IN-HOUSE FABRICATION OF PRECAST CONCRETE BRIDGE SLABS

by

Michael M. Sprinkel
Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

Information is reported on the labor, equipment, material, and cost required for seven bridge maintenance situations in which state forces widened or replaced an existing short span structure. Precast concrete slabs were installed at three of the locations, concrete slabs were cast at the site at two of the locations, and steel stringer-timber deck superstructures were constructed at the other two locations. Data indicate that precast concrete slabs used in the 10'-35' span range provide for considerably more efficiency and economy than may be obtained with conventional alternative superstructures of timber on steel stringers and site-cast concrete. The use of precast slabs provides for a 25% or more reduction in total cost, an 80% reduction in on-site construction time; and a 65% reduction in the fuel required for travel to and from the bridge site. Since precast slabs can be placed in one work day, a closed road and a traffic detour may be eliminated.

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INTRODUCTION

Precast concrete has continued to grow in popularity as a construction material since its development in the last half of the nineteenth century.(1) As has been the case with competitive materials such as steel, timber, aluminum, and plastic, concrete is now being cast more successfully in the factory than in the field. It has been used extensively in the building industry for the last three decades. Precast concrete has received considerable recognition as a construction material in areas where weather conditions are severe and where working conditions at construction sites are undesirable.

In September 1972, the Research Council undertook a project to develop a Secondary Roads Bridge System which would be fabricated by Department personnel during off-peak construction seasons, would be mass produced and stockpiled, and would be competitive with SS4 and SS5 superstructures.(2) Plans to fabricate and install either precast slabs over steel stringers or precast channel members at a bridge site did not materialize. However, in May 1975 the Suffolk District successfully constructed a casting bed and fabricated a precast concrete bridge slab. On June 23, 1976, a 45-ton crane moved the 17 1/2 ton slab from the form to a lowboy for hauling, and later positioned the slab over Quaker Swamp and in the median of Rte. 58 in Suffolk (see Figure 1). With the experience obtained from the first installation, the District personnel moved ahead with the fabrication and installation of somewhat smaller precast slabs to widen four bridges. One of these four, a structure on Rte. 714, was the first secondary road bridge to be widened with state force labor using the new construction technique (see Figure 2).

Setting up forms in the spring of 1975 and casting slabs throughout the winter, the Staunton District crew stockpiled the slabs for numerous bridge replacement projects. On February 26, 1976, Staunton District personnel took their first precast slabs to Bath County. An existing steel stringer timber deck bridge on Rte. 614 was the first in the state to be completely replaced with precast concrete slabs fabricated by state force labor. In less than 1 day, the Covington area bridge crew and Staunton District personnel removed the existing superstructure (see Figure 3) and placed seven 4' wide slabs, holding

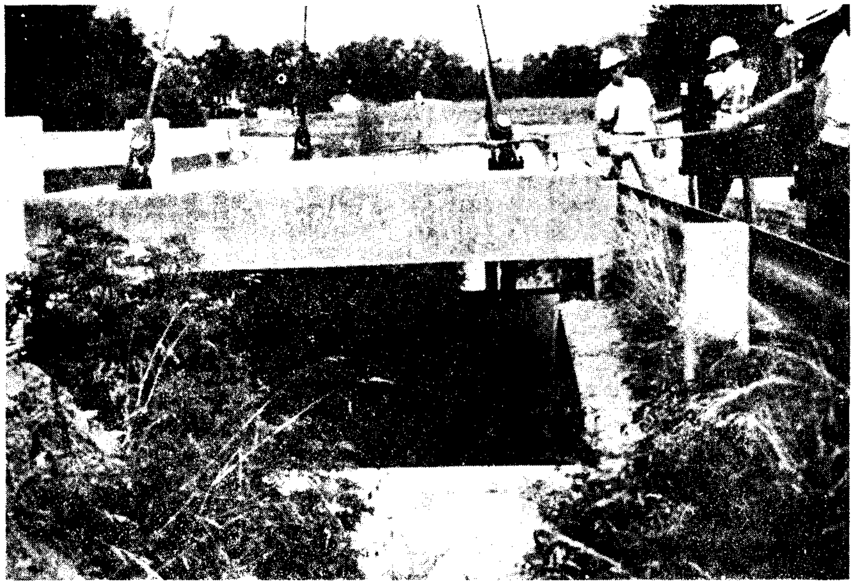

Figure 1. Suffolk District personnel place slab over Quaker Swamp.

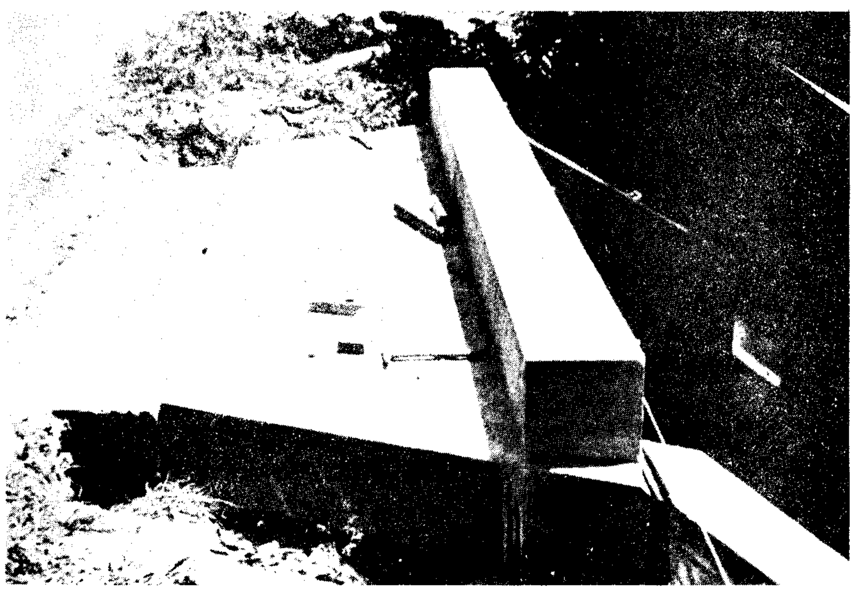

Figure 2. Widened Rte. 714 Bridge in Suffolk District.

up traffic for only a few minutes during the placement operation. On April 20, 1976, the Harrisonburg area bridge crew and Staunton District personnel placed the entire superstructure of a 2-span bridge on Rte. 724 near Harrisonburg in 1 work day. The structure was the first 2-span bridge to be constructed with precast concrete slabs fabricated by state force labor (see Figure 4).

The principal advantage of using precast concrete slabs for widening and replacing bridge decks is to achieve a reduction in the number of work days at the bridge site. With a reduction in on-site construction time there is less inconvenience to the motorist, the appearance and condition of the bridge site is restored in a short time, fuel is conserved because there are fewer trips to the bridge site, and working conditions are improved since most of the construction takes place in the convenience and safety of the District casting yard.

Another reason for using precast slabs is to improve construction efficiency. With precast slabs the same forms can be used for numerous bridges; fabrication can proceed in a systematic manner; fabrication can proceed even in bad weather, since the workers are close to the District office; the number of man-hours lost in traveling to and from a bridge site is reduced; concrete is sometimes cheaper, since it does not have to be hauled a long distance; and high quality concrete is more easily obtained in a casting yard than at a bridge site.

The principal disadvantage in using precast slabs is in handling the large units and making sure they fit properly.

In this report, the Staunton and Suffolk Districts' casting operations are discussed in detail and the precast slab construction technique is compared on a quantitative basis with cast-in-place concrete construction and with steel stringer-timber deck construction.

FABRICATION OF SLABS

Quality control and efficiency at the fabrication plant are probably the most essential ingredients for the successful construction of a modular or prefab structure. Precast components will fit together satisfactorily in the field only if they are cast to close tolerances. Since the major portion of a modular construction project takes place in the factory, the major portion of the supervision and inspection also must take place there. Fabrication errors that are not detected at the plant can be very costly and time-consuming to remedy in the field. Precast components which are cast in a good set of forms and under close supervision will fit together quickly and

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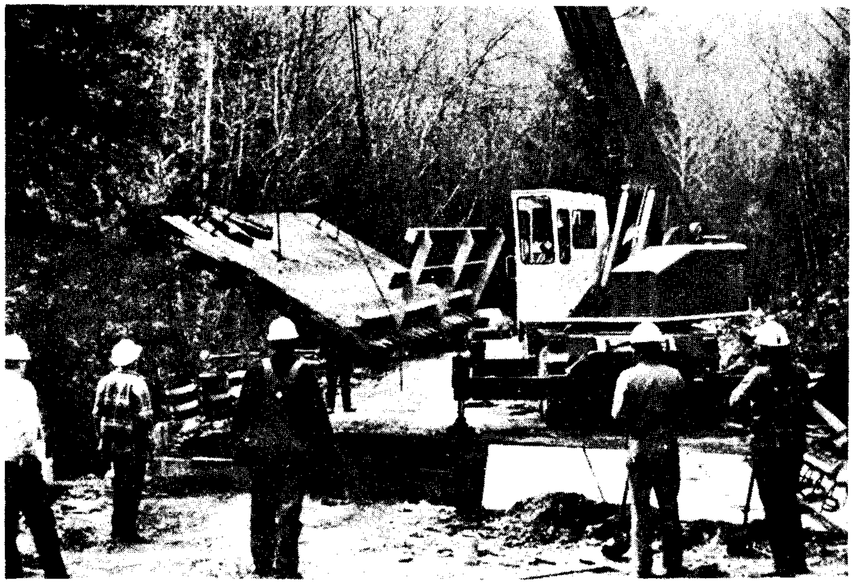

Figure 3. SSTD structure is removed by Staunton District personnel.

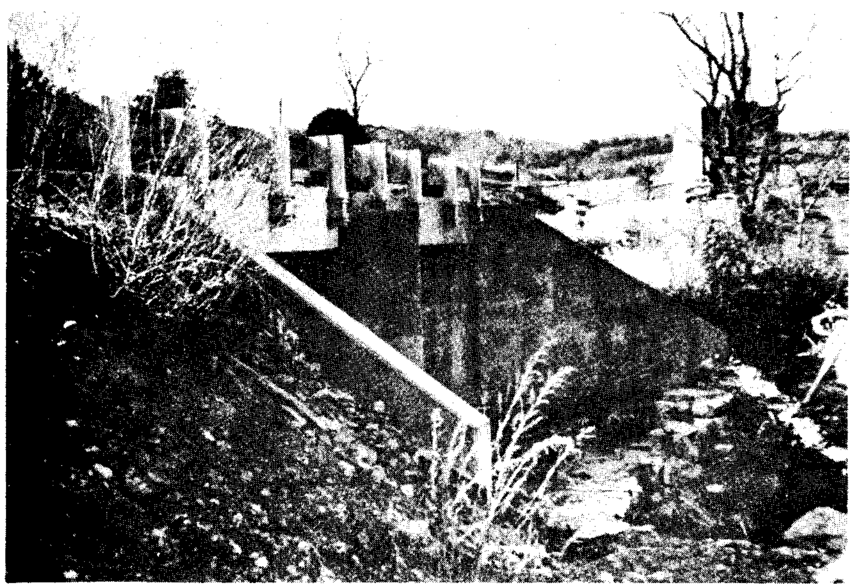

Figure 4. Two-span precast slab bridge on Rte. 724 near Harrisonburg.

securely in the field, and will provide a structure which is far more economical and superior to that which can be obtained with conventional construction techniques.

Forms

A precast member takes the shape of the form in which it is cast. A form constructed and maintained to close tolerances will provide a member that fits to close tolerances.

A precast slab is probably the easiest type of component to fabricate accurately, therefore a good fit is not too difficult to obtain in the field. Even so, particular attention should be devoted to the portion of the form which supports the bearing areas of a slab. Small variations in the bed of the form can be tolerated, except in the slab-bearing area. Prior to each pour, levels should be run on the bottom portion of the bed that will support the bearing areas of the slab and, if necessary, the bed should be adjusted so as to produce a slab that bears uniformly as "on all four legs rather than three". Attention should also be directed toward the depth of the bed a each end of a slab. If the depth is constant on each pour, the slabs will be the same thickness over the bearing area, and therefore will provide a flat top surface when set next to each other in the field. Finally, attention should be directed to the width of the slab forms prior to each pour. Slabs that are uniform in width will have little sweep and will fit together very closely in the field.

Suffolk District Form

The form constructed and used by the Suffolk District is shown in Figure 5, and the labor, equipment, and materials information is shown in Appendix A. The form was prepared by 3 men in about 1 week. Three footings 16" wide x 4' deep x 14' long were cast 15' apart. Twenty W10 x 33 steel stringers 15' long were placed 17" apart on the concrete footings. Twenty-two 4" x 4" x 16' timbers were placed 16" center to center on top the steel stringers. The timbers were covered with standard 4' x 8' sheets of 3/4" thick exterior grade plywood (plyform). Side forms and bulkheads were constructed from exterior grade plywood and 2" x 4" timbers, and were bolted to the floor prior to casting 2 slabs. The steel stringers and the 4" x 4" timbers are not included in the cost figures for the bed (to be discussed later), because these items were already available, would be salvage material in most other districts also, and would be salvage material if the bed is later disassembled.

Two slabs 4' wide and up to 28' in length can be cast in this form in any one pour. Side forms provide for a permament 4' width and 14" depth. Slabs can be cast in lengths up to 28' (slightly less for skewed structures) and widths up to 4' by adjusting the side forms and bulkheads. The depth of the slabs can be increased from 14" by tacking 2" x 4" members to the top of the sides and bulkheads. Two slabs can be cast about every 2 weeks using the forms. The first cost for the form was very low and maintenance costs have been even less. Settlement of the bed has not been a problem and the plywood can be expected to last for ten or more castings.

Staunton District Forms

The casting bed constructed and used by the Staunton District in shown in Figure 6, and the labor, equipment, and materials information is shown in Appendix A. The form was constructed by 3 men in 12 days. Three rows of railroad ties were placed on ground that had been properly leveled and covered with crusher run gravel. Timbers 2"x 6" x 4' were placed on 12" centers transversely to the railroad ties and wedges were placed between the transverse and longitudinal members to provide for the necessary adjustments to maintain a level bed. The timbers were covered with standard 4' x 8' sheets of 3/4" thick exterior plywood. Plywood sides were prefabricated and attached to the bed with through bolts so they could be raised or lowered to accommodate slabs of 9" to 18" in thickness. Figure 7 shows the additional forming required to provide the curb on an exterior beam. Four slabs up to 20' in length (slightly less for skewed structures) may be cast in the bed in any one pour.

Because of problems with differential settlement and higher than anticipated maintenance costs over a period of about 20 pours, the Staunton District has recently constructed the new 100' - 6" x 4' concrete casting bed shown in Figure 8. The base of the bed was constructed in two stages. Concrete was poured to a depth of 16" to form the first stage and, after settlement was essentially complete, a 4" concrete overlay was placed to provide a level surface upon which to cast bridge slabs. The side forms from the old bed were used with the new bed. The total cost for the new bed was $7,926.25.

