ECONOMIC EVALUATION OF THE PROPOSED PRECAST-PRESTRESSED BRIDGE SYSTEM;
INTERIM REPORT.

MISSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 69-1

MISSOURI STATE HIGHWAY DEPARTMENT
UNIVERSITY OF MISSOURI - COLUMBIA
BUREAU OF PUBLIC ROADS
"ECONOMIC EVALUATION OF THE PROPOSED
PRECAST—PRESTRESSED BRIDGE SYSTEM"

Prepared for

MISSOURI STATE HIGHWAY DEPARTMENT

by

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in cooperation with

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Bureau of Public Roads.
ACKNOWLEDGMENT

This paper represents the final phase of a project sponsored by the Bureau of Public Roads and the Missouri State Highway Commission, and covers the economic evaluation of the system which was proposed and evaluated structurally in the first three phases of the project. Sincere appreciation is expressed to those organizations from whom cost information was obtained along with invaluable suggestions concerning modification of the channel cross sections and processing of the cost information. These organizations include Nebraska Prestressed Concrete Company, Prestressed Concrete of Iowa, Inc., Tobin Construction Company, Wilkerson Construction Company, and Wilson Prestressed Concrete Company.
ABSTRACT

Due to the favorable results of structural tests of the proposed system of precast-prestressed channels with a cast-in-place slab, it was apparent that a cost estimate was warranted. For comparison the Missouri Highway Department suggested that three specific bridges be used. These include a precast slab bridge with three 34-foot spans, a continuous composite I-beam bridge with spans of 35'-43'-35', and a continuous slab bridge with spans of 43'-70'-70'-43'. The design loading condition for all three structures was HL5-44.

For each of the three bridges, the proposed system was designed to replace the superstructures. The cost for the precast-prestressed channels were determined by contacting prestressed concrete producers in surrounding area. Likewise, labor costs, equipment requirements, forming requirements, etc., were determined by contacting bridge contractors in the area. This resulted in two estimation methods for determining the cost of the proposed superstructures.

The costs for the proposed superstructures were compared to the costs of the original superstructures which were obtained from the Missouri Highway Department. A significant savings was obtained for all three bridges, however, for the longer span bridge, the savings were noticeably increased.
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CHAPTER I

INTRODUCTION

1.1 GENERAL

In the design of any structural element, the final factor determining feasibility after structural requirements have been satisfied is the cost of the element. The structural engineer has always been concerned with finding the solutions to design problems which minimize the cost of an element while providing sufficient resistance to applied loading conditions. This is true, in particular, for the case of members used in highway bridges.

Extensive research has recently been conducted to determine a structurally feasible design for highway bridges using a system of precast-prestressed composite members (Figure 1.1). This system is proposed for use in bridge construction on primary and secondary roadways. The research conducted to date includes structural tests of full-scale and half-scale members and a one-half scale 18 foot span model bridge. (1,2,3)*

The system introduced by these studies consists of precast-prestressed channels placed side by side with a cast-in-place slab used for the roadway surface. The resulting sections contain voids produced by corrugated metal void forms in the shape of circular segments between the legs of the channel (Figure 1.1). The composite action of the precast-prestressed and cast-in-place concrete causes the system to behave

* Numbers in parenthesis refer to entries in the bibliography.
Figure 1.1 Proposed Composite Section
as continuous unit under the influence of live loads, although dead loads are carried by the simply supported channels alone.

A computer design program was presented for determining a number of acceptable sections with various depths, number of strands, and strand locations, leaving the final choice to the designer. (1) For this work, the design procedure was modified to consider two types of change in the design problem.

The first type of change was that necessary to account for the continuity introduced by the cast-in-place concrete slab under the action of live loads. This was necessary since the earlier designs were for beams of simple spans only. The design was modified to consider the following conditions.

1. The introduction of negative moments at supports.
2. The reduction of midspan moments due to a redistribution of moments.

The second type of change in design was necessitated by the addition of dead load and modification of section properties due to:

1. Additional overall slab thickness to insure sufficient resistance of the slab to applied loads. The slab depth was increased 3/4 inch over the original 4 inch depth of slab.

2. The addition of crown to the roadway by varying slab thickness across the cross-section. A crown of 3/16 inches per foot with a 3/16 inch parabolic crown of 4 foot in width at the center line was used.

3. Changes in the cross sections of the channels suggested by potential producers of the channels.
The computer program previously presented (1) was modified to include these changes.

Two major changes in the cross-section were suggested by producers. The first involved the change of the slope of the inside of the channel leg from 1:10 to 1:12. This was done so that an adjustable soffit could be used to form members of various depth using the same forms for members cast in an upside down position. The second change was to add a 3 inch fillet at the re-entrant corners of the channel legs to reduce stress concentrations normally occurring at these points.

Casting the members in an upside down position was first thought to increase economy by reducing problems in forming and finishing of the sections. Later estimates for the channels in an upright position indicated that the upright position may be the most economical position since the bottom of the channel requires no finishing, and problems encountered in rotating the member to an upright position are eliminated. Also, a simpler and more direct type of horizontal shear reinforcement should be used with beams in the upright position since the shear connectors can be extended out of the channel legs.

1.2 SCOPE

Because of the structural desirability and the advantages in construction of the proposed system, a cost analysis of this system was warranted. The purpose of this work is, therefore, to determine the economic feasibility of constructing the superstructure of short-span highway bridges using the proposed system of precast-prestressed composite construction.

In determining the economic feasibility of the proposed system,
the most practical method was to compare the new system with contemporary bridges designed and constructed, or under construction, in Missouri.

In order to make realistic cost comparisons, the scope of this work was limited to the comparison of three specific highway bridges with the cost of the same bridges using the proposed system for the superstructures to determine economic feasibility. The design of the superstructure for bridge A-2141 is included in Appendix B. The design procedures developed are presented in Appendix B, and the modified computer program is presented along with a flow chart and sample output in Appendix A.
CHAPTER 2
HIGHWAY BRIDGES USED FOR COMPARISON

2.1 GENERAL

To determine the economic feasibility of the proposed system, it was necessary to obtain costs of some standard contemporary highway bridges to use as a basis for comparison with the proposed system. In order to insure that realistic costs for the bridges were obtained, the Missouri State Highway Department was contacted with the following results.

1. Cost breakdowns were obtained for several types of bridges. These included unit costs for excavation, piles, concrete, reinforcing steel, structural steel, and railing. Costs per square foot of superstructure and the total cost per square foot of the bridges were also included (Table 2.1). The costs shown in Table 2.1 are the costs obtained from the Highway Department for the dates indicated.

2. The suggestion was made to use three specific bridges of various span lengths and structural systems for comparison.

3. Information was obtained on the transportation of the precast-prestressed channels to the job site. This included the maximum allowable weights which could be carried, the maximum allowable dimensions which could be carried, and information about special permits for hauling loads or dimensions of members in excess of those normally allowed.

With the aid of the highway department, specific bridges were selected for comparison. These bridges were used because their costs seemed to be typical of the costs of other bridges of their particular
type construction, and because of the variety in type of bridge and span lengths provided.

2.2 DISCUSSION OF BRIDGES USED FOR COMPARISON

The three bridges selected for comparison in this work were; (1) the bridge designated as A-2141, a three-span, 26-foot roadway, precast slab bridge submitted and approved in December of 1966; (2) the bridge designated A-2039, also a three-span bridge with a 26-foot roadway submitted and approved in May of 1967, but with a continuous composite I-beam superstructure; and (3) the bridge designated A-2416, a four-span, 28-foot roadway, continuous slab bridge submitted and approved in November of 1967. Information on quantities of materials used in these bridges are shown in Tables 2.2, 2.3, and 2.4a. Figures 2.1, 2.2, and 2.3 show the original superstructures for these bridges. All three bridges were designed for an H15-44 loading condition.

For bridge A-2141 and A-2039, only the superstructures were affected by the substitution of the proposed system. For bridge A-2416, however, certain changes in the substructure were also required. First, all concrete and steel used above the footings were considered as superstructure in the Highway Department's cost values. This necessitated reducing concrete and steel quantities by the amount occurring in the columns and end bents of the structure. Second, a change of the additional concrete and steel required for transverse beams at the three interior bents was required. These revised quantities are shown in Table 2.4b.

The change in quantities for bridge A-2416 causes an increase in the cost of the substructure of $1.23 per square foot, making the cost
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<th></th>
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<td>A-2141, 26' (34'-34'-34')</td>
<td>Oct. 24, 1968</td>
<td>--</td>
<td>10&quot;</td>
<td>15.40</td>
<td>130.00</td>
<td>115.00</td>
<td>0.174</td>
<td>5.60</td>
<td>7.38</td>
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<tr>
<td>A-2039, 26' (35'-43'-35')</td>
<td>July 25, 1968</td>
<td>10</td>
<td>10 H</td>
<td>13.17</td>
<td>127.00</td>
<td>118.59</td>
<td>0.166</td>
<td>0.239</td>
<td>5.42</td>
<td>8.22</td>
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<tr>
<td>A-2416, 28' (43'-70'-70'-43')</td>
<td>June 27, 1968</td>
<td>--</td>
<td>10 H</td>
<td>9.40</td>
<td>69.00</td>
<td>92.75</td>
<td>0.165</td>
<td>4.50</td>
<td>11.18</td>
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<td>As Revised A-2416, 28' (43'-70'-70'-43')</td>
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<td>10 H</td>
<td>9.40</td>
<td>69.00</td>
<td>92.75</td>
<td>0.165</td>
<td>4.50</td>
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### TABLE 2.2 QUANTITIES FOR BRIDGE A-2141

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<th>Total</th>
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<td>Bituminous Surface</td>
<td>Sq. Yds.</td>
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<td>Cast-in-place Concrete Piles</td>
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<td>Class A or Class X Concrete</td>
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<td>Class B Concrete</td>
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<td>38.6</td>
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<td>Reinforcing Steel</td>
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<td>37240.0</td>
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<td>Bridge Rail</td>
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<td>183.0</td>
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### TABLE 2.3 QUANTITIES FOR BRIDGE A-2039

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<td>Class I Excavation for Structures</td>
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<td>Class B1 Concrete</td>
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<td>24440.0</td>
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<td>Fabricated Structural Steel</td>
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### TABLE 2.4a QUANTITIES FOR BRIDGE A-2416

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<td>for Structures</td>
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<tr>
<td>Concrete</td>
<td>Cu. Yds.</td>
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<td>Class B1 Concrete</td>
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<td>Reinforcing Steel</td>
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<td>Lbs.</td>
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<td>510.0</td>
<td>112680.0</td>
<td>113190.0</td>
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<tr>
<td>Bridge Rail</td>
<td>Lin. Ft.</td>
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<td>478.0</td>
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### TABLE 2.4b REVISED QUANTITIES FOR BRIDGE A-2416

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<td>for Structures</td>
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<td>Class B1 Concrete</td>
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<tr>
<td>Lbs.</td>
<td></td>
<td>12810.0</td>
<td>104000.0</td>
<td>116810.0</td>
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<tr>
<td>Bridge Rail</td>
<td>Lin. Ft.</td>
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<td>478.0</td>
<td>478.0</td>
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Figure 2.1 Original Superstructure A-2141 (H15-44 Loading)
Figure 2.2 Original Superstructure A-2039 (H15-44 Loading)
Figure 2.3 Original Superstructure A-2416 (H15-44 Loading)
of the substructure $1.19 + $1.23 = $2.42 per square foot. The cost of the superstructure is, at the same time, reduced by $0.85 per square foot, making the cost of the superstructure $11.18 - $0.85 = $10.33 per square foot. The total cost would then be $10.33 + $2.42 = $12.75 per square foot. These revised costs are also shown in Table 2.1.
CHAPTER 3
DESIGN PROCEDURE

3.1 GENERAL

In order to make a cost analysis for the proposed system it was necessary to redesign the bridges being considered in the study. This process provides a method by which realistic quantities can be obtained for a built-up unit cost type of estimate. In designing the bridges, only the superstructure was redesigned with the exception of bridge A-2416, where the addition of transverse beams at interior bents was required. The 1965 AASHO code was used as a basis for the designs.

