NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

119

PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS

TRANSPORTATION RESEARCH BOARD
National Research Council

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REPLY TO: Robert J. Reilly
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October 28, 1985

TO: CHIEF ADMINISTRATIVE OFFICERS
STATE HIGHWAY AND TRANSPORTATION DEPARTMENTS

SUBJECT: National Cooperative Highway Research Program
Synthesis of Highway Practice 119, "Prefabricated Bridge Elements and Systems," the Final Report on Project 20-5, Topic 15-10, of the FY '83 Program

I am enclosing one copy of the synthesis report resulting from research administered by the National Cooperative Highway Research Program. The research was conducted by the Transportation Research Board. In accordance with the selective distribution system of the Transportation Research Board, copies of this report will be directed to all persons having requested the subject areas of Maintenance, Structures Design and Performance, and Cement and Concrete together with the highway transportation mode.

The NCHRP staff has provided a foreword that succinctly summarizes the scope of the work and indicates the personnel who will find the results of particular interest. This will aid in its distribution within your department and in practical application of the research findings. These findings add substantially to the body of knowledge concerning prefabricated elements that can be used to construct new bridges or rehabilitate existing bridges. The major benefit from use of the procedures and materials described in this report is the minimizing of the reduction in level of service to motorists due to bridge construction and rehabilitation.

Sincerely yours,

Thomas B. Deen
Executive Director

Enclosure

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **119**

PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. AUGUST 1985

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an assurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation
Research Board

This synthesis will be of interest to bridge designers, maintenance and construction personnel, and others concerned with the design, maintenance, and rehabilitation of bridges. Information is presented on the use of prefabricated elements that can be used to construct new bridges or rehabilitate old ones.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Prefabricated bridge elements can be used to reduce design effort, simplify construction, and reduce delay to the traveling public. This report of the Transportation Research Board presents information on how highway agencies have used prefabricated elements, problems that were encountered and their solutions, costs, and benefits.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Damian J. Kulash, Assistant Director for Special Projects. The principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Anne S. Brennan.

Special appreciation is expressed to Michael M. Sprinkel, Research Scientist, Virginia Highway and Transportation Research Council, who was responsible for the collection of the data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Bernard F. Kotalik, Region Manager, Robson-Downes Associates; Warren J. Sunderland, Assistant Chief Engineer, Bridges and Structures Division, New Jersey Department of Transportation; and Carl E. Thunman, Rochester, Illinois; and Liaison Member Walter Podolny, Structural Engineer, Bridge Division, Federal Highway Administration.

William G. Gunderman, Engineer of Materials and Construction, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS

SUMMARY

Prefabricated elements and systems are usually used to achieve economy through the repeated use of forms and to reduce on-site construction time and labor by concentrating the construction effort in a fabrication facility rather than at the bridge site. The use of the elements can reduce design effort, reduce the impact on the environment in the vicinity of the site, and minimize the delays and inconvenience to the traveling public, saving time and money.

Many prefabricated elements and systems are available for use in highway bridge construction. The most frequently used elements are the prestressed concrete I-beam, precast and prestressed box beam, precast and prestressed channel, and precast slab span. In recent years, steel stay-in-place forms, prestressed concrete subdeck panels, precast parapets, and precast full-depth deck panels have been used on an increasing number of bridges. Prefabricated steel orthotropic plate deck units have been used to achieve a reduction in deadload and allow for deck replacement during off-peak traffic periods. Glued-laminated timber members have been used to replace bridges on rural roads.

As the highway program moves from an era of bridge construction to one of bridge maintenance, rehabilitation, and replacement, the use of prefabricated elements and systems will certainly increase. Bridges subjected to high volumes of traffic can usually be closed for repair only during off-peak traffic periods. Prefabricated elements that can be installed and opened to traffic in a short period of time provide a practical way to repair these bridges. Because of the large number of bridges on low-volume roads in need of repair, rehabilitation, and replacement, identical, mass-produced elements, which may be quickly assembled, will be used to reduce design time and cost, minimize forming and labor costs, and minimize lane closure time.

Early problems with the use of prefabricated elements have been largely eliminated, and bridges containing the elements are expected to provide many years of service with minimal maintenance. The most significant continuing problem is the high cost of the elements in areas where they are not readily available or where demand is insufficient to justify mass production. Even at a higher cost, the use of the elements on bridges subjected to high volumes of traffic can be justified because excessive lane closure times can be avoided.

Significant evolution has occurred in the use of prefabricated elements and systems. Early efforts centered on precasting, and later prestressing, of single elements such as slab spans, channels, and I-beams. Acceptance and use of the elements increased with improvements in quality control and efficiency at precast plants. Efforts were

expanded to include the substructure and portions of the deck as precast subdeck panels gained acceptance. The connections between elements surfaced as a major area of concern as innovators attempted to prefabricate the deck and the parapet and every other element of a bridge. These problems are gradually being resolved with improvements in the design of connections and with developments in high-early-strength, quick-setting materials, such as polymers. It is currently possible to economically replace almost any portion of a bridge with a prefabricated element and to complete the installation during off-peak traffic periods and with a minimum of disruption to the environment.

CHAPTER ONE

INTRODUCTION

The synthesis reports both the state of the art and the state of the practice for prefabricated bridge elements and systems and is based on a review of pertinent literature and ongoing research along with an examination of current practices.

Many prefabricated elements and systems are available for highway bridge construction. Prefabricated elements and systems can be used with less disruption at the site, can reduce much of the environmental impact in the surrounding areas during construction, can reduce design effort, and can speed up field construction, saving time and money.

Prefabricated elements and systems currently utilized for bridges are listed in NCHRP Report 222 (*1*) and NCHRP Report 243 (*2*). Descriptions of these are reproduced herein as Appendix A. To help condense the synthesis, the synthesis panel ranked these elements and systems and concluded that the synthesis should focus primarily on the six elements and systems that were believed to be more promising or most frequently used: precast concrete slab spans (C-1 in Appendix A), precast box beams (C-2), prestressed I-beams (C-8), precast deck panels (S-3), permanent bridge-deck forms (M-4), and parapet and rail systems (M-5). However, the synthesis also covers the other systems in Reports 222 and 243 as well as additional systems that have potential.

STATEMENT OF PROBLEM

Although much of the information that would be in a synthesis on prefabricated bridge elements and systems has been published in NCHRP Reports 222 and 243, the titles of these reports give no indication of this because the reports were aimed at rehabilitation and replacement methods for bridges on secondary roads. One of the methods was the use of prefabricated elements and systems, and 32 of these are covered in Reports 222 and 243. However, the nature of the information is more like a catalog than a synthesis; that is, there is no information on successes, problems, costs, reasons for selection, etc. This synthesis is a compilation of this kind of information and adds to that contained in NCHRP Reports 222 and 243.

PURPOSE AND SCOPE

This synthesis is a study and evaluation of the systems from NCHRP Reports 222 and 243 noted above including history of use, reasons for use, fabrication, construction and maintenance practices, structural effectiveness, cost-effectiveness, serviceability, durability, resolved and unresolved problems, and other aspects. The other systems from NCHRP Reports 222 and 243 are also covered in the synthesis, although in less detail, as well as any additional systems that were found in the literature or practice that have potential.

For the synthesis, a prefabricated bridge element is defined as a part of a bridge that is fabricated or assembled away from its final position and used to minimize design effort, on-site construction time, or disruption or environmental impact in the vicinity of the site. A prefabricated bridge system is a combination of prefabricated bridge elements. Structural steel beams and solid sawn timber members are not considered as prefabricated elements. A bridge is defined as a structure having a span of 20 ft (6 m) or greater (although there is no reason that prefabricated elements cannot be used on shorter spans).

BACKGROUND

The synthesis results from a survey of the literature, the identification of ongoing research, and a compilation of information on the past and present practices of transportation agencies. Much information on past and present practices was obtained from a questionnaire that was distributed to the bridge engineers in most of the 50 states, the District of Columbia, and other selected transportation authorities (Appendix B). They were asked to complete the questionnaire with regard to the use of prefabricated bridge elements and systems in bridges under their authority. They were questioned on the six types of prefabricated elements considered by the synthesis panel to be the most promising. In addition, space was provided for answers to questions about other prefabricated bridge elements or systems that they use. In addition to information on the type and frequency of use of an element, questions on how, when, where, and particularly why an element or system was used were asked. Also, questions were asked about the fabrication and transportation of prefabricated elements; the construction, maintenance, and cost of bridges containing the elements; and resolved and unresolved problems with the elements or bridges containing the elements. It was requested that when possible, answers be based on information on record, but good estimates would be accepted if precise answers were not feasible. Appendix B provides a summary of the responses to the questionnaire.

Thirty-six usable responses were received including replies from 34 states, the District of Columbia, and Alberta. The responding agencies (excluding Alberta, which is responsible for 6,000 bridges) were responsible for approximately 223,000 bridges or approximately 39% of the estimated 570,000 bridges in the United States (*3*). It is believed that the responses provide an accurate indication of the current practice of the use of prefabricated bridge elements and systems in the United States.

The 36 responding agencies indicated that approximately 35,000 bridges (15%) contained prefabricated elements but only about 1,200 bridges (0.5%) contained a completely prefabricated superstructure. The use of prefabricated bridge elements is likely greater than that indicated by the questionnaire for two reasons. First, prefabricated elements lend themselves to mass production and use on multispan bridges; therefore the percentage of bridge spans with prefabricated elements is likely to be higher than the percentage of bridges with prefabricated elements. Second, prefabricated bridge elements are frequently used on secondary highways and local roads, and many are not under the authority of the state highway and transportation departments that responded to the questionnaire. Obviously, a significant number of bridges contain prefabricated elements and a discussion of the most popular elements follows.

CHAPTER TWO

MOST POPULAR PREFABRICATED ELEMENTS

Table 1 shows the use of prefabricated elements based on the responses to the questionnaire. The table shows the number and percent of responding agencies reporting use of the elements and the number and percent of bridges in which the elements have been used. Information on the first seven elements was requested in the questionnaire and zero answers were recorded as a response but blanks were not. The responses for the last five elements were volunteered and therefore there were no zero-use replies; it is reasonable to expect that the number of users is somewhat greater than indicated by the responses.

TABLE 1

USE OF PREFABRICATED ELEMENTS

Element	Replies	Agencies Using		Bridges Used On	
		No.	%[a]	No.	%[b]
Precast concrete slab span	34	26	76	3,002	1.3
Precast box beam	34	26	76	5,948	2.6
Prestressed I-beam	36	35	97	18,299	8.0
Precast deck panel	29	5	17	8	[c]
Steel stay-in-place form	22	18	82	1,926	0.8
Prestressed subdeck panel	21	14	67	702	0.3
Precast parapet	26	8	31	331	0.1
Double-tee and channel	9	9[d]	-	4,482	2.0
Single-tee	3	3[d]	-	25	[c]
Precast substructure	4	4[d]	-	22	[c]
Bulb-tee	2	2[d]	-	18	[c]
Other	8	8[d]	-	32	[c]

[a] Percentage of the agencies responding to the survey.

[b] Percentage of the 229,000 bridges under the jurisdiction of the responding agencies.

[c] Less than 0.1 percent.

