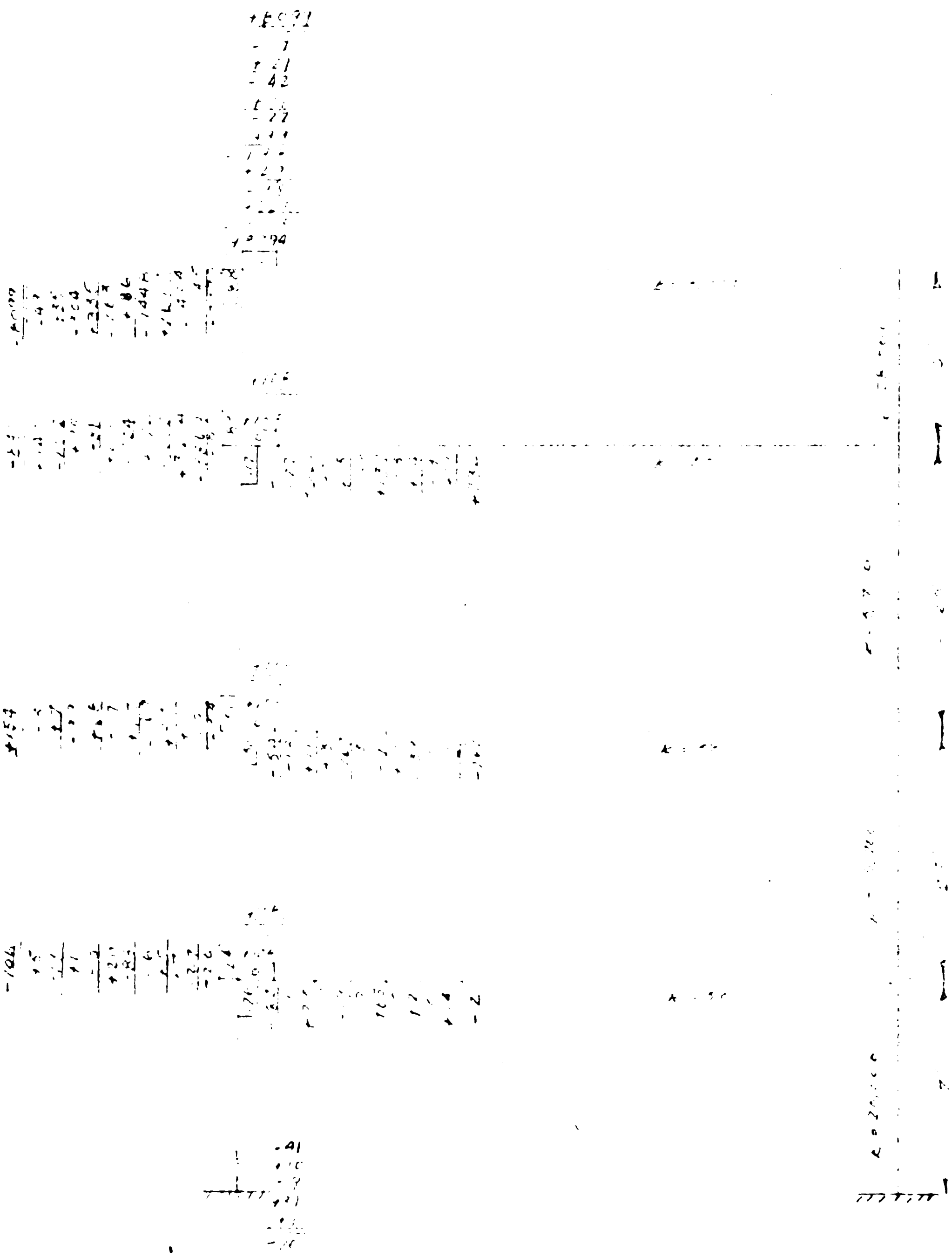
$P_g = .006$

$A_s = .59\ IN^2$

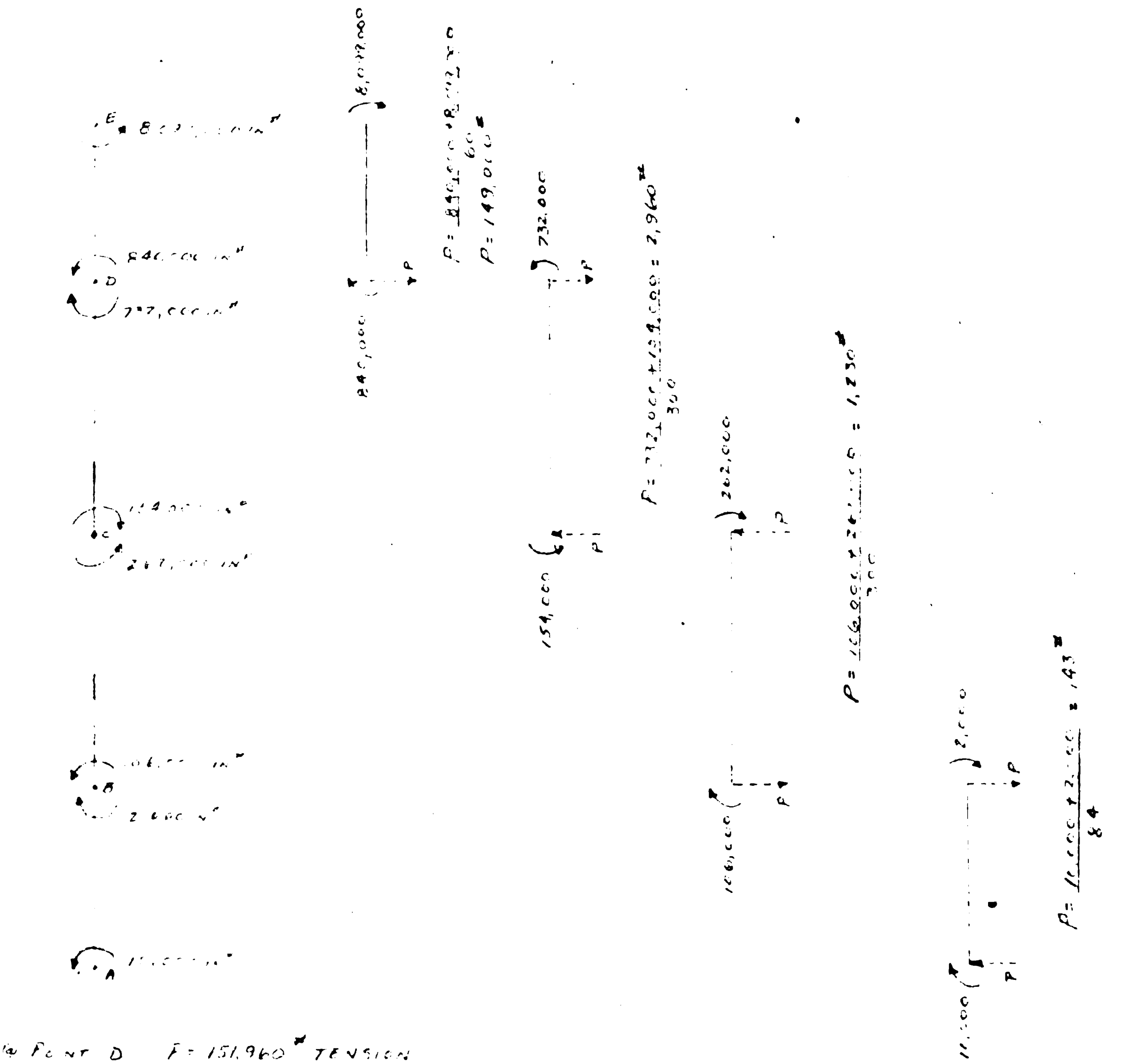
TOTAL $A_s = .59 + .95 = 1.54$ USE 4 #4 BARS

$1/4^{\phi}$ TIE @ $12''\ ^{o}/_{c}$

DESIGN OF SPANDREL "E"



Sim... E ...



