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Superstructure costs of short span self-anchored suspension bridges

David J. Peery

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Superstructure Costs of Short Span Self-anchored Suspension Bridges

by

David J. Peery, B.S., M.S.E.

a

Thesis

Submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the requirements for the
Degree of

CIVIL ENGINEER

Pittsburgh, Pa.
1938

**********

Approved by .. .Joe B. Butler.

Professor of Civil Engineering
Acknowledgment

To Mr. Howard Mullins, for his valuable help and suggestions, the writer owes an expression of appreciation.
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Synopsis

Complete designs and estimates for three self-anchored highway suspension bridges are made in this paper. The span lengths investigated are commonly considered to be shorter than the economic limit for suspension bridges. Simple truss and cantilever bridges are usually considered the most economic types for these span lengths.

In the past twenty years a number of self-anchored suspension bridges have been built. These are of widely varied proportions and carry various kinds of loadings. Most of these bridges are designed to carry street-car loading, and thus have a high ratio of live load to dead load, which is less advantageous in a suspension bridge than in any other type. Consequently the economics of self-anchored suspension bridges for light highway loading are not very well known.

There have been only five self-anchored suspension bridges constructed in the Western Hemisphere. Three of these are almost identical, and carry two lines of street car tracks.

The bridges considered here are designed to meet the specifications of the American Association of State Highway Officials for H-15 loading. As the quantities and costs would vary considerably for different specifications, materials, and unit costs, they are more significant when compared with the quantities and costs of simple truss and
cantilever bridges designed for the same conditions. A comparison is here made with published data on more common types. The relative costs of the various types of bridges will remain essentially the same, even though the prices may fluctuate considerably. As substructure costs depend entirely on local conditions for each crossing, they are not considered here. However, for any particular location, part of the substructure cost will be proportional to the superstructure cost, and part of it will be constant regardless of the superstructure. The pier sizes for suspension bridges can be reduced because the loads are smaller, less bearing area is required, and only one shoe is required for each pier. Consequently, economic comparisons of types based on superstructure estimates only, will remain valid for comparisons of the total cost of the structure.

Introduction

History of Type

The self-anchored suspension bridge was probably originated by Josef Langer, an Austrian Engineer. Langer used this type of structure for his Wsowic Bridge on the Franz Joseph Railway, built in 1870. This bridge, however, had the cable anchored to the stiffening girder near the center of the main span, as well as at the ends. No other bridge has been constructed in this manner.
Charles Bender, an American engineer, patented the self-anchored suspension bridge in the United States in 1867. Bender's patent drawing shows the cable anchored near the middle of the side spans. No bridge of this type was constructed, however, probably because the theory of the stiffening truss was not very well developed at that time. The stiffening truss of an external anchored suspension bridge is not a major stress carrying member, and many trusses on this type of bridge were first designed by guess and later replaced with heavier trusses when failure occurred. The failure of the stiffening truss of a self-anchored bridge would result in the collapse of the structure, and consequently an accurate method of analysis of the truss was necessary before bridges of this type could be built.

Existing Bridges

The general dimensions of existing self-anchored suspension bridges can be conveniently arranged in tabular form. Table I is a chronological and geographical list of the bridges which have been constructed. Several other self-anchored suspension bridges are proposed or under construction at the present time (1938).

Most of the European bridges listed in Table I carry street cars as well as highway loading. The Sixth, Seventh, and Ninth Street bridges in Pittsburgh are designed for two lanes of 18-ton trucks and two lines of 60-ton street cars.
<table>
<thead>
<tr>
<th>Name and Location</th>
<th>Year Built</th>
<th>River</th>
<th>Length, Ft</th>
<th>Side Span, Ft</th>
<th>Main Span, Ft</th>
<th>Seg of Suspension Member, Ft</th>
<th>Suspension Member</th>
<th>Depth of Stiffening Member, Ft</th>
<th>Stiffening Member</th>
<th>Towers</th>
<th>Side Span Condition</th>
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</thead>
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<tr>
<td>Mühlenthal, Lubeck, Germany</td>
<td>1899</td>
<td>Elbe- Trave</td>
<td>137.75</td>
<td>64.51</td>
<td>103.19</td>
<td>Riveted</td>
<td>4.30</td>
<td>Continuous Truss</td>
<td>Rocker</td>
<td>Loaded</td>
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<td>Nesperfeld, Austria</td>
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<td>March</td>
<td>118.11</td>
<td>68.89</td>
<td>49.12</td>
<td>Riveted</td>
<td>5.62</td>
<td>Continuous Truss</td>
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<td>Rhine</td>
<td>605.18</td>
<td>302.59</td>
<td>277.59</td>
<td>Eyeplate</td>
<td>10.50</td>
<td>Continuous Girders</td>
<td>Rocker</td>
<td>Loaded</td>
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<td>Lippstadt, Germany</td>
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<td>Lippe</td>
<td>181.07</td>
<td>37.72</td>
<td>114.20</td>
<td>Riveted</td>
<td>7.18</td>
<td>Continuous Girders</td>
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<tr>
<td>Admiral Scheer, Berlin Germany</td>
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<td>Spree</td>
<td>315.95</td>
<td>121.07</td>
<td>124.88</td>
<td>Eyeplate</td>
<td>19.69</td>
<td>Continuous Girders</td>
<td>Rocker</td>
<td>Loaded</td>
<td></td>
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<tr>
<td>Forst, Germany</td>
<td>1927</td>
<td>Nesse</td>
<td>129.89</td>
<td>64.94</td>
<td>64.94</td>
<td>Eyeplate</td>
<td>14.04</td>
<td>Continuous Girders</td>
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<td>Köln-Mülheim, Köln, Germany</td>
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<td>1,039.46</td>
<td>298.65</td>
<td>740.81</td>
<td>Prestressed Laminated Wire Strands</td>
<td>19.69</td>
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<td>Rocker</td>
<td>Loaded</td>
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<td>Save</td>
<td>855.31</td>
<td>244.07</td>
<td>611.24</td>
<td>Prestressed Laminated Wire Strands</td>
<td>14.04</td>
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<td>Rocker</td>
<td>Loaded</td>
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</table>