[d] The number of agencies using is the same as the number of replies because information on these elements was volunteered.

Responses to the questionnaire indicated that the most frequently used prefabricated element is the prestressed concrete I-beam, which was used in approximately 18,300 bridges or 8% of the population included in the survey. The second most commonly used element is the precast concrete box beam, which was used in approximately 6,000 bridges or 3% of the population included in the survey. The precast concrete double-tee or channel beam is the third most frequently used element as it has been used in approximately 4,500 bridges or 2% of the population included in the survey. However, approximately 3,000 of these bridges are located in Alberta. The double-tee and channel accounted for 95% of the bridges with elements for which information was volunteered under the other elements category of the questionnaire. The fourth most frequently used element is the solid or voided slab span. Approximately 3,000 bridges or more than 1% of the population included in the survey contain the slab span. Approximately 2,600 bridges contain prefabricated steel or concrete forms that are a permanent part of the deck. Only approximately 300 bridges were reported to contain a precast parapet and on about half of these bridges the use was temporary for purposes of construction. Only eight bridges were reported to have precast concrete deck panels. Other occasionally used elements noted from the questionnaire included precast single-tee beam, precast substructure elements (such as reinforced earth, piles, bents, and piers), and precast bulb tees. The Alaska Department of Transportation reported that the bulb tee was used on many bridges but did not cite a number.

PRECAST CONCRETE SLAB SPANS

Precast concrete slab spans (Figure 1) may be fabricated in various lengths and widths to accommodate a range of spans and roadway widths. Solid slabs are frequently used for spans up to 30 ft (9 m) but more structurally efficient pretensioned or post-tensioned or voided slabs are commonly used for longer spans (*4, 5*). Slabs are very easy to transport and erect.

Shear transfer between slabs is usually provided by a grouted keyway or by weld plates (*5, 6*). Special consideration should

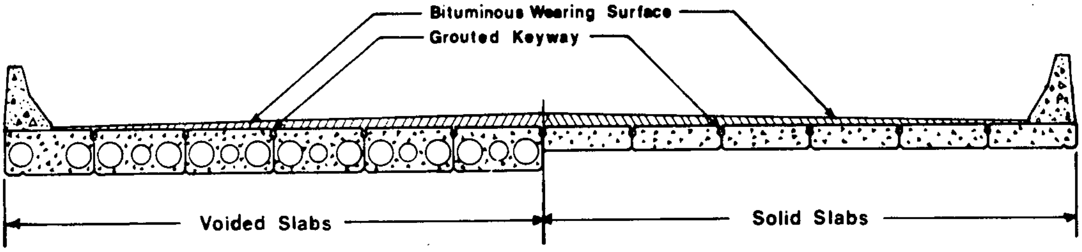


Figure 1 Precast slab spans.

be given to the connection details because premature cracking in the wearing surface and early failures of the system have been attributed to keyway and weld-plate failures (*7*). Martin provides detailed coverage of the problems and solutions to the problems with the connections between modular precast concrete elements (*7*).

Most precast concrete producers are properly equipped to produce slabs. Also, some state and local bridge crews fabricate the slabs because of the ease with which the slabs can be precast. The slabs can be precast by maintenance forces during off-peak maintenance periods when there is a surplus of labor (*6, 8*).

The slabs are particularly suited for the rapid replacement of short-span superstructures because they are easily installed while traffic is maintained in an adjacent lane (*9*). Figure 2 illustrates a bridge maintenance crew replacing a superstructure of steel beams and timber decking with precast concrete slab spans while stopping traffic on the secondary road for very short periods of time. Because the individual slabs are usually not designed to support an HS20-44 loading without being connected, one lane of traffic can usually be maintained as the slabs are placed by limiting the loads that cross the bridge or by connecting the slabs as they are placed. When replacing a lighter superstructure, the capacity of the substructure should be evaluated to ensure that it can support the weight of the slabs.

The most frequently used alternatives to the precast slab span are the culvert (system M-8 in Appendix A), cast-in-place (CIP) concrete, and steel beams with a CIP concrete deck (system S-9).

Examples of the use of precast slab spans can be found in many states. The slabs are frequently used in Illinois, Indiana, Kentucky, New York, North Carolina, Oregon, Virginia, and Alberta, where each has used the slabs on 100 to 500 bridges. Six percent of the bridges in Kentucky contain the slab.

PRECAST BOX BEAMS

Precast box beams (Figure 3) are usually pretensioned but may be post-tensioned and may be precast in various lengths and widths to accommodate a range of spans and roadway widths. Box beams are generally used for spans of approximately 50 to 100 ft (15 to 30 m) (*4*). Except for the longer spans, the boxes are very easy to transport and erect. Box beams that are placed adjacent to each other are usually connected in the same way slabs are connected (*5*). A wearing surface is usually used with the box beams. Box beams that are spaced apart (spread boxes) are tied together with diaphragms and a CIP concrete slab is added (*10*).

Like the slab spans, the box is particularly suited for the replacement of short-span superstructures. More expertise is required to fabricate a box than a slab because the box is usually prestressed and because the proper location of the void material must be maintained during the casting operation. Most prestressed concrete producers can manufacture the boxes, usually pretensioned, and occasionally state and local bridge crews have fabricated the boxes, usually conventionally reinforced (*8*).

The most frequently used alternatives to the box are CIP concrete and steel beams with CIP concrete deck.

Examples of the use of the boxes can be found in many states. The boxes are frequently used in California, Illinois, Indiana, Kentucky, New York, North Dakota, Ohio, Pennsylvania, Texas, Virginia, and West Virginia, where each has used the boxes on 100 to 1,500 bridges. Nineteen percent of the bridges in North Dakota contain box beams.

PRESTRESSED I-BEAMS

The precast, pretensioned I-beam (Figure 4) is widely used because forms for precasting the member are readily available, and the standard cross sections simplify design practice and lead to cost savings (*11*). The beams are usually used for spans of 40 to 100 ft (12 to 30 m), but spans up to 140 ft (43 m) are reported in the literature (*4, 12*). A CIP concrete deck is usually used. Although most decks are constructed with removable forms, the current trend is toward the use of permanent forms, such as steel stay-in-place forms or prestressed concrete subdeck panels. Construction time and safety are improved through the use of permanent forms (*13, 14*). Because of the large amount of CIP concrete required for the deck, other systems better lend themselves to rapid bridge replacement. However, the I-beams provide more rapid construction than CIP concrete beams.

Most prestressed concrete producers can fabricate the beams and they would seldom be cast by state or local crews. The most frequently used alternative to the prestressed I-beam is the steel beam, either the standard rolled shape or the plate girder.

Examples of the use of the I-beam can be found in many states. The I-beam is frequently used in California, Colorado, Georgia, Kentucky, Minnesota, Montana, North Dakota, Pennsylvania, Texas, Virginia, and Washington, where they have been used in approximately 750 to 4,000 bridges. Approximately one third of the bridges in Colorado, Montana, and Washington contain prestressed I-beams.

In recent years, some state highway agencies have developed modified versions of the AASHTO girder that provide more economical cross sections (*15–17*). According to a recent study,

Figure 2 Precast slab spans replace substandard steel stringer-timber deck superstructure (*6*).

a new series of sections called the modified bulb-T, shown in Figure 5, can provide savings of up to 17% when used to replace the AASHTO Type IV, V, and VI beams in spans greater than 80 ft (25 m) (*17, 18*).

PRECAST DECK PANELS

One of the more recent innovations in the use of prefabricated elements is the use of precast concrete deck panels (Figure 6) that are placed on steel stringers (*19–25*). Shear transfer between transverse panels is usually achieved with grouted keyways or a CIP concrete joint (*17, 19, 20, 21, 24*). Transverse panels may be post-tensioned parallel to the direction of traffic to improve shear transfer between panels (*20, 23*). Proper vertical alignment and uniform bearing on the top flanges of the supporting stringers can be obtained by placement of a bed of grout or epoxy mortar before setting the slabs, by use of shim pads with grout placed after the panels are placed on the shims, or by use of a detail that includes adjustable slab support on angles or bolts while grout or epoxy mortar is placed (*25*).

To develop composite action between the deck panel and the stringers, the connection must be adequate to transfer horizontal shear. Composite action was not achieved in the earlier bridges in which the panels were typically attached to the stringers with clips and bolts (*19–21*). Composite action is being achieved in the more recently constructed bridges through the use of studs or bolts as shear connectors (*22, 24*). The studs may be welded to the top flange of the stringers, or holes for high-strength bolts may be drilled in the top flanges. The shear connectors may be placed before or after the slabs are positioned, but if they are installed before, it is necessary to fabricate and erect the slabs

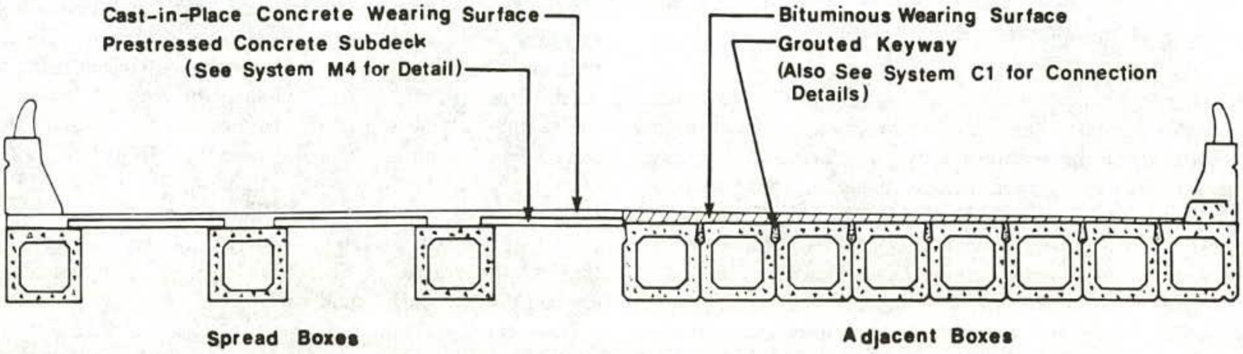


Figure 3 Precast box beams.

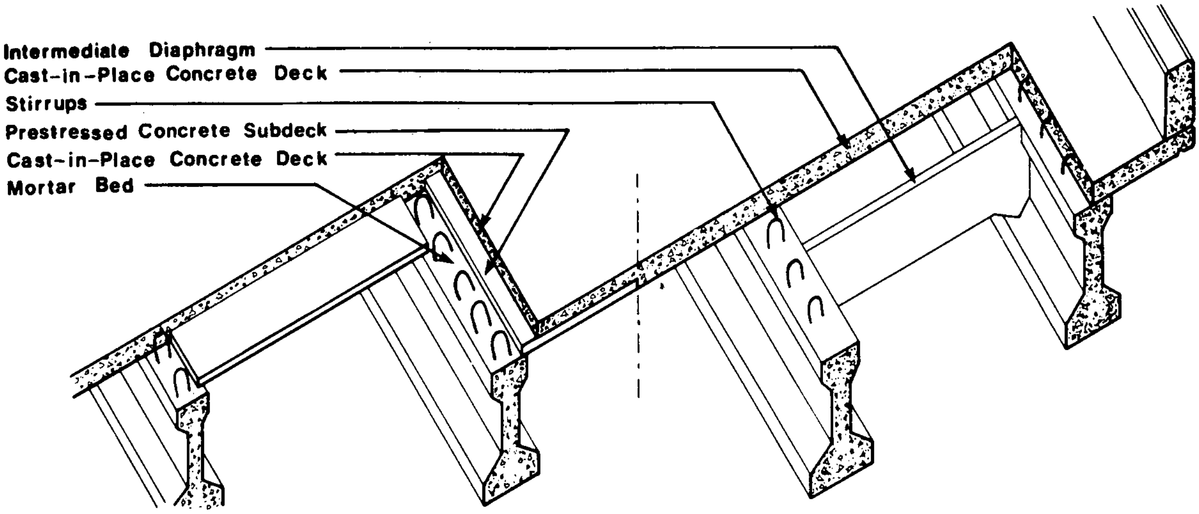


Figure 4 Prestressed I-beams.

with more precision. The voids around the studs or bolts are typically filled with nonshrink grout or epoxy mortar.