As the design was carried out, certain design procedures were developed. This chapter will include discussion of design assumptions, design procedures, a design example (Appendix B), and the computer program used for design of the system.

3.2 DESIGN ASSUMPTIONS

Any design is based upon certain assumptions and approximations which describe the behavior of the elements of a structure or facilitate the design of the elements. The special design assumptions used for this work are as follows.

1. Maximum positive moments due to live and dead loads occur at the same position along the beam.

2. The slab dead load carried by a particular channel includes only the slab section directly above the channel with the exception of the outside channels which also carry the slab overhang.
3. The depth of compressive steel was assumed to be two inches less than the average depth of the slab at the particular location being examined.

4. The dead load of the curb, parapet, and railing is carried by the bridge as a whole.

The design assumptions required for earlier phases of this project are not presented here.

3.3 DISCUSSION OF DESIGN PROCEDURES

A preliminary design can easily be carried out by the methods described in reference 1. The maximum positive and negative moments due to either truck load or lane load must be computed. These were obtained for this work from AISC Tables. The maximum shear was also obtained from these tables. The moments were reduced to that occurring over the width of one channel by using an appropriate impact factor and wheel load distribution factor.

Transverse slab reinforcing steel requirements were determined by treating the slab as a continuous haunched beam of a unit width (Figure 3.1). The distance "B" in Figure 3.1 was determined so as to place the outside wheels to produce a maximum moment in the slab. For all three bridges, this distance was found to be that which placed the outside wheels of the truck over the center of the outside channel. The thickness of the slab was taken as the thickness under the outside wheels as this would be the critical thickness.

Distribution steel requirements in the slab were determined by AASHO code, section 1.3.2E.
Figure 3.1 Loading for Determination of Transverse Slab Steel
After moments were determined, a section chosen, and the ultimate moment checked assuming a rectangular stress block, stresses at all critical stages were checked at the critical locations on the channel cross-section. From these stresses, the allowable live and dead load moments were determined using standard methods.

Cracking moment, vertical shear, and deflections were also checked. Stirrups and shear connectors were then designed to withstand diagonal tension and horizontal shear, respectively.

The computer design program carries out the design procedures to this point. Input for the program consists of the following data.

1. The span length.
2. Type of loading.
5. Width of bridge.
6. Number of prestressing strands to be placed in the bottom section of the channel.
9. The area of transverse slab steel.

The type of loading is read into the program using the following code.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS20-44</td>
<td>-1.</td>
</tr>
<tr>
<td>HS15-44</td>
<td>-2.</td>
</tr>
<tr>
<td>H20-44</td>
<td>+1.</td>
</tr>
</tbody>
</table>
Since maximum moments and shears are determined externally, the type of loading is only used as information in the output and not for calculations in the program.

The width of the bridge is used to determine overhang, crown, dead loads, and the number of channels necessary for the design. It should be noted that this is the entire width of the bridge, not the width for the roadway alone.

The number of strands to be placed in the bottom of the section is dependent on the span length. For intermediate spans, twenty strands are generally required. For short spans the number may need to be reduced to as few as sixteen. Longer spans may require as many as twenty-six. The number read into the program should be an even number.

3.4 DISCUSSION OF DESIGN FOR NEGATIVE MOMENT

After the design of the longitudinal reinforcing for positive moment was completed, it was necessary to determine the amount of additional longitudinal reinforcing steel needed in the slab over supports to resist negative moments. For this, it was assumed that blockouts would be added for a distance of approximately 1.5 times the depth of the channel, that is, the voids would be ended this distance from the ends of the channel (36 in. for the bridges considered in this work).

Negative moment stresses were checked at three locations along the span, at the end of the blockout, at the end of the beam, and directly over the support. In addition, stresses were checked at as many
intermediate points as necessary to determine locations of the points at which negative steel was no longer needed. For all stress checks, it was assumed that the cast-in-place concrete would carry no tension. The design used mild steel reinforcing for slab reinforcement and accounted for the existing stresses due to prestressing.

The stresses used were those taken from a fiber stress diagram (Figure B4) drawn using the end and midspan stresses from the computer output. It was found that using the end stresses from the computer output gave results with large errors. This was also true when the maximum negative moment was used rather than the actual moment at the section being considered. For these reasons it was necessary not only to draw the fiber stress diagrams, but, also, the moment diagram for the loading condition producing the maximum negative moment. The moment diagram can easily be drawn, again using the AISC tables.(5) The moment capacity is then compared to the actual moment to determine if extra slab reinforcing steel is needed.

3.5 DESIGN RESULTS

As a result of the design described above, a channel was obtained which satisfied all design requirements. The results of the design for an H15 loading condition are shown in Figures 3.2, 3.3, and 3.4. Although particular combinations of transverse and longitudinal slab reinforcement were chosen, many other combinations are possible. Several of these combinations are shown in Table 3.1 for transverse steel and Table 3.2 for longitudinal steel. For these tables, a maximum spacing of 12 inches center to center was assumed. Quantities of materials required by the design are shown in Tables 3.3, 3.4, and 3.5.
Figure 3.2 Design Results for Bridge A-2141 (H15-44 Loading)
Figure 3.3 Design Results for Bridge A-2039 (H15-44 Loading)
Figure 3.4 Design Results for Bridge A-2416 (H15-44 Loading)
### TABLE 3.1 REQUIRED SPACING OF TRANSVERSE SLAB STEEL
(in inches center to center)

<table>
<thead>
<tr>
<th>Bar No.</th>
<th>Bridge A-2141 or A-2039</th>
<th>Bridge A-2416</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

### TABLE 3.2 REQUIRED SPACING OF LONGITUDINAL SLAB STEEL
(in inches center to center)

<table>
<thead>
<tr>
<th>Bar No.</th>
<th>Bridge A-2141 or A-2039</th>
<th>Bridge A-2416</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>7 1/2</td>
</tr>
<tr>
<td>5 or larger</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>
### TABLE 3.3 SUPERSTRUCTURE QUANTITIES

**Bridge A-2141**

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class B Concrete</td>
<td>Cu. Yds.</td>
<td>94.50</td>
</tr>
<tr>
<td>Reinforcing Steel</td>
<td>Lbs.</td>
<td>14280.11</td>
</tr>
<tr>
<td>Precast Channels</td>
<td>Lin. Ft.</td>
<td>495.00</td>
</tr>
<tr>
<td>Void Forms</td>
<td>Sq. Ft.</td>
<td>1741.00</td>
</tr>
<tr>
<td>Railing</td>
<td>Lin. Ft.</td>
<td>183.00</td>
</tr>
</tbody>
</table>

### TABLE 3.4 SUPERSTRUCTURE QUANTITIES

**Bridge A-2039**

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class B Concrete</td>
<td>Cu. Yds.</td>
<td>127.10</td>
</tr>
<tr>
<td>Reinforcing Steel</td>
<td>Lbs.</td>
<td>21284.60</td>
</tr>
<tr>
<td>Precast Channels</td>
<td>Lin. Ft.</td>
<td>550.00</td>
</tr>
<tr>
<td>Void Forms</td>
<td>Sq. Ft.</td>
<td>1849.00</td>
</tr>
<tr>
<td>Railing</td>
<td>Lin. Ft.</td>
<td>211.00</td>
</tr>
</tbody>
</table>

### TABLE 3.5 SUPERSTRUCTURE QUANTITIES

**Bridge A-2416**

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class B Concrete</td>
<td>Cu. Yds.</td>
<td>261.39</td>
</tr>
<tr>
<td>Reinforcing Steel</td>
<td>Lbs.</td>
<td>34278.36</td>
</tr>
<tr>
<td>Precast Channels</td>
<td>Lin. Ft.</td>
<td>1322.00</td>
</tr>
<tr>
<td>Void Forms</td>
<td>Sq. Ft.</td>
<td>4085.00</td>
</tr>
<tr>
<td>Railing</td>
<td>Lin. Ft.</td>
<td>478.00</td>
</tr>
</tbody>
</table>
CHAPTER 4
COST ESTIMATE

4.1 GENERAL

The principal objective of cost estimating is the determination of realistic expenses for a structure. One method often used by contractors is that of applying unit prices to itemized quantities of labor, materials, and equipment. This is used advantageously for problems where quantities are defined to a large extent and where an accurate estimate is required. Since the structures presented in this work are well defined as to quantities and since an accurate estimate is required, this method will be used to determine the cost of the bridges considered herein.

4.2 DETERMINATION OF UNIT COSTS

The difficulty encountered in the use of this method is the determination of realistic unit costs. To insure that realistic unit costs were obtained, the following organizations were contacted.

1. The Missouri State Highway Department was contacted for the cost of the original structures, cost of reinforcing steel, and cost for bridge railing.

2. Prestressed concrete producers were contacted for the cost of the precast-prestressed channels and transportation costs.

3. General Contractors were contacted for costs of labor, equipment, forming, additional materials prices, insurance, and overhead.

Quantities of equipment and forming materials were also obtained from the contractors.
The costs obtained from the Highway Department were presented in Chapter 1.

Two general contractors were contacted. The information obtained include not only the items listed above but also the methods used by these contractors in applying the unit costs to obtain estimates for the cost of construction. These two methods are summarized in Table 4.1 and Table 4.2. One check on the reliability of these methods is a comparison of the cost in place per cubic yard of concrete determined by the two estimation methods and the costs obtained from the Highway Department. The figures from the Highway Department ranged from $69.00 per cubic yard to $130.00 per cubic yard, the average being $108.72 per cubic yard. The range of costs for the estimates made in this study was from $66.50 to $92.50 per cubic yard, the average being $80.00 per cubic yard. It can be seen that these values are in the range of costs obtained from the Highway Department. The lower average cost from the two estimation methods was due to the large reduction in forming costs for both labor and materials for the proposed system.

Information on the costs of the channels were obtained from three prestressed concrete producers. Since there were two estimation methods, six estimates were obtained for each bridge. These values tended to agree very well, and, therefore, an average value was obtained which should represent the best estimates for the bridges. The costs obtained from the prestressed concrete producers for the channels are presented in Table 4.3. All values include transportation to a distance of 100 miles. Transportation for various distances were obtained from one of the producers contacted and are shown in Table 4.4. The cost for the channels was based on a total anticipated volume of 20,000 feet per year.
### TABLE 4.1
SUMMARY OF COST ESTIMATION METHOD 1

**Erection costs:**

<table>
<thead>
<tr>
<th>Time</th>
<th>1-- 1 1/2 days.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
</tr>
<tr>
<td>1 crane</td>
<td>$30.00/Hr.</td>
</tr>
<tr>
<td>1 pickup</td>
<td>$ 2.00/Hr.</td>
</tr>
<tr>
<td>1 1/2 service truck</td>
<td>$ 5.00/Hr.</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td></td>
</tr>
<tr>
<td>7 1/2 men crew</td>
<td>$ 5.50/Hr.</td>
</tr>
</tbody>
</table>

**Cost for casting slab:**

Forming, based on actual areas at a labor rate of $5.50/Hr. (includes 10% overtime charge)

1. Bottom and edge of slab erection, stripping, and curing at 5 square feet per hour.

2. Parapet and curbs erection, stripping, and curing at 10 square feet per hour.

3. Construction of forms for parapet and curb at 15 square feet per hour. (estimate 6 re-uses)

**Material**

1. Plyform at $0.25/sq.ft.
2. Dimension lumber at $0.15/bd.ft. (use twice the plyform area as the number of board feet required).
3. Brackets--Rent at $2.00 each per month. Use one month per bridge.
4. Miscellaneous--10% of materials.