**ASIA BRIDGES**

<table>
<thead>
<tr>
<th>Name and Location</th>
<th>Year Built</th>
<th>River</th>
<th>Length, Ft</th>
<th>Side Span, Ft</th>
<th>Main Span, Ft</th>
<th>Seg of Suspension Member, Ft</th>
<th>Suspension Member</th>
<th>Depth of Stiffening Member, Ft</th>
<th>Stiffening Member</th>
<th>Towers</th>
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<tr>
<td>Kyowou, Tokyo, Japan</td>
<td>1928</td>
<td>Sumida</td>
<td>300.00</td>
<td>150.00</td>
<td>42.00</td>
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<td>8.5</td>
<td>Three-hinged Girders</td>
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<td>Loaded</td>
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**AMERICAN BRIDGES**

<table>
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<tr>
<th>Name and Location</th>
<th>Year Built</th>
<th>River</th>
<th>Length, Ft</th>
<th>Side Span, Ft</th>
<th>Main Span, Ft</th>
<th>Seg of Suspension Member, Ft</th>
<th>Suspension Member</th>
<th>Depth of Stiffening Member, Ft</th>
<th>Stiffening Member</th>
<th>Towers</th>
<th>Side Span Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seventh St, Pittsburgh, Pa</td>
<td>1926</td>
<td>Allegheny</td>
<td>442.08</td>
<td>221.36</td>
<td>221.36</td>
<td>Eyebars</td>
<td>3.21</td>
<td>Continuous Girders</td>
<td>Rocker</td>
<td>Loaded</td>
<td></td>
</tr>
<tr>
<td>Ninth St, Pittsburgh, Pa</td>
<td>1927</td>
<td>Allegheny</td>
<td>430.00</td>
<td>215.00</td>
<td>215.00</td>
<td>Eyebars</td>
<td>9.04</td>
<td>One Fixed Girders</td>
<td>Loaded</td>
<td>do</td>
<td></td>
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<tr>
<td>Sixth St, Pittsburgh, Pa</td>
<td>1928</td>
<td>Allegheny</td>
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<td>215.00</td>
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<td>Eyebars</td>
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<td>112.50</td>
<td>112.50</td>
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<td>Two-hinged Girders</td>
<td>Fixed</td>
<td>Loaded</td>
<td></td>
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</table>

*Table compiled by Mr. Howard Mullins*
Method of Design

Notation

$H = \text{horizontal component of cable stress due to live load.}$

$H_w = \text{horizontal component of cable stress due to dead load.}$

$w = \text{dead load in pounds per foot per cable.}$

$M' = \text{bending moments (in the stiffening truss) under given loads, for } H = 0.$

$M = \text{bending moments (in the stiffening truss) with zero loading, for } H = 1.$

$\sigma_c = \text{direct stress in cable for } H = 1.$

$\sigma_t = \text{direct stress in truss for } H = 1.$

$E_c = \text{modulus of elasticity of cable material.}$

$E = \text{modulus of elasticity of stiffening truss material.}$

$A_c = \text{area of cross-section of cable.}$

$A = \text{area of cross-section of stiffening truss.}$

$I = \text{moment of inertia of stiffening truss in main span.}$

$I_s = \text{moment of inertia of stiffening truss in side spans.}$
\[ \theta = \text{angle that the tangent to the cable at any point makes with the horizontal} \]

The notation for the general dimensions of the structure is evident from Fig. 1. Subscripts \( (L_i, f_i, x_i, h_i, \text{ etc.}) \) denote side span terms. The following notation will also be used for constants which appear frequently in equations:

\[ i = \frac{F}{L_i} \quad r = \frac{L_i}{L} \quad F = f + h' \quad F_i = f_i + h'_i \]

\[ v = \frac{F_i}{F} \quad y' = y + h = \frac{4F_i x_i}{L_i^2} (L - x) \]

\[ n = \frac{f}{L} \quad n_i = \frac{f_i}{L_i} \quad y_i' = \frac{4F_i x_i}{L_i^2} (L_i - x_i) \]

\[ e = \frac{2 + 2irn}{3 + 2ir} \]

**Effect of Deflections**

Suspension bridges with external anchorages, unlike most engineering structures, deflect enough to appreciably change the moment arms of the forces acting. In an accurate analysis, these deflections are considered, and the analysis is thus made more difficult. Because of this effect of deflections, deformations are not proportional to loads, and the common methods of superposition and influence lines cannot be used.

The deflections of self-anchored suspension
bridges are also large. However, if a vertical section is passed through the cable and stiffening truss at any point, the horizontal components of stress in the cable and stiffening truss form a couple, the value of which is not affected by deflections.

Fig. 2.

In Fig. 2, the bending moment at any point $A$, will be,

$$ M_A = M' + Hm - (H + H_w)\gamma + (H + H_w)\gamma $$ (1)

or

$$ M_A = M' + Hm $$ (2)

The deflection, $\gamma$, cancels out of the moment equation, as does the dead load cable stress, $H_w$. Therefore, the changes in moment arms caused by deflections may be disregarded, and the live load stresses may be computed separately and superimposed on the dead load stresses. Influence lines can also be used for self-anchored suspension bridges.