The deck panels eliminate most of the on-site formwork and concreting typically required for a steel stringer-concrete deck bridge (*22, 25*). Most precast-concrete producers can fabricate the slabs; based on the questionnaire responses, state or local crews have not fabricated them to date. The use of the slabs to replace the deck of a bridge near Mount Vernon, Virginia is shown in Figure 7.

Berger (*25*) discusses the use of precast, prestressed bridge deck panels on steel and prestressed concrete beams. He gives several details that can be used for connecting precast panels

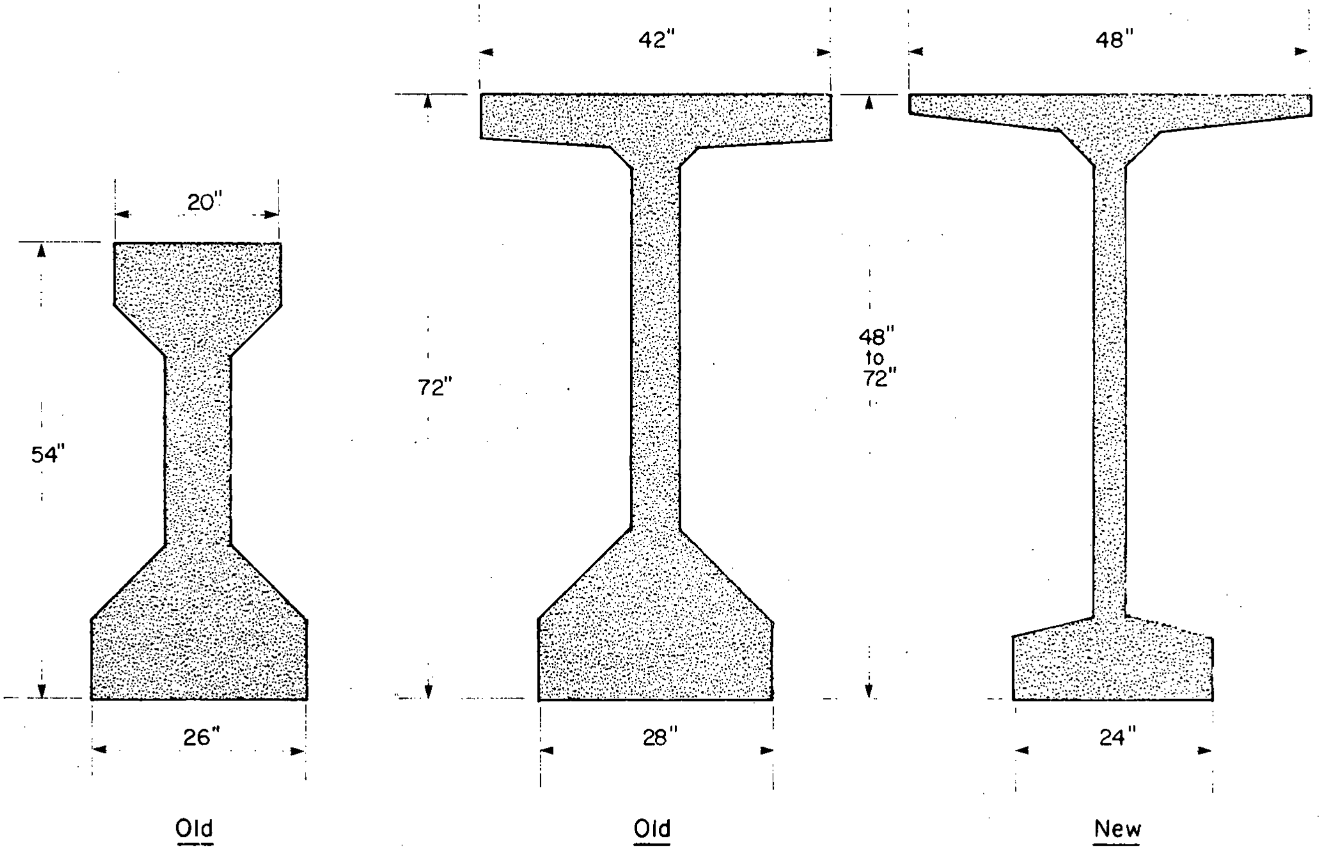


Figure 5 Modified bulb-T proposed to replace standard AASHTO-PCI type IV, V, and VI sections (Concrete Technology Laboratories).

to beams, both on new construction and for replacement of existing bridge decks. Berger concludes that the precast slabs are more economical than CIP concrete decks because they may be pretensioned or post-tensioned and therefore are more structurally efficient, requiring less material and fewer supporting elements, and because on-site construction costs are less as the precast slabs may be installed in less time.

The rehabilitation of the Fremont Street Bridge near Pittsburgh utilized precast deck panels set on the floor beams of a concrete arch bridge (*26*). These panels have the attributes of both deck panels and slab spans; they are longitudinally reinforced two-span continuous slabs (Figure 8). Leveling bolts were used to adjust the elevation of the slabs and dowels were placed and grouted into holes in the slabs and the floor beams to anchor the slabs. Polymer mortar was pumped under the neoprene bearing pads to rigidly connect the slabs to the floor beams after the panels were post-tensioned transversely.

A recent example of the use of precast deck panels on steel beams was the replacement of the deck on the Woodrow Wilson Memorial Bridge on I-495 around Washington, D. C. (*17, 23, 27*). The deck of the 5,900-ft (1800-m) long, six-lane bridge was replaced during a period of twelve months without halting the flow of traffic, which averaged 125,000 vehicles per day.

The major work on the bridge was done each night for 10 hours, leaving open two of the six lanes to traffic as illustrated in Figure 9. A concrete-cutting circular saw cut the existing deck away in 40-ton (36 Mg) segments. These segments were replaced by precast, lightweight concrete panels that were post-tensioned transversely at the plant. A typical panel was 46 ft 8 in. wide, 10 to 12 ft long, and 8 in. thick (14.2 m wide, 3.0 to 3.6 m long, and 200 mm thick). The new panels widened the bridge by 4 ft (1.2 m). After placement, the panels were post-tensioned longitudinally in groups of 17 to reduce cracking, seal the transverse joints between adjacent panels, and eliminate water intrusion.

The concrete deck panels are supported by CIP polymer concrete bearing pads on the exterior girder and interior stringers. The polymer concrete is a methyl methacrylate product that reached 4,000 psi (27.6 kPa) compressive strength after one hour and 8,000 psi (55 kPa) after 24 hours. Each pad includes

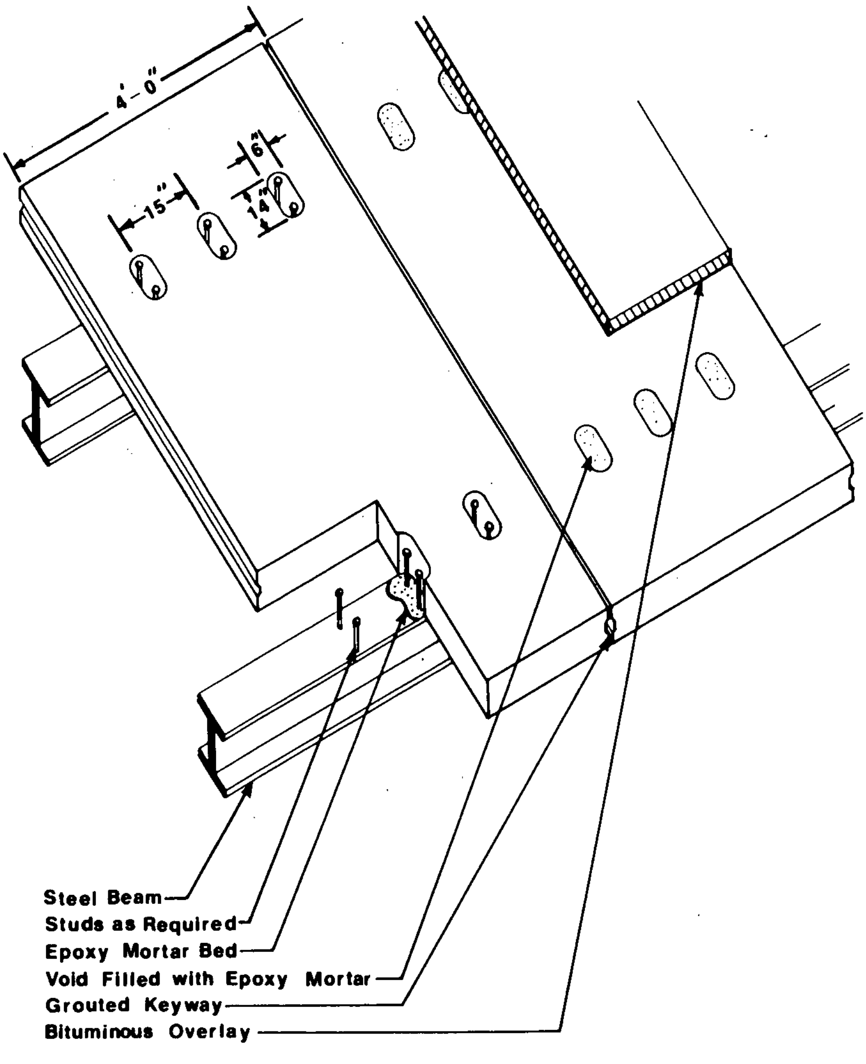


Figure 6 Precast concrete deck panels (See Appendix A, System S-3 for noncomposite and longitudinal panels).