Parapet Details

Staunton District people have tried several parapet details with their standard 4' wide slabs. In Figure 9 all the parapet steel was placed before the slab was cast. The Suffolk District has been using this technique with its precast

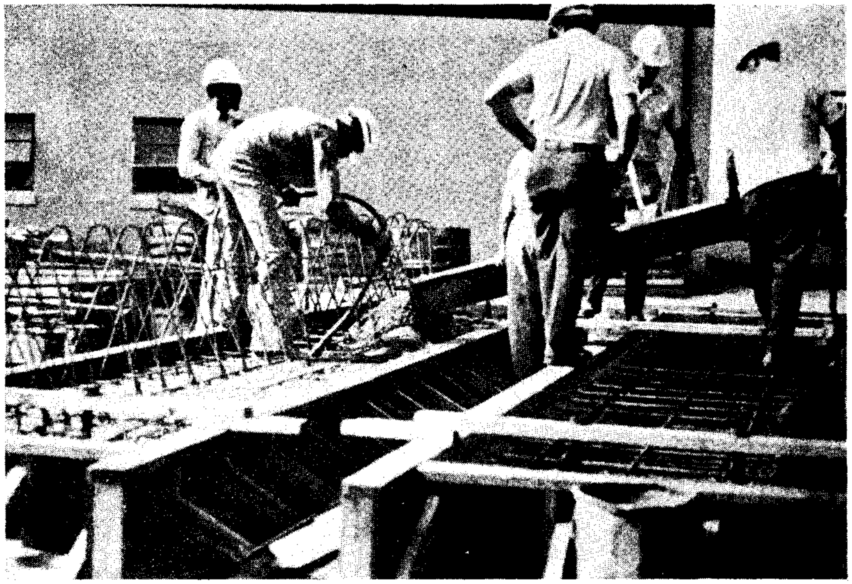

Figure 5. Suffolk District casting form.

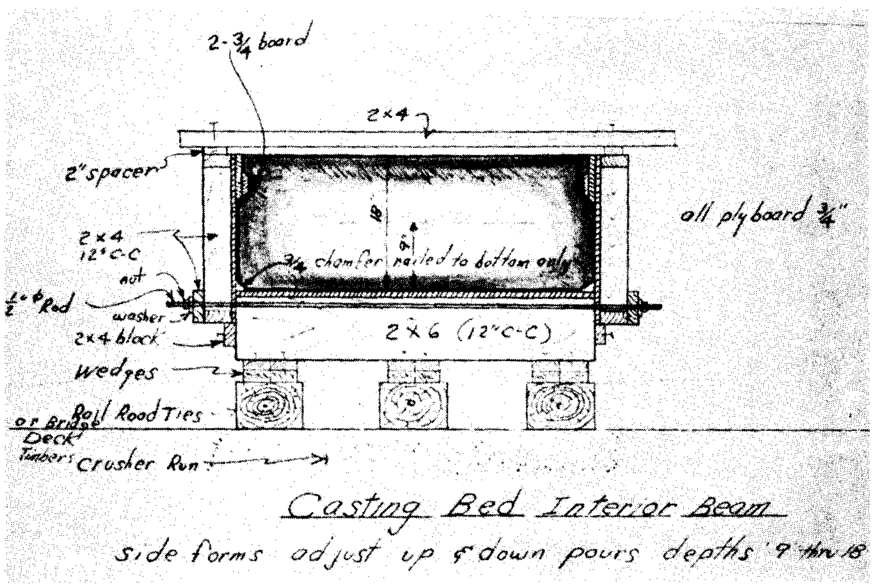

Figure 6. Staunton District casting form for interior beam.

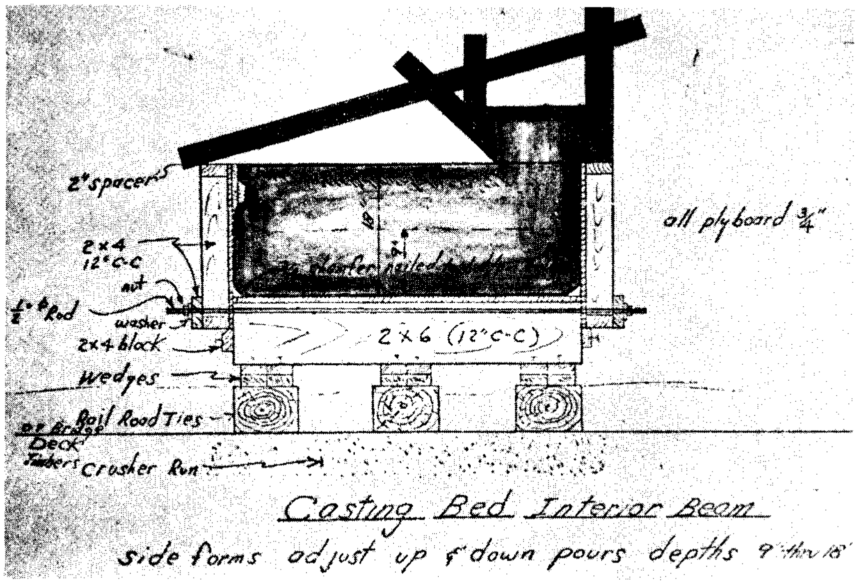

Figure 7. Staunton District casting form for exterior beam with curb.

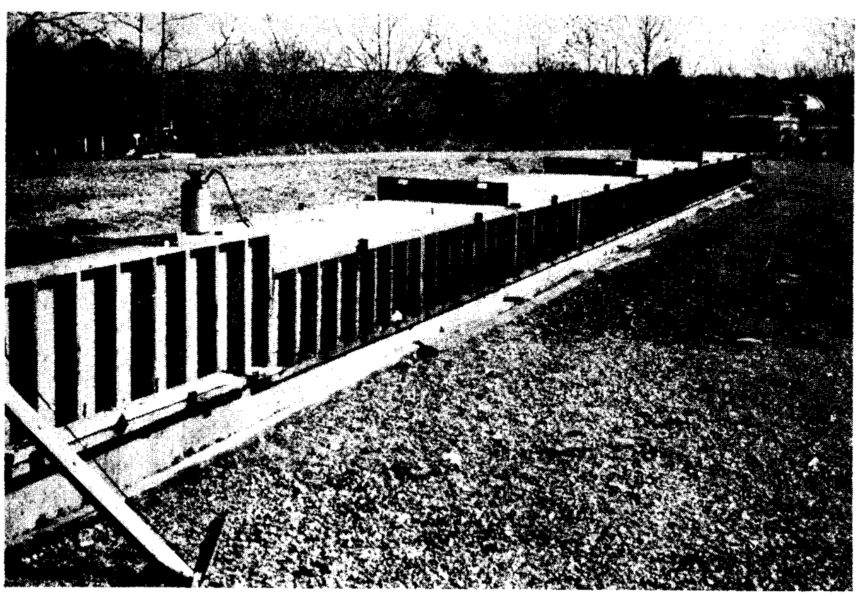

Figure 8. Staunton District casting form with concrete bed.

slabs. With this technique, it is difficult to finish the surface of the slab around the parapet steel, but there is less work in the field, since all of the parapet steel is in place when the slab is delivered. Inserts are placed in the side of the slab so that parapet forms may be attached. It takes 5 men about 4 1/2 days to form and pour the parapets for a 20' bridge with this type arrangement.

In Figure 10 a few large parapet bars are shown in the slab; the remainder are placed in the field. With this arrangement, the surface of the concrete may be easily furnished and there is little chance for damaging the parapet steel when handling the units, but more field labor is required for the parapets than with the previously mentioned technique. It took 5 men 6 days to form and pour the parapets for a 20' span bridge in which this type arrangement was used.

In Figure 11 a third type of parapet arrangement is shown. Here a curb and rail replaces the conventional cast-in-place parapet and is the easiest of the three alternatives to provide. The exterior slab is easy to form and finish and the posts and 40' of the rail can be attached by 2 men in 1 work day. One standard guard rail post provides two bridge rails which are spaced at 6' intervals. The rail does not meet AASHTO rail specifications, but should provide protection equivalent to that provided by the rail used on an SS6 structure.

Slab Connection Details

Three connection details have been tried by the Staunton and Suffolk Districts. In Figure 12, the slabs have been connected by welding a plate or angle to rebar protruding from adjacent slabs. The key way is then grouted.

In Figure 13 adjacent slabs have been connected by running steel threaded rods through holes cast into the slabs. After the nuts are tightened on the rods the key way is grouted. This system works all right for square crossings but may be more difficult to use on skewed crossings.

The Suffolk District connects its slabs by grouting the key way between adjacent units.

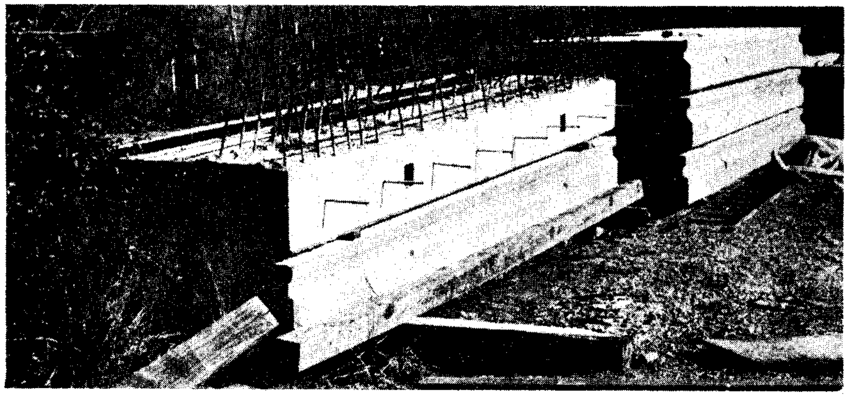

Figure 9. Exterior beam with all the parapet steel cast in slab.

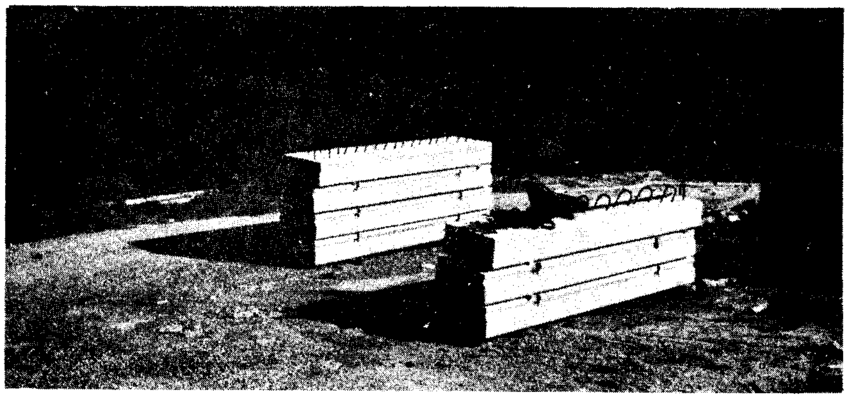

Figure 10. Exterior beam with a few large parapet bars cast in slab.

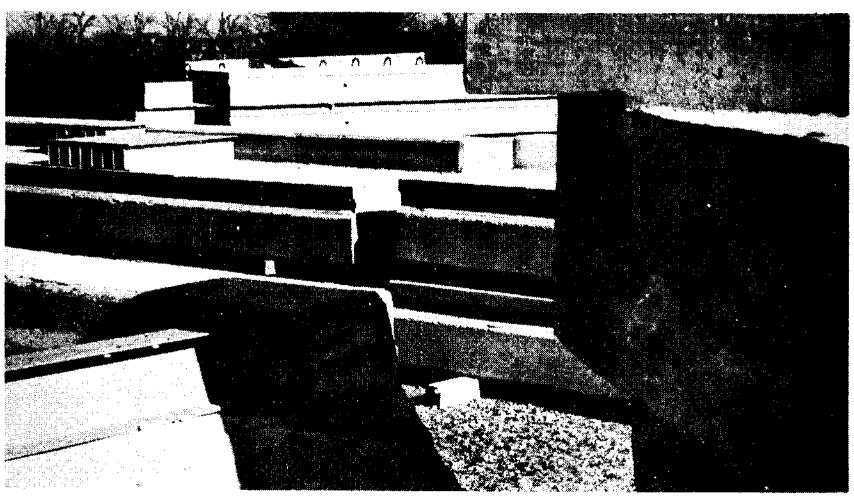

Figure 11. Exterior beam with curb cast in slab. Guardrail and post are attached in field.

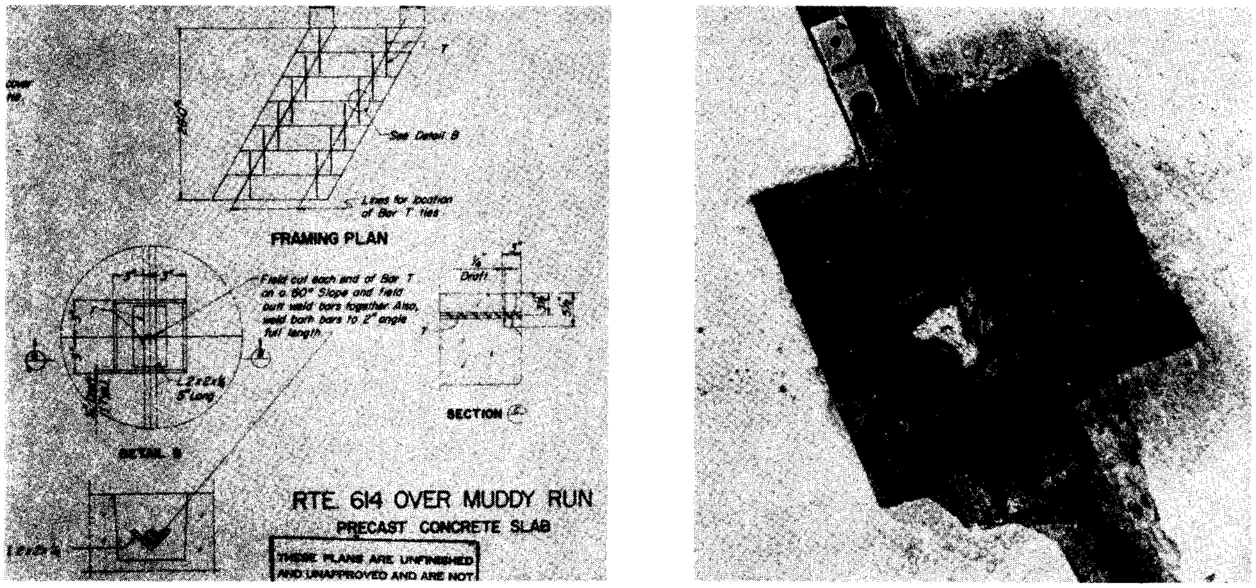

Figure 12. Connection detail requiring field weld and grouted keyway.