Equation (1) has another significance. The stiffening girder functions as a long column carrying a
compression of $H + H_w$. If it were not attached to the
cable, it would tend to buckle vertically from the moment
$(H + H_w)\gamma$, the last term in Equation (1). This tendency
to buckle vertically is counteracted by the cable, as shown
by the fact that this term vanishes from Equation (1).

The bending moment at any point in the stiffen-
ing truss of an external-anchored suspension bridge would
be represented by the equation,

$$M_A = M' + HM - (H + H_w)\gamma.$$  
(3)

The last term of Equation (3) represents the effect of
deflections in reducing bending moments. Since this term
does not appear in Equation (2) for a self-anchored sus-
pension bridge, the bending moments will be larger than for
a similar external-anchored suspension bridge. This dis-
advantage in the self-anchored type is partially offset
by cambering the stiffening girder, and thus reducing the
bending moments.

**Design Equations**

The self-anchored suspension bridge with contin-
uous stiffening truss is statically indeterminate to the
third degree. If the cable is removed, the resulting

![Fig. 3.]

structure is a continuous girder over three spans. If $M_o$
is the bending moment in a beam simply supported at the
towers, and \( M_2 \) and \( M_3 \) are the bending moments in the
girder at the towers, it is seen from Fig. 3 that the
bending moment at any point a distance \( x \) from the end of
the main span is found from the equation,

\[
M' = M_0 + M_2 + \frac{x}{L}(M_3 - M_2)
\]

(4)

In the left side span the equation becomes,

\[
M'_L = M_0 + \frac{x}{L} M_2
\]

(5)

For the right side span the equation is,

\[
M'_R = M_0 + \frac{x}{L} M_3
\]

(6)

The values of \( M_2 \) and \( M_3 \) as determined by using the
three-moment equation are substituted in Equations (4),
(5), and (6).

The bending moment, \( m \), in the stiffening girder
developed by a unit \( H \), is made up of a uniform suspender
pull in each span and of the bending moment caused by the
parabolic camber. These loads are shown in Fig. 4, and
the corresponding bending moment diagram is shown in Fig. 5.

![Fig. 4.](image)

From Fig. 5, the bending moment at any point a distance \( x \)
Fig. 5.

from the end of the main span is,

\[ m = -y' + eF \]  \hspace{1cm} (7)

At any point a distance \( x_i \) from the end of the side span, the bending moment is

\[ m_i = -y_i' + \frac{x_i}{L_i} eF \]  \hspace{1cm} (8)

The horizontal component of the cable stress, \( H \), for any loading, will be found from the equation,

\[
H = -\frac{\int^L M'm \, dx}{\int^L \frac{m^2}{EI} \, dx + \int^{s} \frac{u_s^2}{A_cE_c} \, ds + \int^{s} \frac{u_s^2}{AE} \, dx}
\]  \hspace{1cm} (9)

in which the limits of the integrations are taken over the entire structure. Substituting values from Equations (4) to (8), and evaluating the integrals, the following equation is obtained.

\[
H = \frac{\beta^2}{\beta - 4e + 3e^2 + 2i \left( \frac{L}{3} \xi^2 + e^2 \xi^2 \right)} \left[ \int_0^L M' \left( y' - eF \right) \, dx + \sum \int_0^{N_i} M_i \left( y_i' - \frac{x_i}{L_i} eF \right) \, dx_i \right]
\]
The denominator of Equation (10) is constant for any structure, being independent of the loading conditions. It is also a dimensionless number, containing only ratios. If this denominator is called $N$, and the numerator is evaluated for the case of a load $P$ in the main span at a distance $kL$ from the left tower, Equation (10) becomes,

$$H = \frac{P \theta}{NF} \left[ k \left( k^3 - 2k^2 + 1 \right) - \frac{3}{2} \sigma (k - k') \right] \quad (11)$$

For a load $P_1$ at a distance $k_1L_1$ from the outer end of the side span, Equation (10) becomes,

$$H = \frac{P \theta_1 n^2}{NF} \left[ n k_1 \left( k_1^3 - 2k_1^2 + 1 \right) - \frac{3}{2} \sigma (k_1 - k_1^3) \right] \quad (12)$$

In analyzing a self-anchored suspension bridge, influence lines for $H$ may be constructed from Equations (10), (11), and (12). Influence lines for bending moments at any point may be constructed from Equations (2), (4), (5), (6), (7), and (8).

**Cable Anchored to Chord of Truss**

The self-anchored suspension bridge with a stiffening truss will be analyzed by the preceding equations if the cable is anchored to the truss at the center of gravity of the truss section. Usually, however, it will be more convenient to anchor the cable to the lower chord of the stiffening truss. This will include an end moment of $-HCF$ in the above equations, where $CF$ is the distance from the
center of gravity of the truss to the point where the
cable is anchored (Fig. 6).

\[ \text{Fig. 6.} \]

Equation (7) will be changed by the bending moments shown in Fig. 7. The bending moment, \( m \), for a unit \( H \), will be

\[ m = -y' + (e+a)F \quad (13) \]

Equation (8) will be replaced by the equation

\[ m_i = -y_i' + \frac{x_i}{E_i} (e+a+c)F - cF \quad (14) \]

If the values from Equations (13) and (14) are substituted in Equation (9), the value of \( H \) for a load \( P \) in the main span at a distance \( hL \) from the left tower is obtained.