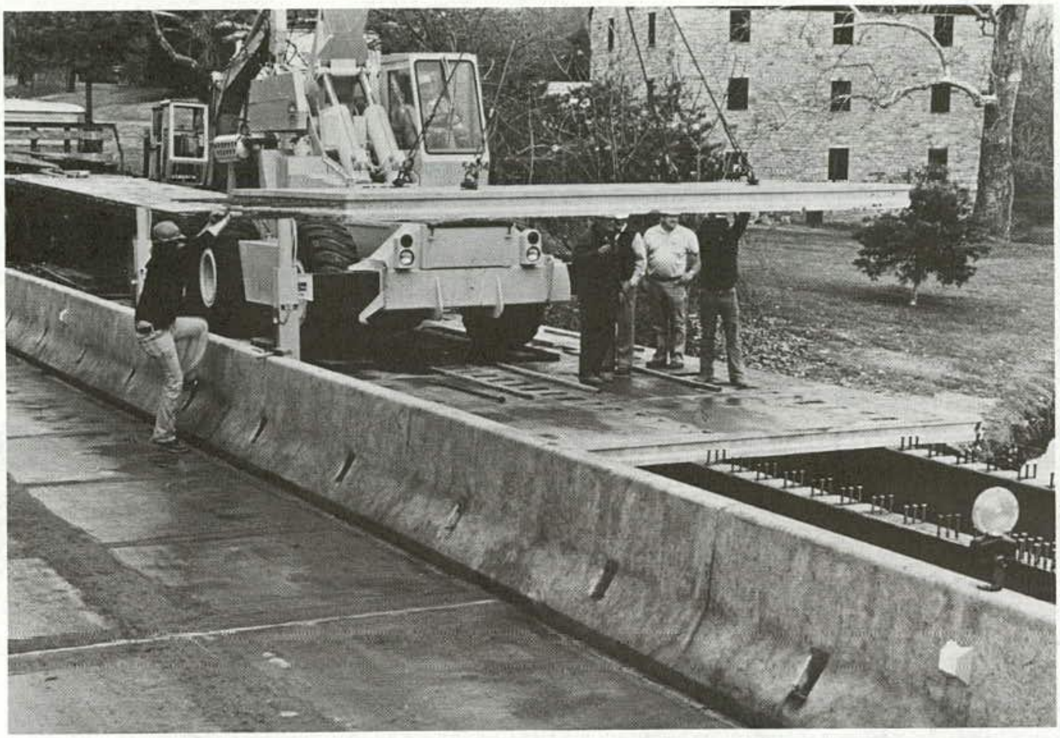


Figure 7 Precast deck panel is lowered onto stringers, which are covered with epoxy mortar (*24*).

a sliding steel bearing plate on the stringer's flange that is tied into the polymer concrete by welded studs. The sliding plates prevent the introduction of stresses in the structural steel caused by shrinkage, creep, and foreshortening during post-tensioning of the deck.

Each night the contractor covered the gap between the old and the new deck with a steel grating deck that carried traffic during the day. The following night, crews lifted away the grating to install new deck while other workers removed concrete.

The redecking of the Woodrow Wilson Bridge exemplifies how, with proper planning and design that takes advantage of recent developments in high-early-strength materials and technology, prefabricated deck panels can be erected and connected with a minimum of disruption to the environment and at a savings to the public.

The alternative to the precast concrete deck panels is CIP concrete, which requires considerable on-site construction time and subsequent lane closure time for strength development (*24, 25*). Precast concrete deck panels have been used in a limited number of states but an increase in use is anticipated as highway agencies are confronted with replacing the decks of bridges during off-peak traffic periods and with minimal lane closure time. Although the New York Thruway Authority has not experienced the cost savings and reduced construction time anticipated, their nine years of experience indicates that precast panels are an acceptable approach to deck replacement (*2*). Other examples of the use of the panels in highway bridges can be found in Alabama, California, Indiana, Maryland, Massachusetts, New York, Pennsylvania, Virginia, and West Virginia. Examples of use on railroad bridges can be found in Delaware, New Mexico, and British Columbia (*24*).

PERMANENT BRIDGE-DECK FORMS

The concrete required for site-cast concrete bridge decks must be formed with temporary or permanent bridge-deck forms. In recent years, steel stay-in-place forms and prestressed concrete subdeck panels (Figure 10) have become popular because the high cost of the form removal is eliminated (*7, 14, 28*). Prestressed concrete subdeck panels provide an added advantage in that less concrete and reinforcing steel must be placed at the bridge site because the panels become an integral part of the deck. Most prestressed concrete producers can fabricate the subdeck panels, and the steel forms are available from most steel fabricators.

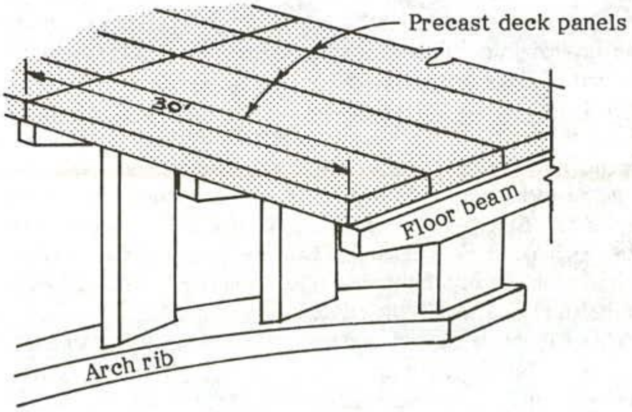


Figure 8 Use of precast deck panels in rehabilitation of Fremont Street bridge.

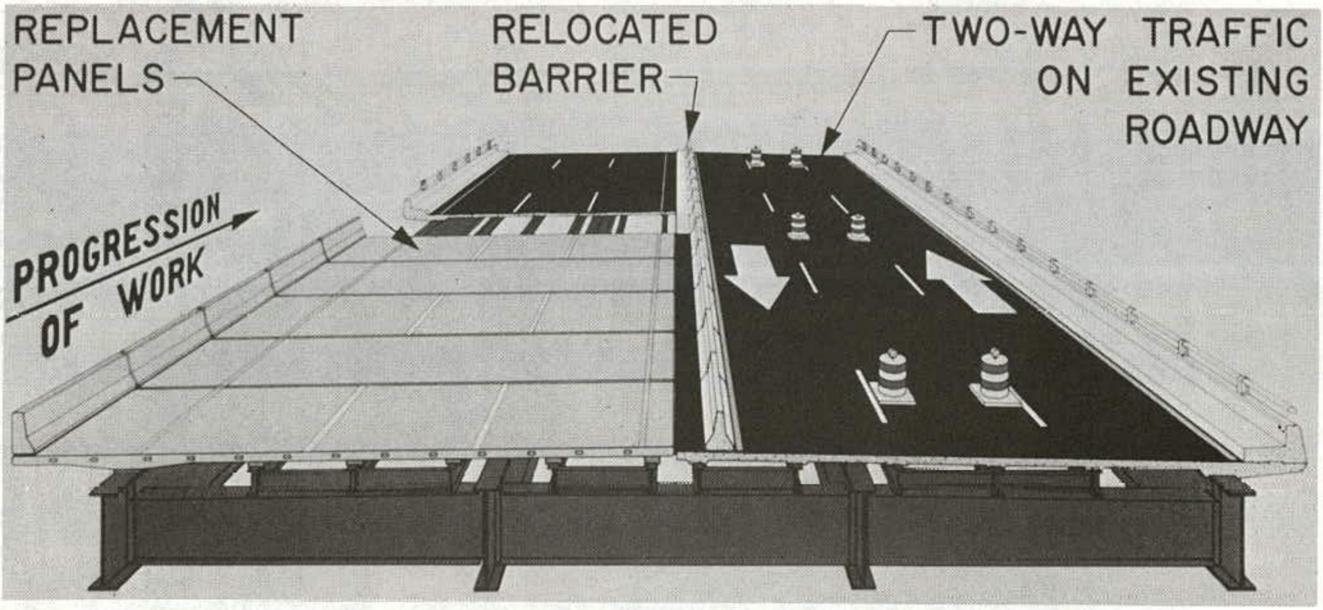


Figure 9 Precast post-tensioned lightweight concrete panels were installed at night to replace the deck of the Woodrow Wilson Bridge (*23*).

The prestressed panels are usually pretensioned and precast in widths of approximately 4 ft (1.2 m), but have been precast in widths of up to 8 ft (2.4 m), and in lengths that are controlled by the spacing of the beams in the bridge (*29*). On earlier installations the panels were set on a grout bed, approximately ½ in. (13 mm) thick, which was placed along the supporting edge of the beams in the bridge (see Figure 11). The grout provided for the uniform bearing of the panel by compensating for camber and surface irregularities. Because the panels are a constant thickness, they followed the camber in the supporting beams, and the thickness of the CIP concrete typically varied from a maximum at the bearings to a minimum at midspan. On more recent installations the thickness of the grout bed was varied to account for the camber in the supporting beams and to provide a deck of constant thickness.

The rectangular panels can be used on skewed bridges by cutting the end panels to the desired skew with a portable power saw and a concrete cutting blade (*29*). The installation of the panels can proceed rapidly with a minimum of labor and without the need for temporary platforms. Once the panels are in place, the finished grade of the deck surface can be set and the required concrete for the overlay placed.

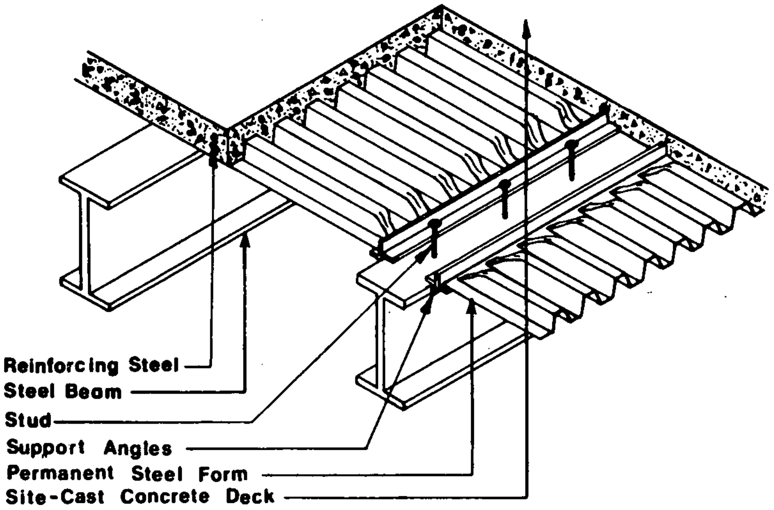
Although cracks will usually occur in the deck surface directly above the butt joints between the panels, the cracks typically extend only halfway through the CIP concrete and are not believed to have a significant effect on the performance of the deck (*29*). Epoxy-coated rebar can be used for the top mat of the steel in the deck or calcium nitrite can be used in the concrete to curtail the corrosion that might be accelerated by the presence of moisture and salt in the cracks.

Considerable laboratory and field work to evaluate prestressed concrete subdeck panels has been conducted (*7, 29–33*). Composite action between the panel and the CIP concrete and across adjacent panels has not been a problem (*7, 14, 29, 30, 32*). The experience to date has generally been good and indicates the panels provide a suitable method for forming a bridge deck (*28, 32, 34*). Unfortunately, a recent study for the Florida Department of Transportation concluded that the majority of the approximately 200 bridges that were constructed in Florida with the subdeck panels will have a reduced service life (*32, 33*). According to the study, the panels in these bridges do not have positive bearing on the girders because they were placed on fiberboard strips rather than grout. The study recommends that positive bearing be required on future subdeck panel installations and that the prestressing strand extensions should be beneficial in maintaining continuity between the panels and the CIP concrete (*32*). On the other hand, the Illinois Department of Transportation, which considers subdeck panels to be a viable and cost-effective concept, requires that the strand extensions be removed because they interfere with the placement of the shear connectors and the bearing grout (*34*). Obviously, the state of the art is being refined as the prestressed subdeck panels gain wider acceptance.