**Concrete**

1. Labor at $6.00/cu.yd.
2. Material at $14.00/cu.yd.
TABLE 4.1
SUMMARY OF COST ESTIMATION METHOD 1
CONTINUED:

Insurance: 17% of labor cost.
Equipment: 18% of labor cost.
Overhead: 5% of total cost of bridge.
TABLE 4.2
SUMMARY OF COST ESTIMATION METHOD 2

Erection costs:

Labor at $35.00/Hr., assume one member per hour.
(equipment added later)

Concrete costs:

Labor--Pouring, finishing, curing, stripping

Slab at $6.00/cu.yd.
Curb and parapet at $12.00/cu.yd.

Material--$14.00/cu.yd.

Curb forming:

Labor
1. $4.00 per linear foot of overhanging slab.
2. $2.00 per linear foot of curb.
3. $2.00 per linear foot of parapet.
(based on 18" overhang, 8"x18" curb, and 10"x18" parapet)

Material
1. Plyform at $0.25/square foot.
2. Brackets at $5.00 each at 4 feet on center ($50.00 each with 10 re-uses).

Overhead, Supervision, Insurance, Equipment:

25% of total cost for materials when materials cost is approximately equal to labor costs.

20% of total cost for materials when materials cost is approximately equal to twice the labor costs.
## TABLE 4.3 COST OF CHANNELS PER SQUARE FOOT

<table>
<thead>
<tr>
<th>Producer</th>
<th>Casting Position</th>
<th>Channel Length and Depth</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inverted</td>
<td>33' 20&quot;</td>
<td>3.15</td>
<td>3.50</td>
<td>3.75</td>
<td>4.26</td>
</tr>
<tr>
<td>1</td>
<td>Upright</td>
<td>34' 26&quot;</td>
<td>3.25</td>
<td>3.60</td>
<td>3.50</td>
<td>4.05</td>
</tr>
<tr>
<td>2</td>
<td>Upright</td>
<td>42' 26&quot;</td>
<td>3.15</td>
<td>3.54</td>
<td>3.46</td>
<td>3.71</td>
</tr>
<tr>
<td>3</td>
<td>Upright</td>
<td>42' 34&quot;</td>
<td>3.21</td>
<td>3.52</td>
<td>3.81</td>
<td>4.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>69' 34&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## TABLE 4.4 TRANSPORTATION COSTS

<table>
<thead>
<tr>
<th>Mileage from Plant to Jobsite</th>
<th>Dollars per Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>$34.00</td>
</tr>
<tr>
<td>50</td>
<td>50.00</td>
</tr>
<tr>
<td>100</td>
<td>77.00</td>
</tr>
<tr>
<td>150</td>
<td>104.00</td>
</tr>
<tr>
<td>200</td>
<td>130.00</td>
</tr>
<tr>
<td>250</td>
<td>157.00</td>
</tr>
<tr>
<td>300</td>
<td>184.00</td>
</tr>
</tbody>
</table>
A second difficulty with the use of the unit cost method is that the costs must be updated if they are not current and they must be transformed to the location for which they will be used when they are for other areas. To insure current costs, the Highway Department furnished updated costs which represent their best estimate of the cost of materials at the time of construction of each of the original structures.

4.3 DETERMINATION OF QUANTITIES:

For cost estimation purposes, the construction was broken into the following divisions.

1. Erection of the beams on the job site.
2. Construction and placement of forms.
3. Concrete placement (both labor and materials)
4. Reinforcing steel, post-tensioning rods, and bridge railing.
5. Overhead (includes insurance, supervision, and equipment in method 2).

The quantities for labor and equipment for erection of the precast-prestressed beams were obtained through discussions with certain Missouri and Kansas contractors. The length of beams and area of voids were determined by the bridge design and the channel design. The void area is the horizontal projection of the area of the corrugated metal void forms.

The slab area to be formed included the underside of the overhang past the outside channels plus edge of the slab. The width of the overhang used was 4 feet for the two shorter bridges and 3 feet for the
longer bridge. This not only allows for forming of the overhanging slab, but also for space from which construction crews may work, and an area from which the forms for the curb and parapet may be braced. The area for the curb and parapet includes only the vertical sides, both inside and outside of both curbs and parapets. For construction of curb and parapet forms, six re-uses were assumed. This, in essence, reduced the construction cost by one sixth. This was also true for the plyform and dimension lumber for the curb and parapet. Brackets were spaced at four feet on center along both edges of the bridge.

Concrete labor and materials included only that required for the slab, blockouts, over bents between the ends of the beams, and in the curb and parapet.

Costs and amounts of railing were obtained from the Missouri Highway Department. Post-tensioning rods were those used to hold the beams together laterally. One inch diameter rods were used across the width of the five or six channels. Reinforcing steel includes the reinforcement used in the slab, curb, and parapet.

Although several different combinations of bars will satisfy the steel requirements, it can be shown that the costs of all of the combinations are approximately equal. For this reason, the costs of the bridges would be the same for any combination of steel satisfying area requirements.

For Estimation Method 1, insurance was taken as 17 percent of labor cost, equipment was taken as 18 percent of labor cost, and overhead was taken as 5 percent of the total cost of the bridge. The equipment figure includes only that not included elsewhere. For Estimation
Method 2, all of the insurance, supervision, equipment, and overhead were included as 18 percent of the total cost.
CHAPTER 5
RESULTS

5.1 GENERAL
The application of unit prices to the quantities of materials, labor, and equipment required resulted in the total cost for the superstructures for the three bridges considered. The computations of these costs for bridge A-2141 are presented in Appendix C for low, average, and high channel costs and for both estimation methods. After estimations were completed, they were returned to the contractors who examined the estimates and revised values where necessary. These estimates and revisions were made independently without knowledge of the other contractors values.

5.2 DISCUSSION OF RESULTS
The costs were subsequently broken down into percentages of the total cost according to five basic divisions.
1. Overall costs including comparisons with costs for the original structures.
2. Percent of cost for channel sections
3. Percent for materials (including channels).
4. Percent for on-site labor.
5. Percent for equipment.
The percent for equipment includes overhead since Estimation Method 2 combines overhead and equipment. This results in a more meaningful comparison of the two estimation methods. This cost break down is presented in Table 5.1. All highway department costs are for the same time period as for other costs used in the cost estimates.
<table>
<thead>
<tr>
<th>Bridge</th>
<th>Cost of Superstructure</th>
<th>Saving</th>
<th>Chann. Cost (% of total)</th>
<th>Mat'l's (% of total)</th>
<th>Labor (% of total)</th>
<th>Equipment &amp; Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proposed System</td>
<td>State</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>$/sq.ft.</td>
<td></td>
<td>$/sq.ft.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-2141</td>
<td>High</td>
<td>$19,882.40</td>
<td>6.83</td>
<td>7.38</td>
<td>41.8</td>
<td>70.6</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>19,284.23</td>
<td>6.63</td>
<td>7.38</td>
<td>42.1</td>
<td>71.5</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>18,760.58</td>
<td>6.45</td>
<td>7.38</td>
<td>42.5</td>
<td>72.5</td>
</tr>
<tr>
<td>A-2039</td>
<td>High</td>
<td>24,820.91</td>
<td>7.44</td>
<td>8.22</td>
<td>41.5</td>
<td>71.6</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>23,956.68</td>
<td>7.18</td>
<td>8.22</td>
<td>41.8</td>
<td>72.8</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>23,156.60</td>
<td>6.94</td>
<td>8.22</td>
<td>42.2</td>
<td>74.0</td>
</tr>
<tr>
<td>A-2416</td>
<td>High</td>
<td>58,756.60</td>
<td>8.36</td>
<td>10.33</td>
<td>51.2</td>
<td>74.0</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>54,376.58</td>
<td>7.74</td>
<td>10.33</td>
<td>52.1</td>
<td>76.6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>50,088.78</td>
<td>7.13</td>
<td>10.33</td>
<td>52.8</td>
<td>79.2</td>
</tr>
</tbody>
</table>

* For bridge A-2416, the cost of the substructure was increased by $.38/sq.ft. Actual savings would be

  High $1.97 - .38 = +$1.59/sq.ft.
  Average $2.59 - .38 = +$2.21/sq.ft.
  Low  $3.20 - .38 = +$2.82/sq.ft.

TABLE 5.1 BASIC COST BREAKDOWN
The difference in the values obtained from the two estimation methods averaged 4.3 percent of the total value of Method 1 for the two shorter bridges irrespective of the channel estimate. Approximately 95 percent of this error is due to a difference in estimating equipment and overhead. The remaining 5 percent is distributed through the other values. For the longer bridge, the error was 8.8 percent with 82 percent due to the difference in estimating equipment and overhead.

The costs for bridge A-2416 exhibit a large deviation. There are four possible reasons for this deviation. First, the values of the high and low costs of the channels vary considerably for the longer spans. When the prestressed concrete producers were originally contacted, it was thought that casting the channels upside down would be the most economical. It was later concluded that the increased handling of the beams cast in this manner would offset any advantages in casting. For this reason, the early channel costs are somewhat higher than later costs for the channels cast in an upright position. The effect is most pronounced for the longer spans which would be more difficult to handle.

The second factor producing deviation in the costs is introduced in the estimation methods. Method 1 sets a fixed time for erection of beams while for Method 2 the time required varies with the number of beams to be erected. Since for bridge A-2416, nine additional beams must be erected, the labor cost by Method 2 is increased while Method 1 does not.

The third factor causing deviation is that Method 2 estimates the cost of forming the overhanging portion of the slab at a fixed rate based on an 18 inch overhang. For bridge A-2416, the overhang was
only 4.5 inches. Therefore Method 2 would again have an increase in cost over Method 1.

Finally, for Method 1, the equipment and overhead are broken down further than in Method 2. It is probable, therefore, that Method 1 gives the better values for these quantities. However, it can be seen that although costs average 11.2 percent less than the costs of the original structures for both methods for the two shorter bridges, the costs average 21.4 percent less for the longer bridge. Even assuming that the high cost obtained by Method 2 gives better values, a savings of $1.59 per square foot was derived for bridge A-2416. Using average values, which probably gives the most realistic costs, a savings of $2.21 per square foot was obtained.

It can be seen from Table 5.1 that the average cost of the channels was about 45 percent of the total cost. The increase to better than 50 percent in bridge A-2416 is due to the additional width making the bridge six channels wide rather than the five channels used for the other two bridges.

Table 5.1 also shows that the on-site labor cost for the proposed system is relatively low when compared with other systems. It was indicated in Table 4.4 that material costs are expected to be from one to two times labor costs. For the proposed system the materials are approximately 5.7 times the labor costs.