\[ H = \frac{P \ell}{E \frac{3 \tau}{2} \left( k^3 - 2k^2 + 1 \right) - \frac{3}{2} (e+a)(k^2-k^2)} \]

\[ \frac{\ell}{\frac{3 \tau}{2} - 4(e+a) + 3(e+a)^2 + 2ir\left[ \frac{4}{3} \sqrt{2 + (e+a)^2 - 2(e+a)v + c^2 - c(e+a) + c} \right] + \frac{E \frac{3 \tau}{2} \frac{E_i}{A_i} \sec^2 \alpha_i (1 + \phi_n^2)}{E \frac{3 \tau}{2} \frac{E_i}{A_i} F \frac{\ell}{A_i}}} \]

-11-
In designing the stiffening truss it will be more convenient to compute the direct stress in the lower chord, and the bending moment about the lower chord, than to use the above forms for the bending moment about the center of gravity of the truss section.

![Diagram](image)

\[ M_{Lc} = M + HcF \]

Fig. 9.

The bending moment shown in Fig. 8, in which \( H \) acts at the center of gravity of the truss section must be increased by the moment \( HcF \), as shown in Fig. 8. The bending moment at any point in the main span will then be

\[ M_{Lc} = M' - H\left[y' - (e + a + c)F\right]. \] (16)

For any point in the side span, the bending moment will be

\[ M_{Lc} = M' - H\left[y' - \frac{C}{x'(e + a + c)F}\right]. \] (17)
Designs and Estimates

Design Specifications

The self-anchored suspension bridges are designed according to "Standard Specifications for Highway Bridges," adopted by the American Association of State Highway Officials (A.A.S.H.O.), and published by the Association in 1935. The loading used is H-15 loading, consisting of a 15-ton truck preceded and followed by 11½-ton trucks on each traffic lane. For loaded lengths of 60 feet or greater, an equivalent loading is used, as given in the specifications.

The costs of simple span and cantilever bridges are computed from quantities published by Dr. J. A. L. Waddell. These quantity curves have been plotted from actual weights of hundreds of structures, and are probably the most reliable data of their kind available. The structures are designed for Dr. Waddell's specifications, which differ from the A.A.S.H.O. specifications in many respects. Dr. Waddell gives formulas for finding quantities in structures designed for other specifications.

The simple truss and cantilever spans were designed for a standard 8-inch reinforced concrete floor with 1-inch wearing surface, which weighs 110 lb. per sq. ft. and is estimated to cost $0.80 per sq. ft. The suspension bridges are designed for a 3-inch steel-concrete floor which weighs 47 lb. and is estimated to cost $1.25 per sq. ft.

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per sq. ft. Studies made by Dr. Waddell show that for the
span lengths considered here, the costs of simple truss
and cantilever bridges will be approximately the same for
the lighter, more expensive floor as for the heavier,
cheaper floor.¹

The estimates for simple trusses and cantilevers
are made for 20-foot roadways and for steel with a working
stress of 16,000 lb. per sq. in. The estimates for the
self-anchored suspension bridges are made for 22-foot
roadways and for a working stress of 18,000 lb. per sq. in.
Waddell gives the formula,²

\[ w' = w \left( 0.3 + 0.7 \frac{16,000}{18,000} \right) = 0.922 w \]  

(18)

for converting the weight, \( w \), based on a working stress
of 16,000 lb. per sq. in. to the weight, \( w' \), obtained
with a working stress of 18,000 lb. per sq. in. If the
weight for a wider structure is proportional to the width
of roadway, the weight of steel, \( w'' \), for a 22-foot road-
way would be

\[ w'' = 0.922 w \times \frac{22}{20} = 1.014 w \]  

(19)

Equation (19) shows that the effect of the
wider roadway compensates for the effect of the higher
working stress within an accuracy of 1.4%. As this error
is within the limits of the accuracy of the estimates, it

¹Waddell, J.A.L., "Economics of Highway-Bridge Floorings
will be disregarded, and the designs compared as if they were based on the same specifications.

The most important difference in the specifications by which the bridges were designed, is the magnitude of the live load. The H-15 loading is represented by an equivalent uniformly distributed load and a concentrated load. The uniformly distributed load is the same for all span lengths. Waddell's Class "A" loading is represented by an equivalent uniformly distributed loading, without a concentrated load.¹ The distributed load is greater for shorter span lengths and decreases for longer spans. Waddell's Class "A" loading probably gives higher stresses than H-15 loading for shorter span lengths, and approximately equal stresses for the longer spans considered here.

The working stress for prestressed wire strand cables is not given in the A.A.S.H.O. specifications. In the suspension bridge designs a working stress of 65,000 lb. per sq. in. is used. This is a conservative value for the working stress in this type of cable.

**Bridges with 240-foot Main Span**

The stress sheet for a self-anchored suspension bridge with a main span of 240 feet and side spans of 100 feet is shown in Fig. 10. These stresses are computed by Equations (4) to (12). The main cables are each composed of four 1½-inch galvanized bridge strands.

---

¹Waddell, J.A.I., "Bridge Engineering."
These strands are prestressed to increase the modulus of elasticity to 24,000,000 lb. per sq. in., and to eliminate inelastic action under load. The lengths of the strands for cables and suspenders are measured after restressing, and while the strands are carrying their dead-load tension. The cables and suspenders are socketed in the shoe, with no provision for adjusting the lengths in the field, except by shims between the sockets and bearing blocks of the main cable strands. The strands of the main cables are spaced in an open arrangement for convenience in inspecting and painting.