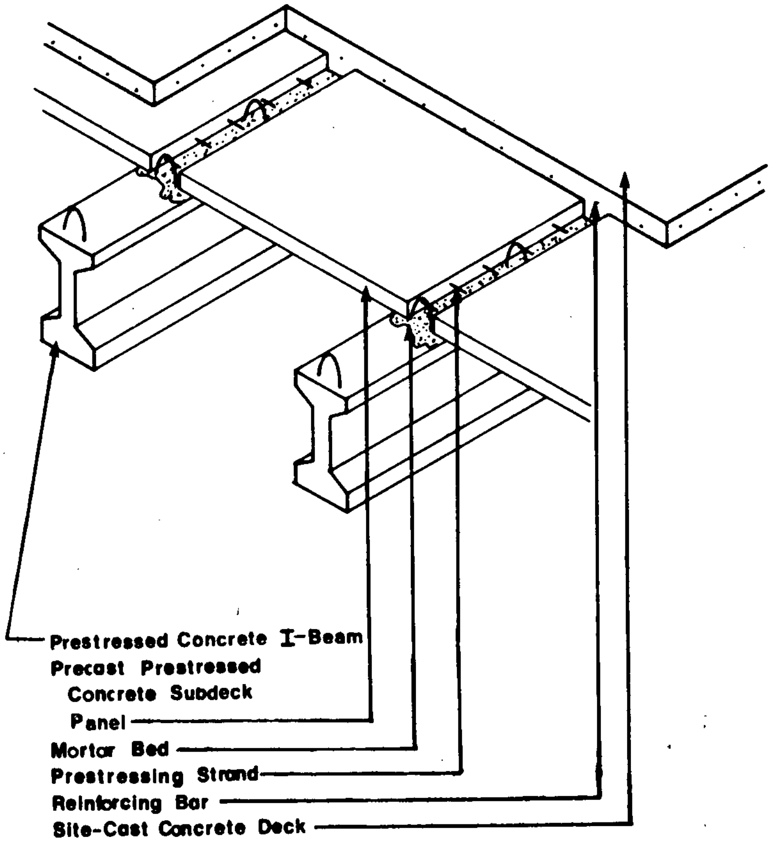
Like the prestressed concrete subdeck panels, the steel stay-in-place forms can be placed with a minimum of labor. Metal screws are usually used to fasten the forms to metal angles that have been field welded to supporting devices at the proper elevation. The supporting devices are precast into the top flange of a concrete beam and hang from the top flange of a steel beam (see System M-4 in Appendix A).

Opinions vary as to the advantages and disadvantages of using steel stay-in-place forms. Corrosion of the forms can be a problem if moisture has ready access to the form by drainage; penetration through poor quality, permeable concrete; or via other means. The forms are generally accepted in many states that believe the advantages outweigh the potential disadvantages (*14, 35, 36*).

Examples of the use of the permanent bridge deck forms can be found in many states. The steel stay-in-place forms have been used on three times as many bridges as the prestressed subdeck panels. The steel stay-in-place forms have been used in Georgia, Maryland, and Virginia, where each has used them on 450 to



Permanent Steel Forms



Prestressed Concrete Subdeck Panels

Figure 10 Permanent bridge-deck forms.

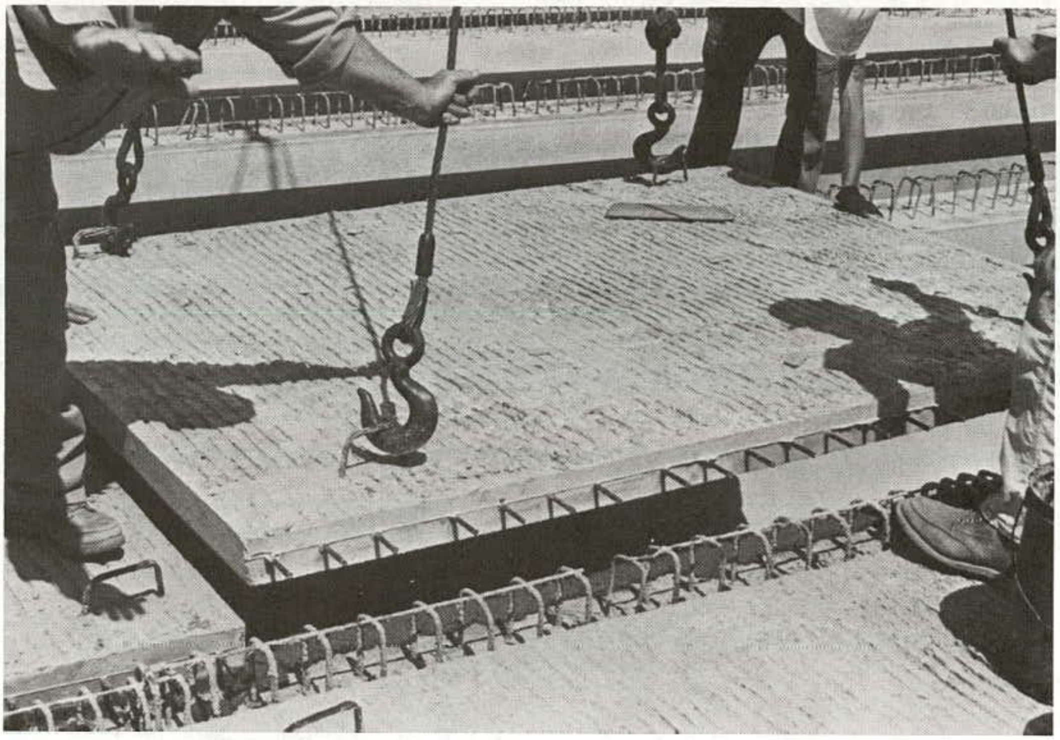


Figure 11 Prestressed subdeck panels are set on a grout bed, which is placed along the top edge of the supporting beam (Virginia Highway and Transportation Research Council photo).

650 bridges, and in Pennsylvania, where they have been used on 90% of the bridges built in the last 10 years. The prestressed concrete subdeck panels have been used in Georgia, Illinois, and Texas, where each has used them on 150 to 200 bridges. Approximately 28% of the bridges in Maryland contain steel stay-in-place forms and 3% of the bridges in Illinois contain prestressed concrete subdeck panels.

PRECAST PARAPET

Because placing the forms for conventional CIP concrete parapets can be a costly and time-consuming job, precast parapets have been used in some states in recent years. The parapet lends itself ideally to prefabrication as it has a constant shape suitable for mass duplication (see Figure 12) and is used in sufficient volume statewide to make precasting economical. The standard precast parapets, typically 8 to 12 ft (2.4 to 3.7 m) long, are fabricated upside down to help eliminate honeycombing.

With the aid of a light truck crane, three workers can place and connect the 2-ton (1.8-Mg) parapet sections on a three-span structure in two or three days (*37*). The parapets may be set in cement mortar spread on top of the deck or they may be set on temporary wooden shims and grouted. The parapets may be anchored to the bridge deck in several ways, which include the use of stainless steel bolts that extend through the base of the parapet and the deck and the use of threaded metal rods that screw into inserts precast into the deck and extend upward through voids cast into the parapet (*4, 38*). Portland cement mortar is usually used to grout the voids and anchor the parapet. A problem with water and salt leaking between the base of the parapet and the deck needs to be resolved.

Examples of the use of the precast parapet can be found in Missouri, Pennsylvania, Texas, and Virginia, where each has used precast parapets on up to approximately 150 bridges.

DOUBLE-TEE AND CHANNEL

Most prestressed concrete producers have forms in several standard sizes to allow the production of pretensioned or post-tensioned double-tee and channel beams (Figure 13) for a range of span lengths (*4, 10*). However, available forms may not be suitable for the fabrication of members that are heavy enough for bridge loadings (*39*). Double-tee and channel beams have been fabricated at the bridge site and at precasting plants (*40, 41*). Channels are usually fabricated in double-tee forms by blocking off a portion of the exterior flanges. Both the channel and double tee may be fabricated for use with or without a topping. Both members are among the easiest to transport and erect. The members are typically used for spans of 20 to 60 ft (6 to 18 m) (*4*). Shear transfer between the beams may be achieved through the use of grouted keyways or weld plates (*40–42*).

Numerous examples of the use of the channel can be found in Alberta where approximately 3,000 bridges (50%) contain the beam and in Arkansas, North Carolina, and Pennsylvania where each has used them on 200 to 700 bridges. Approximately 5% of the bridges in Arkansas contain the channel. The double-tee can be found in Missouri, New York, and Oklahoma where each has used them on 20 to 70 bridges.

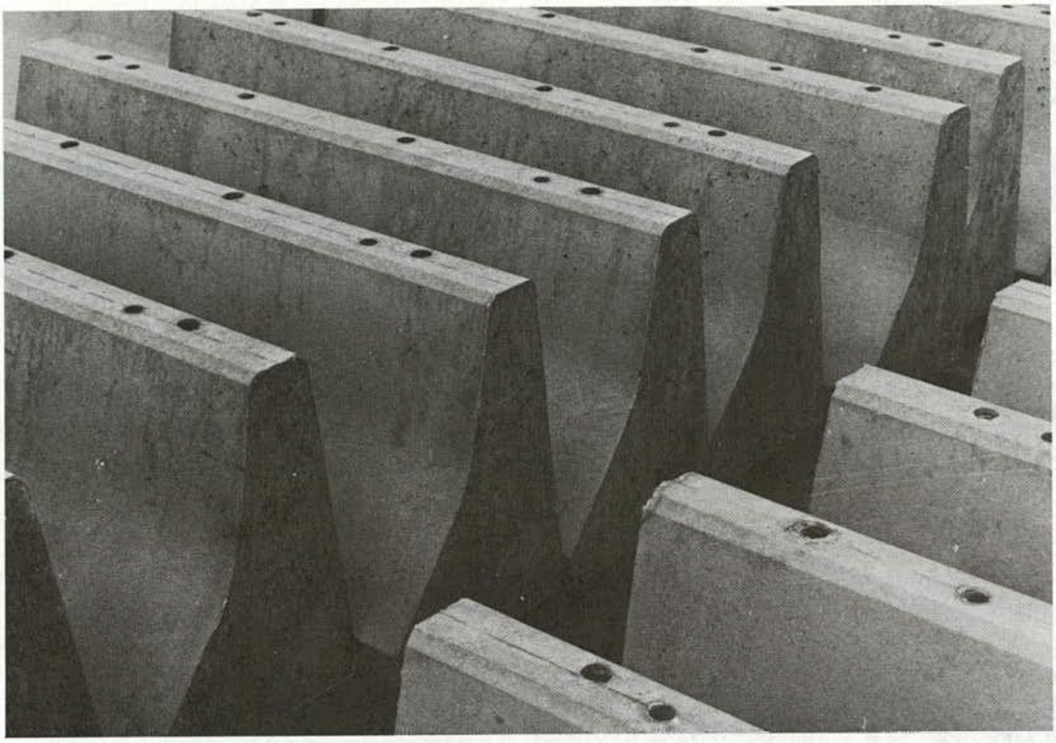


Figure 12 Modular precast parapet is ideally suited for mass production (*37*).