In addition to the H15-44 loading, all three superstructures were designed for an HS20-44 loading. This resulted in an increase of cost averaging 1.73%. The cost results from the HS20-44 loading are given in Table 5.2, along with the H15-44 results for comparison.
TABLE 5.2
COST PER SQUARE FOOT FOR H15 LOADING AND HS20 LOADING

<table>
<thead>
<tr>
<th></th>
<th>BRIDGE A-2141</th>
<th></th>
<th>BRIDGE A-2039</th>
<th></th>
<th>BRIDGE A-2416</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H15-44</td>
<td>HS20-44</td>
<td>H15-44</td>
<td>HS20-44</td>
<td>H15-44</td>
<td>HS20-44</td>
</tr>
<tr>
<td>High</td>
<td>6.83</td>
<td>7.00</td>
<td>7.44</td>
<td>7.54</td>
<td>8.36</td>
<td>8.49</td>
</tr>
<tr>
<td>Average</td>
<td>6.63</td>
<td>6.76</td>
<td>7.18</td>
<td>7.30</td>
<td>7.74</td>
<td>7.87</td>
</tr>
<tr>
<td>Low</td>
<td>6.45</td>
<td>6.56</td>
<td>6.94</td>
<td>7.05</td>
<td>7.13</td>
<td>7.23</td>
</tr>
</tbody>
</table>

The reinforcement required for the HS20-44 loading was as follows:

Bridge A2141 or A-2039:
Transverse: - .53 sq. in./ft.
Longitudinal:
Continuous - .22 sq. in./ft.
Negative Moment Reinforcement - .68 sq. in./ft.

Bridge A-2416:
Transverse: - .53 sq. in./ft.
Longitudinal:
Continuous - .22 sq. in./ft.
Negative Moment Reinforcement - 1.32 sq. in./ft.
CHAPTER 6
SUMMARY AND CONCLUSIONS

6.1 SUMMARY

Due to the favorable results of structural tests of the proposed system of precast-prestressed channels with a cast-in-place slab, a cost estimate was warranted. For comparison, the Missouri Highway Department suggested that three specific bridges be used. These bridges included a precast slab bridge with spans of 34'-34'-34', a continuous composite I-beam bridge with spans of 35'-43'-35', and a continuous slab bridge with spans of 43'-70'-70'-43', all designed for H15-44 loading.

For the three bridges, the proposed system was designed to replace the superstructures. This resulted in channels of 20 inches in depth for the shortest span bridge. The depth required for the bridge with spans 35'-43'-35' was 26 inches, while for the longest span bridge, the depth required was 34 inches. Both positive and negative moment reinforcing steel were also determined.

The costs of the channels were determined by contacting prestress concrete producers in the surrounding area. High, average, and low costs were obtained in this manner. Likewise, contractors were contacted to determine labor costs, equipment requirements, forming requirements, etc. This resulted in two methods of cost estimation. High, average, and low costs for the entire superstructures were obtained in this manner.

This information was analyzed and compared to the costs obtained from the Highway Department for the original structures. For the two shorter spans, little difference was obtained in the cost of the proposed system and the Highway Department's costs. For the longer bridge, a
noticeable saving was realized.

6.2 CONCLUSIONS

The following conclusions were drawn from this cost estimate.

1. The cost of field labor is reduced greatly, the average labor cost being 13.81 percent of the total cost of the superstructure. Prefabrication of the channels and reduction in the amount of forming are primarily responsible for the reduction in labor.

2. Since for shorter spans the costs averaged 11.2 percent less than the Highway Department's cost and for the longer span bridge the average savings was 21.4 percent, actual usage of this system in the field should indicate a range of spans for which the proposed system would be most economical.

3. The cost of the proposed system depends greatly upon the cost of the channels, since it is seen from Table 5.1 that the channels make up about 45 percent of the total cost of the bridge superstructure. The area of the channels was at least 87 percent of the area of the bridges considered. Thus, a reduction of $1.00 per square foot in the cost of the beam would result in the reduction in the cost of the bridge of more than $0.87 per square foot. As more members are used, producers would become more familiar with the section. The production would become more standard and prices should decrease, further increasing savings.

4. Precast-prestressed voided sections provide a desirable structural shape. Compression area is provided by the top slab and tension area is provided by the bottom of the
channel. Because of reduced dead weights due to the voids and an increased carrying capacity, it would be expected that the use of this system would become more economical as the spans increased. This was exhibited by the results of this study. For the two shorter bridges (34'-34'-34' and 35'-43'-35'), the savings were not as great as for the longer span bridge (43'-70'-70'-43').
REFERENCES


APPENDIX A

COMPUTER PROGRAM
LIST OF TERMS USED IN PROGRAM

A - depth of rectangular stress block
AICH - moment of inertia of channel
AICOM - moment of inertia of composite section
AIN - area of slab over center channel (in²)
ALIC - allowable compressive stress in channel at release of prestress force (ksi)
ALIT - allowable tensile stress in channel at release of prestress force (ksi)
ALLMO - maximum moment (lane or truck) (ft-k)
ALOWC - allowable compression in channel at working load (ksi)
ANI - ratio of modulus of elasticity of channel to modulus of elasticity of top slab
AOUT - area of slab over outside channel (in²)
AREA - cross sectional area of channel (in²)
ASPI - Initial area of longitudinal reinforcing steel required by AASHO code for one channel (in²)
ASP - area of longitudinal reinforcing steel required from ultimate moment calculations (in²/ft.)
ASPF - area of longitudinal reinforcing steel per channel
ATRANS- area of transverse slab steel (in²)
BCLL - live load moment capacity (in-k) of composite beam as governed by bottom channel stress
BEML - live load on beam (in-k)
CRMOM - cracking moment (in-k)
DELF1 - final deflection of channel under dead loads (in)
DELGB - dead load deflection of beam (in)
DELGS - deflection of beam due to dead load of slab (in)
DELM - difference between cracking moment and dead load
DELPR - deflection due to prestressing (in)
D(I) - channel depth (in)
DLMCH - dead load moment of channel (in-k)
DLMSF - dead load moment of slab and forms (in-k)
DLSHR - maximum dead load shear (k)
DS - average depth of slab reinforcing steel from top of slab (in)
DSTR - distance from top of channel legs to a prestressing strand in the leg
E - distribution of wheel load
EE - end eccentricity
EM - eccentricity at holddown
FCII - $f'_c$ of channel at release of prestress force (ksi)
FCIP - $f'_c$ of top slab (ksi)
FCPS - $f'_c$ of channel (ksi)
FSU - stress in cables at ultimate conditions
FULT - stress in cables at ultimate conditions
FULT - ultimate force in prestress cables
HORSH - horizontal shear stress (ksi)
MD - ratio of modulus of elasticity of steel to modulus of elasticity of cast-in-place concrete
NCH - number of channels at a cross-section
OVER - slab overhang (ft.)
P - percent steel
PACT - impact factor
PERATI - percent of transverse steel area required in longitudinal direction
PSF - final prestress force after losses
PSFI - initial prestress force
PSHR - prestressing shear effect (k)
SB - bottom section modulus of channel
SBOT - additional stress at bottom of channel corresponding to ZX added at top
SFEB - final condition stress at bottom of channel at end (ksi)
SFET - final condition stress at top of channel at end (ksi)
SFMB - final condition stress at bottom of channel at midspan (ksi)
SFMT - final condition stress at top of channel at midspan (ksi)
SHEAR - shear due to live load, curb and parapet, rails, etc. at end of beam (k)
SIEB - initial stress at bottom of channel at end (ksi)
SIET - initial stress at top of channel at end (ksi)
SIMB - initial stress at bottom of channel at midspan (ksi)
SIMT - initial stress at top of channel at midspan (ksi)
SLMM - live load moment capacity of composite section (in-k)
SPAN - span length (feet)
ST - top section modulus of channel
STT - number of prestressing strands in channel legs
STB - number of prestressing strands in bottom of channel
STRAN - number of prestressing strands
TC - thickness of slab of center line of roadway (in)
TCLL - live load moment capacity (in-k) of composite beam as governed by top channel stress
TLEG - slab thickness at channel leg on either side of center (in)
TYPE - numberical designation for type of loading
ULTD - ultimate moment developed by the section (in-k)
ULTM - required ultimate moment (in-k)
WEIGHT - the larger value of WTIN and WOUT (kips/ft.)
WIDTH - total width of bridge including curb and parapet (ft.)
WTIN - weight of slab over inside channel (k/ft.)
WOUT - weight of slab over outside channel (k/ft.)
YBAR - neutral axis of channel
YCOM - neutral axis of composite section
YEST - distance to centroid of steel at end of channel (in.)
YMST - distance to centroid of prestressing steel
YSHR - distance from neutral axis of composite section to centroid of cast-in-place slab
Z - distance from bottom of channel to centroid of cast-in-place slab
ZAREA - area of slab used for horizontal shear calculations (in)
ZX - additional compressive stress that can be applied at top of channel after dead load is acting
COMPUTER FLOW CHART

Start

READ

1. Span
2. Type of load
3. $f_c$ for prestressed concrete
4. $f_c$ for cast-in-place concrete
5. Width of bridge
6. No. of strands in channel bottom
7. Maximum live load moment
8. Maximum live load shear
9. Area of transverse slab steel

Calculate

1. Allowable stresses
2. Wheel load distribution
3. Impact factor

Do $i = 1$ to $20$

$D(1) = 12.1 + 2.9^i$

Compute channel section properties

Determine weight per foot of slab and longitudinal steel requirements.
Determine whether center or outside channel controls.

Compute dead load moment for the channel and slab.
Compute ultimate moment required as $1.5M_{DL} + 2.5M_{LL}$

$Stran = No. of prestressing strands = 26$

Compute center of gravity for prestressing steel at ends and midspan. Calculate end and midspan strand eccentricities.

Determine if strands will fit in the section.

If yes, Compute percent of steel, $f_{su}'$ and $F_{ULT} = f_{su}'A_s$

Write: xxx strands will not fit into the section
Determine depth of rectangular stress block, A, and ultimate moment developed by the section.

If \( A > d_x + 2 \), equations are invalid for this condition.

If ultimate moment developed > ultimate moment required.

Compute critical stresses due to prestressing and dead load of channel.

If stresses \( > \) allowable values

Compute final critical stresses after prestressing losses and addition of dead load of slabs and forming.

If stresses \( > \) allowable values

Compute composite section properties depending upon whether inside or outside channel controls as determined earlier.

Determine additional allowable bottom stress and corresponding live load moment

Compute cracking moment, \( M_{cr} \)

If \( 1.2 * M_{cr} \) < Ult. moment developed

Yes

No
Compute horizontal shear at interface of prestressed and cast-in-place concrete.

Compute dead load and prestressing deflections using a creep factor of 2 for prestressing and channel dead load deflection.