@ Point D   F = 151,960# TENSION

A_s = .75 + 151,960/... = 1.04 in² USE 13 #8 BARS

PROVIDE HOOK FOR 11,700# TENSION

@ Point C   F = 4,[illegible]# COMPRESSION

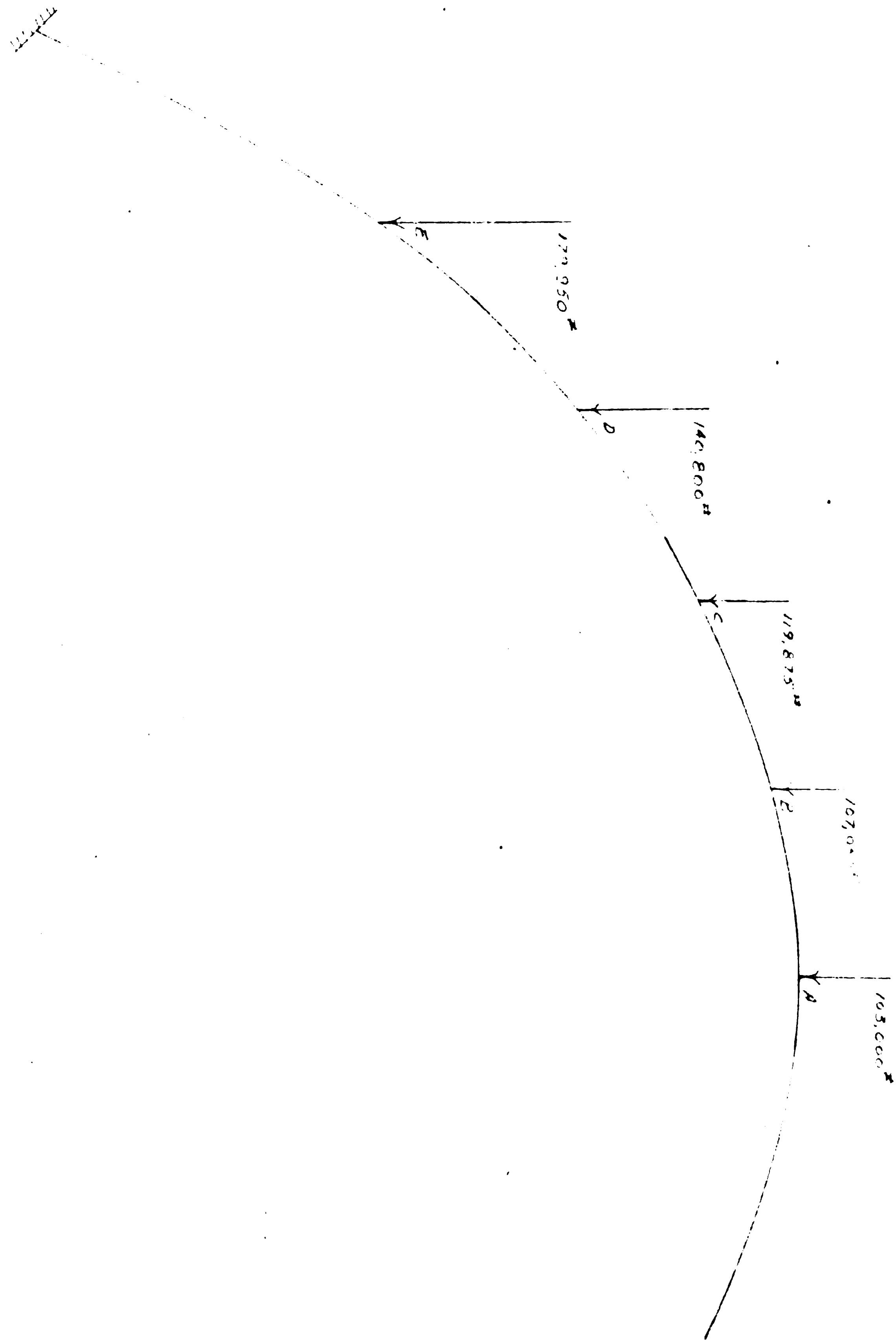
[illegible] STEEL WILL TAKE THIS FORCE [illegible] ANY ADDITIONAL STEEL OTHER THAN .95 in² FOR LEAD LOAD ∴ USE 5 #4 BARS

@ Point A   F = [illegible]# TENSION

A_s = [illegible] = [illegible] in² USE 7 #4 BARS

PROVIDE HOOK

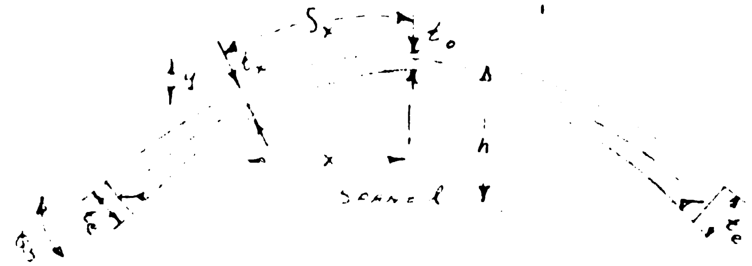
Dead Load Due To Superstructure



PRELIMINARY ANALYSIS OF ARCH

V. H. COCHRANE'S METHOD OF PRELIM. ANALYSIS WAS USED.

NOTATIONS:



ℓ = SPAN OF ARCH IN FEET

h = RISE OF ARCH AXIS IN FEET

r = RISE RATIO $\frac{h}{\ell}$

U_s = RATIO OF THICKNESS OF SPRINGING TO THICKNESS OF CROWN

T_c = THRUST AT CROWN

M_c = MOMENT AT CROWN

T_s = THRUST AT SPRINGING

M_s = MOMENT AT SPRINGING

T_{m_1} = COEFFICIENT FOR $w\ell$ FOR T_c CORRESPONDING TO MAX. + M_c

T_{m_2} = COEFFICIENT FOR $w\ell$ FOR T_c CORRESPONDING TO MAX − M_c

w_c = DEAD LOAD IN #/FT

W = LIVE LOAD IN #/FT

ω = COEF. OF LINEAR EXPANSION

FORMULAE FOR ARCH AXIS

$$y = \frac{8 r \ell}{6+5r}\left(3\left(\frac{x}{\ell}\right)^2 + 10\left(\frac{x}{\ell}\right)^4 r\right)$$

$$\text{TAN } \phi_s = \frac{8 r}{6+5r}\left(3+5r\right)$$

1ST TRIAL

ASSUME $\ell_o = 4.25'$ $\quad \ell_s = 6.4'$ $\quad U_s = 1.5$ $\quad r = \frac{100}{250} = 0.4$ $\quad I_c = 23 FT^4$ $\quad A_c = 2000 \text{ IN}^2$

$\phi_s = 63.5°$

$w = 2130$ #/FT $\quad w_c = 4510$ #/FT $\quad$ TEMP. CHANGE + 30°F, − 40°F

$\omega = 0.000006$ $\quad E = 432 \times 10^6$

b = WIDTH OF RIB = 36"

SECTION AT CROWN

DEAD LOAD

$$T_c = \frac{6+5r}{48r} w_c \ell = \frac{6+5(.4)}{48(.4)} \times 4510(250) = 470,000^{\#}$$

M_c ASSUMED = 0

LIVE LOAD MAX. + MOM.

$$T_c = \frac{59.5 + 31.5r + 5r^2}{1000r} w\ell = \frac{59.5 + 31.5(.4) + 5(.4)^2}{1000(.4)} \times 2130(250) = 97,000^{\#}$$

$$M_c = \frac{67.5 + 50r + 40r^2 - (20+13r)U_s + 3U_s^2}{10,000} w\ell^2 = \frac{67.5 + 50(.4) + 40(.4)^2 - [20 + 13(.4)]1.5 + 3(1.5)^2}{10,000} \, 2130(250)^2$$

M_c = 1,000,000 FT.#

LIVE LOAD MAX. − M.

$$T_c = \frac{61 + 2U_s + (7+2U_s)r - 70r^2}{1000r} w\ell = \frac{61 + 2(1.5) + [7 + 2(1.5)].4 - 70(.4)}{1000(.4)} \times 2130(250) = 75,500^{\#}$$

$$M_c = \frac{55 - 9U_s + 0.85U_s^2}{10,000} w\ell^2 = \frac{55 - 9(1.5) + 0.85(1.5)^2 \times 2130 \times 250^2}{10,000} = -2,220 \text{ FT.}^{\#}$$

TEMPERATURE (FALL OF 40°)

$$T_c = [84U_s - 25 - (20.5U_s - 15)r - (10U_s - 2)r^2] \frac{\omega t EI_c}{h^2}$$

$$T_c = \left[84(1.5) - 25 - [20.5(1.5) - 15].4 - [10(1.5) - 2].4^2\right] \frac{0.000006 \times 40 \times 432 \times 10^6 \times 23}{100^2}$$

$T_c = 2800$

$$M_c = [46.25 - 17U_s + 2.44U_s^2 + 5r + (25.5 - 3.6U_s)r^2] \frac{hT_c}{100}$$

$$M_c = \left[46.25 - 17(1.5) + 2.44(1.5)^2 + 5(.4) + [25.5 - 3.6(1.5)].4^2\right] \frac{100 \times 2800}{100}$$

M_c = −86,240

SECTION A1 - SPRINGING

DEAD LOAD

$V_s = \frac{3+5r}{6} w \ell = \frac{3+5(4)}{6} \times 450 \times 250 = 940{,}000^{\#}$

$T_s = (T_c^2 + V_s^2)^{1/2} = (940^2 + 470^2)^{1/2} = 1{,}050{,}000^{\#}$

$M_s = 0$ ASSUMED

LIVE LOAD MAX. + MOM.