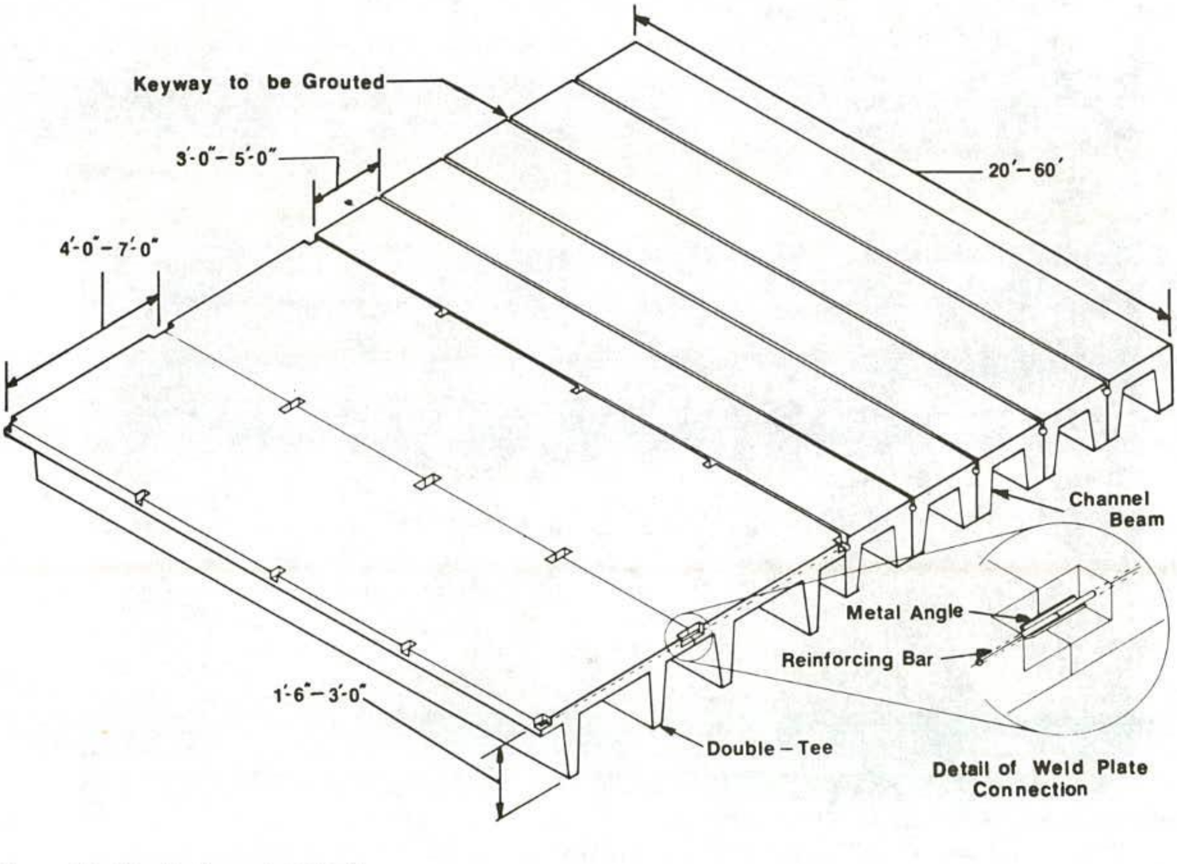


Figure 13 Double-tee and channel.

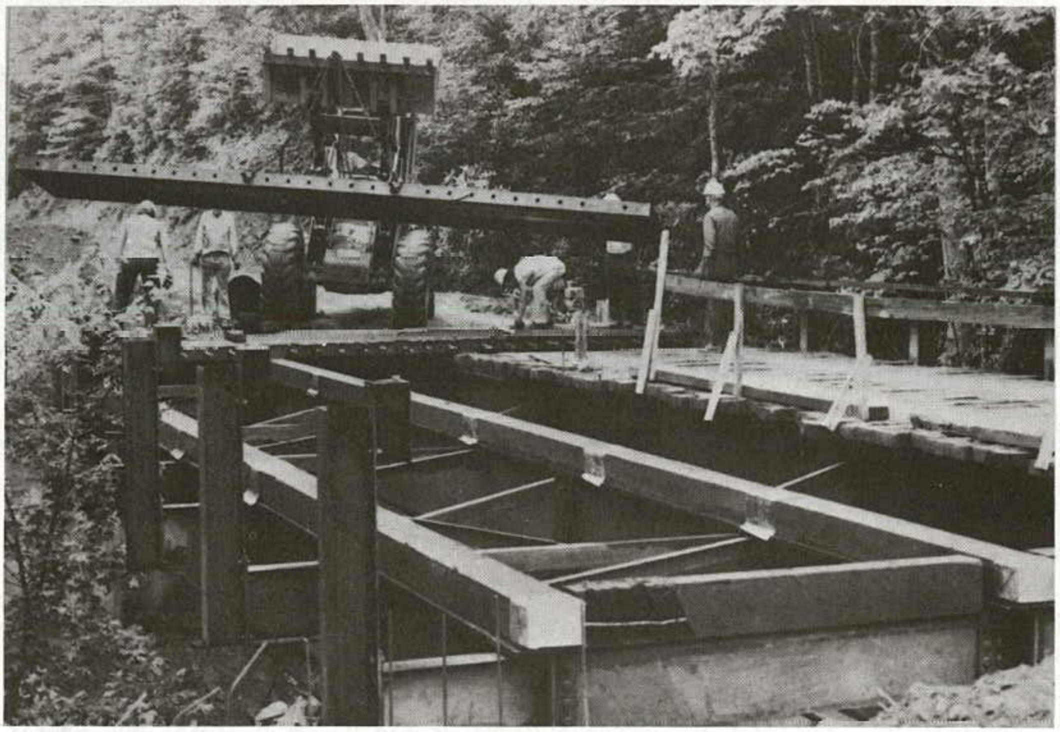


Figure 14 Traffic was maintained as temporary timber planks were replaced with glulam panels (*52*).

Figure 15 Precast wing wall is placed into position on site-cast concrete footing (Hancock Concrete Products photo).

OTHER ELEMENTS

Brief descriptions and illustrations of numerous other prefabricated bridge elements and systems can be found in Appendix A. The elements are grouped according to the materials used for the primary element of the superstructure and are designated as concrete, steel, timber, or miscellaneous.

Steel Elements

Elsasser (*43*) reports that nearly all steel work is prefabricated into the largest subassemblies that can be reasonably shipped and handled. However, other than the conventional steel beam and plate girder, which have been used extensively in bridge construction, the use of prefabricated steel elements has been limited. Zuk (*44*) describes a number of innovative concepts that involve the use of prefabricated steel or aluminum elements in bridges that are relocatable, such as the Bailey bridge. He concludes that the military is at the forefront of the technological development of relocatable bridges.

Prefabricated elements of steel that have been frequently used in deck replacement are steel grids (system S-6 in Appendix A) (*45*) and orthotropic steel plates (system S-8). (*46, 47*). The elements are light and easy to install and therefore lend themselves to rapid deck replacement, particularly in situations where lanes can be closed for only short periods of time. The elements are relatively expensive and must be justified on the basis of reduced dead load and rapid installation. Open steel-grid decks have a low skid resistance; the skid resistance can be improved by filling the grids with concrete or installing studs.

The replacement of the deck on the George Washington Bridge was one of the more notable examples of the use of orthotropic steel plates. The panels, which were 11 ft wide and 60 ft long (3.3 × 18 m), were prefabricated with a 1 1/2 in. (38 mm) asphaltic concrete wearing surface (*2, 48, 49*). The panels were installed at night and exemplify how the use of prefabricated elements can minimize delays and inconvenience

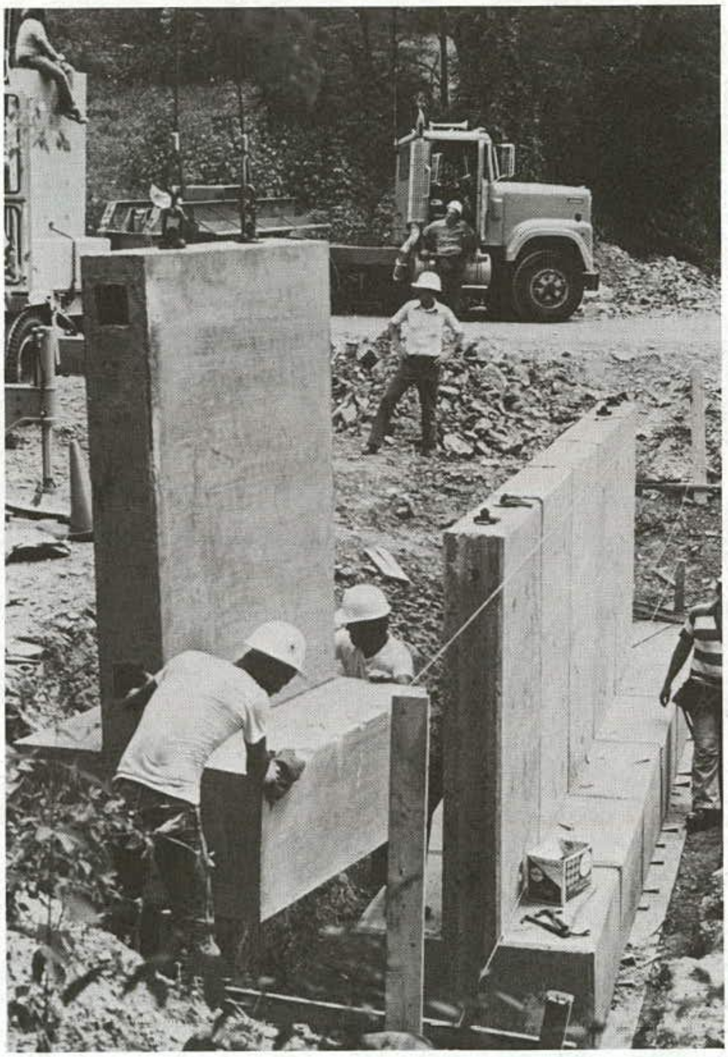


Figure 16 Maintenance crew constructs prefabricated abutment (Virginia Highway and Transportation Research Council photo).

to the traveling public (*50*). Orthotropic steel plates are currently being used to replace the deck on the Golden Gate Bridge.

Timber Elements

Glued-laminated timber beams and deck panels, illustrated in systems S-4 and T-1 of Appendix A, provide examples of innovation in the use of prefabricated timber elements. Glued-laminated (glulam) elements are preferred to solid, sawed elements because defects will be scattered and higher allowable stresses can be used in design. Elements may be laminated according to design stress so that economical, low-strength timbers can be placed in areas subject to low stress. In addition, laminated elements can be more uniformly treated with preservatives, drying shrinkage is more uniform, and elements may be fabricated to much larger dimensions than are available with solid, sawed timbers so that bridges may be assembled in a much shorter time as there are fewer elements to connect (*51–54*).