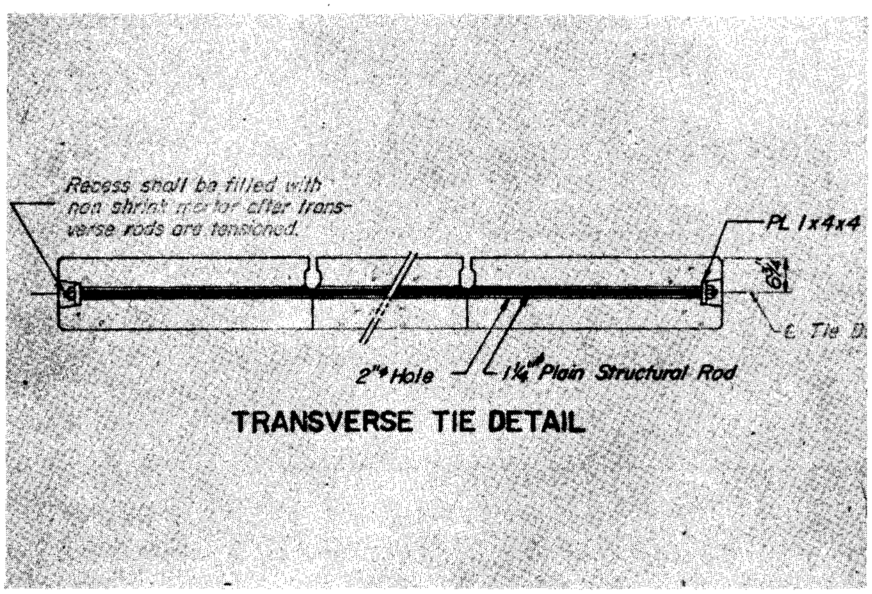

Figure 13. Connection detail requiring field tensioning.

HANDLING AND STORAGE OF PRECAST SLABS

Precasting operations should be organized so as to minimize the number of times a slab must be moved. Excessive handling is not only costly and time-consuming but increases the chances for damaging a slab. It is desirable to move precast slabs from the casting bed as soon as strength requirements are satisfied so that new slabs may be cast. Slabs that cannot be hauled to the field when removed from the form should be stored in such a manner that they will not have to be moved again until they are needed in the field.

The hardware, rigging, and equipment required for satisfactory handling of precast slabs are dictated by the size and weight of the units and the handling requirements. The hardware used by the Staunton and Suffolk Districts is shown in Figure 14. The lifting insert is cast into the concrete at least 1' from each edge, and the swivel lifting plate is bolted into the insert when it is necessary to move the slab. A swivel lifting device is preferable to an eyebolt because it prevents the anchor bolt from being bent when a slab is lifted. The swivel lifting device can be used many times. Four inserts and four crane slings are required for the four-point pickup used by the Staunton and Suffolk Districts. A spreader bar can be placed between each pair of slings and the crane hook to reduce the horizontal component of lifting force on the slings and inserts. In Figure 15 a Suffolk District crane lifts a slab with four slings and four anchors. In Figure 16 the Staunton District personnel move a beam from the storage area to a trailer using a gantry crane fabricated from salvaged materials and two dump trucks. With the gantry crane rig two spreader bars are used to reduce lifting forces. A 45-ton crane was available to the Suffolk District and therefore it was not necessary for personnel there to purchase or fabricate alternative equipment.

Slabs should be stored so as to induce the same dead load stresses that will be encountered in the field. Slabs should be stored on top of each other to save space, and timber spacers should be placed between the slabs directly above the timbers which support the bottom slab. Although protruding rebar for the parapet or a protruding curb makes it necessary to store an exterior slab on the top of the stack, it is desirable to stack the interior slabs in the order opposite to that in which they will be shipped to the field. In Figure 17 beams are stored by Staunton District personnel. If the form is not needed, it is best to leave the beams in the form.

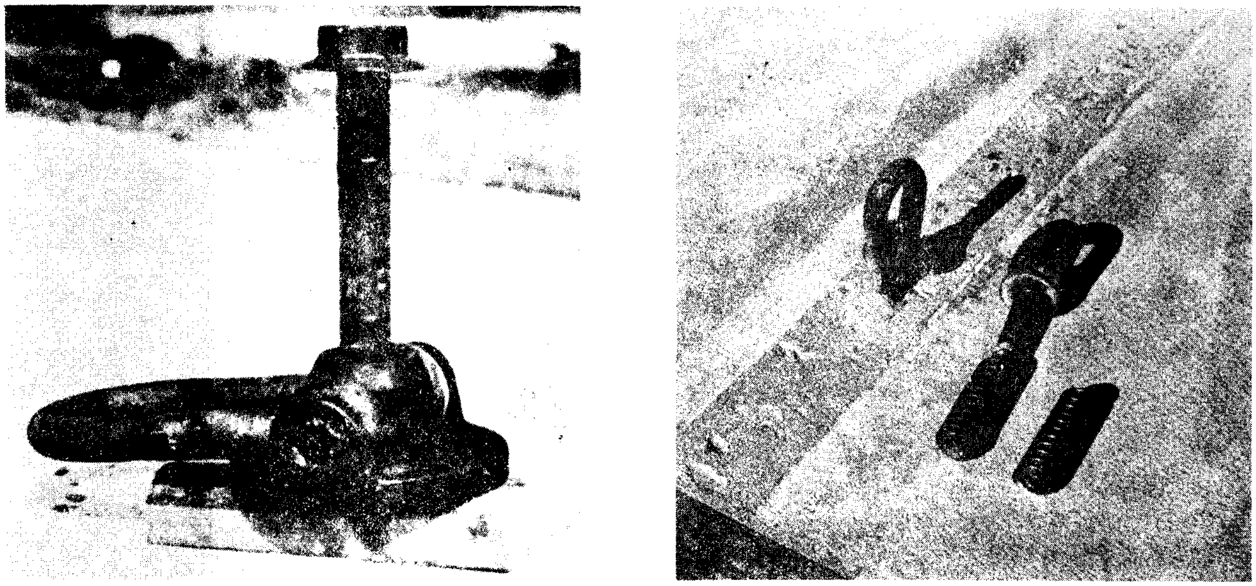

Figure 14. Lifting hardware used by Staunton and Suffolk Districts.

Figure 15. Truck crane lifting precast slab.

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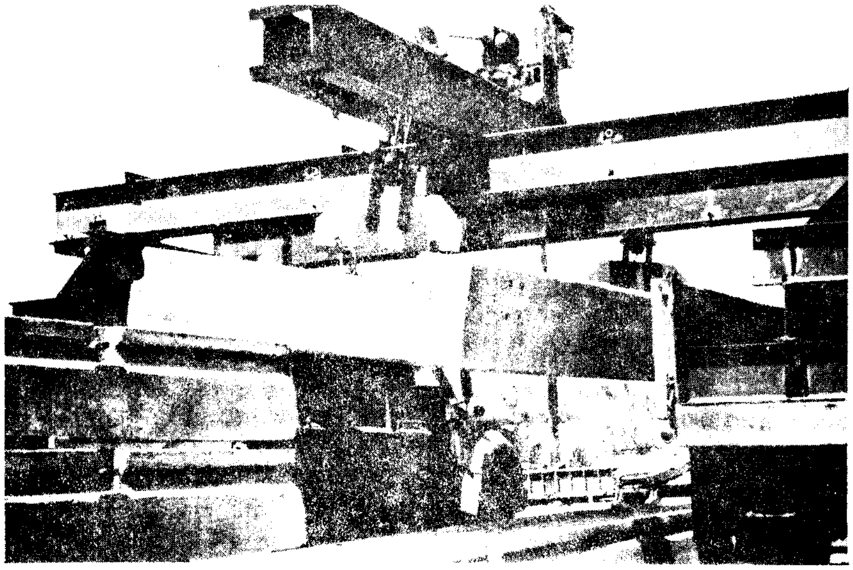

Figure 16. Gantry crane moving precast slab from storage area to trailer.

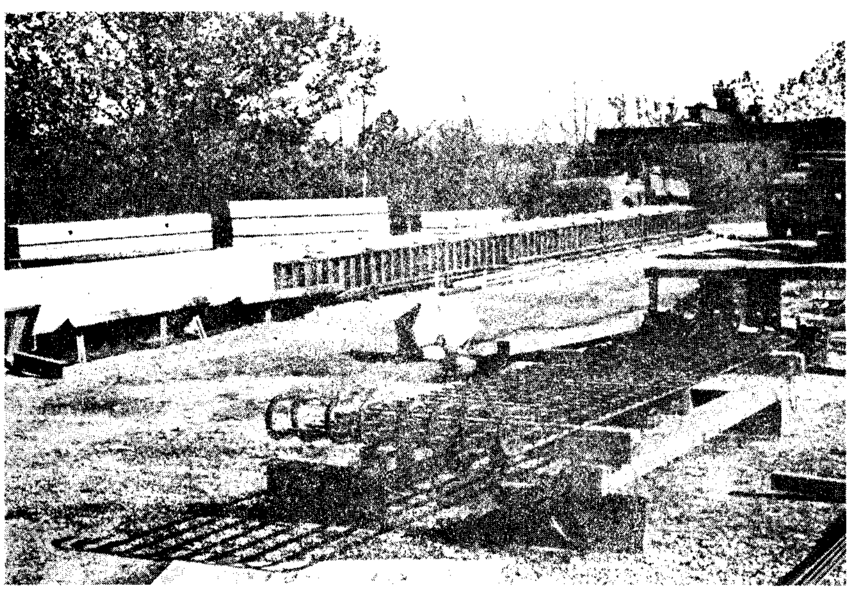

Figure 17. Slabs in storage at Staunton District casting yard.

TRANSPORTATION OF SLABS

Slabs should be loaded so that they are properly balanced on the trailer and are supported during transportation as they were during storage. Slabs should be properly braced and secured so that the flexure of the trailer bed is not transferred to them and trailer movements will not cause them to shift. Small peices of timber make excellent pads for distributing the forces from the chains which secure the slabs to the trailer. In Figure 18 Staunton District personnel have properly secured and transported three slabs 4' wide by 20' long.

Slabs should be transported to the bridge site in the order in which they are to be placed, and deliveries should be scheduled so that they can be placed as soon as possible after they arrive.

In most instances three slabs 4' wide by 20' long can be delivered on a trailer. Either four slabs 4' x 12' or two slabs 4' x 35' would weigh approximately 20 tons and could be hauled in one trip. However, the capacity of structures between the bridge site and the casting yard will occasionally dictate the number of members that can be hauled in one trip. For some bridges, the length of the slabs will be such that the use of lightweight concrete or voided material will allow one more slab to be transported on each trip than if solid slabs of normal weight concrete were fabricated.

ERECTION OF PRECAST SLABS

Men and equipment should be ready at the bridge site when the slabs arrive. The crane should be secured in an appropriate, predetermined location. When possible the crane should be located so that it will not interfere with traffic and will have to be moved as few times as possible. At times a considerable amount of time and effort will be required to get the crane to the site and to the most appropriate location.

A 45-ton crane should be satisfactory for handling most slabs for most site conditions. Although a smaller crane can handle smaller slabs, it's better to have a crane which is too large than one which is too small. The boom distance, weight of the crane, weight of the slabs, and crane cost should be taken into account when selecting a crane for a particular job. At times it will be appropriate to use a Department owned crane and at other times it will be more desirable to rent one.

Figure 18. Three slabs properly secured to lowboy trailer.

Figure 19. Epoxy and shims placed on building paper to correct for nonuniform bearing between slab and abutment.

Bearing areas should be properly prepared before the slabs arrive. Staunton and Suffolk District personnel have been placing building paper (felt) on top of the abutments prior to placing the slabs. Once a slab is placed, it is examined for fit. If uniform bearing is not obtained when the slab is set on the building paper, corrective measures must be taken. In the Staunton District epoxy and temporary wooden shims have been used to improve the bearing on troublesome slabs (see Figure 19). This practice requires that the slab be moved and set until the proper amount of epoxy is placed on the abutment. Other possible corrective measures include placing the beams on neoprene pads and pressure grouting the bearing area after the slab has been set. Slabs which are fabricated accurately will fit together in the field easily and quickly. Slabs which have excessive sweep, and variable thickness and which don't bear properly will require additional time and attention in the field. The best procedure is to try to achieve a properly prepared abutment surface and an accurately fabricated slab, and to be ready at the site to apply some suitable corrective measure. Slabs can be lifted from a trailer and put into place and connected in a few minutes. On-site construction time is primarily a function of the time required to apply the necessary corrective measures for poor fitting slabs. Figure 20 shows the time and sequence data for the first precast slab bridge erected by Staunton District personnel. Although epoxy and shims were used on the bearing areas of some of the slabs, all seven slabs were placed in 6 hours and traffic was delayed only a few minutes. A delay in getting the last slab to the site accounted for some of the time required. Although on-site construction time for the slabs was minimal— 1 work day— it is believed that with more experience slabs for this same type structure could be placed and connected in less than 2 hours. The finished structure is shown in Figure 21.

QUANTITATIVE COMPARISONS

Seven construction situations were investigated to allow quantitative comparisons between the precast slabs and the more conventional types of construction (Figure 22). Precast (PC) slabs were installed in plans A, B, and C (Figure 23), cast-in-place (CIP) concrete was used in plans D and E (Figure 24), and steel stringer-timber deck (SSTD) construction was used for the superstructure of plans F and G (Figure 25). Since the span length can affect the quantities involved in the comparison, a span length of 20' was selected for the comparative analysis. Plans A, B, C, and D were constructed with span length of 19' 20', 22 1/2', and 22 1/2', respectively, and therefore no adjustment was made in the quantities for these structures. Plans E, F, and G were constructed with span lengths of 12', 44', and 32', respectively, and the corresponding quantities adjusted to a 20' span length as represented by plans E', F', and G'.