$T_s = \frac{93.5 - 42.5 r + \ldots r^2}{\ldots r} w \ell = \frac{\ldots - 42 (4) + 155 (4)^2}{\ldots (4)} \times 2130 \times 250 = 134{,}700^{\#}$

$T_c = (\ldots) \ldots = (\frac{20.8 + 74.9}{10{,}000}) \ldots = 531^{\#}$

$M_s = \frac{322 + 271 - (\ldots)(\ldots)^2}{10{,}000} w \ell^2 = \frac{322 + 271(4) - (\ldots)(\ldots)^2}{10{,}000} \ldots$

$M_s = 3{,}120{,}000 \text{ FT}^{\#}$

LIVE LOAD MAX. - MOM.

$T_s = \frac{244 + (211 - 2 \ldots) r + (120 + 30 \ldots) r^2}{\ldots r} w \ell = \frac{244 + (211 - 2 \times 15) \cdot 4 + (120 + 30 \times 15) \cdot 4^2}{1000 (4)} \times 2130 (250)$

$T_s = 179{,}000^{\#}$

$T_c = (\ldots) w \ell = \left[\frac{20.6}{10{,}000} + \frac{0.0063}{1.5 \times 4}\right] 2130 (250) = 6{,}930^{\#}$

$M_s = \frac{\ldots - (\ldots)^2}{10{,}000} w \ell^2 = \frac{\ldots (4) - (\ldots)^2}{10{,}000} \times 2130 (250)^2$

$M_s = -2{,}230{,}000 \text{ FT}^{\#}$

TEMPERATURE (FALL OF 40°)

$T_s = (\ldots) T_c = [\ldots - \ldots (4)] \ldots = 1090^{\#}$

$M_s = M_c + h T_c = \ldots + 100 (\ldots) = \ldots \text{ FT}^{\#}$

AVERAGE STRESSES

DEAD LOAD

$f_a = \left[\text{[illegible]} + 2.5(1 + 0.05)^2 - \text{[illegible]} \right] f_{ac} = \left[\text{[illegible]} \right] \text{[illegible]}$

$f_a = 54{,}000$

LIVE LOAD MAX + MOM AT [illegible]

$f_a = \left[0.9\text{[illegible]} + \text{[illegible]}(4 - 0.5)^2 \right] f_{ac} = \left[0.92\text{[illegible]}(4)^3 - 0.04(1.5) + \text{[illegible]} \right] \text{[illegible]}$

$f_a = \text{[illegible]}$

LIVE LOAD MAX - MOM AT [illegible]

$f_a = \left[\text{[illegible]}(4 - 0.5)^2 \right] f_{ac} = \left[0.54 + 1.1(.4 + 1)^2 - \text{[illegible]} \right] \text{[illegible]}$

$f_a = \text{[illegible]}$

LIVE LOAD MAX + MOM AT [illegible]

$f_a = \left[\text{[illegible]} - 0.04 U_s + \text{[illegible]}(4 - 0.5)^2 \right] f_{ac} = \left[\text{[illegible]} \right] \text{[illegible]}$

$f_a = 46$

LIVE LOAD MAX - MOM AT [illegible]

$f_a = \left[0.05\text{[illegible]} + \text{[illegible]}(4 - 0.5)^2 \right] f_{ac} = \left[\text{[illegible]} \right] \text{[illegible]}$

$f_a = 64\text{[illegible]}$

TEMPERATURE [illegible]

$f_a = \left[\text{[illegible]} \right] f_{ac} = \left[\text{[illegible]} \right] \text{[illegible]}$

$f_a = 162$

$f_1 f_2 f$ [illegible] $\times 40 \times 432 \times 10^6 = 105{,}000$

SUMMARY OF [illegible] TRIAL

SECTION AT CROWN

MAX. + MOM.

A. D.L. + L.L. + ARCH SHORTENING.

	THRUST	MOM.	AV. STRESS	UNIT STRESS f_2
DEAD LOAD	470,000	0	54,000	
LIVE LOAD	97,[illegible]	+1,000,000	[illegible]	
ARCH SHORT.	-1,680	+51,600	-97	
TOTAL	563,[illegible]	+1,0[illegible],600	61,863	[illegible]

B. D.L. + L.L. + TEMP. FALL + ARCH SHORT.

	THRUST	MOM.	AV. STRESS	UNIT STRESS
D.L. + L.L.	567,[illegible]	+1,[illegible]	6[illegible],960	
TEMP	-2[illegible]	+86,240	-162	
ARCH S.	-1680	+51,600	-97	
TOTAL	+[illegible],500	+1,1[illegible]	61,[illegible]	1160

MAX. [illegible]

A. D.L. + L.L. + ARCH SHORTENING

	THRUST	MOM.	AV. STRESS	UNIT STRESS
D.L.	470,000	0	54,000	
L.L.	75,[illegible]	-2,220	7,2[illegible]	
A.S.	-1,680	+51,600	-97	
TOTAL	543,[illegible]	+[illegible],380	61,153	O.K.

[illegible] Cont.

SECTION AT SPRINGING

MMAX + NMIN

A. D.L. + L.L. + A.S.

	THRUST	MOM	AV. STRESS	UNIT STRESS
D.L.	[illegible]	0	54,000	
L.L.	174,700	3,120,000	46	
A.S.	-57	192,000	55	
TOTAL	1,184,643	3,312,000	53,961	1260

B. D.L. + L.L. + T + A.S.

	THRUST	MOM	AV. STRESS	UNIT STRESS
DL + LL	1,184,700	3,120,000	54,046	
T.	-1090	366,740	-162	
A.S.	-57	192,000	-85	
TOTAL	1,182,[illegible]	3,678,000	53,[illegible]	1430

MMAX - NMIN

A. D.L. + L.L. + A.S.

	THRUST	MOM	AV. STRESS	UNIT STRESS
D.L.	[illegible]	0	54,000	
L.L.	179,000	-2,230,000	640	
A.S.	-56	195,000	-85	
TOTAL	1,28[illegible]	-2,035,000	54,555	640

B. D.L. + L.L. + T + A.S.

	THRUST	MOM	AV. STRESS	UNIT STRESS
DL. + LL.	1,284,000	-2,230,000	54,640	
T	-1090	366,740	-162	
A.S.	-56	195,000	-86	
TOTAL	1,182,852	-1,668,760	54,392	OK

2ND. TRIAL OF PRELIMINARY DIMENSIONS

$t_e = 8.5'$ $\quad c_s = 1.7$ $\quad w_c = 4850\ \#/FT$

$t_o = 5.0'$ $\quad \lambda = .4$ $\quad W = 2130\ \#/FT$

$I_c = 36.6\ FT^4$ $\quad A_{T_o} = 11.24\ FT^2$

SECTION AT CROWN

SYMMETRY A DL + LL + AS MAX + MOM

	THRUST	MOM	AV. STRESS	UNIT STRESS	ALLOWABLE
DL	505,000	0	42,000		
LL	91,000	955,000	6,700		
AS	-1,400	67,600	-100		
TOTAL	594,600	1,022,600	48,600	715	1020
B DL + LL + T + AS					
DL + LL	596,000	955,000	48,700		
T	-5,450	143,000	-213		
AS	-1,400	67,600	-100		
TOTAL	589,150	1,165,600	48,387	870	1350

MAX - MOM

A DL + LL + AS

	THRUST	MOM	AV STRESS	UNIT STRESS	ALLOWABLE
DL	505,000	0	42,000		
LL	75,500	-561,000	6,050		
AS	-2,400	+67,600	-100		
TOTAL	578,100	-493,400	47,950	500	1000
B DL + LL + T + AS					
DL + LL	580,500	-561,000	48,050		
T.	-5,450	143,000	-213		
AS	-2,450	66,000	-97		
TOTAL	572,600	-352,400	47,737	430	1210

SUMMARY OF [illegible] TRIAL [illegible]