The stiffening girders are composed of 36-inch wide flange rolled sections, with cover plates where required. These girders are field spliced at several points. Structural plates are riveted to the girder webs and pass through slots in the upper flange to attach to the suspender sockets. The cable attaches to the stiffening girder at the end, through cast steel bearing blocks which bear on a 7\(\frac{1}{2}\)-inch pin through the girder web. The girder web is reinforced by bearing plates.

The roadway surface is composed of a 3-inch steel and concrete floor weighing 47 lb. per sq. ft. The stringers are spaced at 5'-0" centers, and the floorbeams are spaced at 20'-0" centers. As the economic panel length is determined by the floor and live load, it will be approximately the same for bridges of any span length. The floor systems are the same for all three suspension bridges designed in
this paper. Additional details of the stiffening girders and floor system are shown in Fig. 11.

The main tower columns are made up of rolled steel sections as shown in Fig. 12. The towers are of the rocker type, so that temperature stresses are eliminated. The reactions at the tower base are distributed to the pier masonry by rolled steel slabs. The rocker plates are also made of rolled slabs, which are machined to a cylindrical surface. The cable reaction is distributed to the top of the tower columns by cast-steel saddles.

The superstructure quantities and costs for the suspension bridge with 240-foot main span, as computed from the designs of Figs. 11 and 12, are as follows:

<table>
<thead>
<tr>
<th>Structural Steel</th>
<th>lb.</th>
<th>Cost @ $0.06=</th>
</tr>
</thead>
<tbody>
<tr>
<td>Towers</td>
<td>30,860</td>
<td>$27,700</td>
</tr>
<tr>
<td>Main Girders</td>
<td>219,460</td>
<td></td>
</tr>
<tr>
<td>Laterals</td>
<td>15,940</td>
<td></td>
</tr>
<tr>
<td>Floor System</td>
<td>154,500</td>
<td></td>
</tr>
<tr>
<td>Curb, rail</td>
<td>59,720</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>460,480</td>
<td>$27,700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cast Steel-- Saddles</th>
<th>lb.</th>
<th>Cost @ $0.18=</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,750</td>
<td>680</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pins and Nuts</th>
<th>lb.</th>
<th>Cost @ $0.10=</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,100</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1(^{3/4}) - in. Prestressed Strands</th>
<th>lb.</th>
<th>Cost @ $0.20=</th>
</tr>
</thead>
<tbody>
<tr>
<td>23,500</td>
<td>4,700</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1-in. Prestressed Strands</th>
<th>lb.</th>
<th>Cost @ $0.20=</th>
</tr>
</thead>
<tbody>
<tr>
<td>650</td>
<td>130</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1-1/8 in. Open Sockets</th>
<th>lb.</th>
<th>Cost @ $6.00=</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>170</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Special Open Sockets</th>
<th>lb.</th>
<th>Cost @ $10.00=</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>280</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sockets for Main Strands</th>
<th>lb.</th>
<th>Cost @ $6.25=</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>190</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cable Clamps</th>
<th>lb.</th>
<th>Cost @ $12.00=</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>460</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strand Spreader Clamps</th>
<th>lb.</th>
<th>Cost @ $50.00=</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strand Bearing Blocks</th>
<th>lb.</th>
<th>Cost @ $50.00=</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

Floor-3" Steel-Concrete 9680 sq.ft. @ $1.25= 12,100

Total Superstructure Cost $47,030
**SELF-ANCHORED SUSPENSION BRIDGE**

**SPANS 100'-240'-100'**

**LOADING** H-15

**DESIGNED BY** D.J. PEERY

**PITTSBURGH, PA. 1938**

---

**Panel Point**

<table>
<thead>
<tr>
<th>Panel Point</th>
<th>L0</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
<th>L5</th>
<th>L6</th>
<th>L7</th>
<th>L8</th>
<th>L9</th>
<th>L10</th>
<th>L11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dead Load</strong></td>
<td>H</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0</td>
<td>+3</td>
<td>+24</td>
<td>+65</td>
<td>+124</td>
<td>+203</td>
<td>+95</td>
<td>+5</td>
<td>-62</td>
<td>-110</td>
<td>-141</td>
<td>-151</td>
</tr>
</tbody>
</table>

| M  | 0   | +663 | +390 | +965 | +634 | +453 | 495 | +710 | +859 | +910 | +904 | +925 |

| Maximum Neg. Moment | H  | 415 | 401 | 401 | 401 | 327 | 370 | 363 | 355 | 320 | 295 | 261 |

**Note:** Stresses are in kips
Bending moments are in ft-kips

---

**ELEVATION OF SUPERSTRUCTURE**

**Cable:** 4-1/8" Galvanized prestressed strands

**Hangers:** 1-1/4" Galvanized prestressed strands

**Maximum Cable Stress**

DL 860

LL 310

Total 1170

---

**BENDING MOMENTS IN STIFFENING GIRDER**

**FIG 10**
FIG 11

SECTION THROUGH ROADWAY

SELF-ANCHORED SUSPENSION BRIDGE
SPANS 100'-240'-100' - LOADING H-15
DESIGNED BY D.J. PEERY
PITTSBURGH, PA. 1938
SELF-ANCHORED SUSPENSION BRIDGE
SPANS 100'-240'-100'
LOADING H-15
DESIGNED BY D.J. PEERY
PITTSBURGH, PA. 1938
This estimated cost will have more significance when compared with superstructure costs of simple span bridges designed for the same lengths and with the same unit prices. This span length is too short for a cantilever bridge to be economical. There are two simple span layouts which might be used, the choice being determined by local conditions. If piers can be placed at any point in the stream, three equal spans of 146'-8" might be used, as shown in Fig. 13. With this layout,

![Fig. 13.](image)

the weight of steel per foot of bridge will be 1970 lb.