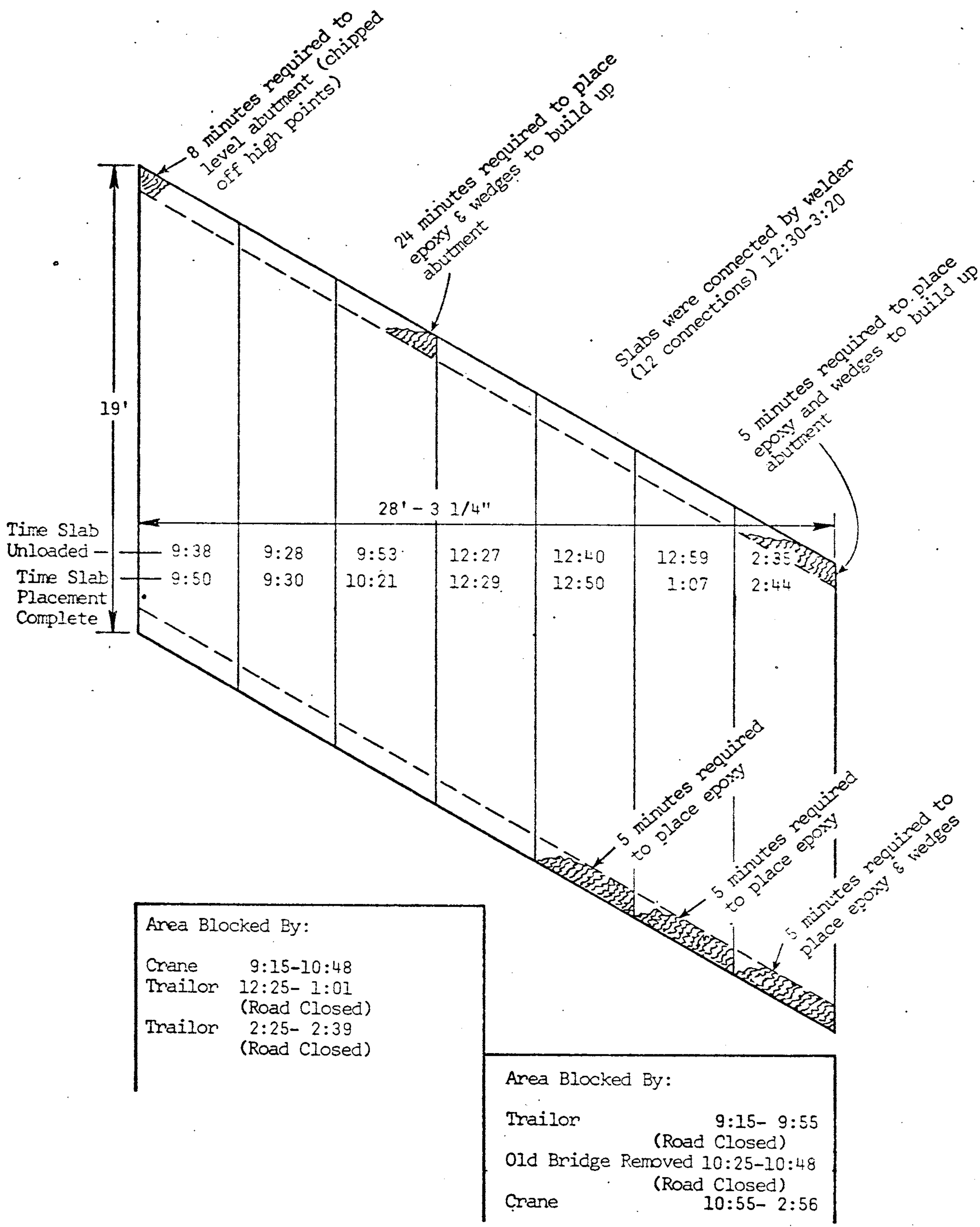

Figure 20. Time and sequence data for Rte. 614 bridge in Bath County.

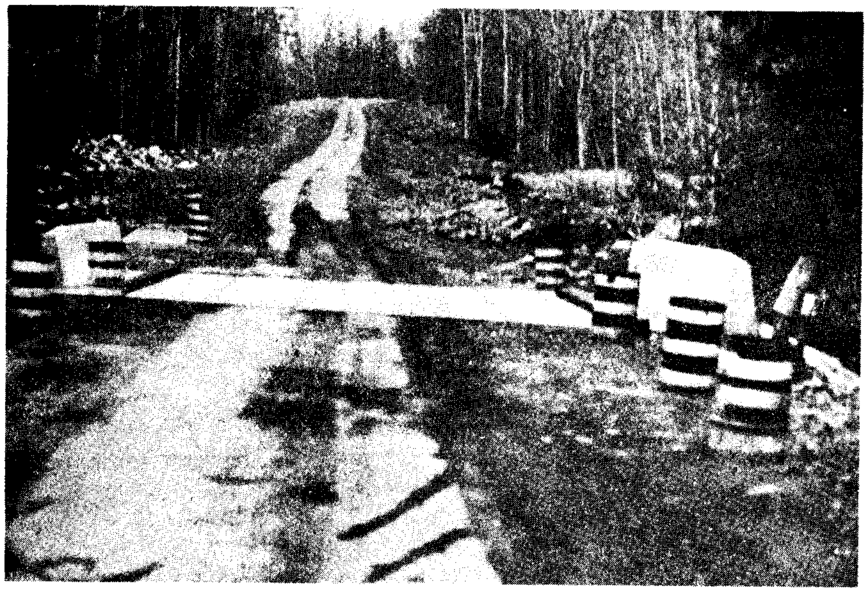

Figure 21. Completed Rte. 614 bridge.

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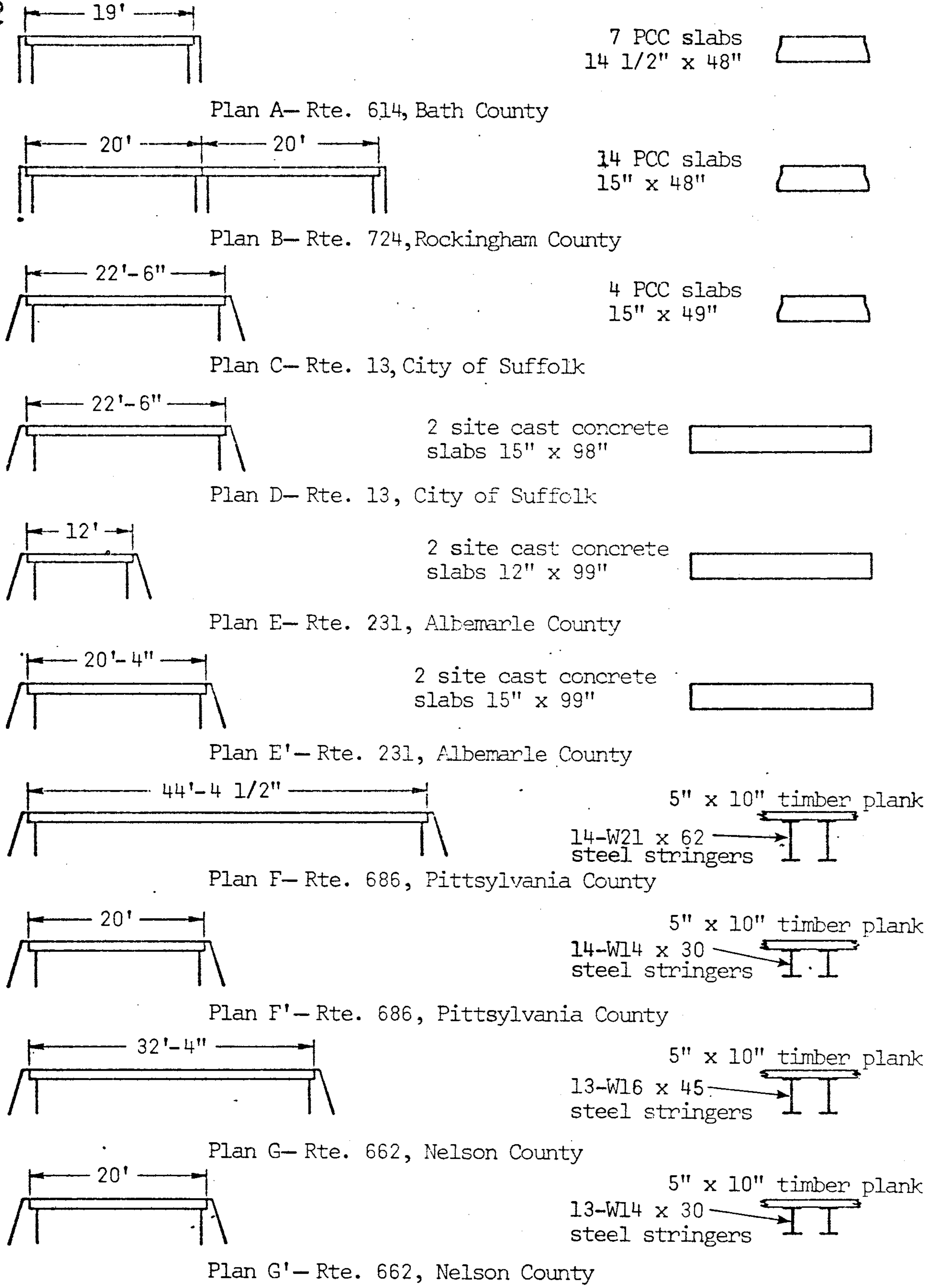

Figure 22. Profile and partial cross section views for bridges considered in quantitative comparisons.

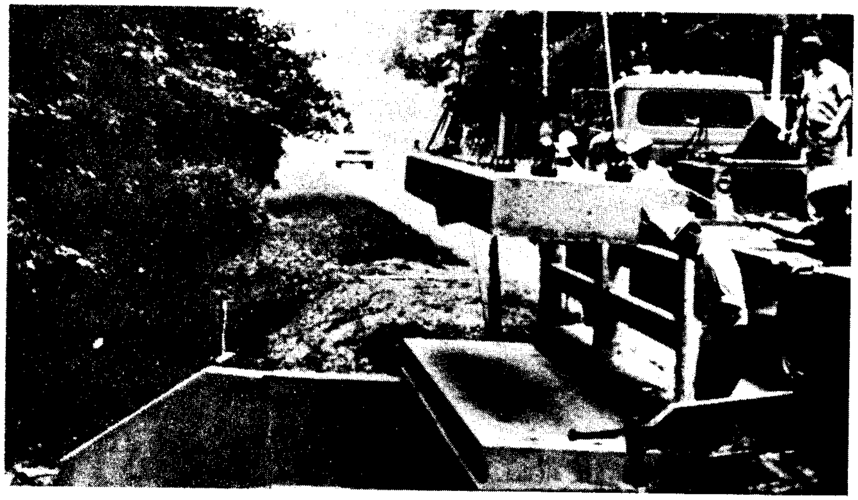

Figure 23. Precast slab being installed by Suffolk District bridge crew to widen Rte. 58 over Spivy Swamp.

Figure 24. Concrete being finished by Culpeper District crew to widen B1110 on Rte. 231 in Albemarle County.

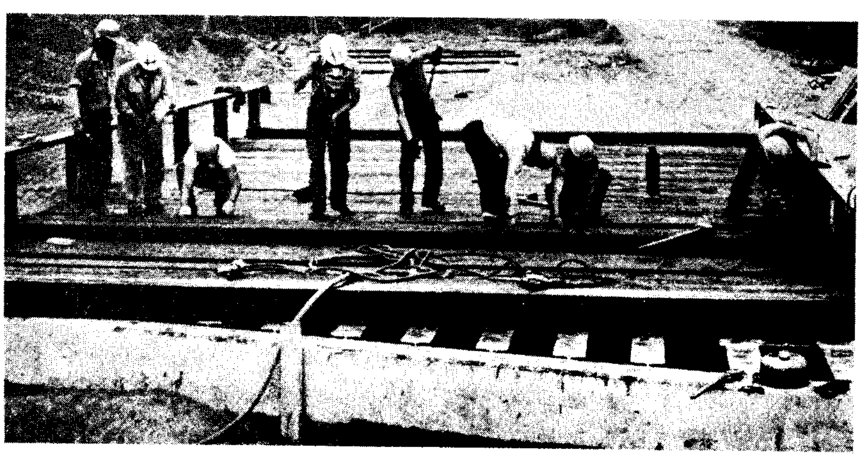

Figure 25. Timbers placed and connected to steel stringers over Elkhorn Creek on Rte. 686 in Pittsylvania County.

The bar chart in Figure 26 shows how the 10 plans compare with regard to labor, equipment, material, and total cost requirements on a square-foot basis. The bar chart in Figure 27 shows how the labor requirements for the 10 plans compare with regard to travel time, on-site construction time and total time. Part (a) of Figure 27 shows the actual values and part (b) shows the 10 plans with a uniform travel time of 30 minutes between the bridge site and the residency or district office. The bar chart in Figure 28 compares the amounts of fuel consumed by the equipment used in each of the 10 plans. Part (a) shows the values based on fuel consumption data for several vehicles and upon estimates made by the drivers of other vehicles. Part (b) compares the 10 plans with a uniform travel distance of 15 miles between the bridge site and the residency or district office, and part (c) is based on the assumption of a uniform work force size of 3 to 4 men. The data used to construct the bar charts in Figures 26-28 are displayed in detail in Appendix A, B, & C.

As can be seen from Figures 27 and 28, the travel time and work crew size can affect the quantitative comparisons of the different types of construction as represented by the seven construction situations. In Figure 29, the data in Figure 26 have been adjusted so that the labor, equipment, material, and total cost requirements for the 10 plans are based on a uniform travel time of 30 minutes and a uniform bridge crew size of 3 to 4 men.

The table in Figure 30 was developed from the data in Figures 27(b), 28(b) and (c), and 29. Figure 30 shows that for span lengths of approximately 20', construction with PC slabs is a superior technique to construction with either CIP slabs or SSTD superstructures. The total cost of the PC slabs is 26% less than that for SSTD structures. On-site construction time is 87% less than for the CIP slabs and 76% less than for the SSTD structures. PC slabs require 78% fewer man-hours in travel and 74% fewer gallons of fuel than do the CIP slabs. Construction with the PC slabs also requires 58% fewer man-hours in travel and 49% fewer gallons of fuel than does construction of the SSTD structures. It should be stressed that the fuel consumed in moving the PC slabs to the bridge site is included in the fuel consumption figures, but the fuel required to move the ready-mix concrete to the bridge site for the CIP slabs and the fuel required to move the steel to the site for the SSTD structures is not. Except for the fuel required to move and operate the privately owned truck cranes used in plans A and B, all fuel consumption is for the movement of materials and men with state equipment. Although the cost of the crane may be considerable, it represents the major portion of the equipment cost required for PC slabs, and therefore the total average equipment cost for the PC slabs is 22% less than that for the CIP slabs and only 15% more than that for the SSTD structures.