SECTION AT SPRINGING

MAX. + MOM

	THRUST	MOM	AV. STRESS	UNIT STRESS	ALLOWABLE
A DL + LL + AS					
DL.	1,130,000	0	42,000		
LL.	134,700	+3,590,000	33		
AS	-805	139,000	-67		
TOTAL	1,263,895	+3,729,000	41,966	11[illegible]	1040
B DL + LL. + T + AS					
DL + LL.	1,264,700	+3,590,000	42,033		
T.	-1920	+340,000	-213		
A.S	-805	+139,000	-67		
TOTAL	1,261,975	+3,818,000	41,733	1150	[illegible]

MAX - MOM

	THRUST	MOM	AV. STRESS	UNIT STRESS	ALLOWABLE
A DL + LL + AS.					
DL	1,130,000	0	42,000		
LL	179,000	-2,320,000	400		
A.S	-805	+139,000	-67		
TOTAL	1,308,195	-2,181,000	42,[illegible]	[illegible]	[illegible]
B. DL. + LL. + T. + AS.					
DL + LL.	1,309,000	-2,320,000	42,400		
T.	-1920	+340,000	-213		
A S.	-805	+139,000	-67		
TOTAL	[illegible]307,225	-1,841,000	+42,120	640	[illegible]

THIS SECTION IS CLOSE ENOUGH FOR AN EXACT ANALYSIS

CHANGE $p_g = 0.0L$

A_s = 0.012 x AREA OF RIB AT CROWN

THICKNESS OF ARCH

S_x/S	t_x/t_0	S_x	T_x
0	1.000	0	5.00
0.05	1.006	8.16	5.03
0.15	1.018	24.47	5.09
0.25	1.030	40.78	5.15
0.35	1.042	57.08	5.21
0.45	1.054	73.40	5.27
0.55	1.072	89.70	5.36
0.65	1.125	106.00	5.63
0.75	1.223	122.32	6.12
0.85	1.393	138.63	6.97
0.95	1.611	154.95	8.06
1.00	1.700	163.13	8.50

EQUATIONS FOR ANALYSIS

$$H_c = \frac{-\Sigma \frac{xy}{I} + a \Sigma \frac{y}{I}}{2\Sigma \frac{y^2}{I} + 2\Sigma \frac{1}{A}} \qquad V_c = \frac{\Sigma \frac{x^2}{I} - a \Sigma \frac{x}{I}}{2\Sigma \frac{x^2}{I}}$$

$$M_c = \frac{\Sigma \frac{x}{I} - a \Sigma \frac{1}{I}}{2\Sigma \frac{1}{I}} - H_c y_c$$

LEFT SPRINGING

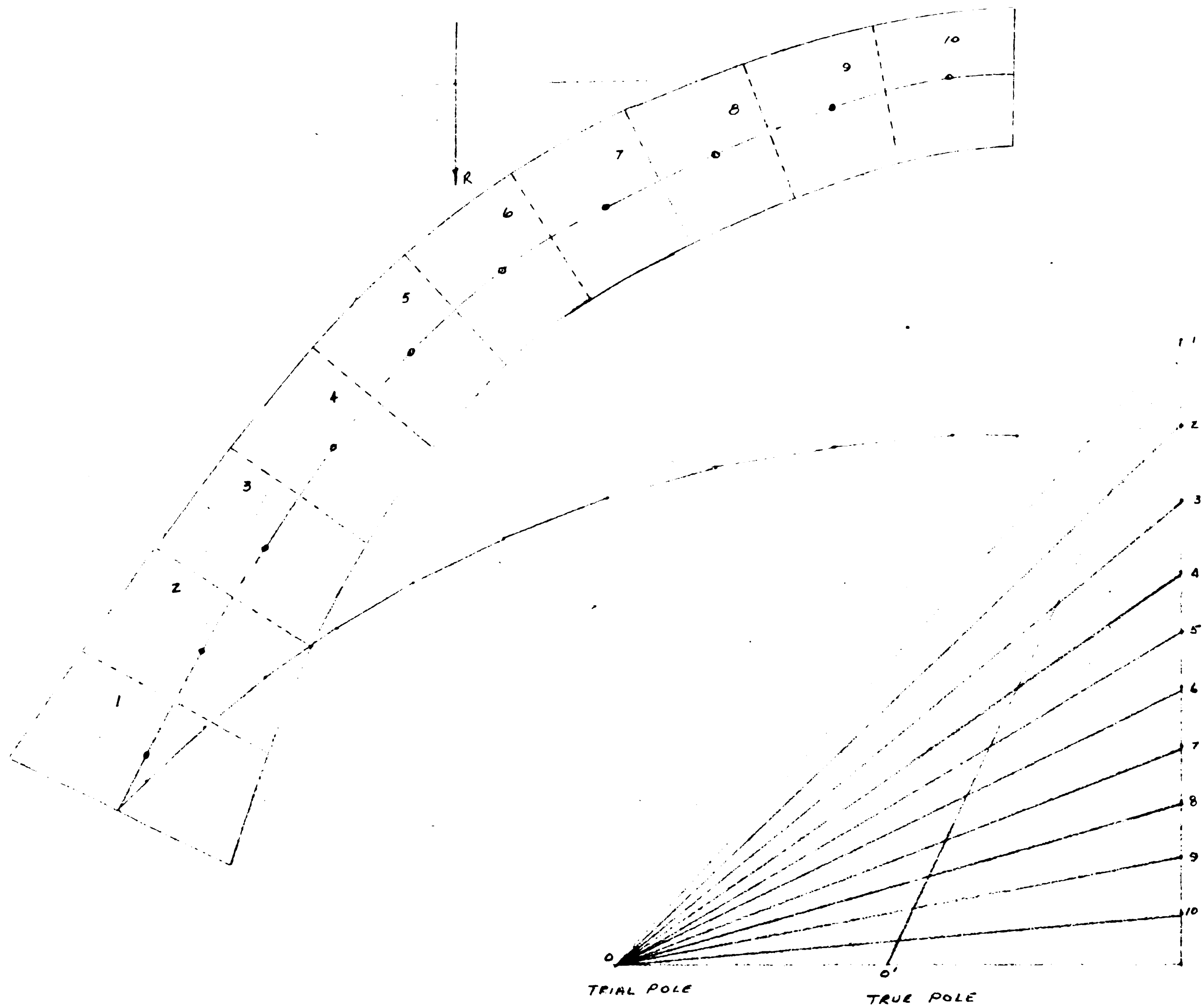
$$N_s = H_c \cos\phi_s + (1 - V_c)\sin\phi_s$$

$$M_s = M_c + h H_c + \frac{\ell}{2} V_c - 1\left(\frac{\ell}{2} - a\right)$$

LOAD TO RIGHT OF CROWN

$$N_s = H_c \cos\phi_s - V_c \sin\phi_s$$

$$M_s = M_c + h H_c + \frac{\ell}{2} V_c$$



R
1
2
3
4
5
6
7
8
9
10
0
TRIAL POLE
0'
TRUE POLE

CROSS SECTION DATA

Δ_s	y'	t_x	I	y'/I	$1/I$	A	$1/A$
1	7.7	8.06	130.90	0.0588	0.0077	24.18	0.0413
2	22.0	6.97	84.16	0.2549	0.0116	20.91	0.0478
3	36.1	6.12	57.31	0.6300	0.0175	18.36	0.0543
4	50.2	5.63	44.61	1.1253	0.0242	16.89	0.0592
5	63.9	5.36	38.50	1.6597	0.0259	16.08	0.0621
6	75.0	5.27	36.59	2.0497	0.0275	15.81	0.0633
7	84.0	5.21	35.36	2.3756	0.0282	15.63	0.0641
8	91.7	5.15	34.15	2.6900	0.0292	15.45	0.0645
9	97.0	5.09	32.97	2.9400	0.0303	15.27	0.0653
10	99.5	5.03	31.82	3.1300	0.0314	15.09	0.0662
TOTAL				16.9700	.2336		.5881

$$y_s = \frac{\Sigma \frac{y'}{I}}{\Sigma \frac{1}{I}} = \frac{16.97}{.2336} = 72.65'$$

$$y_c = h - y_s = 100 - 72.65 = 27.35'$$

Cross Section, [illegible]

Δ_3	x	y	I	x^2	y^2	x^2/I	y^2/I
1	121	−64.95	130.90	14,641	4,225	111.84	3[illegible]
2	114	−50.65	84.65	12,996	2,5[illegible]	153.52	30.36
3	105	−36.55	[illegible]	11,025	1,324	192.31	23.[illegible]
4	95	−22.45	44.61	9,025	502	202.30	11.25
5	84	−8.75	38.50	7,056	76	183.27	1.97
6	71	+2.65	36.59	5,041	6	137.76	0.16
7	57	+11.35	35.36	3,249	130	91.88	3.67
8	42	+19.05	34.15	1,764	365	51.65	10.68
9	26	+24.35	32.91	676	595	20.50	18.04
10	9	+26.85	31.80	81	724	2.54	22.75
TOTAL	724					1,147.63	154.18