The total quantities and costs will be as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Steel</td>
<td>66,000 lb</td>
<td>$0.06</td>
<td>$52,000</td>
</tr>
<tr>
<td>9&quot; Concrete Floor</td>
<td>9680 sq.ft</td>
<td>$0.90</td>
<td>7,740</td>
</tr>
<tr>
<td>Curbs</td>
<td>440 ft.</td>
<td>$3.60</td>
<td>1,590</td>
</tr>
<tr>
<td><strong>Total Superstructure Cost</strong></td>
<td></td>
<td></td>
<td><strong>$61,330</strong></td>
</tr>
</tbody>
</table>

For locations where it is important that the main span be long enough to give satisfactory foundations or clearance, the simple span arrangement would be as shown in Fig. 14. This arrangement of spans should be compared with the suspension bridge, as all the spans...
are the same lengths as the spans of the suspension bridge.

Fig. 14.

The quantities and costs of this bridge will be as follows:

- **Structural Steel** -- 936,000 lb. @ $0.06 = $56,200
- **9" Concrete Floor** -- 9680 sq.ft. @ $0.80 = 7,740
- **Curbs** -- 440 ft. @ $3.60 = 1,590

Total Superstructure Cost $65,530

**Bridges With 340-Foot Main Span**

The stress sheets for a self-anchored suspension bridge with a main span of 340 feet and side spans of 140 feet are shown in Figs. 15 and 16. These stresses are computed from Equations (13) to (17). The bending moments tabulated in Fig. 15 are about the lower chord, as computed from Equations (16) and (17). In Figure 16, the maximum positive and negative stresses for each member of the stiffening truss are given, and the sections designed to resist these stresses are shown.

The main cables are each composed of nine 1½-inch prestressed strands. The strands have a similar open arrangement to that used for the bridge with a 240-foot main span.
The bridge is stiffened by a truss having a depth of 6'-8" between centers of chords. The cable is anchored to the lower chord of the stiffening truss, since this chord is braced laterally, and is better able to resist compressive stress. However, part of this compressive stress is carried by the upper chord, as is evident from Figs. 6 and 7. The design equations for a bridge having the cable anchored to the lower chord of the stiffening truss will not be the same as for a bridge in which the cable is anchored at the center of gravity of the truss section.

The towers are similar in design to the towers for the bridge with 240-foot main span. Tower details are shown in Fig. 17. Details of the stiffening truss and suspender connections are shown in Fig. 18.

The superstructure quantities and costs for the 340-foot span suspension bridge are as follows:

<table>
<thead>
<tr>
<th>Structural Steel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Towers</td>
<td>71,600 lb.</td>
</tr>
<tr>
<td>Trusses</td>
<td>398,880 lb.</td>
</tr>
<tr>
<td>Laterals</td>
<td>35,010 lb.</td>
</tr>
<tr>
<td>Floor System, Curb &amp; Rail</td>
<td>250,000 lb.</td>
</tr>
<tr>
<td></td>
<td>755,490 lb. @ $0.06 = $45,300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Steel--Saddles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5,770 lb. @ $0.18 = 1,030</td>
<td></td>
</tr>
</tbody>
</table>

| 1 1/4-in. Prestressed Strands | 55,100 lb. @ $0.20 = 11,020 |
| P1ns and Nuts                | 2,500 lb. @ $0.10 = 250   |
| 1-in. Prestressed Strands    | 1,440 lb. @ $0.20 = 290   |
| Open Sockets (attached)      | 68 @ $7.00 = 620         |
| Sockets for Main Strands     | 36 @ $7.00 = 250         |
| Cable Clamps                 | 52 @ $15.00 = 780        |

Floor--3" Steel-Concrete 13,640 sq.ft. @ $1.25 = 17,060

Total Superstructure Cost $76,600
Cable: 9-1/4" Galvanized prestressed strands
Hangers: 1-1/" Galvanized prestressed strand

Maximum Cable Stress
BL. 439
L.L. 225
Total 744

Maximum Pos. Moment H 654 426 425 425 425 426 539 469 402 506 533 553 573 497 621 M 0 +300 +1480 +1770 +1370 +830 +390 680 +340 +1270 +1470 +1560 +1540 +1470 +1430
Maximum Pos. Shear +35 +24 +19 +19 +22 +25 +32 +59 +49 +42 +38 +34 +32 +30 +30 +33

Note: Stresses are in kips
Bending moments are in ft-kips

SELF-ANCHORED SUSPENSION BRIDGE
SPAN 140'-340'-140' - LOADING H-15
DESIGNED BY D.J. Peery
PITTSBURGH, PA. 1938
FIG 16

SELF-ANCHORED SUSPENSION BRIDGE
SPANS 140'-340'-440' - LOADING H-15
DESIGNED BY D.J. PEERY
PITTSBURGH, PA. 1938

Note: All vertical members 1OW-21
Stresses shown are in kips
Tension (+), Compression (-).
SELF-ANCHORED SUSPENSION BRIDGE
SPANS 140'-340'-140'
LOADING H-15
DESIGNED BY D.J. PEERY
PITTSBURGH, PA. 1938
SELF-ANCHORED SUSPENSION BRIDGE
SPANS 340'-340'-140' LOADING H-15
DESIGNED BY O.J. PEERY
PITTSBURGH, PA. 1938

SECTION THROUGH ROADWAY

TYPICAL TRUSS DETAILS

SPAN detail E

SPANS 140'-140'-140'
45° JOINT 25'-6"
End Tie Pk. 10'-6"
Int. Tie Pk 18'-3"-18"
The cost of a cantilever bridge for the same span lengths will be commuted. For a cantilever structure, silicon steel will be more economical than carbon steel. It is possible that some saving could also have been made in the cost of the suspension bridge by the use of silicon steel.