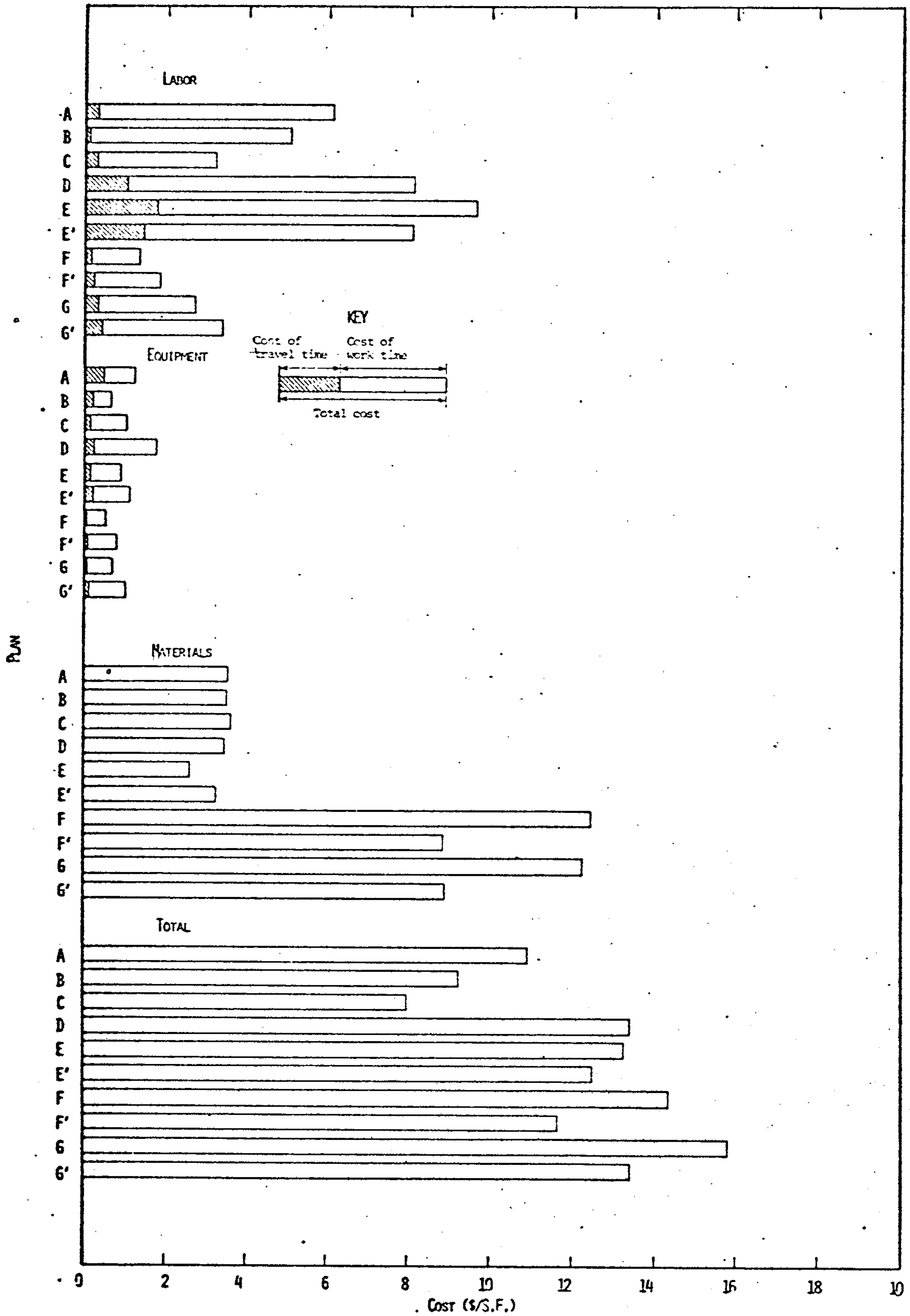

Figure 26. Comparison of labor, equipment, material, and total costs per square foot for 10 plans.

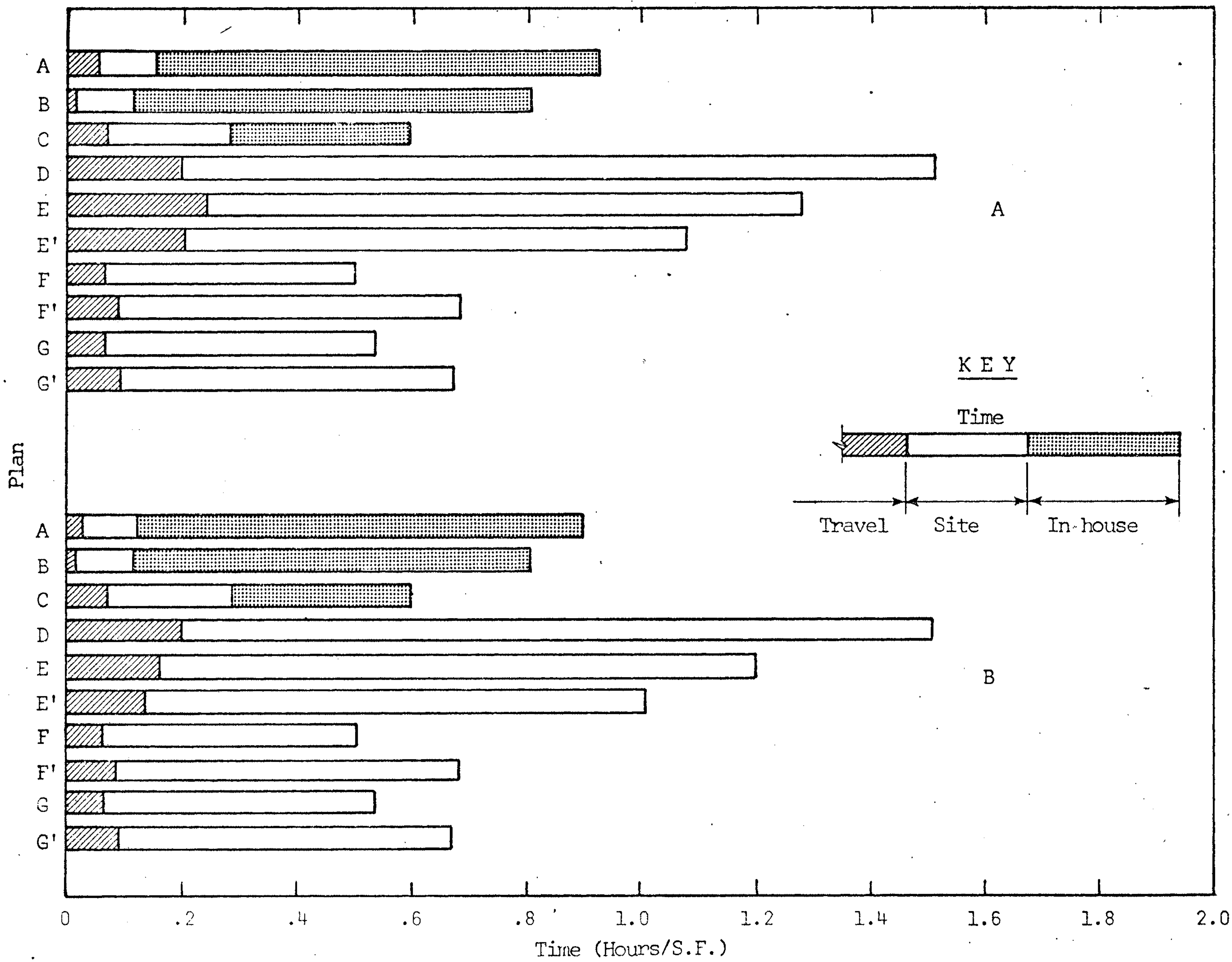

Figure 27. Plans compared with regard to travel time, on-site construction time, and total time with actual values(A), and values for uniform travel

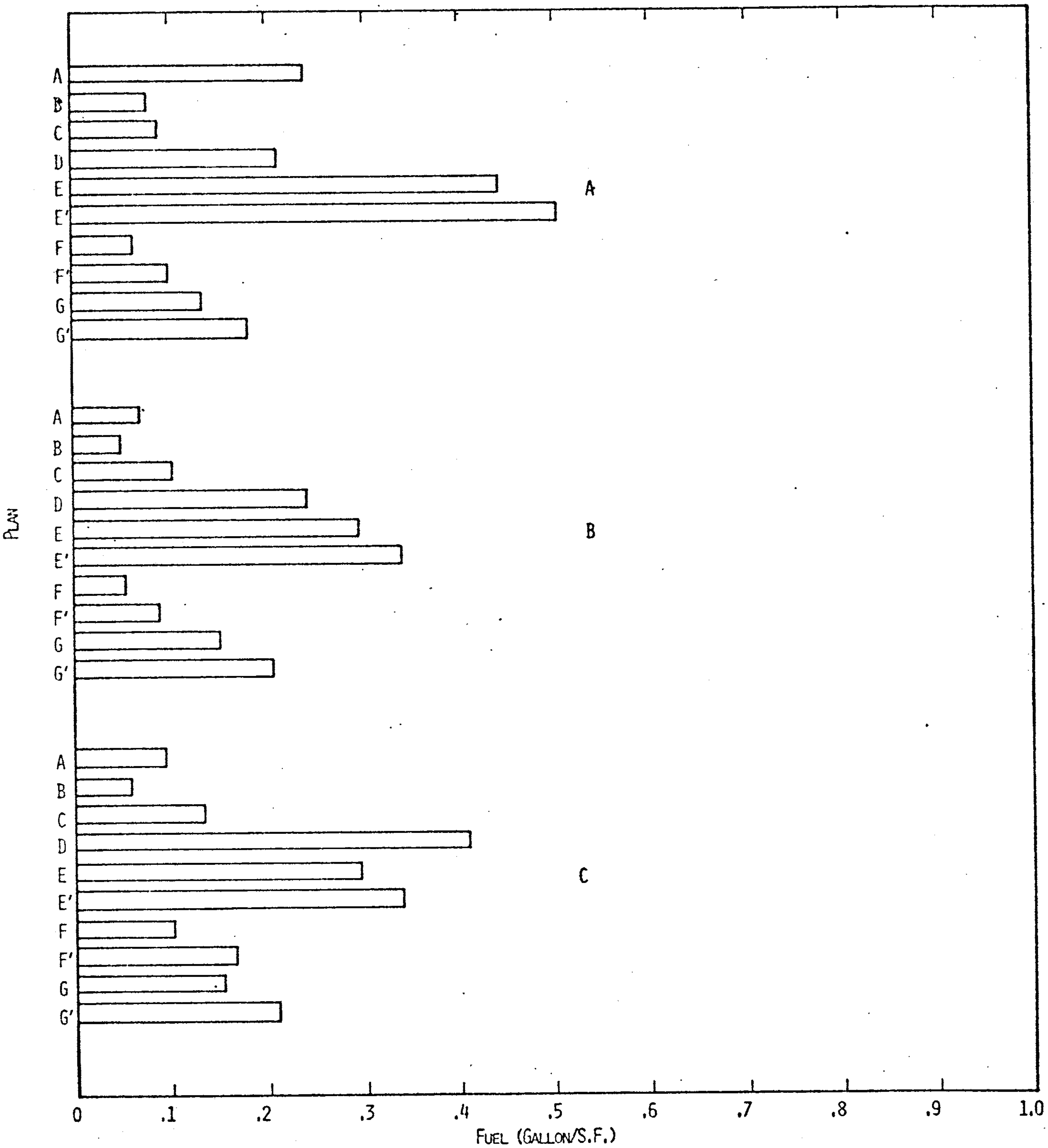

Figure 28. Plans compared with regard to fuel consumed by construction equipment in traveling between bridge site and district or residency with actual values (A), uniform travel distance (B), and uniform travel distance and work crew size (C).

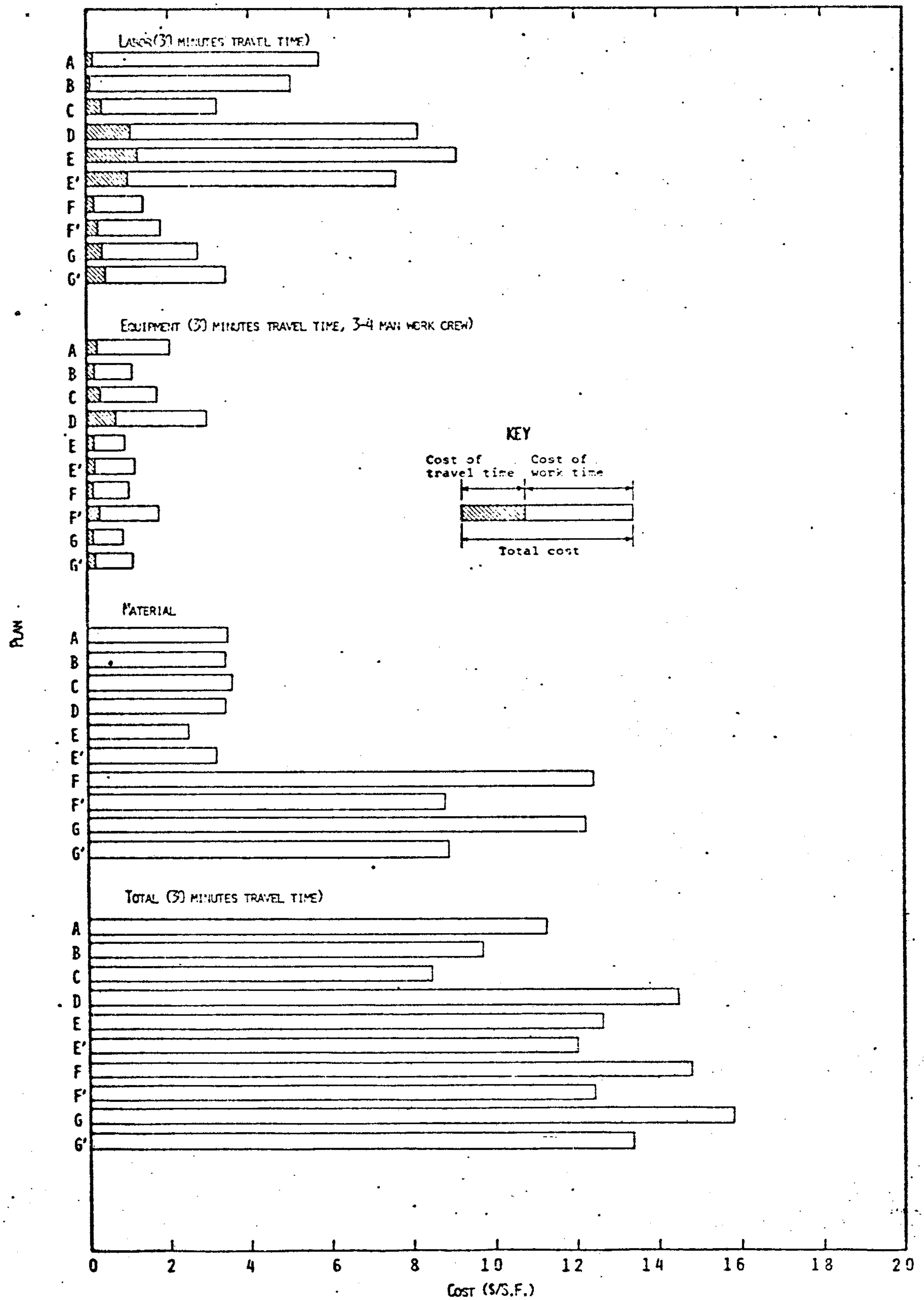

Figure 29. Comparison of labor, equipment, material, and total costs for 10 plans after corrections for travel time, distance, and work crew size.