INFLUENCE LINE VALUES FOR H_C

LOAD AT Δ_S	$\frac{a}{l_{25}}$	a	Δ_S DIVISIONS INCLUDED	$\Sigma\, xy/I$	$\Sigma\, y/I$	$a\,\Sigma\, y/I$	$\Sigma\, xy/I - a\,\Sigma\, y/I$	$2\Sigma\, y^2/I + 2\Sigma\, 1/A$	H_C
1	0.97	121	10	-60.01	-0.496	-60.62	0.00	309.54	0.00
				-68.17	-0.595				
2	0.91	114	9-10	-128.[illegible]8	-1.094	-124.[illegible]	-3.46	309.54	0.011
				-66.93	-0.[illegible]				
3	0.84	105	8-10	-195.[illegible]	-1.732	-181.86	-13.31	309.54	0.043
				-47.70	-0.503				
4	0.76	96	7-10	-142.96	-2.235	-212.33	-30.63	309.54	0.099
				-19.[illegible]	-0.227				
5	0.67	84	6-10	-262.05	-2.462	-206.81	-55.22	309.54	0.178
				+4.54	+0.064				
6	0.57	71	5-10	-257.49	-2.398	-170.26	-87.25	309.54	0.281
				+18.30	+0.321				
7	0.46	57	4-10	-239.[illegible]	-2.077	-118.39	-120.80	309.54	0.390
				+23.44	+0.558				
8	0.34	42	3-10	-215.15	-1.519	-63.80	-151.90	309.54	0.491
				+19.71	+0.739				
9	0.21	26	2-10	-196.54	-0.780	-20.28	-176.26	309.54	0.569
				+[illegible]	+0.780				
10	0.07	9	[illegible]	-[illegible]	0	0	-189.52	309.54	0.612
				0	0				
CROWN	0	0	1-10	[illegible]	0	0	-189.52	309.54	0.612

INFLUENCE LINE VALUES FOR V_c

Δ_s	a	$\Sigma x^2/I$	$\Sigma x/I$	$a \Sigma x/I$	$\Sigma \frac{x^2}{I} - a \Sigma \frac{x}{I}$	$2 \Sigma \frac{x^2}{I}$	V_c
1	121	111.84	0.924	111.80	0.04	2295.26	0.0000
		153.52	1.347				
2	114	265.36	2.271	[illegible]	6.4[illegible]	2295.26	0.[illegible]28
		192.37	1.632				
3	105	457.[illegible]3	4.103	[illegible]	26.91	2295.26	0.0117
		[illegible].30	2.130				
4	[illegible]	[illegible]	6.233	[illegible]14	67.8[illegible]	2295.26	[illegible]
		163.2[illegible]	2.182				
5	84	[illegible]43.30	8.415	[illegible]	136.44	2295.26	0.[illegible]594
		137.76	1.940				
6	71	[illegible]	10.355	[illegible]	245.65	2295.26	[illegible]
		91.58	1.612				
7	57	1072.94	11.967	[illegible]	[illegible]	2295.26	0.1702
		51.65	1.230				
8	42	1124.5[illegible]	13.197	554.[illegible]	570.32	2295.26	0.2484
		[illegible]	0.769				
9	26	1145.09	13.966	363.64	781.45	2295.26	0.3[illegible]4
		2.[illegible]4	0.283				
10	9	1147.63	14.269	128.42	1,019.[illegible]	2295.26	0.444[illegible]
CROWN	0	1147.63	14.269	0	1,147.63	2295.26	0.5[illegible]

INFLUENCE LINE VALUES FOR M_c

Δ_s	a	$\sum x/I$	$\sum 1/I$	$a \sum 1/I$	$\sum \frac{x}{I} - a \sum \frac{1}{I}$	$\frac{\sum \frac{x}{I} - a \sum \frac{1}{I}}{2 \sum \frac{1}{I}}$	$H_c y_c$	M_c
1	121	0.924	0.0076	0.9196	0.004	0.0065	0.0000	+0.0065
			0.0118					
2	114	2.271	0.0194	2.2116	0.059	0.1262	0.3009	-0.1147
			0.0176					
3	105	4.103	0.0363	3.8[illegible]	[illegible]	0.46[illegible]	1.1761	-0.688[illegible]
			0.0231					
4	95	6.[illegible]	0.0[illegible]	5.[illegible]45	[illegible].428	0.7160	1.8325	-0.9165
			0.0[illegible]9					
5	84	8.415	0.08[illegible]	7.30[illegible]	1.107	2.3624	4.9683	-2.4669
			0.02[illegible]5					
6	71	10.355	0.1145	8.1295	2.225	4.7624	7.7127	-2.9503
			0.0282					
7	57	[illegible]767	0.1427	8.1339	3.633	8.2641	10.6665	-2.4624
			0.0[illegible]					
8	42	13.[illegible]7	0.1719	7.2198	5.977	12.7932	13.4189	-0.6358
			0.0303					
9	26	13.9[illegible]	0.2022	5.2572	8.729	15.65[illegible]	15.5622	+3.1214
			0.0214					
10	9	14.269	0.[illegible]	2.1024	12.167	26.[illegible]423	16.7382	+9.3041
CR.	0	14.269	0.23[illegible]	0	14.269	30.5415	16.7382	+13.9033