Write:
1. General information
2. Channel properties
3. Channel stresses
4. Composite properties
5. Moment information

Continue
Stop
DIMENSION D(20)
READ(5,11) SPAN, TYPE, FCPS, FCIP, WIDTH, STB, ALLMC, SHEAR, ATRANS
11 FORMAT (I8,2)
12 FCIP=5*FCPS
13 ALLMC=.4*FCPS
14 ALIC=.6*FCII
15 ALIT=-.CO3*SQRT(FCII*1000.)
16 ANI=5*FCP/FCIP
17 STRAN=.26.
18 CONTINUE
19 E=4.*CC*SPAN
20 IF(7.E155,55,54)
21 55 E=7.
22 54 CONTINUE
23 PACT=.5*.SPAN+125.
24 IF(3.=PACT,.56,.57)
25 56 PACT=.5
26 57 CONTINUE
27 HEML=ALLMC
28 CC 60 I=1,80
21 E=1
22 CC 60 I=12,.2*8
23 AREA=.40+.2*14.*(D(I)-.4)+(D(I)-9.)*1.2CH+.521+.0208*(D(I)-9.)*
$+(D(I)-9.)*
24 YBAR=(.8*(D(I)-4.)*(.D(I)+4.)/.0+(D(I)-9.)*2.47*.4+(D(I)-9.0)
$+.2+.1*.047*(D(I)-9.)*(D(I)-9.)*((D(I)-3.33))+.047*(D(I)-9.)*((D(I)-3.33)/3.1)
$+.46.6)
25 AIIC=.3*C-.2*0.*(YBAR-2.)*2*2*.14.*(D(I)-4.)*D(I)-3.)/12.*D(I)-4.)*
$.2+(D(I)-4.)/12.*YBAR)**2+1.28*YBAR*(D(I)-9.)*3/12.+1.208*(D(I)-9.)*
$.2+.5+(D(I)-2.)*YBAR)**2+.073+.521*(D(I)-3.33 -YBAR)**2+.047*
$+(D(I)-9.)*((D(I)-9.)*3)/36.+.028*(D(I)-9.)*(D(I)-9.)*(4.+1.*3.*D(I)
$.7.5.1-YBAR)**2)
26 SB=AICL*YBAR
27 SI=AICL*YBAR
28 PERAT1 = 2.2/5*SQRT(51./12.)
29 IF(PERAT1 = .67,12,12)
30 12 PERAT1 = .67
31 ASPF=PERAT1*ATRANS
32 ASP=5*SPF*5.
33 ASP1=ASP
34 IF(WIDTH>30.1306,307,307)
35 306 NCH=5
36 GVER=WIDTH-25.*2.
37 GC IC 308
38 307 NCH=6
39 GVER=WIDTH-30.*12.
40 308 IF(GVER<.131,13,12)
41 312 AOUT=15.5+.1875*(5.*GVER)/(5.*GVER)*6.+2.5*GVER+12.*69.*6
42 OS=2.75+.09375*(5.*GVER)
43 LCCLNT=1
44 GC IC 314
45 313 AOUT=15.5+.1875*(5.*GVER)/(5.*GVER)*6.+5.*GVER+12.*69.*8
46 OS=2.75+.09375*(5.*GVER)
47 LCCLNT=2
48 314 WOUT=AOUT*(15.1/144.)*0.5
IF (N1-5) .LE. 0, N1 = 1

WRITE (*, 31) N1

FORMAT (* NUMBER OF CHANNELS IS IN ERROR *)

TLEG = TCG-4.76*OS375*WIDTH

LS = TLEG-I.766

ALT = AINE/0.15

G1 - TC = 0.15

TLEG = TC-I.531

ALT = AINE/0.15

330 IF (GOUT-WIN) .LT. 335, 335, 340

335 WEIGHT = TIN

NCOUNT = 1

340 WEIGHT = GOUT

NCOUNT = 2

347 CONTINUE

IF (ASPR.GT.4.) GC = 66

346 ULMCF = 1.5*KREA*SPAN*SPAN/96.

DLMSF = I.5*WEIGHT*SPAN*SPAN

345 DLSF = 1.5*KREA/144.*WEIGHT*SPAN/2.

344 ULM = I.5*(ULMCF+DLMSF)*2.5*BMML

STRAN = C6.

343 CONTINUE

IF (STRAN-BSTRAN) IC00, 101, 104

342 YMS = I.5*(SPAN-STD)*(1.5*2.25*(STRAN-STRB)*7./16.)/STRAN

341 GC = TCG

340 YMSL = I.5*GC

339 NCOUNT = 2

338 CONTINUE

337 EM = YEAR-VMST

336 STT = STRAN-STB

335 PSR = 0.0

334 DSTR = 0.0

333 IFIL = STRAN-1LST1GC TO 212

332 YMSL = 0.0

331 GC = TCG

330 DSTR = DSTR+2.

329 PSR = PSR+1D11-DSTR-VMST)/(SPAN*6.)*31.

328 GC = TCG

327 YMSL = 1.5*(SPAN-STD)*IC0.15*(STRAN-STRB)*7./16.)/IC1

326 GC = TCG

325 YMSL = 1.5*(SPAN-STD)*IC0.15*(STRAN-STRB)*7./16.)/IC1

324 GC = TCG

323 YMSL = 1.5*(SPAN-STD)*IC0.15*(STRAN-STRB)*7./16.)/IC1

322 GC = TCG

321 YMSL = 1.5*(SPAN-STD)*IC0.15*(STRAN-STRB)*7./16.)/IC1

320 GC = TCG
LCI\$1(11)*OS+2,A, YSTI*51*A*FCIP

IF (UTC < LTC) GO TO 101
ASP = ASP + 31
101 STRAN = STRAN + 2
GO TO 111
109 PSFI = STRAN * 17.766
110 S1 = PSFI / AREA
125 S2 = PSFI * M / SB
130 S3 = LCMCH / SB
135 S4 = PSFI / LT
140 S5 = LCMCH / ST
145 S6 = PSFI * LT
150 S7 = LCMCH / ST
155 S8 = S1 - S2 - S3
160 SIMT = S1 - S6 + S5
165 SIET = S1 - S7
170 PSFI = PSFI / STK
175 S1 = PSFI / SB
180 S2 = PSFI / ST
185 S3 = PSFI / LT
190 S4 = PSFI / ST
195 S5 = PSFI / LR
200 S6 = PSFI / SB
175  LEB=PSI*EE/SB
176  LEY=PSF*EE/ST
177  SFM=CELCE2=OL3=DE4
178  SMT=CELCE5=OL6=DE7
179  SFEB=CELCE8
180  SPECT=CEL=DE9
181  IF(SPFM)=15C,110,137
182  137 IF(SFMT)138,139
183  138 WRITE(6,203)
184  203 FORMAT('LSFMT IS TENSILE!')
185  WRITE(6,3001,D11)
186  GC TC 66
187  139 IF(SFMT)140C,110,110
188  140 CONTINUE
189  143 WRITE(6,204)
190  204 FORMAT('LSFEB REQUIRES SPECIAL STRAND ARR.*')
191  WRITE(6,3001,D11)
192  GC TC 66
201  150 WRITE(6,206)
202  206 FLFORMAT('LSFET REQUIRES SPECIAL STRAND ARR.*)
203  WRITE(6,3001,D11)
204  GC TC 66
205  149 CONTINUE
206  145 WRITE(6,205)
207  205 FORMAT('LSFETT REQUIRES SPECIAL STRAND ARR.*)
208  WRITE(6,3001,D11)
209  GC TC 66
210  154 WRITE(6,207)
211  211 ZAREA = TLEG60.6*83.87+MD*ASP
212  165.8*IOD(1)-1.33)+MD*ASP*(D1)+2.*1.089*STRAN*YMST))
213  14.07*(D11)+TLEG+156.)/
214  1.331+TLEG+6)]+14.07*MD*ASP]+1.089*STRAN)/
215  1.331+TLEG+6)]+14.07*MD*ASP]+1.089*STRAN)
216  27 YCOM = (AREA*YBAR*AN1*64.8*(D11)-1.33)+TLEG60.6*(D1)+TLEG/2.*+
217  26.14*IOD(11)+TLEG+312)+MD*ASP*(D1)+2.*1.089*STRAN*YMST)/
218  1.331+TLEG+6)]+14.07*MD*ASP]+1.089*STRAN)
219  1.331+TLEG+6)]+14.07*MD*ASP]+1.089*STRAN)
220  24.75*USD(RI)**2*1.375+28.14*(D11)+TLEG+312)
221  217 Z = L0.8*(D11)-1.33)+MD*ASP*(D1)+2.*1.375+28.14*(D11)+TLEG+312)
222  1.375+28.14*(D11)+TLEG+312))/ZAREA
223  GC TC 28
224  214 YCOM = (AREA*YBAR*AN1*64.8*(D11)-1.33)+TLEG60.6*(D1)+TLEG/2.*+
225  26.14*IOD(11)+TLEG+312)+MD*ASP*(D1)+2.*1.089*STRAN*YMST)/
226  1.331+TLEG+6)]+14.07*MD*ASP]+1.089*STRAN)
227  1.331+TLEG+6)]+14.07*MD*ASP]+1.089*STRAN)
228  24.75*USD(RI)**2*1.375+28.14*(D11)+TLEG+312)
229  216 ZAREA = TLEG6C.9*97.9*MD*ASP
230  2.0.8*(D11)-1.33)+MD*ASP*(D1)+2.*1.375+28.14*(D11)+TLEG+312)
231  1.375+28.14*(D11)+TLEG+312))/ZAREA
232  GC TC 28
233  215 IF(LNCLN1-1,41C,41C,415
234  405 IF(LNCLN1-1,41C,41C,415
235  410 YCOM = (AREA*YBAR*AN1*5.3*(5.5*OVER)*(D11)+2.375)+69.8*(D11)-1.33)+MD
236  1.125*(5.5*OVER)*2*(D11)+4.75*.0625*(5.5*OVER)
237  3.0*(OVER)*(D11)-1.67)+MD*1.089*STRAN*YMST)
315 743 FORMAT('1*********** COMPOSITE PROPERTIES ***********'/)
320  WRITE (6,755)
321 755 FORMAT('1 SLAB REINFORCING STEEL '
322  WRITE (6,756) ATRANS, ASPF
323 756 FORMAT('
324  WRITE (6,754) YCCM
325 744 FORMAT('1 COMPOSITE NEUTRAL AXIS = ',F6.3,3H IN)
326  WRITE (6,745) AICCM
327 745 FORMAT('1 COMPOSITE MOMENT OF INERTIA = ',F10.3,6H IN**4)
328  WRITE (6,746) DLMSF
329 746 FORMAT('1 TOP SLAB DEAD LOAD MOMENT = ',F8.3,5H IN-K)
330  WRITE (6,847) DLSHR
331 847 FORMAT('1 MAXIMUM DEAD LOAD SHEAR = ',F6.3,'K')
332  WRITE (6,848) SHEAR
333 848 FORMAT('1 MAXIMUM LIVE LOAD SHEAR = ',F6.3,'K')
334  WRITE (6,849) PSHR
335 849 FORMAT('1 PRESTRESS SHEAR EFFECT = ',F6.3,'K')
336  WRITE (6,753) FKRSH
337 753 FORMAT('1 ULTIMATE HOK. SHEARING STRESS= ',F6.3,4H KSI
338  WRITE (6,754) DELFL
339 754 FORMAT('1 FINAL DEFLECTION DUE TO U.L. = ',F6.3,3H IN///)
340  WRITE (6,471)
341 471 FORMAT('1*********** MOMENT INFORMATION ***********'/)
342  WRITE (6,748) BEML
343 748 FORMAT('1 APPLIED LIVE LOAD MOMENT = ',F9.3,5H IN-K)
344  WRITE (6,749) SLLM
345 749 FORMAT('1 LIVE LOAD CAPACITY = ',F9.3,5H IN-K)
346  WRITE (6,750) CKRM
347 750 FORMAT('1 CRACKING MOMENT = ',F9.3,5H IN-K)
348  WRITE (6,751) ULTM
349 751 FORMAT('1 ULTIMATE MOMENT REQUIRED = ',F9.3,5H IN-K)
350  WRITE (6,752) ULTD
351 752 FORMAT('1 ULTIMATE MOMENT DEVELOPED = ',F9.3,5H IN-K////)
352  WRITE (6,753) GCDAT
353 999 GCDAT
354  STOP
355  END

/TATA
************** GENERAL INFORMATION **************

CHANNEL DEPTH  = 20.0 INCHES
THE SPAN LENGTH  = 31.000 FEET
TYPE OF LOADING  = H15-44
NUMBER OF STRANDS  = 26.
NUMBER OF STRANDS
IN BOTTOM FLANGE= 12.