Item		Percentage of Item Required for Precast Slabs	
		Cast-in-Place = 100%	Steel Stringer-Timber Deck = 100%
Total Costs	Labor	59 (63*)	175 (114)
	Equipment	78	115
	Materials	107	40
	Total Cost	74 (77)	76 (69)
Man-hours	In travel	22	42
	At site	13	24
	Total Man-hours	61	113
Travel	Fuel Consumed	26	51
	Labor Cost	20 (21)	59 (38)
	Equipment Cost	57	117

*Using $6.07 as the average hourly wage rate (including 30.9% overhead factor) for all 10 plans.

Figure 30. Percentages of indicated items required for precast slab construction as compared with those for CIP construction and SSTD construction.

According to Figure 30, material costs is the only item which is less for the CIP slabs than for the PC slabs. The 7% disadvantage on this item is easily eliminated when ready-mix concrete must be hauled a considerable distance. For example, according to a local ready-mix producer, concrete hauled within a 15-mile radius is about $31/yd.^{3}, whereas concrete hauled 60 miles costs $50/yd.^{3}. Also, according to Figure 30, the labor and equipment costs for the SSTD construction are slightly less than those for the PC slabs.

There was some difference in the average hourly rates for the labor involved in the 10 study plans. The average hourly rate for the PC slab sites was $6.07, for the CIP sites $6.46, and for the SSTD sites $3.96. Correctional unit labor was used on plans F and F', which fact accounts for the corresponding low average wage rate. The values in parentheses in Figure 30 apply in the cost comparisons if a uniform average hourly labor rate of $6.07 is applied to all 10 plans.

It is obvious from Figures 26-30 that the use of PC slabs in the 20' span range represents extremely efficient use of labor, construction equipment and fuel. In an effort to determine the span range over which the PC slabs are the optimum type of construction, Figure 31 was developed. The solid curves are based on the following assumptions.

1. Labor costs and equipment costs are constant per square foot in the 10'-35' span range.

2. Material costs are constant per unit of volume or weight with structural steel costing $.32/lb. (curve 5), rebar $.17/lb., and concrete $31/yd.^{3}.

3. For a 20' span structural steel costs amount to 50% of the total cost of SSTD structures (curve 5); concrete and rebar costs represent 25% of the total cost of CIP slabs (curve 3); and concrete and rebar costs amount to 33% of the total cost of PC slabs (curve 1). These percentages were reflected in the 20' span structures under investigations.

4. The curves pass through the cost per square foot value for a 20' span as determined for plans A, B, C, D, E', F', and G'. It is reasonable to believe that for spans other than 20' in length, the labor and equipment costs per square foot would drop slightly from the solid curve for longer spans and rise slightly for shorter spans, primarily because there is economy in quantity.

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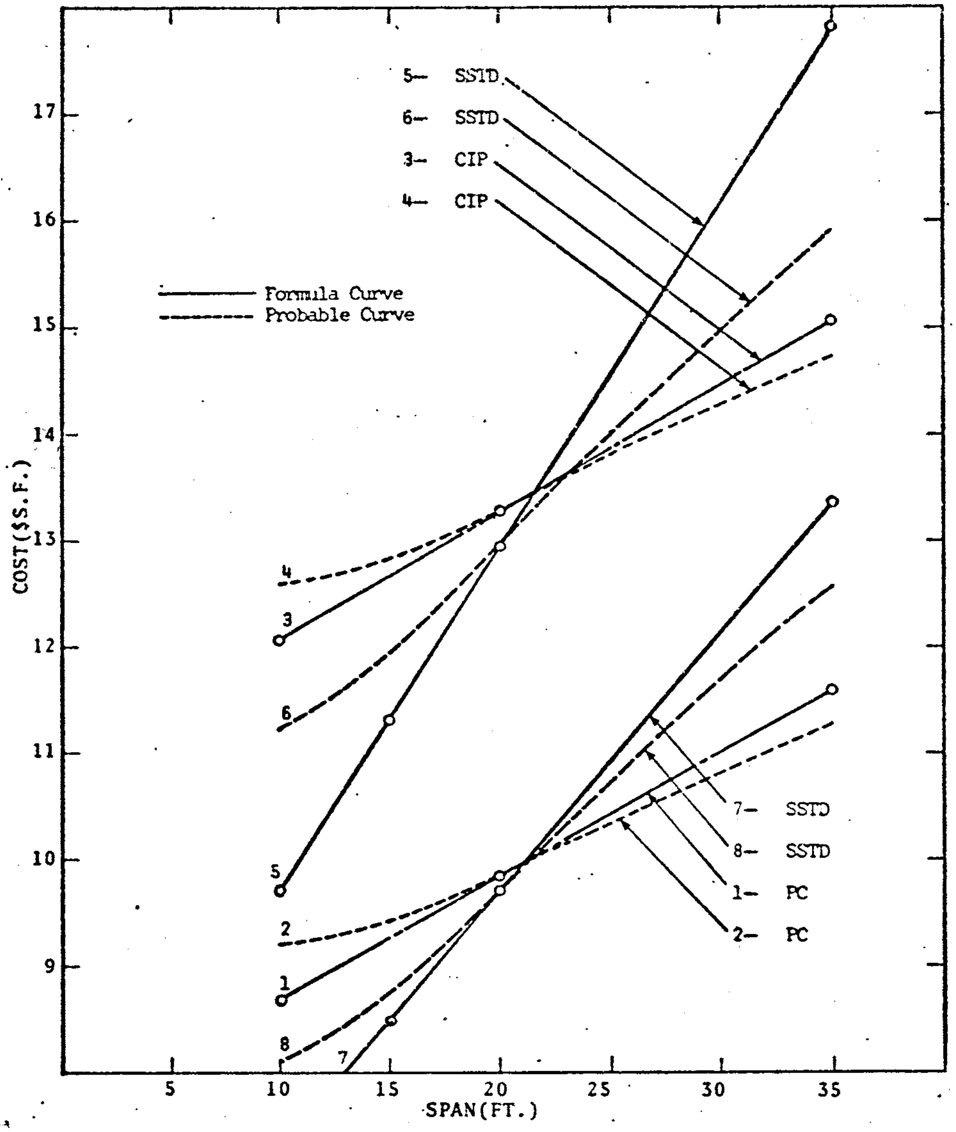

Figure 31. Total superstructure costs compared for the three types of construction for span lengths between 10' and 35'.

NOTE— The curves are drawn based on the following assumptions:

1. Concrete costs (CC) = \$ .31 per yard.
2. Rebar costs (RC) = \$ .17 per lb.
3. Structural steel costs (SC) = \$ .32 per lb. for curve no's. 5 & 6 and SC = \$ .16 per lb. for curve no's. 7 & 8.
4. For a 20' span CC + RC = 33% total cost (TC) for precast slabs(PC).
5. For a 20' span CC + RC = 25% TC for cast-in-place slabs (CIP).
6. For a 20' span SC = 50% for steel stringer timber deck structures (SSTD) in curves 5 & 6, and SC = 33% TC for SSTD in curves 7 & 8.
7. Labor costs are constant per square ft. in curves 1, 3, 5, & 7 and vary slightly with quantity in curves 2, 4, 6, & 8.
8. X = span length.
9. Formula for curve 1— $TC)_X^{PC} = [\frac{(Vol.C+R)_X}{(Vol.C+R)_{20'}}(.33)+(.67)][9.848]$
10. Formula for curve 3— $TC)_X^{CIP} = [\frac{(Vol.C+R)_X}{(Vol.C+R)_{20'}}(.25)+(.75)][(13.278)]$
11. Formula for curve 5— $TC)_X^{SSTD} = [(\frac{X}{20'}X.5)+(.5)][12.939]$
12. Formula for curve 7— $TC)_X^{SSTD} = [(\frac{X}{20'})(.33)+(.67)][9.704]$

The dashed curves reflect the anticipated cost per square foot based on the economy in quantity principle. It is obvious from Figure 31 that the PC slabs are considerably superior to the SSTD structure and the CIP structure for span lengths between 10' and 35'.

CIP slabs can be preferable to PC slabs only in a few unique instances. For example, if the span length is short (12' or less), the site is close to the residency or district headquarters, the same forms can be used on 10 or more structures, and the working and traffic conditions are favorable, a reduction in equipment costs may give the CIP slab an economic advantage over the PC slab. Another example would be the case where a large crane cannot be obtained. A final case example would be a situation where the load limit on a bridge leading to the construction site prevents the hauling of large PC slabs and the movement of a large crane.

From curves 7 and 8 in Figure 31, it can be seen that structural steel costs would have to drop to \$.16/lb. or less for the SSTD structures to be competitive with the PC slabs. When the maintenance costs involved with the SSTD structure are considered, the costs would have to drop even lower for the structure to be economical over its useable life.

Because of the high material cost of structural steel, it usually is used in place of concrete on short span structures only if labor is at a premium and the nearest ready-mix plant is a considerable distance from the bridge site. With the advent of the PC slab there is no reason to use the SSTD structure, because the PC slabs accomplish everything, and more, than the SSTD structures accomplish, and at less cost than both the SSTD and the CIP structures.

The advantages of the PC slabs should become more pronounced than reflected by this report when the following conditions hold:

1. The superstructure is high above ground level, which results in the need for a considerable amount of falsework for CIP construction.

2. The superstructure is very low to the ground, which means the forms may have to be left in place for CIP construction.

3. The travel distance from the residency to the site is considerable and therefore travel time and cost of travel are high, the cost of concrete is high, and high quality concrete is more difficult to obtain with CIP construction.

4. Span length increases (up to a limit of approximately 35'), and therefore much more time is required for the falsework and formwork for CIP construction than for the PC slabs. At 35' the weight of the units would approach 20 tons and for longer spans hauling and handling problems can arrise.

5. Traffic conditions are severe, and on-site construction increases the chances of accidents, injuries, and delays.

6. Weather conditions are severe and therefore it is difficult to make progress except in an area close to the residency or district headquarters.

7. A high quality maintenance free superstructure is difficult to obtain with conventional construction techniques.

As a final point, it should be mentioned that rail costs are included in the superstructure costs for the SSTD structure but not for the concrete structures. However, a rail comparable to the one used on the SSTD structure was used for plan B at an additional cost of only $.44/ft.^{2} for labor, equipment, and materials. Also, it should be noted that the substructure costs would be somewhat less for the SSTD structures than for the concrete structures, and therefore as the span length approaches 35', the total cost advantage of the PC slabs over the SSTD structure could diminish somewhat. Even so, when it is considered that plans A, B, and C represent the first time precast slabs were fabricated and installed by state force labor, the advantages of PC slabs used in greater quantity can only show improvement over that shown by this report. The Staunton District has already constructed a new concrete casting bed 100.5' x 4' x 20" thick at a cost of $7,926.25. The new bed will reduce both fabrication and installation costs for PC slabs when compared to those in plans A and B, for which the slabs were fabricated in plywood forms.

FURTHER CONSIDERATIONS

Although the in-house fabrication of PC slabs has been shown to be a success, several items need further consideration and some justify further research.

Wing Wall Ears

The Staunton and Suffolk Districts have been forming and pouring either one or both sets of ears on the wing walls after the PC slabs are placed. With CIP construction the ears would be poured when the wing walls are poured. Forming and pouring the ears on the wing walls after the slabs are placed is an additional construction step which would not be required if a CIP slab deck was used. The ears are cast after the slabs are placed to allow for the uncertainty in the final width of the structure caused by the sweep in the members. By allowing additional space between each slab member there is no reason why the ears on the wing walls can't be cast when the wing walls are cast, and the variability in the width of the slabs be taken up by the grouted joint between the slabs. With the appropriate amount of width reduction applied to each member, there should be no problem in placing each of the slabs with the ears in place.

Overlays

With the recent interest in providing high quality concrete over the top reinforcing steel in bridge decks, PC slabs offer an additional advantage over CIP construction. Many of the high quality overlays require considerably more quality control at the batch plant and during the placement operations than is required with conventional A4 concrete. The required quality control is much more readily obtained in a casting yard than at a bridge site where there are variables such as distance to the site from a batch plant and differences among bridge crews, equipment, and construction techniques. Experienced personnel at a casting yard should be able to install the most sophisticated overlay material in a satisfactory manner.

Elaborate Casting Operations

The Staunton and Suffolk District casting operations are notable pioneering maintenance efforts which are both efficient and economical. The success of their operations means that there is a high probability that their casting yards could be expanded so that they could produce precast parapets, precast substructure components, prestressed slabs, and match-cast components.

A precast parapet is an easily fabricated component and a necessary addition to a precast slab casting operation.

It would be a shame to replace a bridge deck with PC slabs in 1 day and spend more than 1 week forming and pouring a CIP parapet. Precast parapets have been successfully fabricated and installed by private industry on several bridges in Virginia.

State forces should be able to fabricate and install precast substructure components using much of the casting bed and equipment that is required to fabricate and install the PC slabs. Piers and abutment sections which are 4' wide and as long as the pier or abutment is tall could be cast in the Staunton and Suffolk District beds. The units could be placed on end at the bridge site, and could be tied together with a cast-in-place footing and with steel bolts and grouted keyways similar to the ones used for the deck slabs.

When there is a crane at a bridge site, why not erect the whole bridge in 1 or 2 days instead of just placing PC slabs on a substructure that has taken several months to form and pour with the CIP technique.

Prestressed slabs should be economical for span lengths between 30' and 50'. With a casting bed 100' long, very little additional investment is required to provide the jacks and other equipment necessary to produce precast prestressed slabs.

Match casting is often required to obtain the desired fit between certain PC members, particularly if the members are posttensioned. Match casting requires a bed wide enough to accommodate several slabs side by side.

More elaborate casting operations should be justified on the basis that they would provide for more efficient bridge maintenance operations and in no way tend to reduce or eliminate private industry work.

Residency, District, or Central Casting Yard

There is no doubt that PC slabs offer an economical and efficient construction technique for widening and replacing existing bridges of short span lengths. The Staunton and Suffolk Districts have both established satisfactory casting yards at minimal expense. Certainly the more expensive the casting yard, the better the final product should be. It would seem unlikely that a casting yard could be justified in each residency. The Department must decide whether is is advantageous to have a casting yard in each district or to have one or two more elaborate central casting yards. More elaborate forms and equipment could be justified and more effective systems organization could be achieved with one or two central yards. The final decision should be based on full consideration of the engineering, economic, and administrative needs of the Department with regard to the in-house fabrication of precast bridge components.