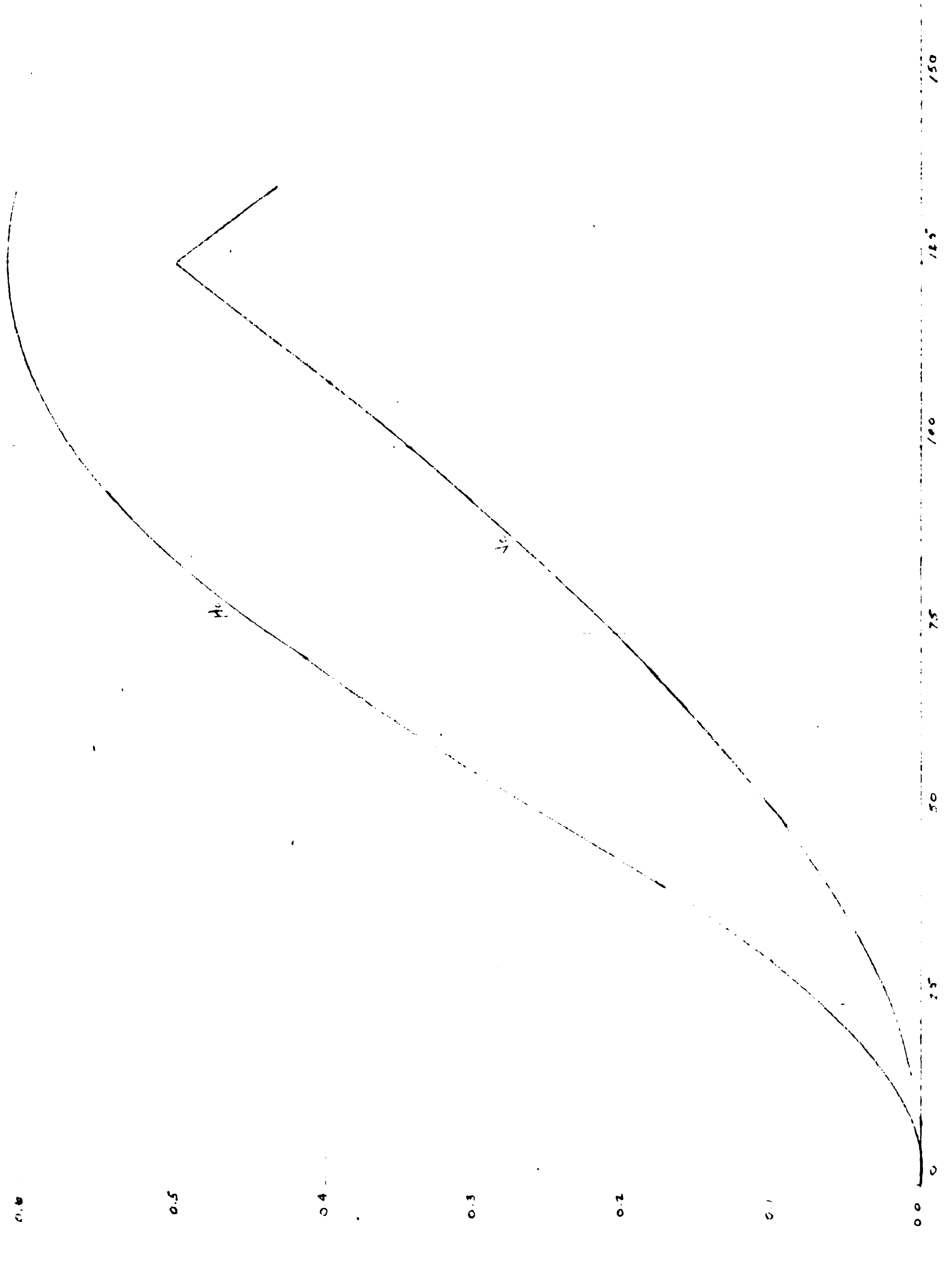
Influence Line Values for N_s

Load Point	H_c	$H_c \times \cos\phi_s$	$\sin\phi_s (1-V_c)$	$\sin\phi_s \cdot V_c$	N_s	Δ_s
.97	0.000	0.0000	0.9100		0.9100	1
.94	0.011	0.0046	0.9075		0.9121	2
.84	0.043	0.0178	0.8993		0.9171	3
.76	0.079	0.0411	0.8831		0.9242	4
.67	0.178	0.0738	0.8559		0.9297	5
.57	0.282	0.1169	0.8125		0.9294	6
.46	0.390	0.1617	0.7551		0.9168	7
.34	0.491	0.2036	0.6840		0.8876	8
.21	0.569	0.2360	0.6402		0.8762	9
.07	0.612	0.2538	0.5060		0.7598	10
Crown	0.612	0.2538	0.4[illegible]	-0.4550	0.7058	Crown
.07	0.612	0.2538		-0.4040	0.6578	10'
.21	0.569	0.2360		-0.3098	0.5458	9'
.34	0.491	0.2036		-0.2660	0.4296	8'
.46	0.390	0.1617		-0.1549	0.3166	
.57	0.282	0.1169		-0.0975	0.2144	6'
.67	0.178	0.0738		-0.0541	0.1279	5'
.76	0.099	0.0411		-0.0269	0.0680	4'
.84	0.043	0.0178		-0.0107	0.0285	3'
.94	0.011	0.0046		-0.0025	0.0071	2'
.97	0.000	0.0000		0.0000	0.0000	1'

INFLUENCE LINE VALUES FOR M_s

LOAD Pt.	M_c	$h \cdot H_c$	$l/2 \times V_c$	$-1(l/2 - a)$	M_s	A_s
.07	-0.00[illegible]	0.00	0.00	-4.00	-3.99	1
.31	[illegible].1747	[illegible]10	0.35	-11.00	-9.37	2
.64	-0.[illegible]	4.30	1.46	-20.00	-15.55	3
[illegible]	-0.316[illegible]	[illegible]	[illegible]69	-30.00	-15.49	4
.67	-2.4669	[illegible]	7.43	-41.00	-13.30	5
.57	-2.9503	[illegible]	13.39	-54.00	-9.46	6
.46	-2.46[illegible]	39.[illegible]	21.26	-66.00	-5.26	7
.4	-0.[illegible]6	49.[illegible]	[illegible]5	-83.00	-2.21	8
21	+3.[illegible]14	56.90	42.55	-99.00	+3.57	9
[illegible]	+[illegible]	61.20	[illegible]	-116.00	+10.00	10
CROWN	+13.8093	61.20	[illegible]	-125.00	+12.50	CRN
.07	+9.3041	61.[illegible]	-55.50		+15.00	10'
.21	+3.[illegible]14	[illegible]	-42.55		+17.47	9'
.34	-0.6456	[illegible]	-31.05		+18.69	8'
.46	-2.4624	[illegible]	-21.28		+20.18	7'
.57	-2.9503	28.[illegible]	-13.39		+17.76	6'
.67	-2.4689	17.80	-7.43		+12.84	5'
.76	-0.[illegible]65	9.00	-3.69		+7.15	4'
.84	-0.6[illegible]	4.30	-1.46		+3.53	3'
.91	-0.1747	1.10	-0.35		+0.93	2'
.97	+0.0065	[illegible]	0.00		+0.0065	1'