************** CHANNEL PROPERTIES **************

CHANNEL AREA = 400.651 IN**2
CHANNEL NEUTRAL AXIS = 5.302 IN
CHANNEL MOMENT OF INERTIA = 12243.060 IN**4
GCITCH SECTION MODULUS = 2116.400 IN**3
TOP SECTION MODULUS = 862.410 IN**3
MIDSPAN STRAND LOCATION = 1.497 IN
END STRAND LOCATION = 5.654 IN
MIDSPAN STRAND ECCENTRICITY = 3.235 IN
END STRAND ECCENTRICITY = 0.248 IN
CHANNEL DEAD LOAD MOMENT = 881.733 IN-K

************** CHANNEL STRESSES **************

INITIAL MIDSSPAN BOTTOM STRESS = 1.005 KSI
INITIAL MIDSPLAN TOP STRESS = -0.110 KSI
INITIAL END BOTTOM STRESS = 1.497 KSI
INITIAL END TOP STRESS = 1.073 KSI
FINAL MIDSPLAN BOTTOM STRESS = 0.926 KSI
FINAL END BOTTOM STRESS = 1.034 KSI
FINAL END TOP STRESS = 0.936 KSI

************** COMPOSITE PROPERTIES **************

SLAB REINFORCING STEEL
TRANSVERSE STEEL AREA = 0.400 IN**2/FT
LONGITUDINAL STEEL AREA = 0.248 IN**2/FT
COMPOSITE NEUTRAL AXIS = 14.159 IN
COMPOSITE MOMENT OF INERTIA = 82108.060 IN**4
TOP SLAB DEAD LOAD MOMENT = 1031.676 IN-K
MAXIMUM DEAD LOAD SHEAR = 17.307K
MAXIMUM LIVE LOAD SHEAR = 33.340K
PRESTRESS SHEAR EFFECT = 8.161K
ULTIMATE HOR. SHEARING STRESS = 0.214 KSI
FINAL DEFLECTION DUE TO C.L. = 0.174 IN
APPLIED LIVE LOAD MOMENT = 1276.560 IN-K
LIVE LOAD CAPACITY = 4766.041 IN-K
CRACKING MOMENT = 5372.953 IN-K
ULTIMATE MOMENT REQUIRED = 5740.504 IN-K
ULTIMATE MOMENT DEVELOPED = 13325.340 IN-K
APPENDIX B

DESIGN EXAMPLE

Bridge No. A-2141
DESIGN NOTATION

a - length of haunch from the end indicated by a subscript expressed as a fraction of the total span

$A_S$ - area of transverse slab reinforcing steel ($\text{in}^2$)

$A'_S$ - area of continuous longitudinal slab reinforcing steel ($\text{in}^2$)

$A''_S$ - area of negative moment slab reinforcing steel ($\text{in}^2$)

$A_V$ - area of shear reinforcement at a section ($\text{in}^2$)

B - ratio of distance from loading point to end A to length of span

b - width of cross-section for moment calculations (in)

$b'$ - width of section at critical location for shear (in)

$C_{AB}$ - carry over factor for end A of span AB, the notation is similar for any combination of subscripts

d - depth of precast-prestressed channel (in)

$D_{AB}$ - depth of slab at center of channel AB where A indicates the outside channel leg, the notation is similar for other subscripts lettered sequentially from the outside to the center (in)

E - wheel load distribution factor

$f_e$ - cylinder strength of concrete in compression (ksi)

$f_i$ - stress at location i, where i=1 to 5 as defined by figures B6 and B7 (ksi)

$FM_{AB}$ - fixed and moment at end A in span AB, the notation is similar for all combination of subscripts
fs - steel stress (ksi)
fy - yield stress of slab reinforcing steel (ksi)
jd - internal moment arm of stresses (in)
k - fraction of depth to neutral axis of the section
L - span (ft)
Ls - length which negative moment reinforcing steel must be
extended past the point where it is no longer required
M(+) - maximum positive moment in a given span acting on channel
(in-k)
M(-) - maximum negative moment in a given span acting on one
channel (in-k)
mAB - fixed end moment coefficient for end A of span AB, the
the notation is similar for any combination of subscripts
MAB - moment at end A of span AB, the notation is similar for
any combination of subscripts (in-k)
MALLOW - moment capacity of a section (in-k)
MMAX - maximum moment occurring in a given span (in-k)
n - ratio of center span of bridge to outside span
nC - ratio of modulus of elasticity of cast-in-place
concrete to that of the precast concrete
ns - ratio of modulus of elasticity of the reinforcing
steel modulus to that of the precast concrete
p - percent steel
Pact - impact factor
rA - ratio of haunch depth at channel leg indicated
by subscript to depth at center of channel
$R_A$ - reaction at end A, the notation is similar for any subscript
$S$ - spacing of stirrups for shear reinforcement (in)
$V$ - maximum shear occurring in one channel (kips)
$V_c$ - shear force carried by concrete (kips)
$V_u$ - shear stress due to specified ultimate load and effect of prestressing (kips)
$V_{\text{max}}$ - maximum shear occurring in a given span for the entire bridge (kips)
$w$ - uniformly distributed load (kips/ft.)
$\bar{Y}$ - location of the neutral axis measured from the bottom of the section (in)
TRANSVERSE DESIGN COMPUTATIONS FOR SLAB

TRANSVERSE SLAB REINFORCING STEEL (Figure B1)

Average Depth of Slab

\[ D_{AB} = 4.75 + \frac{(21 + 30) \times 3}{12} = 5.547 \text{ in.} \]
\[ D_{BC} = 4.75 + \frac{(21 + 90) \times 3}{12} = 6.485 \text{ in.} \]
\[ D_{CD} = 4.75 + \frac{(21 + 135) \times 3}{12} = 7.188 \text{ in.} \]

Impact Factor

\[ P_{Ac} = \frac{50}{L + \frac{125}{12}} = \frac{50}{4.25 + \frac{125}{12}} = 0.386 > 0.30, \quad P_{Ac} = 0.30 \]

Fixed End Moments (H15-44)

For Span AB, \( a_A = a_B = 0.5 \)
\[ r_A = r_B = \frac{4}{5.547} = 0.725 \]
\( B = 0.5 \)

From PCA Tables

\[ k_{AB} = k_{BA} = 9.47 \]
\[ C_{AB} = C_{BA} = 0.656 \]

For Concentrated Loads,

\[ m_{AB} = m_{BA} = 0.1565 \]

For Dead Load,

For Haunches

\[ m_{AB} = m_{BA} = 0.0187 \]

For Uniform Load,

\[ m_{AB} = m_{BA} = 0.0990 \]

Concentrated Live Load = \( 1.3(12) = 3.9k \) (Assumes 4 foot Load distribution and impact)

Uniform Dead Load = \( \frac{5.547 \times (0.150)}{12} = 0.069 \text{ k per ft.} \)

Haunch Load = \( \frac{4}{12} \times (0.150) = 0.050 \text{ k per ft.} \)

Fixed End Moments

\[ F_{MA} = F_{MB} = 0.1565(3.9) \times (4.25) + 0.0990 (0.069) (4.25)^2 + 0.0187(0.050) \times (4.25)^2 = 2.74 \text{ ft.-k.} = 32.9 \text{ in-k.} \]
Figure B1 Slab as Haunched Beam
For Span BC,

\[ a_B = a_C = 0.5 \]
\[ r_B = r_C = \frac{4}{6.485} = 0.618 \]
\[ B = 0.735 \]

From PCA Tables,

\[ k_{BC} = k_{CB} = 8.56 \]
\[ C_{BC} = C_{CB} = 0.639 \]

For Concentrated Loads

\[ m_{BC} = 0.0488 \]
\[ m_{CB} = 0.177 \]

For Dead Load,

For Haunches

\[ m_{BC} = m_{CB} = 0.0186 \]

For Uniform Load

\[ m_{BC} = m_{CB} = 0.0974 \]

Concentrated Load = \( \frac{1.3(12)}{4} = 3.9k \)

Uniform Dead Load = \( \frac{6.485(0.150)}{12} = 0.081 \text{ k per ft.} \)

Haunch Load = \( \frac{4(0.150)}{12} = 0.050 \text{ k per ft.} \)

Fixed End Moments

\[ F_{M_{BC}} = 0.0488(3.9)4.25 + 0.0186(0.050)(4.25)^2 + 0.0974(0.081)(4.25)^2 \]
\[ = 0.966 \text{ ft-k} = 11.6 \text{ in.-k.} \]

\[ F_{M_{CB}} = 0.1770(3.9)(4.25) + 0.0186(0.050)(4.25)^2 + 0.0974(0.081)(4.25)^2 \]
\[ = 3.10 \text{ ft-k} = 37.2 \text{ in.-k.} \]

For Span CD,

\[ a_C = a_D = 0.5 \]
\[ r_C = r_D = \frac{4}{7.188} = 0.557 \]
From PCA Tables,

\[ k_{CD} = k_{DC} = 8.08 \]
\[ c_{CD} = c_{DC} = 0.628 \]

For Uniform Dead Load

\[ m_{CD} = m_{DC} = 0.0965 \]

For Haunch Dead Load

\[ m_{CD} = m_{DC} = 0.0184 \]

Uniform Dead Load = \( \frac{7.188 	imes 0.150}{12} = 0.090 \) k per ft.

Haunch Load = \( \frac{4 	imes 0.150}{12} = 0.050 \) k per ft.

Fixed End Moments

\[ FM_{CD} = FM_{DC} = \frac{0.0965(0.090)(4.25)^2 + 0.0184(0.050)(4.25)^2}{2} = 0.173 \text{ ft-k.} = 2.07 \text{ in-k.} \]

For Span DE -- same as span CB but without concentrated load,

For Span EF -- same as span BA but without concentrated load,

Moment Distribution Results

\[ M_{AB} = 0.0 \]
\[ M_{BA} = 40.92 \text{ in-k per foot of slab} \]
\[ M_{CB} = 11.24 \text{ in-k per foot of slab} \]

Steel Requirements for Span AB (Figure B2)

\[ R_A = \frac{3.9}{2} + \frac{0.069(51)}{12(2)} + \frac{1}{3} \left( \frac{0.05(51)}{24(51)} \right) - 40.92 = 1.33 \text{ k per foot of slab} \]
\[ R_B = \frac{3.9}{2} + \frac{0.069(51)}{12(2)} + \frac{1}{3} \left( \frac{0.05(51)}{24(51)} \right) + 40.92 = 2.93 \text{ k per foot of slab} \]

Total = 4.26 k per foot of slab, checks.
\[ M_{\text{MAX}} = R_A \left( 25.5 \cdot 0.069 \frac{(25.5)^2}{24} \right) - 0.05 \frac{(25.5)^2}{48} = 31.35 \text{ in-k per foot of slab} \]

\[ A_s = \frac{M_{\text{MAX}}}{20(0.86)(4.24)} = 0.430 \text{ sq. in. per foot} \]

Use No. 5 bars at 8 in. cts.
Figure B2 Transverse Slab Shear and Moment
LONGITUDINAL DESIGN COMPUTATIONS

LONGITUDINAL SLAB REINFORCING STEEL

AASHO Requirement

Percent of $A_s = \sqrt{S} < 67$

\[
\frac{220}{\sqrt{S}} = \frac{220}{\sqrt{51/12}} = 106 \quad \text{Use 67%}
\]

$A_s' = 0.67(0.400) = 0.268 \text{ sq. in. per ft.}$

Use No. 5 bars at about 12 in. cts.