Systems or Turnkey Concept

The PC slabs fabricated by state forces are more economical than the conventional alternatives, primarily because of the turnkey concept. State forces design, fabricate, and construct the precast slab superstructures. In Europe where the design and construct concept prevails, very elaborate prestressed and posttensioned concrete systems have been competitively constructed since the 1950's. Theoretically the mass production of bridge components from economical materials has to lead to overall economy. However, PC slabs design by the state, fabricated by a subcontractor, and erected by a prime contractor may not be as economical as shown by this report. The economies are drained because of the safety factors that are built into the final product by three separate parties. When bridges are widened or replaced by state forces, the PC slab construction technique represents a systems concept. The CIP construction represents a less efficient design and construct operation. The SSTD structures are not competitive, because 50% of the total cost and responsibility is vested in the fabricators of the steel girders. Under contract situations, the three types of construction will tend to be competitive, but from a cost to society standpoint the PC slab construction technique will always be more economical because it reduces delays and inconvenience to the motorist, conserves fuel in travel to and from the job site, helps maintain a pleasant environment at the bridge site, and provides for a more efficient use of manpower, equipment, and materials.

CONCLUSIONS

1. Precast components cast in a good set of forms and under close supervision will fit together quickly and securely in the field, and will provide a structure which is far more economical and superior to that which can be obtained with conventional construction techniques. Bearing areas deserve particular consideration during fabrication. Costs for a satisfactory form can be written off over one to five bridge spans.

2. A larger crane is required to handle the precast slabs than is required for the more conventional construction techniques, but, in general, precast slabs can be economically fabricated and installed by state personnel using currently available materials and equipment.

3. More efficient mobilization of men, materials, and equipment and more favorable working conditions are achieved by using PC slabs than are achieved with alternative construction techniques.

4. When compared with timbers on steel stringers and site cast concrete slab superstructures in the 10'-35' span range, PC slabs reduce total costs by 25% or more, on-site construction time by 80%, and fuel consumed in travel to and from the bridge site by 50% to 75%.

5. The success of the Staunton and Suffolk Districts in designing, fabricating, and installing PC slabs suggests that the systems concept is particularly suitable for the Department's bridge maintenance operations.

RECOMMENDATIONS

1. The Department should increase its use of precast slabs for widening and replacing existing bridges in the 10' to 35' span range because of the benefits to be derived from reduced costs, on-site construction time, motor fuel consumption, and from the elimination of detours and closed roads.

2. The Department should consider applying the systems concept to widening and replacing bridge substructures and to replacing bridge parapets.

3. Department management should give full consideration to the engineering, economic, and administrative needs of the Department with regard to the in-house fabrication of bridge components when deciding whether to establish a casting yard in each district or one or two central casting yards.

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ACKNOWLEDGEMENTS

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1. Waddell, Joseph J., Precast Concrete: Handling and Erection, American Concrete Institute, Iowa State University Press, 1974, pg. 1.

2. Brown, H. E., "Working Plan— Industrialized Bridge Construction for Secondary Roads", Virginia Highway & Transportation Research Council, Charlottesville, Virginia, September 14, 1972.

APPENDIX A

Labor, Material, Equipment, and Cost Data for Precast Slab Structures

Project Number

Name: Casting bed & gantry crane preparation and maintenance

Location: Staunton District Office

Travel Distance for Field Forces: 0

Design Type: Plywood bottom and sides placed on bridge timbers
Length: 80 feet
Width: 4 feet

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Preparing casting bed	12	3	0	288	2,138.62	0	0	0	0	0	Timber, plywood, misc.	--	1,430.20	3,568.82
Construction of gantry crane	11	3	0	264	1,956.59	Welding Trk.	0	32	0	27.20	Steel beams, misc.	--	835.95	2,819.74
Maintaining and improving casting bed and gantry crane over 10 spans	33	$2\frac{1}{2}$	0	660	4,516.36	Heating	0	68	0	190.4	Plywood, nails, misc.	--	1,213.05	5,919.81
Totals	56			1,212.0	8,611.57		0	100	0	217.60			3,479.20	12,308.37
Total/10	5.6			121.20	861.16		0	10	0	21.76			347.92	1,230.84
New concrete casting bed 100.5'x 4' x 20"					5,202.30					negligible	concrete and misc. ---	19.25 cy 5.5 cy	2,723.95	7,926.25

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Project Number	
Name:	Rt. 614 (Plan A)
Location:	Bath County
Travel Distance for Field Forces:	45 Miles one way to Covington Headquarters (1 hr. travel time) 60 Miles one way to Staunton District (1 1/2 hr. travel time)
Design Type:	7 Precast concrete slabs 4' x 19'
Length:	19 feet
Width:	28 feet

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours							
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Prepare casting bed and yard	5.6	2.6	0	121	861.16	Misc.	0	10	N.A.	21.76	Misc.	--	347.92	1,230.84
Set side forms	4.5	3	0	108	802.89	Figure in Bed Costs				---	Figure in Bed Costs			802.89
Place steel	2.2	3	0	52	256.50	Figure in Bed Costs				---	Reinforcing steel & misc.	4647/lb.	735.88	992.38
Place concrete	0.9	6	0	44	310.75	Figure in Bed Costs				---	Concrete	25.5 c.y.	778.05	1,088.80
Strip forms & store beams	2.5	3	0	59	343.48	Gantry crane	Figure in Bed		2.0	---	Figure in Bed Costs			343.48
Load beams & transport	1.2	4	9	37	228.48	2 Trcts. and lowboy tr. & gantry crane	9	19.5	74.0	266.30	Figure in Bed Costs			494.78
Place beams	1	7	16	56	333.65	1 cr. 1 br. tr. 1 we. tr.	8	24	47	381.00	Figure in Bed Costs			714.65
Pour keyway	0.5	4	4	16	87.05	1 br. tr. 1 A.C.	2	8	6	25.20	Concrete	1 c.y	30.51	142.76
Totals	17.9		29	493	3,223.96		19.0	61.5	129	694.26			1,892.36	5,810.58
Total/ S.F.	0.03		0.5	0.93	6.06		0.04	0.12	0.24	1.31			3.56	10.92

Project Number

Name: Rt. 614 - Additional work

Location:

Travel Distance for Field Forces:

Design Type:
Length:
Width:

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Bal. Fwd. Used	Total Cost	Type	Quantity	Total Cost	COST
Form parapet	3	5	30	120	620.13	Br. Trk.	6	24	36	67.20	Lumber		65.28	752.61
Place parapet steel	1.5	5	15	60	310.07	" "	3	12	18	33.60	Steel		?	343.67 +
Pour parapets	.5	4	4	16	87.06	" " Air Com	2	8	6	25.20	Concrete	4.5	?	112.26 +
Terminal walls	1	4	8	32	174.11	Br. Tr.	2	8	12	22.40	Concrete		"	196.51 +
Terminal walls	1.5	3	9	36	194.37	" "	1	12	6	33.60				227.97
Terminal walls	1	5	10	40	206.71	" "	2	8	12	22.40				229.11
Wing wall ears	1	5	10	40	206.71	" "	2	8	12	22.40				229.11
Bad weather & misc.	2	4	16	64	348.22	" "	4	16	24	44.80				393.02
Totals	11.5		102	408	2,147.38		22	96	126	271.60			65.28 +	2,484.26 +
Total/S. F.	0.02		0.19	0.77	4.04		0.04	0.18	0.24	0.51			0.12 +	4.67 +

Project Number

Name: Rt. 724 - Rockingham County (Plan B)

Location: Rockingham County

Travel Distance for Field Forces: 7 Miles one way to Harrisonburg Headquarters (15 minute travel time)
32 Miles one way to Staunton District (45 minutes travel time)

Design Type: 14 Precast concrete slabs 4' x 20'
Length: Two 20 ft. spans
Width: 28 feet

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours							
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Preparing casting bed and yard	11.2	2.6	0	242	1,722.32	Misc.	0	20	N.A.	43.52	Misc.	--	695.84	2,461.68
Setting side forms	13.0	2.1	0	221	1,332.14	Figured in Bed Costs					Figured in Bed Costs			1,332.14
Placing steel	5.1	2.1	0	87	587.31	Figured in Bed Costs					Reinforcing steel	8,778/lbs.	1,404.48	1,991.79
Placing concrete	3.9	4	0	126	640.52	Figured in Bed Costs					Concrete	57.75 c.y.	1,746.93	2,387.45
Stripping forms and storing beams	4.7	2	0	75	446.28	Gantry crane	Figured in Bed Costs		3.0		Figured in Bed Costs			446.28
Loading beams and transporting	1	4	7.5	32	222.74	2 Trots, 1 lwby.& gantry crane	7.5	20	67	273.13	Figured in Bed Costs			495.87
Placing beams	1.2	8	5	78	482.33	3 trks. 1 crane	3.5	39.5	10	459.50	Figured in Bed Costs			941.83
Welding connections and grouting keyway	1	5	3.5	40	202.50	1 br. Tr. 1 we. tr.	2.4	16	8	24.40	Concrete	1.75 c.y.	59.50	286.40
Totals	41.1		16.0	901	5,636.14		13.4	75.5	88	800.55				10,343.44
Total/S.F.	0.04		0.01	0.80	5.03		0.01	0.06	0.08	0.71				9.24

Project Number

Name: Rt. 724 - Additional work

Location:

Travel Distance for Field Forces:

Design Type:
Length:
Width:

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Pier wingwall tops	.2	5	.5	10	50.62	1 br. tr.	.10	2	0.4	4.20	Concrete	.25 c.y.	8.50	63.32
Drilled holes on rails and placing rails	2.1	2	2	34	174.64	1 br. tr. 1 pickup	2	34	6	56.00	Guardrails and posts	80' rail 16 posts	256.00	486.64
Hot joint sealer	2.1	2	2	34	174.64	1 br. tr. 1 A.C. 1 Sand-blaster	3	51	4	134.50	Hot joint sealer	150 lbs.	49.50	358.64
Totals	4.4		4.5	78	399.90		5.1	87	10.4	194.70			314.00	908.60
Total/S.F.	0.00		0.00	0.07	0.36		0.00	0.08	0.01	0.17			0.28	0.81

2810

Project Number

Name: Suffolk District Casting Bed Preparation

Location: Suffolk District

Travel Distance for Field Forces: 0

Design Type: Plywood bottom and sides placed on bridge timbers and steel stringers
Length: 28 ft.
Width: 12 ft.

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Preparing footings, placing steel, stringers, timbers, and plywood floor	3.0	4	0	96	474.21	0				0	A3 concrete 10" stringers 4"x 4" timbers, plywood and miscellaneous	9 1/2 yds. 20 22 392 s. f.	285.00 0 0 140.00	$ 899.21
Building side forms	2.5	3	0	60	329.75	0				0	Plywood 2 x 4's, misc.	106 s.f. 318 ft.	90.00	$ 419.75
											Crane Slings		580.00	$ 580.00
Totals	5.5		0	156	803.96					0			1,095.00	$1,898.96
Total / 10	0.55		0	15.6	80.40					0			109.50	$ 189.90

Project Number	0013-061-701, M600 (Plan C)
Name:	Rt. 13 over Spivey Swamp
Location:	City of Suffolk - 0.0 mi. to W.C. L. of Whaleyville
Travel Distance for Field Forces:	13 Miles one way (30 Min. travel time)
Design Type:	4 Precast concrete slabs 4' x 22' - 6"
Length:	22' - 6"
Width:	Bridge widened 8' - 2" on each side

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours							
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Preparing casting bed and yard	0.55	3.5	0	15.6	80.40	0	0	0	0	0	Fig. in bed		109.50	$ 189.90
Setting side forms	0.5	3	0	12	65.95	0	0	0	0	0	Fig. in bed		---	$ 65.95
Placing reinforcing steel	3	2	0	48	292.19	0	0	0	0	0	Steel	3,340 lbs.	701.40	$ 993.59
Placing concrete	1	4	0	32	141.40	0	0	0	0	0	Concrete	16.5 cy.	528.00	$ 669.40
Trans, slabs	1	4	8	32	213.29	Crane lowboy	2	16	20.5	168.00	--		---	$ 381.29
Placing slabs	1	8	16	64	346.74	1 Pickup 1 crane 1 bridge truck lowboy	6	32	10.5	224.00	--		---	$ 570.74
Grouting keyway	1	2	2	16	52.34	1 pick-up	1	8	2.0	9.60	Grout	9 cf.	10.00	$ 71.94
Totals	8.05		26	219.60	1,325.47		9	56	33.0	401.60			1,348.90	$2,942.81
Total / S. F.	0.02		0.07	0.60	3.24		0.02	0.15	0.09	1.09			3.67	8.01

APPENDIX B

Labor, Material, Equipment, and Cost Data for Cast-in-Place Slab Structures

Project Number	0013-061-701, M600
Name:	Rt. 13 over Spivey Swamp (Plan D)
Location:	City of Suffolk - 0.0 Mi. to W. C. L. of Whaleyville
Travel Distance for Field Forces:	13 Miles one way (30 Min. travel time)
Design Type:	Widen existing structure 8' - 2" each side (Cost and labor estimated by Suffolk District Bridge Office)
Length:	22' - 6"
Width:	8' - 2" each side

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours		Gal. Fuel					
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Used	Total Cost	Type	Quantity	Total Cost	COST
Moving forms and equipment to bridge site and back	1	2	2	16	89.06	Crane lowboy	2	8.0	10	84.00				$ 173.06
Cutting and placing beam stand	2	8	16	128	693.48	Pickup bridge truck	4	32	10.5	80.00				$ 773.48
Setting beam stand	1	3	3	24	133.59	Crane	2	8	10.5	108				$ 241.59
Forming deck slab	2	8	16	128	693.48	1 pick-up, 1 bridge truck	4	32	10.5	80.00	Plywood and miscellaneous	Assume 10 reuses	30.0	$ 803.48
Placing rebar	1.25	8	16	80	433.42	"	4	32	10.5	80.00	Steel	3,340	701.40	$1,214.82
Setting screed pipe	0.75	3	-	18	114.44	-	-	-	-	-	-	-		$ 114.44
Pouring concrete	1	4	4	32	141.40	1 pick-up, 1 br. truck	2	16	5.25	40.00	Concrete	16.5 cy	528.00	$ 709.48
Removing falsework	2	8	16	128	693.98	1 pickup 1 br. tr. 1 crane	5	40	21.0	188.00				$ 881.48
Totals	11		73	554.00	2,992.35		23.0	168.0	78.75	660			1,259.40	$4,911.75
S. F. Costs	0.03		0.20	1.51	8.14		0.06	0.46	0.214	1.80			3.43	13.37

Project Number	0231-002-701 M600 - Preparation of falsework and forms for reuse on 10 spans
Name:	Rt. 231 over various streams
Location:	Albemarle County
Travel Distance for Field Forces:	29 Miles one way (45 minute travel time) to Culpeper District
Design Type:	Cast-in-place concrete widen existing bridges on each side
Length:	12' - 0"
Width:	8' - 3" each side