INFLUENCE LINE FOR H_c & V_c



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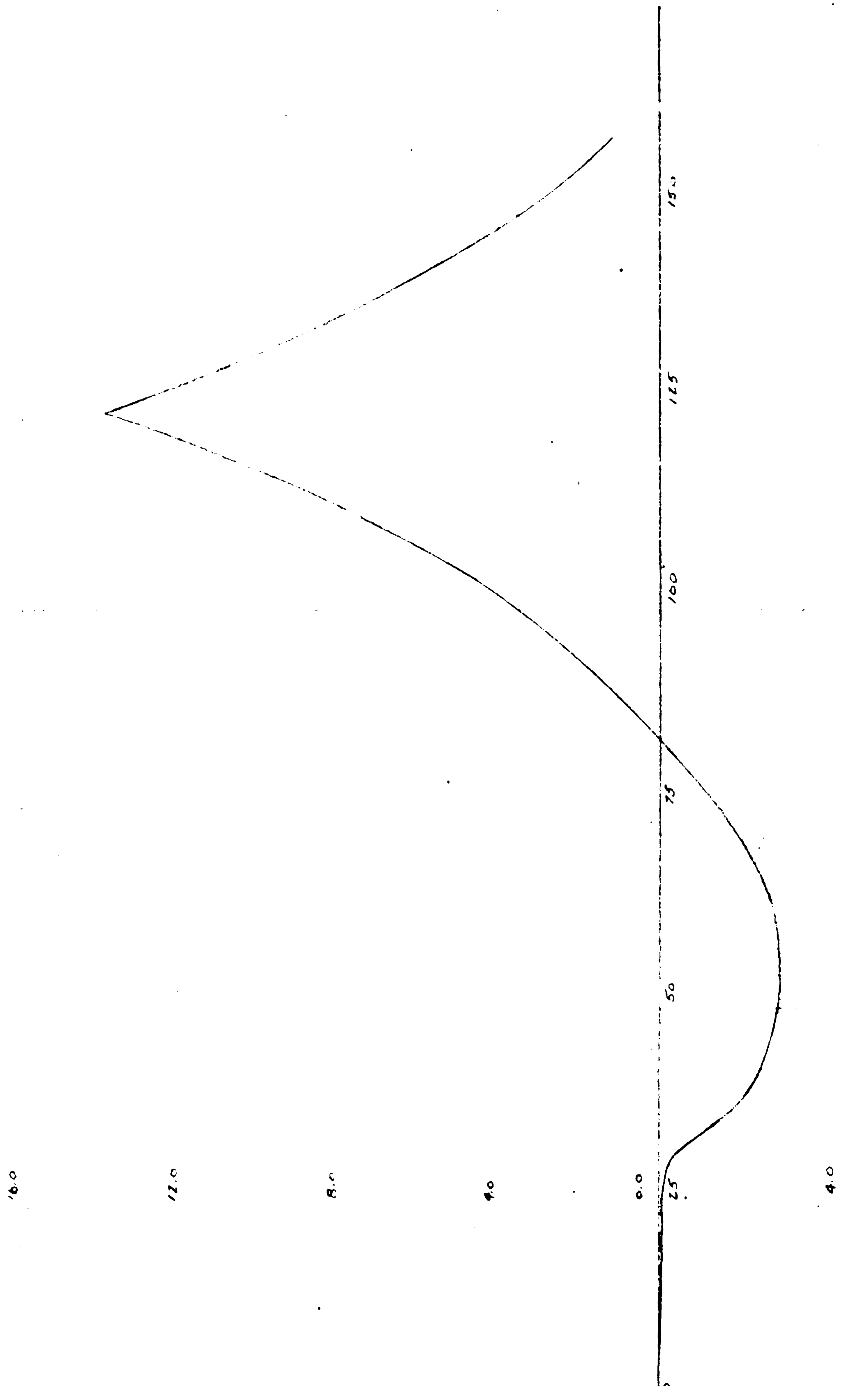
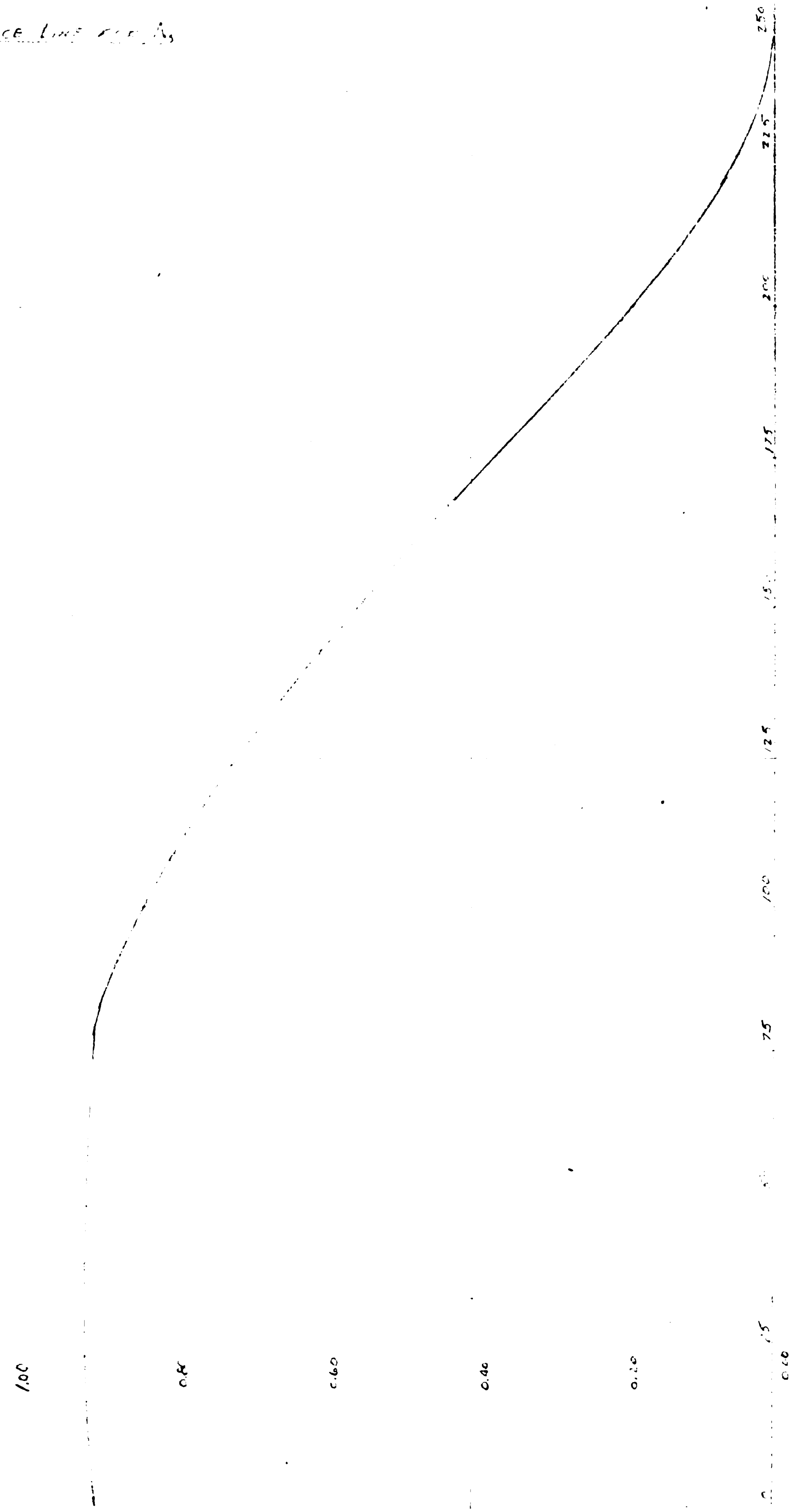
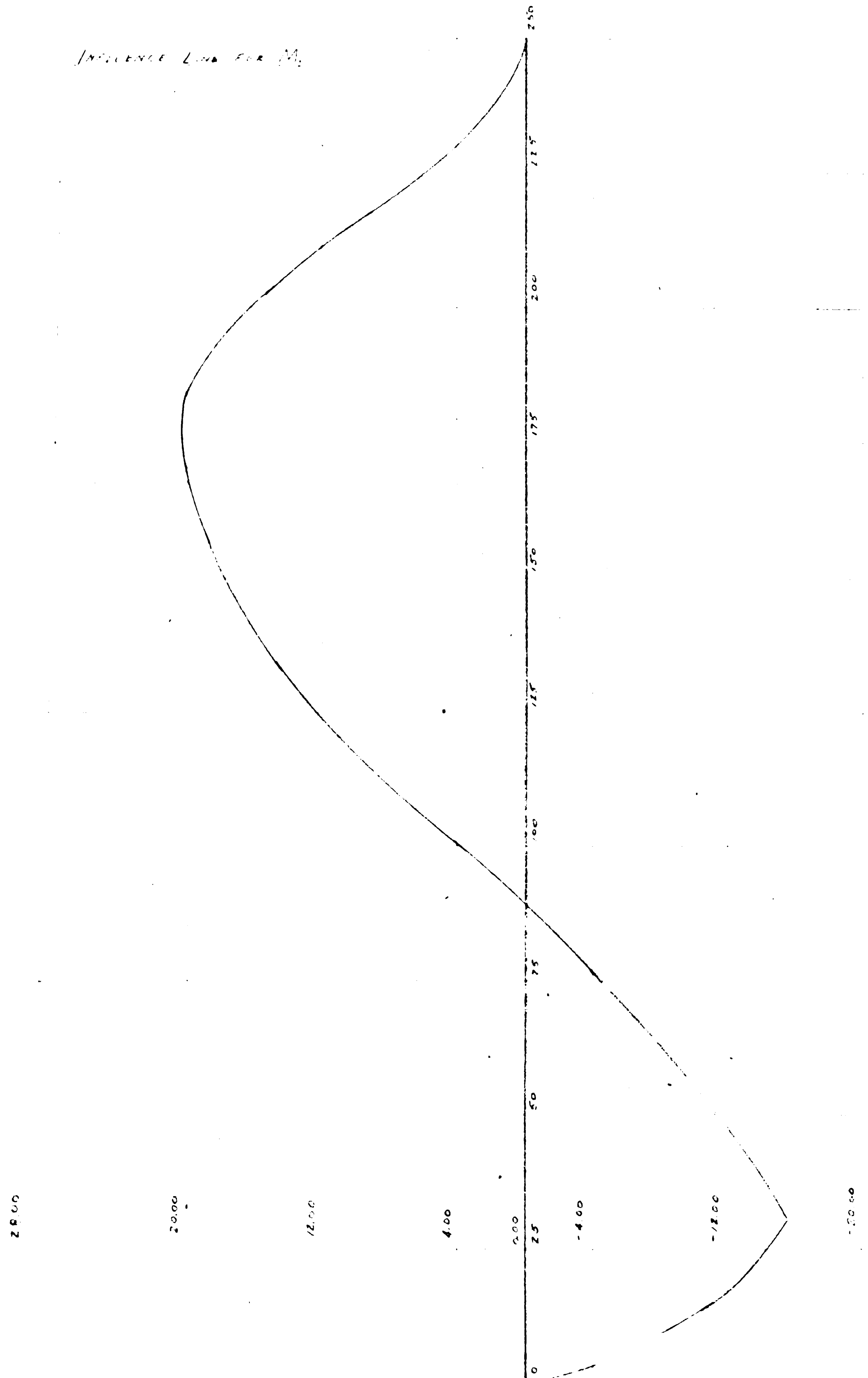
INFLUENCE LINE FOR M_c



INFLUENCE LINE FOR R_3



INFLUENCE LINE FOR M



MOMENTS OF DEAD LOAD OF ARCH AT CROWN

Δ_s	Mom. Arm.	Total D.L.	$M_om.$	Total M_om M_L	M_L/I	y	$M_L y/I$
10	0	37,800	0	0	0	+26.85	0
9	17.0	38,751	642,600	642,600	19,470	+24.35	474,094
8	16.0	76,551	1,216,816	1,859,416	54,294	+19.65	1,034,300
		38,702					
7	15.0	114,753	1,721,295	3,580,711	100,976	+11.35	1,146,077
		39,213					
6	14.0	153,966	2,154,684	5,735,395	157,723	+2.35	370,649
		39,544					Σ +3,025,120
5	13.0	193,510	2,515,630	8,251,025	213,701	-5.05	-1,669,888
		40,780					
4	11.0	23[illegible]	2,571,690	10,822,715	261,909	-22.45	-5,879,857
		4[illegible]					
3	[illegible]	276,093	2,760,990	13,583,705	237,714	-36.55	-8,688,446
		45,[illegible]					
2	[illegible]	322,090	2,898,810	16,482,515	194,493	-50.[illegible]	-9,851,670
		52,379					
1	7.0	374,469	2,621,263	19,103,738	145,188	64.05	-9,[illegible]
		60,570					Σ -35,[illegible]
							+ 3,025,120
TOTAL		435,039			1,385,468		-32,694,096