MAXIMUM LIVE LOAD MOMENTS AND SHEARS (AISC Tables) (Figure B3)

\[
n = \frac{34}{34} = 1.0
\]

\[
E = 4 + 0.06L = 4 + 0.06(34) = 6.04 < 7.0 \text{ checks}
\]

Moment and Shear on One Section (H15-44)

\[
M = \frac{(1 + \text{Pact})(60)M_{\text{MAX}}}{2E} = 0.54 M_{\text{MAX}}
\]

Maximum positive moment:

$M = 0.54(171.4)(12) = 1110.0 \text{ in-k}$

Maximum negative moment:

$M = 0.54(-148.4)(12) = -962.0 \text{ in-k}$

Maximum live load shear:

$V = 0.54(28.2) = 15.2^k$
Figure B3 Maximum Live Load Shear and Moments

- $V = 28.2^k$
- $M = 171.4$ ft.-k.
- $M = -148.4$ ft.-k.
DEAD LOAD MOMENTS FOR CURB, PARAPET, RAILS, FORMS, ETC.

Weight per foot = (Area of curb + Area of parapet) $\times \frac{15 \times 2}{144}$ + Wt/ft of rail, forms, etc.

$= [(9)(15)+(9)(18)] \times \frac{15}{144} \times 2 + 0.100 = 0.72\text{K/ft.}$

For One Channel:

Weight per foot $= \frac{1}{5} \times 0.72 = 0.144\text{ k/ft.}$

Fixed end moments $= \frac{WL^2}{12} = \frac{0.144(1156)}{12} = 13.87\text{ ft.-k.}$

Moment Distribution Results

$M_{12} = 0$

$M_{21} = 16.65\text{ ft.-k.}$

$M_{23} = 16.65\text{ ft.-k.}$

$M_{32} = 16.65\text{ ft.-k.}$

$M_{34} = 16.65\text{ ft.-k.}$

$M_{43} = 0$

Span 1-2

$\Sigma M, \Rightarrow R_2 = 2.94\text{ k.}$

$\Sigma F_{vert} \Rightarrow R_1 = 1.96\text{ k.}$

Maximum moment occurs at

$x = 34 - 1.96 = 20.4\text{ ft.}$
\[ M_{\text{max}} = 1.96 (13.6) - \frac{.144(13.6)^2}{2} = 13.38 \text{ ft.-k.} \]
\[ = 160.56 \text{ in.-k.} \]

Span 2-3

By symmetry & \( \Sigma \)Fvert;
\[ R_2 = R_3 = \frac{.144(34)}{2} = 2.45 \text{ k.} \]

\[ M_{\text{max}} = 2.45(17) - \frac{.144(17)^2}{2} - 16.65 \]
\[ = 50.4 \text{ in.-k.} \]

Maximum Moments For Live Load Plus Dead Load Of Curb, Parapet, Rails, Forms, Etc.

\[ M(+) = 1110 + 160.56 = 1270.56 \text{ in.-k.} \]
\[ M(-) = -962 - 16.65(12) = -1161.8 \text{ in.-k} \]

FOR RESULTS OF COMPUTER DESIGN PROGRAM (See page A16)

CHECK SHEAR REINFORCEMENT:

Using a load factor of 2,
\[ V_u = 2 \times \text{Live load shear} + \text{Dead load shear - Prestressing effect} \]
\[ V_u = 2(15.2) + 2.94 + 17.3 - 8.16 = 42.5 \text{ k} \]
\[ V_c = .180(8)(1)(24) = 30 \text{ k} \]
\[ (p225 \text{ T.Y.LIN}) \]

Use #4 stirrups,
\[ A_v = 2(.20) = .40 \text{ sq. in.} \]
\[ f_y = 40 \text{ ksi} \]
\[ j_d = 24 \left(\frac{7}{8}\right) = 21.0 \text{ in.} \]
\[ S \leq 2 Av f_y j_d = \frac{2(0.4)(40)(21)}{42.5-30} = 39 \text{ in} \]

And

\[ S \leq \frac{Av}{0.0025 b'} = \frac{0.4}{0.0025(8)} = 20 \text{ in} \]

Spacing used of 6 inches is satisfactory.

**NEGATIVE MOMENT REINFORCEMENT REQUIREMENTS**

Plot Influence Lines for moment at 2 using AISC Tables

(Figure B4)

Plot Moment diagram for maximum negative moment at 2 using

AISC tables (Figure B5)

Plot Moment diagram for dead load of curb, parapet, rails,

forms, etc. (Figure B6)

Plot Top and bottom fiber stress diagrams from computer

output (Figure B7)
Figure B4 Influence Line for Moment at 2
Figure B5  Moment Diagram for Maximum Negative Moment at 2
Figure B6  Moment Diagram for Dead Load of Curb and Parapet
Figure B7 Top and Bottom Fiber Stress Diagrams
From Bottom Fiber Stress Diagram

Stress at g support 2 = 1.033 ksi.
Stress at end of channel = 1.009 ksi.
Stress at 1 ft from end of channel = .920 ksi.
Stress at 3 ft. from end of channel = .866 ksi.

From Top Fiber Stress Diagram,

Stress at g support 2 = .936 ksi.
Stress at end of channel = 1.005 ksi.
Stress at 1 ft. from end of channel = 1.070
Stress at 3 ft. from end of channel = 1.350 Ksi.

From Moment Diagrams,

Moment at g Support 2 = -1161.8 in.-k.
Moment at end of channel = -1010.4 in.-k.
Moment at 1 ft from end of channel = -844.0 in.-k.
Moment at 3 ft. from end of channel = -522.4 in.-k.

Stress Check at Support 2:

# 5 bars at 12.0 in. centers

\[ P = \frac{1.55}{60 \times 26} = .00100 \]

\[ K = \sqrt{2Pn_s + (Pn_s)^2} - Pn_s = \sqrt{2(.00100)60 + [.00100(6)]^2} - .00100(6) \]

\[ = .1098 - .0060 = .1038 \]

\[ K_d = 0.1038(22) = 2.28'' \quad jd = 22-.76 = 21.24'' \]

\[ M = A_s f_s jd = 1.55(20)(21.24) = 660 \text{ in.-k.} \]

or \[ M = f_c \frac{(K_d)(jd)b}{2} = .8(2.28)(21.24)60 = 2322 \text{ in.-k.} \]
Figure B8 Cross Section and Stresses Outside Blockout

Figure B9 Cross Section and Stresses Inside Blockout
\[ M_{allow} = 660 < 1161.8 \text{ in.-k.} \]

Need extra steel

Try \( A''_s = 3.0 \text{ sq. in.} \)

\[ P = \frac{3.0}{(1560)} = 0.00192 \]

\[ K = \sqrt{\frac{(0.00192)2(6) + (0.00192)(6)}{2} - 0.00192(6)} = 0.140 \]

\[ K_d = 3.08'' \quad \text{jd} = 22-1.03 = 20.97 \]

\[ M_{allow} = 3.0(20) \times 20.97 = 1258 > 1161.8 \text{ in.-k.} \quad \text{O.K.} \]

Add #5 @ 12 in. cts. over interior supports

Total reinf. at supports is #5 @ 6 in. cts. which gives

\[ A''_s = 0.61(5) = 3.05 \text{ sq. in.} \quad \text{O.K.} \]

**Locate Cutoff Point.**

Stress Check 3 ft. from end of channel (Figure B8)

\[ \bar{y} = \frac{(240(2) + 8(16)12 + 2.417(11)9.5 + .208(5)(15+1(5)) + .459(5.5)2}{3} \times (4+11) + 22(10.07)) / (240 + 128 + 26.58 + 1.04 + 5.05 + 10.07) \]

\[ = 6.2'' \]

(1) Additional allowable bottom L.L. stress = 2.400 - .866 = 1.534 ksi

(2) Additional allowable top L.L. stress = 1.350 + .233 = 1.583 ksi

or proportioning to the bottom of the section gives;

Additional allowable bottom stress = \( \frac{1.583(6.2)}{20 - 6.2} \) = 0.715 ksi

\[ f_4 = 0.715 \]

\[ f_1 = \frac{0.715(15.6)}{6.2} = 1.75 \]

\[ f_2 = \frac{0.715(13.6)}{6.2} = 1.52 \]

\[ f_3 = \frac{0.715(2.4)}{6.2} = 0.26 \]

\[ f_5 = \frac{0.715(8.6)}{6.2} = 0.96 \]
\[ \sum_{N,A} = M_{ALLOW} = 1649 \text{ in.-k.} > 522.4 \text{ in.k.} \]

No extra steel is needed.

Check Stress at 1 ft. from end of channel:

Assume only cast-in-place concrete cracks,

Summing moments of areas about the neutral axis of Figure B9 gives

\[
\begin{align*}
&n_s A_s'(d+2-kd) + 4(d-kd)^2 + 1.208 (d-5-kd)^2 \\
+ &.208(2.5)2(d-5-Kd+5/3) + \frac{5(d-5-Kd)^3}{36} -240(kd-2) \\
- &\left[5.208 + \frac{.5(d-5-kd)}{12}\right] (kd-4)^2 + \frac{.5(kd-4)^3}{36} \\
- &.5\frac{(kd-4)^3}{36} n_c - (kd-4)^2 \left\{60-\frac{5.208+.5(d-5-Kd)}{12}\right\} \\
+ &\frac{5(kd-4)}{12} n_c = 0
\end{align*}
\]

Simplifying,

\[
K^3(-20.56d^3 + .0339d^4) + K^2 (-.324d^3 +246d^2) \\
+ K(-.0834d^3 - 7.82d^2-1174.6d - n_s A''d) \\
+ (.0139d^3 + 5d^2 + n_s A''d - 16.68d + 1745.3 + 2n_s A'') = 0
\]

For \(d = 20\) in. and \(A'' = 1.55 \text{ sq. in.}\)

\[
K^3(-159056) + K^2(95808) + K(-27475) + 3740 = 0
\]

By trial and error,

\(K = .29\)

\(Kd = .29(20) = 5.8''\)

(1) Additional allowable bottom stress = 2.4 - .92 = 1.98 ksi

(2) Additional allowable top stress = 1.07 + .233 = 1.303 ksi

or proportioning to the bottom of the section gives;

Additional allowable bottom stress of \(\frac{1.303(5.8)}{14.2} = .533 \text{ ksi}\)
\[ f_4 = 0.533 \]
\[ f_1 = \frac{0.533 \times (16.2)}{5.8} = 1.49 \]
\[ f_2 = \frac{0.533 \times (14.2)}{5.8} = 1.31 \]
\[ f_3 = \frac{0.533 \times (1.8)}{5.8} = 0.161 \]
\[ f_5 = \frac{0.533 \times (9.2)}{5.8} = 0.845 \]

\[ \sum M_{N,A.} = M_{ALLOW} = 1365 \text{ in.-}k. > 844.0 \text{ in.-k. O.K.} \]

No extra steel required.