Fig. 19.

The quantities and costs for the cantilever shown in Fig. 19 will be as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Steel</td>
<td>712,000 lb.</td>
<td>@ $0.075</td>
<td>$53,400</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>475,000 lb.</td>
<td>@ $0.06</td>
<td>28,500</td>
</tr>
<tr>
<td>9&quot; Concrete Floor</td>
<td>13,640 sq.ft.</td>
<td>@ $0.80</td>
<td>10,920</td>
</tr>
<tr>
<td>Curbs</td>
<td>620 ft.</td>
<td>@ $3.60</td>
<td>2,230</td>
</tr>
</tbody>
</table>

Total Superstructure Cost $95,050

The cost of a simple span layout with the same span lengths will be estimated. The side spans will be

Fig. 20.
shorter than the economic limit for silicon steel and the cost of the main span will be approximately the same for carbon steel as for silicon steel. The estimate will therefore be made for carbon steel in the entire structure.

The quantities and costs for the bridge shown in Fig. 20 will be as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Steel</td>
<td>1,536,000 lb. @ $0.06</td>
<td>$92,200</td>
</tr>
<tr>
<td>9&quot; Concrete Floor</td>
<td>10,920</td>
<td></td>
</tr>
<tr>
<td>Curbs</td>
<td>2,230</td>
<td></td>
</tr>
<tr>
<td><strong>Total Superstructure Cost</strong></td>
<td></td>
<td><strong>$105,350</strong></td>
</tr>
</tbody>
</table>

The layout for three equal simple spans of the same total length as the above structure is shown in Fig. 21.

![Fig. 21.](image)

The quantities and costs are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Steel</td>
<td>1,366,000 lb. @ $0.06</td>
<td>$81,900</td>
</tr>
<tr>
<td>9&quot; Concrete Floor</td>
<td>10,920</td>
<td></td>
</tr>
<tr>
<td>Curbs</td>
<td>2,230</td>
<td></td>
</tr>
<tr>
<td><strong>Total Superstructure Cost</strong></td>
<td></td>
<td><strong>$95,050</strong></td>
</tr>
</tbody>
</table>

**Bridges with 480-foot Main Span**

The design of a self-anchored suspension bridge with a main span of 480 feet and side spans of 200 feet is shown in Figs. 22, 23, and 24. This structure is similar to the suspension bridge with a 340-foot main...
Cable: - 1/8" Galvanized pregressed strands
Hangers: - 1/8" Galvanized pregressed strands

Maximum Cable Stress
D.L. 860
L.L. 310
Total 1170

BENDING MOMENTS AND SHEARS IN STIFFENING TRUSS

| Panel Point | L0 | L2 | L4 | L6 | L8 | L10 | L12 | L14 | L16 | L18 | L20 | L22 | L24 | L26 | L28 | L30 | L32 | L34 | L36 | L38 | L40 | L42 | L44 |
|-------------|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Dead Load   | 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760| 760|
| H           | -8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 | +8 |
| M           | 0  | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 | -8 |
| Maximum     | 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080|
| Pos. Moment | 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020|
| Maximum     | 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080|
| Neg. Moment | 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020| 1020|
| Maximum     | 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080| 1080|
| Pos. Shear  | +63 | +57 | +41 | +32 | +32 | +27 | +27 | +34 | +44 | +55 | +75 | +65 | +58 | +53 | +49 | +46 | +43 | +40 | +38 | +37 | +38 | +41 |

Note: Stresses are in kips
Bending moments are in ft-kips

SELF-ANCHORED SUSPENSION BRIDGE
SPANS 200'-480'-200'- LOADING H-15
DESIGNED BY D. J. PEERY
PITTSBURGH, PA. 1938
FIG. 23

SELF-ANCHORED SUSPENSION BRIDGE
SPANS 200'-480'/200' LOADING H-15
DESIGNED BY D.J. PEERY
PITTSBURGH, PA. 1938

Note: All vertical members 12 W-25
Stresses shown are in kips
Tension (+) ; Compression (-).
FIG. 24

TOWER DETAILS

SELF-ANCHORED SUSPENSION BRIDGE
SPANS 200'-480'-200'
LOADING H-15
DESIGNED BY D.J. PEERY
PITTSBURGH, PA. 1938
span. The truss depth for the 480-foot main span is also 6'-8". This is sufficiently deep for this span length. For the 340-foot span a shallower truss would have been desirable, but this would have made it necessary to shorten the panel lengths or use an uneconomical slope for the diagonals. The main cables for the 480-foot span are each composed of twelve 1-5/8 inch prestressed strands.

The superstructure quantities and costs for the 480-foot span suspension bridge are as follows:

**Structural Steel**
- Towers: 123,860 lb.
- Trusses: 649,280 lb.
- Laterals: 68,000 lb.
- Floor System: 303,000 lb.
- Curb and Rail: 65,500 lb.
  