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours							
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Prepare falsework	1	3	4.5	24.0	184.00	3/4 T. Pickup	1.5	8.0	5.8	11.60	Str. steel		N.C.	195.60
Prepare falsework	2	4	12.0	64.0	465.60	3/4 T. Pickup and 1/2 T. Pickup	6.0	32.0	19.4	40.80				506.40
Prepare slab forms	3	3	13.5	72.0	552.00	3/4 T. Pickup	4.5	24.0	17.4	34.80	Mise., 2"x 6" Plywood	30 - 12' long (8 sheets)	175.00	761.80
Prepare slab forms	2	4	12.0	64.0	465.60	3/4 T. Pickup 1/2 T. Pickup	6.0	32.0	19.4	40.80				506.40
Totals	8		42.0	224.00	1,667.20		18.0	96.0	62.0	128.00			175.00	1,970.20
Totals/10	0.8		4.2	22.40	166.72		1.8	9.6	6.2	12.80			17.50	197.02

Project Number	0231-002-701 M600	# 1110
Name:	Rt. 231 over various streams (Plan E)	
Location:	Albemarle County	
Travel Distance for Field Forces:	29 Miles one way (45 minutes travel time)	
Design Type:	Cast-in-place concrete widen existing bridge on each side with 1'-0" thick slab (cost & labor based on typical values for structures #1112 & 1110)	
Length:	12' - 0"	
Width:	8' - 3" (each side)	

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours							
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Move materials to bridges and back	1	3	4.5	24	184.00	$1\frac{3}{4}$ Ton Pickup, 1 dmtr.	3.0	16.0	13.5	33.60				217.60
Prepare falsework and deck forms	0.8	3.5	4.2	22.4	166.72	See sht. #	1.8	9.6	6.2	12.80	See sheet #		17.50	197.02
Placing falsework	1	4	6.0	32.0	244.80	$1\frac{3}{4}$ Ton Pickup, 1 we.tr.	3.0	16.0	10.6	21.20			---	266.00
Placing deck forms	1	4	6.0	32.0	232.80	$1\frac{3}{4}$ Ton Pickup $1\frac{1}{2}$ T.Pkup.	3.0	16.0	9.7	20.40			---	253.20
Placing steel	1	4	6.0	32.0	232.80	''''''''''	3.0	16.0	9.7	20.40	Rebar	1995/lbs.	256.06	509.20
Placing steel	1	3	4.5	24.0	184.00	''''''''''	3.0	16.0	9.7	20.40				204.40
Placing concrete	1.5	3	6.75	36.0	276.00	''''''''''	4.5	24.0	14.6	30.60	A4 concrete	8 cu. yds.	238.00	544.60
Removing falsework and form work	1,5	3	6.75	36.0	276.00	$1\frac{3}{4}$ Ton Pickup	2.25	12.0	8.7	17.40			---	293.40
Cleaning up site	0.5	4	3.0	16.0	122.67	$1\frac{3}{4}$ Ton Pickup $1\frac{1}{2}$ T.Pkup.	1.5	8.0	4.9	10.20			---	132.87
Totals	9.3		47.70	254.4	1,919.79		25.05	133.6	89.6	187.0			511.56	2,618.35
Total/S.F.	.05		.241	1.28	9.70		0.13	0.67	0.442	0.94			2.58	13.22

Project Number: 0231-002-701 M600 #1107

Name: Rt. 231 over various streams (Plan E')

Location: Albemarle County

Travel Distance for Field Forces: 29 Miles one way (45 minutes travel time)

Design Type: Cast-in-place concrete widen existing bridge on each side with 1' - 4" thick slabs, cost estimated based on costs of #1112 & 1110

Length: 20' - 4"

Width: 8' - 3" (each side)

Activity	LABOR: No. Days	LABOR: No. Man	LABOR: No. Manhours Travel	LABOR: No. Manhours Total	LABOR: Total Cost
Move materials to bridge site and back	1	3	4.5	24	184.00
Prepare false work and deck forms	1.2	3.5	6.3	33.6	250.08
Placing falsework	1.5	4	9.0	48.0	367.20
Placing deckforms	1.5	4	9.0	48.0	349.20
Placing steel	1.5	4	9.0	48.0	349.20
Placing steel & sonitube	2.0	3	9.0	48.0	368.00
Placing concrete	2.0	3	9.0	48.0	368.00
Removing falsework and form work	2.0	3	9.0	48.0	368.00
Clean-up site	0.5	4	3.0	16.0	122.67
Totals	13.2		67.8	361.6	2,726.35
Total/S. F.	0.04		0.202	1.08	8.13

Activity	EQUIPMENT: Type	EQUIPMENT: No. Hours Travel	EQUIPMENT: No. Hours Total	EQUIPMENT: Gal. Fuel Used	EQUIPMENT: Total Cost
Move materials to bridge site and back	$1\frac{3}{4}$ Ton Pickup, 1dm tr. 1bm tr.	4.5	24.0	21.2	55.60
Prepare false work and deck forms	Set stg. #2	2.7	14.4	9.3	19.20
Placing falsework	$1\frac{3}{4}$ Ton Pickup, 1 bm tr. 1 we. tr.	6.75	36.0	27.5	64.80
Placing deckforms	1 bm tr. $1\frac{3}{4}$ Ton Pickup $1\frac{1}{2}$ T.Pkup.	6.75	30.0	26.2	63.60
Placing steel	''''''''''''	4.5	24.0	14.6	30.60
Placing steel & sonitube	''''''''''''	6.0	32.0	19.4	40.80
Placing concrete	''''''''''''	6.0	32.0	19.4	40.80
Removing falsework and form work	$1\frac{3}{4}$ T.Pkup. 1 bm tr.	6.0	32.0	27.1	67.20
Clean-up site	$1\frac{3}{4}$ T. and $1\frac{1}{2}$ T. Pkup.	1.5	8.0	4.9	10.20
Totals		44.7	238.40	169.6	392.80
Total/S. F.		0.133	0.711	0.506	1.171

Activity	MATERIALS: Type	MATERIALS: Quantity	MATERIALS: Total Cost	TOTAL: COST
Move materials to bridge site and back				239.60
Prepare false work and deck forms	Lumber and misc.	See sheet number	29.65	298.93
Placing falsework				432.00
Placing deckforms				412.80
Placing steel	Rebar	4110/lbs.	527.52	907.32
Placing steel & sonitube	Sonitube	1/6 lot	75.53	484.33
Placing concrete	A4 concrete	15 c.y.	446.25	855.05
Removing falsework and form work				435.20
Clean-up site				132.87
Totals			1,078.95	4,198.10
Total/S. F.			3.22	12.51

Project Number 0024-014-701-M600

Name: Rte. 24 over Grease Creek

Location: Buckingham County

Travel Distance for Field Forces:

Design Type: Widen existing structure 7'-6" each side with CIP concrete
Length: 22'-6"
Width: 7' -6" each side

NOTE: The information shown below support the conclusion that CIP concrete slab spans are not as economical as precast concrete slabs but the information is not included in the cost comparisons reported in the text of this report because of the following reasons:

1. The structure was widened in 1971 whereas other structures considered in the report were build in 1975 and 1976.

2. The author was not present at the time of the construction.

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Bal. Fwd. Used	Total Cost	Type	Quantity	Total Cost	COST
placing falsework and forming slabs					$2,239.42					$415.80	plywood, rebar and misc.		$1,522.90	$4,178.12
pouring concrete					$ 376.60					46.40	23 c.y. concrete		$ 672.75	$1,095.75
Totals					$2,616.02					$462.20				$5,273.87
Totals/SF					$ 7.75					$ 1.37			$ 6.51	$ 15.63

APPENDIX C

Labor, Material, Equipment, and Cost Data for Steel Stringer Timber Deck Structures

Project Number	0686-071-6265
Name:	Rt. 686 over Elkhorn Creek (Plan F)
Location:	Pittsylvania County (1.1 Mi. W. Rt. 680)
Travel Distance for Field Forces:	17 Mi. one way (30 minutes travel time)
Design Type:	Steel stringer - timber deck (15^{o} skew)
Length:	44 ft. - 4 1/2 in.
Width:	24 ft. - 0 in.

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours		Total Cost	Type	No. Hours		Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
			Travel	Total			Travel	Total						
Placing structural steel	1	7	7	56	152.22	1 br. tr. 1 crane	3	16	11.5	122.4	Structural steel	44,500 lbs.	10,796.29	$ 11,070.91
Placing diaphragm and rails	1	8	8	64	198.76	1 br. tr. 1 crane 1 A.C.	3	24	11.5	137.60				$ 336.36
Hauling timber	1	7	7	56	150.54	1 br. tr. 1 dp. tr. 1 A.C. 1 trailer	4	32	11.5	72.00	Treated lumber	5.62 M. F. B. M.	2,064.99	$ 2,287.53
Placing timbers	3	7	21	168	479.46	1 br. tr. 1 A.C.	6	48	13.5	104.40				$ 583.86
Placing timbers	2	8	16	128	337.94	1 br. tr. 1 A.C.	4	32	9.0	69.60				$ 407.54
Painting steel	2	4	8	64	171.82	1 br. tr. 1 A. C.	4	32	9.0	69.60	Paint and miscellaneous		350.00	$ 591.42
Totals	10		67	536	1,490.74		24	184	66.0	575.00			13,211.28	$ 15,277.62
S. F. Costs	0.01		0.06	0.50	1.40		0.02	0.17	0.06	0.54			12.40	14.35
Substructure Work	62			4008	13,068.93					4773.60			10,172.30	$ 28,014.83

Project Number

Name: (Plan F')

Location:

Travel Distance for Field Forces: 17 Miles one way (30 minutes travel time)

Design Type: Steel stringer - timber deck (15^{o} skew)
Length: 20 ft.
Width: 24 ft.

(Costs estimated based on project 0686-071-6265, Rte. 686 over Elkhorn Creek, Pittsylvania County)

Activity	LABOR					EQUIPMENT					MATERIALS			TOTAL
	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Placing structural steel	1	7	7	56	152.22	1 br. tr. 1 crane	3	16	11.5	122.40	Structural steel	9,790 lbs.	3,132.80	$ 3,407.42
Placing diaphragms and rails	1	8	8	64	198.76	1 br. tr. 1 crane 1 A.C.	3	24	11.5	137.60				$ 336.36
Hauling timbers	0.5	7	3.5	28	75.27	1 br. tr. 1 crane 1 A.C. 1 trailer	4	32	11.5	72.00	Treated timber	2.55 M.F. B.M.	938.63	$ 1,085.90
Placing timbers	1.5	7	10.5	84	239.73	1 br. tr. 1 A.C.	2	16	4.5	34.80				$ 274.53
Placing timbers	1	8	8	64	168.97	1 br. tr. 1 A.C.	2	16	4.5	34.80				$ 203.77
Painting steel	1	4	4	32	85.91	1 br. tr. 1 A.C.	2	16	4.5	34.80	Paint and miscellaneous	·	159.09	$ 279.80
Totals	6		41	328	920.86		16	120	48	436.40			4,230.52	$ 5,587.78
Total / S. F.	0.01		0.09	0.68	1.92		0.03	0.25	0.10	0.91			8.81	11.64

Project Number: 0662-062-176-I 615

Name: Rt. 662 over Fresh Water (Brown) Cr. (Plan G)

Location: Nelson County - (1.4 Mi. N. E. Rt. 739)

Travel Distance for Field Forces: 13 Mi. one way (30 minutes travel time)

Design Type: Steel stringer - timber deck (no skew)
Length: 32 ft. - 4 in.
Width: 22 ft. - 0 in.

	LABOR					EQUIPMENT					MATERIALS			TOTAL
Activity	No. Days	No. Man	No. Manhours Travel	No. Manhours Total	Total Cost	Type	No. Hours Travel	No. Hours Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Placing steel stringers	2	4	8	64	326.90	1 br. tr. 1 bm. tr.	4	32	14	78.40	Structural steel	22,100 lbs.	7,007.00	$ 7,412.30
Placing steel stringers	1	2	2	16	81.73	" "	2	16	7	39.20				$ 120.93
Placing diaphragms and rails	2	4	8	64	326.90	" "	4	32	14	78.40				$ 405.30
Hauling timbers	2	5	10	80	408.60	1 br. tr. 1 bm. tr. 1 lowboy	6	48	17.5	113.60	Treated lumber	3.87 M.F. B.M.	1,476.57	$ 1,998.77
Placing timbers	3	4	12	96	490.35	1 br. tr. 1 bm. tr.	6	48	21	117.60				$ 607.95
Placing timbers	1	2	2	16	81.73	" "	2	16	7	39.20				$ 120.93
Painting steel	2	3	6	48	245.16	1 br. tr. 1 bm. tr. 1 A.C.	6	48	14	134.40	Painting and miscellaneous		203.84	$ 583.40
Totals	13		48	384	1,961.37		30	240	94.5	600.80			8,687.41	$11,249.58
Total/ S. F.	.02		.07	0.54	2.76		.04	.34	0.13	0.85			12.21	15.81
Substructure Work	42			1349	6,433.39					2148.19			6,503.06	15,084.64

Project Number

Name:

Location: (Plan G')

Travel Distance for Field Forces: 13 Mi. one way (30 minutes travel time)

Design Type: Steel stringer, timber deck (Costs estimated based on Project 0662-062-176-I615, Rt. 662, Nelson County)
Length: 20 ft.
Width: 22 Ft.

	LABOR					EQUIPMENT					MATERIALS			TOTAL
			No. Manhours				No. Hours							
Activity	No. Days	No. Man	Travel	Total	Total Cost	Type	Travel	Total	Gal. Fuel Used	Total Cost	Type	Quantity	Total Cost	COST
Placing steel stringers	2	4	8	64	326.90	1 br. tr. 1 bm. tr.	4	32	14	78.40	Structural steel	9061/lbs.	2,872.87	$ 3,278.17
Placing steel stringers	1	2	2	16	81.73	" "	2	16	7	39.20				$ 120.93
Placing diaphragms and rails	2	4	8	64	326.90	" "	4	32	14	78.40				$ 405.30
Hauling timbers	1.25	5	7.5	50	255.38	1 br. tr. 1 bm. tr. 1 lowboy	6	48	17.5	113.60	Treated lumber	2.39 M.F. B.M.	913.34	$ 1,282.32
Placing timbers	2	4	8	64	326.90	1 br. tr. 1 bm. tr.	4	32	14	78.40				$ 405.30
Placing timbers	0.50	2	1	8	40.87	1 br. tr. 1 bm. tr.	-	-	-	-				$ 40.87
Painting steel	1.25	3	6	30	153.23	1 br. tr. 1 bm. tr. 1 A.C.	6	30	14	84.00	Miscellaneous		126.09	$ 363.32
Totals	10		40.50	296	1,511.91		26	190	80.5	472.0			3,912.30	$ 5,896.21
S. F. Cost	0.02		0.09	0.67	3.44		0.06	0.43	0.18	1.07			8.89	13.40