DEAD LOAD OF ARCH VALUES

$$H_c = \frac{-\Sigma \frac{(m_L + m_R)\, y}{I}}{2\Sigma \frac{y^2}{I} + 2\Sigma \frac{1}{A}} = \frac{2 \times 37{,}624{,}096}{2(154.18 + .5861)} = 211{,}243^{\#}$$

$V_c = 0$

$$M_c = \frac{\Sigma \frac{(m_L + m_R)}{I}}{2\Sigma \frac{1}{I}} - H_c y_c = \frac{2(1{,}385{,}466)}{2(0.2336)} - 211{,}243(27.35) = 153{,}545 \text{ FT}^{\#}$$

$$N_s = H_c \cos\phi_s + W_T \sin\phi_s = 211{,}243(.4147) + 435{,}039(.9100) = 483{,}487^{\#}$$

$$M_s = -W_T(47) + H_c h - M_c = -435{,}039(47) + 211{,}243(100) - 153{,}545 = 818{,}922 \text{ FT}^{\#}$$

VALUES FOR TEMP. FALL OF 40°F

$$H_c = \frac{-t_c\, t_p\, F}{\Sigma \frac{y^2}{I} + \Sigma \frac{1}{\mu}} = \frac{.0000056 \times 40 \times 30 \times 10^6 \times 144}{154.77} = 6{,}700^{\#}$$

$$M_c = -H_c y_c = (-)-6{,}700(27.35) = +183{,}245 \text{ FT}^{\#}$$

$$N_s = H_c \cos\phi_s = 6{,}700(.4147) = 2{,}779^{\#}$$

$$M_s = H_c h + M_c = 6{,}700(100) + 183{,}245 = 853{,}245 \text{ FT}^{\#}$$

VALUES FOR SHRINKAGE AND FLOW

$$H_c = \frac{1361 \times 10^{-6} \times 750{,}000 \times 144}{154.77} = -945^{\#}$$

$$M_c = 0 - (-945)(27.35) = 25{,}845 \text{ FT}^{\#}$$

$$N_s = 945(.4147) = -391^{\#}$$

$$M_s = -94{,}500 + 25{,}845 = -68{,}655 \text{ FT}^{\#}$$

Summary

H_c

Spandrel	D.L. Super	L.L.	Inf. Crd	H_c D.L.	H_c L.L.
E	179,950	12,600	0.056	10,770	716
D	140,600	46,600	0.250	35,200	12,200
C	119,875	10,752	0.440	52,745	4,730
B	107,050	14,848	0.569	60,911	8,450
A	103,000	46,600	0.612	63,036	28,600
B'	107,050	14,848	0.569	60,911	8,450
C'	119,875	10,752	0.440	52,745	4,730
D'	140,600	46,600	0.250	35,200	12,200
E'	179,950	12,600	0.056	10,770	716
Total				382,288	+ 46,700 − 35,292

M_c

Spandrel	D.L. S.F.	L.L.	Inf. Crd.	M_c D.L.	M_c L.L.
E	[illegible]	12,6[illegible]	−0.7881	−141,800	−10,100
D	[illegible]	30,600	−2.7563	−367,247	−84,000
C	[illegible]	[illegible]	−1.8624	−223,255	−20,000
B	107,050	14,848	+3.4124	+365,297	+50,600
A	103,000	30,600	+13.8033	+1,421,739	+425,000
B'	107,050	14,848	+3.4124	+365,297	+50,600
C'	119,875	10,752	−1.8624	−223,255	−20,000
D'	140,600	30,600	−2.7563	−367,247	−84,000
E'	179,950	12,600	−0.7881	−141,800	−10,100
Total				+647,741	+ 520,2[illegible] − 411,000

N_s

Spandrel	D.L. Super	L.L.	Inf. Crd	N_s D.L.	N_s L.L.
E	179,950	48,600	0.9171	165,014	+ 44,600
D	140,600	12,600	0.9304	130,859	+ 11,900
C	119,875	12,600	0.9078	108,822	11,400
B	107,050	12,600	0.8361	89,5[illegible]	[illegible]
A	103,000	12,600	[illegible]	73,[illegible]6	9,[illegible]
B'	107,050	12,600	0.5418	58,417	7,000
C'	119,875	48,600	[illegible]	44,0[illegible]	17,9[illegible]
D'	140,600	12,600	0.1800	25,344	[illegible]
E'	179,950	12,600	0.0475	8,547	6[illegible]
Total				[illegible]	+ 47,[illegible] − 15,300

SUMMARY CONT

M_s

SPANDREL	DL SUPER	L.L.	INF ORD	M_s D.L.	M_s LL.
E	179,950	30,600	-14.25	-2,564,428	-438,000
D	140,500	12,800	-10.92	-1,537,[illegible]	-140,000
C	119,825	12,800	-4.70	-563,412	-[illegible]
B	107,050	12,800	+3.57	+3[illegible],168	+45,600
A	105,000	12,800	+12.50	+1,267,500	+160,000
B	107,050	12,800	+17.47	+1,8[illegible],163	+223,000
C	119,825	30,600	+19.68	+2,3[illegible],140	+605,000
D	140,800	12,800	+16.12	+2,269,63[illegible]	+[illegible]
E	179,950	12,800	+6.50	+1,169,675	+83,000
TOTAL				+4,[illegible]	+1,319,000 638,[illegible]

CROWN

		THRUST	MOM	ACTUAL STR	ALLOWABLE
+M	DEAD	593,531	+2,[illegible]		
	LIVE	46,[illegible]	526,200		
	ARCH S	-945	25,645		
	Σ	639,[illegible]	2,[illegible]	[illegible]	[illegible]
	TEMP FALL	-6,[illegible]	183,245		
	Σ	633,[illegible]	[illegible]	[illegible]	[illegible]
-M	D.	593,531	+551,250		
	L.	35,292	-411,[illegible]		
	A.S.	-9[illegible]	+25,645		
	Σ	[illegible]	+416,[illegible]	[illegible]	[illegible]
	TEMP	+6,[illegible]	[illegible]127,[illegible]		
	Σ	63[illegible]	+2[illegible]	[illegible]	[illegible]

SPRINGING

		THRUST	MOM	ACTUAL STR.	ALLOWABLE
+M	D	1,167,075	+5,[illegible]		
	L.	47,5[illegible]	319,[illegible]		
	A.S.	-331	[illegible]		
	Σ	+1,234,254	[illegible]	[illegible]	[illegible]
	T	+2,779	[illegible]		
	Σ	+1,237,033	+6,94[illegible]	1,2[illegible]	[illegible]
-M	D	+1,167,075	[illegible]		
	L	68,300	-6[illegible],000		
	A.S.	-391	-68,[illegible]		
	Σ	1,255,000	+3,4[illegible]	[illegible]	[illegible]
	T	+2,779	-852,[illegible]		
	Σ	1,257,779	+3,576,[illegible]	810	[illegible]

DESIGN OF RIB STRUTS

$M = 3,849,000 \text{ IN}^{\#}$

ASSUME THAT STRUT TAKES HALF OF MOM. AND THAT THE REST IS TAKEN BY THE ARCH RIB.

ASSUME $b = 15"$, $w = 470^{\#}/FT.$ $\qquad M_{DL} = \frac{470 \times 32^2}{8} = 720,000 \text{ IN}^{\#}$

$$d = \left(\frac{1,924,500 + 720,000}{15 \times 248}\right)^{1/2}$$

$d = 27"$ $\qquad t = 30"$

CHECK OF ASSUMED W

$$W = \frac{30 \times 15}{144} \times 150 = 470^{\#}/FT \quad \therefore OK$$

$$A_S = \frac{2,695,000}{16,000 \times .875 \times 27"} = 7.12 \text{ IN}^2$$

USE 9 #8 BARS

CONCLUSION

The design of the arch is not complete as the stresses at the crown were found to be a little larger than the allowable. This can be remedied by the use of a larger per cent of steel or by increasing the section at the crown. In the preliminary analysis it seemed that the section at the springing was going to be the trouble spot but in this instance the crown was the critical section and this did not show up in the preliminary analysis.

The temperature and arch shortning stresses were relatively small due to the large rise in this design.

This bridge was not a problem in economic design but rather it was a problem in design procedure.

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