  Total Structural Steel: 1,406,640 lb. @ $0.06 = $84,400

**Cast Steel**
- Saddles: 8,990 lb. @ $0.18 = 1,600
- Pins and Nuts: 5,500 lb. @ $0.10 = 550
- 1-5/8 in. Prestressed Strands: 121,200 lb. @ $0.20 = 24,240
- 1-1/8 in. Prestressed Strands: 4,470 lb. @ $0.20 = 894
  
  Total Cast Steel: 126,744 lb. @ $0.20 = 25,348

**Open Sockets (attached)**
- 136 @ $8.00 = 1,088

**Cable Clamps**
- 74 @ $18.00 = 1,336

**Floor**
- 3" Steel-Concrete: 19,400 sq.ft. @ $1.25 = 24,250

**Total Superstructure Cost**
- $138,350

A cantilever bridge with the same span lengths will be more economical if built of silicon steel than if
built of carbon steel. The quantities and costs of a cantilever bridge layout as shown in Fig. 25 are as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Steel</td>
<td>1,430,000 lb</td>
<td>$0.045</td>
<td>$107,200</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>877,000 lb</td>
<td>$0.06</td>
<td>52,600</td>
</tr>
<tr>
<td>9&quot; Concrete Floor</td>
<td>19,400 sq.ft</td>
<td>$0.60</td>
<td>11,640</td>
</tr>
<tr>
<td>Curbs</td>
<td>880 ft</td>
<td>$3.60</td>
<td>3,170</td>
</tr>
</tbody>
</table>

Total Superstructure Cost $178,490

The simple span layout with the spans the same lengths as in the suspension bridge, is shown in Fig. 26.

The quantities and costs will be as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Steel</td>
<td>1,470,000 lb</td>
<td>$0.045</td>
<td>$110,000</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>900,000 lb</td>
<td>$0.06</td>
<td>54,000</td>
</tr>
<tr>
<td>9&quot; Concrete Floor</td>
<td></td>
<td></td>
<td>15,520</td>
</tr>
<tr>
<td>Curbs</td>
<td></td>
<td></td>
<td>3,170</td>
</tr>
</tbody>
</table>

Total Superstructure Cost $182,690

Fig. 26.

Fig. 27.
The quantities and costs of the simple span layout shown in Fig. 27, which consists of three equal spans of the same total length as the suspension bridge, will be as follows:

Silicon Steel -- 1,230,000 lb. @ $0.075 = $92,200
Carbon Steel -- 753,000 lb. @ $0.06 = 45,200
9" Concrete Floor 15,520
Curbs 3,170
Total Superstructure Cost 156,090

Summary and Conclusions
The costs of the structures which have been estimated are tabulated in Table II. The costs are

| Type                  | Spans (feet) | Superstr. Cost | Difference in Cost of Trusses and  \\
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Suspension Bridges Diff. %</td>
</tr>
<tr>
<td>Self-anchored Sus.</td>
<td>100-240-100</td>
<td>$47,030</td>
<td>--</td>
</tr>
<tr>
<td>Simple Spans</td>
<td>100-240-100</td>
<td>$65,530</td>
<td>$18,500 28.3%</td>
</tr>
<tr>
<td>Simple Spans</td>
<td>$61,330</td>
<td>$14,300</td>
<td>23.3%</td>
</tr>
<tr>
<td>Self-anchored Sus.</td>
<td>140-340-140</td>
<td>$76,600</td>
<td>--</td>
</tr>
<tr>
<td>Cantilever</td>
<td>140-340-140</td>
<td>$95,050</td>
<td>$18,450 19.4%</td>
</tr>
<tr>
<td>Simple Spans</td>
<td>140-340-140</td>
<td>$105,350</td>
<td>$28,750 27.3%</td>
</tr>
<tr>
<td>Simple Spans</td>
<td>$95,050</td>
<td>$18,450</td>
<td>19.4%</td>
</tr>
<tr>
<td>Self-anchored Sus.</td>
<td>200-480-200</td>
<td>$138,350</td>
<td>--</td>
</tr>
<tr>
<td>Cantilever</td>
<td>200-480-200</td>
<td>$178,490</td>
<td>$40,140 22.4%</td>
</tr>
<tr>
<td>Simple Spans</td>
<td>200-480-200</td>
<td>$182,690</td>
<td>$44,340 24.2%</td>
</tr>
<tr>
<td>Simple Spans</td>
<td>$156,090</td>
<td>$17,740</td>
<td>11.2%</td>
</tr>
</tbody>
</table>
FIG. 28. - SUPERSTRUCTURE COSTS OF HIGHWAY BRIDGES
Plotted for the various types and span lengths in Fig. 28. From the cost curves it is possible to determine the superstructure costs of bridges of other span lengths.

For unit prices other than those used in this investigation, the curves may be adjusted by multiplying by the ratio of the unit prices.

The above investigation shows self-anchored suspension bridges to have an economy of from 19.4% to 28.3% over cantilevers and simple trusses of the same span lengths. However, the validity of the cost estimates will depend somewhat on the location for which the bridge is designed. For locations where it is difficult to use falsework or a temporary anchorage for erection, a cantilever bridge might be more easily erected and hence the unit prices would be lower for the cantilever.

The quantities for the suspension bridges are believed to be correct within an accuracy of 3%. The greater accuracy obtained by completely detailing the structures would not be justified, as the variation in practice of different designers would introduce differences as great as this error. The economic proportions of self-anchored suspension bridges have not been thoroughly studied. It is possible that by varying the ratios of cable sag to span length, side span to main span, truss depth to span, or panel length to width, an additional economy may be obtained from self-anchored suspension bridges.
The recent use of self-anchored suspension bridges carrying light live loads shows economy which has not long been appreciated. The aesthetic advantages of suspension bridges have always been recognized, and have been responsible for the construction of several of the existing self-anchored bridges. The economic and aesthetic advantages of self-anchored suspension bridges should make this type of structure very popular in the future.
Bibliography

Books


Articles


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