Since the late 1950s, glulam stringers and deck panels have been used on a number of bridges (*52–58*). A bridge with glulam panels on steel beams can be assembled 45% faster than one with solid, sawn plank on steel beams (see Figure 14) (*52*). The glulam elements tend to be more expensive than alternative elements in some areas (*52, 54*) but can be economical for rural bridges where precast concrete and CIP concrete is not readily available (*53*). Timber bridges are widely used on low-volume roads in the National Forests, Canada, and the western part of the United States (*53, 54, 59*). The use of prefabricated elements of glulam timber illustrates how far timber bridge construction has advanced since the early native log stringer bridges, and the use of prefabricated elements is at the heart of the innovation.

Substructure Elements

The substructure often consumes 60 to 70% of the time required to construct a bridge (*10, 37*). Significant reductions in the time required to construct a bridge may be achieved by using prefabricated elements in the substructure as well as the superstructure. Although the number of bridges built with prefabricated substructure elements is low, significant innovation has occurred in recent years (*4, 60, 61*). Systems M-1 and M-2 of Appendix A illustrate the use of precast concrete abutments

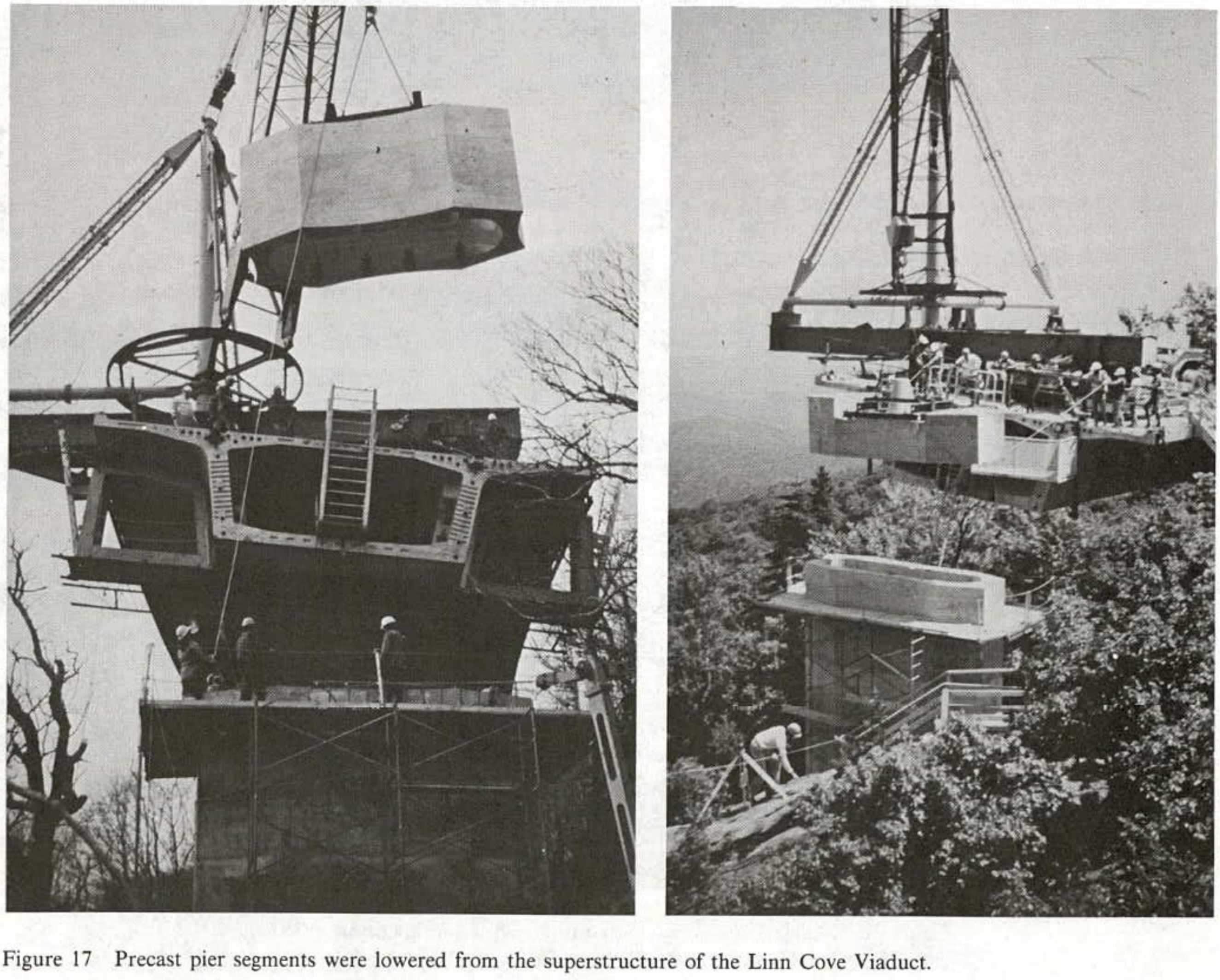


Figure 17 Precast pier segments were lowered from the superstructure of the Linn Cove Viaduct.

and wing walls and prefabricated piling, piers, and caps. Willis (*62*) reports that county crews make precast abutment and wing wall panels during off-peak winter maintenance periods.

Figure 15 shows a precast wing wall element being placed into position as part of the construction of a precast concrete arch bridge located in Edina, Minnesota (see System M-7 of Appendix A). The 40-ft (12-m) span structure has a 10-ft (3-m) rise and consists of 12 precast arch elements, 2 precast spandrel end walls, and 4 2-piece precast wing wall elements (*63*). The elements were precast by a local manufacturer, trucked to the site, and positioned on site-cast concrete footings. Grout was used to fill the voids between the footings and the precast elements and a mastic was used to seal the joints. A typical bridge can be constructed in 7 to 14 days, which includes 5 to 10 days for excavation and construction of the footings, 1 to 2 days for setting the precast arch, end wall, and wing wall elements, and 1 to 2 days for backfilling (*64*). Approximately 100 precast concrete arch bridges have been constructed in Europe since 1967 (*63, 64*) and 13 bridges have been constructed in the United States since 1981 (Personal communication, Neal FitzSimons, Engineering Counsel, Kensington, Maryland, January 19, 1984).

Hanson (*65*) and GangaRao (*66*) have presented concepts for the use of prefabricated substructure elements, but such elements have seen only limited use because typically there are so many differences between bridge sites, such as soil bearing characteristics, the location of bedrock, and depth at which acceptable bearing can be obtained, that it is difficult to standardize these elements (*67, 68*). Successful results have often been obtained by prefabricating a part but not all of the substructure. For example, a prefabricated abutment was used in a bridge in Virginia by first constructing a level surface from which to work (the footing was site-cast concrete) and then placing the prefabricated abutment elements on top of the footing (Figure 16). Portland cement mortar was placed in the keyways between the elements and between the site-cast footing and the bottom of the elements, and two post-tensioning strands were used to tie the elements together.

The construction of the Linn Cove Viaduct along the side of Grandfather Mountain in North Carolina provides a spectacular example of the successful use of prefabricated elements in the substructure. To minimize the impact on the environment of the National Park, it was necessary to construct the substructure by working from the superstructure. After the pier foundation piles were placed in holes drilled into the ground, the forms and reinforcing steel for the footing were set. The bottom precast segment of the pier was then lowered into place and supported off the ground in its final position in the forms. Concrete was then site-cast in the footing beneath the bottom segment. After the footing concrete reached sufficient strength, other precast pier segments were placed on top of each other and post-tensioned until the pier was completed (Figure 17). With the completion of a pier, additional precast superstructure box segments were progressively placed and post-tensioned as the superstructure cantilevered past the completed pier to the location of the next pier (*17*).

Almost all concepts for using prefabricated concrete elements in the substructure require the use of either portland cement grout, mortar, concrete, or post-tensioning to tie the elements together. Whereas prefabricated elements are used routinely in the construction of bridge superstructures, their use in substructures is just beginning but looks promising and should be expanded.

CHAPTER THREE

PRACTICES AND PROBLEMS IN USE OF PREFABRICATED ELEMENTS

The questionnaire distributed for this synthesis asked agencies when, where, how, and why prefabricated elements were used. It also asked about problems, both those that had been solved and those that remained.

PERIODS OF USE

Table 2 shows the results of the response to a question as to when the prefabricated elements were used. The table shows the use in the time periods before 1965, 1965 through 1974, 1975 through 1984, and the use anticipated for the next 10 years. Results are in terms of the number of agencies indicating the element was used during the periods and the percent of bridges containing the element that were constructed by those agencies.

From the table it is obvious that the use of the elements has generally increased over the years, with the use during the past 10 years about equal to or exceeding the use during the 1965 to 1974 period. It is anticipated that during the next 10 years the use of deck panels on steel stringers will increase and the use of the other elements will be equal to or slightly less than the use during the past 10 years. The exception is that in Alberta the use of the double-tee and channel has declined over the years with low use anticipated over the next 10 years; because of the large number of bridges with these members in Alberta the trend is reflected in use based on percentage of bridges. In Alberta other prefabricated elements will be used rather than the double-tee or channel. Also, based on the percentage of bridges, the use of the precast parapet anticipated for the next 10 years is low because the majority of the use was in Virginia, and the Virginia response to the questionnaire did not cite anticipated use in terms of numbers of bridges.

WHERE THE ELEMENTS ARE USED

The results of the response to a question as to where the elements are used revealed that the elements are used on all types of roadways (high- or low-volume, Interstate, primary, or secondary roadways). The slab spans and box beams were used most often on the low-volume primary and secondary roadway. The I-beams and permanent deck forms were used equally on all systems. The parapet was used more often on the Interstate system and the number of bridges with deck panels on steel stringers was too small to draw conclusions.

TABLE 2

USE OF PREFABRICATED ELEMENTS BY HIGHWAY AGENCIES DURING VARIOUS TIME PERIODS

Element	Replies	Before 1965		1965-1974		1975-1984		1985-1994	
		No.[a]	%[b]	No.	%	No.	%	No.	%[c]
Precast concrete slab span	27	15	22	20	27	20	51	18	89
Precast box beam	25	14	16	20	33	22	51	18	72
Prestressed I-beam	33	22	18	32	39	30	43	27	65
Precast deck panel	7	0	0	0	0	6	100	7	550
Permanent bridge-deck form	22	3	d	8	36	20	64	16	47
Precast parapet	9	0	0	1	10	8	90	6	17
Double-tee and channel	9	1	51	5	37	9	12	7	14

[a] Number of responding agencies that used prefabricated elements during the period.

[b] Percentage of total number of bridges containing the elements that were constructed during the period.

[c] Percentage of the 1975-1984 use expected in 1985-1994.

[d] Less than 1%.

TYPES OF USES

The results of the questionnaire revealed that the elements were used for most types of construction; for new construction, the widening of a structure, and the replacement of a structure. The box beam, I-beam, permanent deck form, parapet, and double-tee and channel beam were used most often in new construction. The slab span and deck panel on steel beams were used slightly more often in bridge replacement than in new construction.

REASONS FOR USE OF THE ELEMENTS

Table 3 shows the results of the replies to the question as to why the elements were selected for use and, as would be expected, the principal reasons were to reduce first cost and to accelerate construction. Improved quality and reduced life-cycle cost were cited on a small percentage of the replies. The slab span and box beam were also frequently selected to minimize the depth of the superstructure and thereby provide more clearance below the structure. Low first cost, minimal maintenance, and rapid construction are frequently cited in the literature as reasons for using precast prestressed concrete elements (*4, 11*).