Stress Check at end of channel:

1. Additional allowable bottom stress = 2.40 - 1.009 = 1.39 ksi

2. Additional allowable top stress = 1.005 + 233 = 1.238 ksi

or proportioning to the bottom of the section gives;

Additional allowable bottom stress = \( \frac{1.238 \times (5.8)}{14.2} \times 0.505 = 1293 \text{ in.-}k. > 1010.4 \text{ in.-k. O.K.} \)

No extra steel required.

\[ L_s = \frac{33 \times (12)}{20} = 19.8'' \text{ or} \]
\[ L_s = 15 \times 0.625 = 9.4 \]

Therefore \( L_s = 19.8'' \)

Length = \( 2 \times (0.5)'' + 2(20'') = 4''-4'' < \frac{L}{10} = 6''-8'' \)

Let length = 6''-8'' alternating with 8''-8''
Quantities for Bridge A-2141

Computation of Quantities

Area for bottom and edge of slab for forming

\[
\text{Area} = 2 \left( 4.396 \right) 102 + 4 \left( 1 \right) \left( \frac{15}{12} \right) + \left( \frac{2 \left( 2.5 \right) 21}{144} \right) + 4 \left( \frac{28.5}{12} \right) + 2 \left( \frac{12.25 \times 3 \times 12.25}{16} \right) \\
= 983.28 \text{ sq.ft.}
\]

Area for curb and parapet for forming

\[
\text{Area} = 4 \left( \frac{27}{12} \right) 102 + 4 \left[ \left( \frac{9 \times 18 + 9 \times 15}{144} \right) + \frac{573}{144} \right] \\
= 942.15 \text{ sq.ft.}
\]

Area of Voids for void forming

\[
\text{Area} = 15 \left( 33 - 6 \right) \times \frac{51.583}{12} = 1741 \text{ sq.ft.}
\]

Cross sectional area of slab

\[
\text{Area} = 5 \left( \frac{69.82}{144} \right) + 2 \left( \frac{2.5 \times 21}{144} \right) + 4 \left( \frac{28.5}{12} \right) + 2 \left[ \left( \frac{12.25 \times 3 \times 12.25}{16} \right) + \frac{\left( 3 \times 12.25 \right)^4}{12} \right]
\]
\[
\frac{+2(4)3 + 9(18)2 + 9(15)2}{3(12)16 \frac{144}{144}} = 19.931 \text{ sq.ft.}
\]

**Volume of Concrete**


Vol. of end posts = 9.88 cu ft.

Vol. at bents = 2\left[19.931-2.424+20(25)\right]\frac{12}{12} = 118.35 \text{ cu.ft.}

Vol. for blockouts = 30(36)5.067 = 456.03 \text{ cu.ft.}

Total = 2548.33 \text{ cu.ft.}

Vol. in curb and parapet

\[
= \left[\frac{9(18)2}{144} + \frac{9(15)2}{144}\right]\frac{102}{27} + .37 = 15.97 \text{ cu.yd.}
\]
## Reinforcing Steel Quantities

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<td>13,480.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$.174/# = $2,341.00
### A-2141 Low Channel Costs

#### Cost Estimate (Method 1)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit cost</th>
<th>Labor</th>
<th>Mat'ls.</th>
<th>Equip.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Errection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 1/2 men, 12 hrs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crane, 1/2 Truck, Pickup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Beams</td>
<td>33' / beam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1741 sq.ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$5.50/hr./man $37/hr.</td>
<td>$495.00</td>
<td></td>
<td></td>
<td>$444.00</td>
</tr>
<tr>
<td></td>
<td>$15.75/ft. $0.10/ft' void</td>
<td></td>
<td></td>
<td>$7796.25</td>
<td></td>
</tr>
<tr>
<td><strong>Forming:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab</td>
<td>983.28 sq.ft</td>
<td>5.50/hr = $1.22 4.5/hr / ft</td>
<td>$1,199.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curb &amp; Parapet</td>
<td>942.15 sq.ft</td>
<td>5.50/hr = $1.00 10/hr / ft'</td>
<td>$516.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Const. of forms C &amp; P</td>
<td>(942.15) 156.59 sq.ft.</td>
<td>5.50/hr = $0.367 15/hr / ft'</td>
<td>57.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plyform</td>
<td>983.28 sq.ft</td>
<td>$0.25/ft'</td>
<td>$245.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>942.15 sq.ft</td>
<td>$0.25/ft'</td>
<td>39.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub totals =</td>
<td>$2,268.83</td>
<td>$8,255.32</td>
<td>$444.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Cost Estimate (Method 1)

**ITEM** | **Quantity** | **Unit cost** | **Labor** | **Mat'ls.** | **Equip.**
---|---|---|---|---|---
Dimen- | 2(983.28) | $0.15/bd. ft. | $2,268.83 | $8,255.32 | $444.00
sion Lumber | = 1966.56 bd. ft.) | | | | |
1(2) (942.15) | $0.15/bd. ft. | | | | |
6 = 313.19 bd. ft. | | | | | |
Brac- | 2(102) = 51 | $2.00/each | | | $102.00
kets | $728.92) | | | | |
Misc.(10% Forming Mat'ls. | | | | | $72.89
Concrete: | 94.50 cu. yd. | $6.00/cu. yd. | $567.00 | | |
Labor | | | | | |
Mat'ls. | 94.50 cu yd. | $14.00/cu yd. | | $1323.00 | |
Railing | 183 ft. | $5.60/ft. | | $1024.80 | |
| Sub total | $2,835.83 | $11,119.96 | | $1,436.54 | |
# Cost Estimate (Method 1)

Continued: A-2141

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Quantity</th>
<th>Unit cost</th>
<th>Labor</th>
<th>Mat'ls.</th>
<th>Equip.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sub totals =</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$2,835.83</td>
<td>$11,119.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1,436.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post tensioning rods</td>
<td>12(25)</td>
<td>$.174/#</td>
<td></td>
<td></td>
<td>$139.10</td>
</tr>
<tr>
<td></td>
<td>490 #</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforcing Steel</td>
<td>13,480.69#</td>
<td>$.174/#</td>
<td></td>
<td>$2,341.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total less overhead =</td>
<td>$2,835.85 +</td>
<td>$13,600.06</td>
<td></td>
<td></td>
<td>+$1,436.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>=$17,872.45</td>
</tr>
<tr>
<td>Overhead</td>
<td>.05(total)</td>
<td></td>
<td></td>
<td></td>
<td>$893.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost Superstructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>=$18,760.58</td>
</tr>
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</table>
## Cost Estimate (Method 2)

### A-2141 Low Channel Costs:

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Quantity</th>
<th>Unit cost</th>
<th>Labor</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Errection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 members</td>
<td></td>
<td>$35/hr.</td>
<td>$525.00</td>
<td></td>
</tr>
<tr>
<td>1/hr. = 15 hrs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 members</td>
<td></td>
<td>$15.75/ft.</td>
<td>$7,796.25</td>
<td></td>
</tr>
<tr>
<td>33 ft. Long</td>
<td></td>
<td>$0.10/ft.</td>
<td>$174.10</td>
<td></td>
</tr>
<tr>
<td>17410 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Forming</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curb, Parapet &amp; Over-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hang</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mat'l.</td>
<td></td>
<td>$0.25/sq.ft</td>
<td></td>
<td>$245.82</td>
</tr>
<tr>
<td>Plyform</td>
<td></td>
<td>$0.25/sq.ft</td>
<td></td>
<td>$39.15</td>
</tr>
<tr>
<td>983.28 sq.ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>942.15 sq.ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimension</td>
<td></td>
<td>$0.15/bd.ft.</td>
<td></td>
<td>$294.98</td>
</tr>
<tr>
<td>Lumber</td>
<td></td>
<td>$0.15/bd.ft.</td>
<td></td>
<td>$46.97</td>
</tr>
<tr>
<td>2(983.28)=1044.56 bd.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(942.15)/6=314.05 bd.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brackets</td>
<td></td>
<td>$5/each</td>
<td></td>
<td>$255.00</td>
</tr>
<tr>
<td>2(102)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor cost</td>
<td></td>
<td>$6/cu. yd.</td>
<td>$471.18</td>
<td></td>
</tr>
<tr>
<td>slab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td></td>
<td>$12/cu. yd.</td>
<td>$191.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub totals =</td>
<td>$2821.82</td>
<td>$8,852.27</td>
</tr>
</tbody>
</table>
### Cost Estimate (Method 2)

Continued:
A-2141

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Quantity</th>
<th>Unit cost</th>
<th>Labor</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>94.50 cu. yd.</td>
<td>$14.00/cu. yd.</td>
<td>$2,821.82</td>
<td>$8,852.27</td>
</tr>
<tr>
<td><strong>Railing</strong></td>
<td>183 ft.</td>
<td>$5.60/ft.</td>
<td></td>
<td>$1,024.80</td>
</tr>
<tr>
<td><strong>Post tensioning steel</strong></td>
<td>800#</td>
<td>$0.174/#</td>
<td>$139.10</td>
<td>$2,341.00</td>
</tr>
<tr>
<td><strong>Reinforcing steel</strong></td>
<td>13,480.11</td>
<td>$0.174/#</td>
<td></td>
<td>$2,341.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sub totals = $2,821.82 + $13,680.17 = 16,501.99</td>
<td>= $2,970.36</td>
</tr>
<tr>
<td><strong>Overhead, Supervision, Insurance, Equipment (.18X16501.99)</strong></td>
<td></td>
<td></td>
<td></td>
<td>Total Superstructure = $19,472.35</td>
</tr>
</tbody>
</table>
## Cost Estimate

### A-2141 Average Channel Costs

<table>
<thead>
<tr>
<th></th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost less overhead for low channel costs</td>
<td>$17,872.45</td>
<td>$16,501.99</td>
</tr>
<tr>
<td>Cost of low cost channels</td>
<td>$10,076.20</td>
<td>$8,705.74</td>
</tr>
<tr>
<td>Cost of bridge less overhead and cost of channels</td>
<td>+$7,895.25</td>
<td>+$7,895.25</td>
</tr>
<tr>
<td>Cost of average cost channels = 15.95 x 15 x 33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost less overhead for average channel costs</td>
<td>$18,870.02</td>
<td>$19,589.17</td>
</tr>
<tr>
<td>Overhead - 5% for method 1, 18% method 2.</td>
<td>+$898.57</td>
<td>+$2,988.18</td>
</tr>
<tr>
<td>Total cost for superstructure for average channel costs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### A-2141 High Channel Costs

<table>
<thead>
<tr>
<th></th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of bridge less overhead and cost of channels</td>
<td>$10,076.20</td>
<td>$8,705.74</td>
</tr>
<tr>
<td>Cost of high cost channels = 16.25 x 15 x 33</td>
<td>+$8,143.75</td>
<td>+$8,143.75</td>
</tr>
<tr>
<td>Total cost less overhead for high channel costs</td>
<td>$18,219.95</td>
<td>$16,849.49</td>
</tr>
<tr>
<td>Overhead - 5% for method 1, 18% for method 2.</td>
<td>+$910.99</td>
<td>+$3,032.91</td>
</tr>
<tr>
<td>Total cost for superstructure for high channel costs</td>
<td>$19,130.94</td>
<td>$19,882.40</td>
</tr>
</tbody>
</table>