TABLE 3

REASONS ELEMENTS ARE USED

		Replies Noting Indicated Use				
Element	Replies	Accelerate Construction	Improve Quality	Reduce First Cost	Reduce Life-Cycle Cost	Other
Precast concrete slab span	27	19	3	18	2	8
Precast box beam	26	17	4	21	2	5
Prestressed I-beam	33	13	3	26	9	5
Precast deck panel	6	4	0	2	0	0
Permanent bridge-deck form	21	15	3	19	3	3
Precast parapet	10	8	1	8	1	1
Double-tee and channel	9	8	3	5	4	3

RESOLUTION OF PROBLEMS

According to replies to the questionnaire, a number of the early problems with the use of prefabricated elements have been resolved. The replies indicated that quality control at precast plants has improved, first costs have decreased, problems caused by a lack of experience have been eliminated, and elements have become more standard. Several replies also indicated that the problem of deck deterioration and rebar corrosion in slab spans and boxes have been solved by using CIP concrete overlays, epoxy-coated rebar, and/or waterproofing membranes.

The replies to the questionnaire also revealed that some construction problems have been eliminated because of the use of prefabricated elements and these include excessive on-site construction time, excessive depth of superstructure because thinner sections can be achieved with prestress, and the need for shoring and on-site form removal.

CONTINUING PROBLEMS

Based on the replies to the questionnaire, some problems with the use of prefabricated elements have continued and therefore the elements have not been used extensively. As can be seen from Table 4, the most frequently cited continuing problem was high first cost. A high percentage of the replies indicated no continuing problems and others cited length and weight limitations, deck deterioration and corrosion, and supply. Although connections have been cited as a problem in some of the literature (*7, 11*), those responding to the questionnaire noted it was a significant problem only for the precast parapet. Other problems cited at least once in the response to the questionnaire include inability to use slab spans and I-beams in continuous spans; inability to obtain a satisfactory design for slab spans, deck panels on steel beams, and prestressed subdeck panels; camber in I-beams; fabrication difficulties with box beams; poor alignment of precast parapets; and reflective cracking, grading problems, and inability to obtain skews greater than 15° with prestressed subdeck panels. Obviously, the majority of those responding to the questionnaire believe that with the exception of high first cost there are few continuing problems with the use of most prefabricated elements. The problem of high cost can be minimized by specifying larger quantities of the elements, eliminating design details that are difficult to fabricate, and taking into account benefits, such as the savings to the motorist of reduced lane closure time and off-peak traffic construction.

TABLE 4

CONTINUING PROBLEMS

		Replies Indicating Problem					
Element	Replies	First Cost	None	Length and Weight	Deterioration and Corrosion	Supply	Keyways and Connections
Precast concrete slab span	20	10	4	2	3	2	1
Precast box beam	19	9	4	2	3	2	0
Prestressed I-beam	23	10	8	4	0	2	0
Precast deck panel	5	2	1	1	0	0	0
Permanent bridge-deck form	13	5	5	0	0	1	0
Precast parapet	6	1	1	0	1	0	5
Double-tee and channel	5	2	2	0	1	0	0

Some specific deficiencies noted in the literature are as follows. A number of states have reported problems with the placement and the long-term stability of epoxy mortar shear keys between standard PCI box beams (*11*). A deficiency with the double-tee is that the slab thickness is insufficient to adequately anchor typical bridge railings (*11*). The New York Thruway Authority has reported minor problems with the use of precast concrete deck panels, including hairline cracks in the slabs, difficulties in placing the epoxy mortar bedding between the top of stringers and the bottom of the slabs, and excessive cure times for epoxy mortar placed in cold weather (*2*). It is anticipated that improvements in quality control will likely minimize the number of cracks, the installation of neoprene strips to retain the epoxy bedding will eliminate the bedding difficulties, and the use of cold weather polymeric materials will permit installation in cold weather (*2*). A recent study in Virginia indicates that the concrete used in precast elements (with accelerated curing) is typically more permeable to chloride ions than the CIP concrete used in bridge decks (*69*). Problems that could result from the higher permeability can be minimized by applying the technology for curtailing the corrosion of the reinforcement and the deterioration of the concrete caused by freezing and thawing, which is well established for bridge decks (*70*). Alternative protective systems, such as epoxy-coated reinforcement, one of a number of waterproofing membranes or sealers of epoxy or polymer materials, and dense concrete overlays such as latex-modified concrete, can be used to extend the service life of the prefabricated elements (*69–72*). The value of sealers, membranes, and epoxy-coated reinforcement in extending the life of precast concrete elements should be studied.

CHAPTER FOUR

CONSTRUCTION AND MAINTENANCE

The principal advantage of using prefabricated bridge elements and systems 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 delays for the motorist and fewer work trips to the bridge site, and working conditions are improved because most of the construction takes place in the convenience and safety of a fabricating plant (*4, 10, 25, 37*).

Another reason for using prefabricated elements is to improve design and construction efficiency. For economy, prefabricated elements should be mass produced. Mass production requires that many elements have the same design. Sufficient quantity can be obtained by either specifying an element for a long multispan bridge or by specifying an element for many short bridges. Design costs are less when the same element is specified for many spans because one design may replace a number of individual designs. Also, forming costs are less because the same forms can be used to produce elements for many spans.

In addition, construction is more efficient when prefabricated elements are specified because fabrication can proceed in an established, repetitive, and systematic manner; fabrication can proceed in bad weather; the number of man-hours lost in traveling to and from a bridge site is reduced; concrete is sometimes cheaper, because it does not have to be hauled a long distance; and high-quality concrete is more easily obtained in a fabricating plant than at a bridge site because the plant provides for repetitive process and environmental control (*13, 37*).

The principal disadvantages in using prefabricated bridge elements are in handling the large units and making sure they fit properly.

FABRICATION OF ELEMENTS

Quality control and efficiency at the fabrication plant are probably the most essential ingredients for the successful construction of a structure containing prefabricated elements. Prefabricated elements will fit together satisfactorily in the field if they are fabricated with the tolerance prescribed by the Prestressed Concrete Institute (*73, 74*). The allowable tolerances must be obtainable with economical precasting methods; sometimes the use of CIP concrete is more practical than precasting to a close tolerance (*13, 68*). Because the major portion of the construction of a bridge containing prefabricated elements takes place in the factory, the major portion of the supervision and inspection 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. Prefabricated elements that are cast in a good set of forms and under close supervision will fit together quickly and securely in the field.

Based on results of the questionnaire, the elements are usually fabricated by a precast concrete producer (with the exception of the steel stay-in-place forms, which are fabricated by a steel fabricator). Only 24% of the replies indicated that the slab spans are occasionally fabricated by a contractor. Only 12 and 4% of the replies, respectively, noted that the slab spans and box beams were occasionally fabricated by state and local crews. Elements are usually fabricated by state and local crews during off-peak maintenance periods when there is a surplus of manpower (*37, 62*)

FORMS

Based on the questionnaire, the elements (with the exception of the precast deck panels on steel stringers) are usually fabricated in forms and casting beds that are versatile and suited to producing members for many projects (multiple-project forms). Sixty-seven percent of the replies indicated the deck panels are fabricated in special forms, but only 23% or less of the replies indicated the other elements were fabricated in special forms. Thirty-eight percent of the replies indicated the prestressed concrete subdeck panels are fabricated in more versatile forms that are suited for producing elements for use in construction other than bridges (multi-purpose forms). Fewer replies noted the multi-purpose forms were used to fabricate the other elements.

For economy it is desirable to use multiple-project forms but it is usually not possible to use multi-purpose forms for most members because the sections required for bridge construction are usually heavier than those required for other types of construction (*4*). Forms can be designed to provide members for many bridge projects by specifying the same section for many projects, which was typical when the I-beam, parapet, subdeck panel, and double-tee and channel were specified, and less typical when the slab span and box beam were specified. Forms that provide for some adjustment in either width or depth can be made without much added expense to allow the precasting of slab spans and box beams with slightly different sections. Also, most forms are suited to providing elements of various lengths.

HANDLING AND STORAGE OF ELEMENTS

Precasting operations should be organized to minimize the number of times an element must be moved (*75*). Excessive handling is not only costly and time-consuming but increases the chances for damaging an element. It is desirable to move elements from the casting bed as soon as strength requirements are satisfied so that new elements may be cast. Elements 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 elements are dictated by the size and weight of the units and the handling requirements. Care should be taken in the selection of lifting hardware and the location of lifting points to minimize handling stresses.

Elements should be stored to induce the same dead load stresses that will be encountered in the field. Elements such as slabs may be stored on top of each other to save space, and timber spacers may be placed between them directly above the timbers that support the bottom slab.

LOCATION OF PLANTS

Based on replies to the questionnaire, the plants at which the elements were fabricated were usually located between 1 and 200 miles (1.6 and 320 km) from the bridge site. Fifty percent of the replies indicated the double-tee and channel were transported more than 200 miles and a lower percentage of the replies indicated the other elements were transported more than 200 miles. Only 13% of the replies indicated the slab span and the double-tee or channel were transported less than one mile and fewer replies indicated the other elements were transported less than one mile. The response suggests that the members are usually fabricated at a permanent plant and only occasionally fabricated at a temporary plant next to the bridge. A temporary plant should be economical for precasting elements for bridges with many spans.

TRANSPORTATION OF ELEMENTS

The elements are almost always transported to the site by commercial truck. Ninety-five percent or more of the replies indicated a truck was used to transport the members. Fourteen percent of the replies indicated that the I-beam was transported by rail and 17% of the replies indicated that the deck panels were transported by barge. A lower percentage of the responses indicated that the other elements were transported by rail or barge.

The recommended practice for transporting the elements to the bridge site is to load them so that they are properly balanced on the trailer and are supported during transportation as they were during storage. Also, elements 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 (*75*). Small pieces of timber make excellent pads for distributing the forces from the chains that secure the elements to the trailer.

Elements 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 (*75*). Proper communication between the fabricator and erector is essential.

The number of elements that can be transported on a trailer is usually controlled by the weight of the elements but size can also be a factor. The roadway clearance and the capacity of structures between the bridge site and the casting yard will occasionally dictate the number of elements that can be hauled in one trip. For some bridges, the weight of the elements will be such that the use of lightweight concrete or voided material will allow one more element to be transported on each trip than if solid elements of normal-weight concrete were fabricated. Requirements may vary from state to state, and therefore the weight, length, depth, and width of the element and the need for a special permit must be considered when designing and fabricating an element (*76*).

ERECTION AND CONNECTION OF ELEMENTS

Eighty-eight to 100% (depending upon the element) of the replies to the questionnaire indicated the elements are usually installed by a contractor. However, 50% of the replies indicated that the double-tee and channel are erected by the precast concrete producer and 38% indicated that these elements are erected by state and local crews. Other elements sometimes erected by producers or state and local crews are the slab spans and box beams. Evidently, it is acceptable practice to purchase the members as delivered or as installed.

Personnel and equipment should be ready at the bridge site when the elements arrive. Lifting equipment should be secured in appropriate, predetermined locations. When possible, lifting equipment 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 lifting equipment to the site and to the most appropriate location. When lifting equipment is to be placed on a structure, the design should be checked to ensure that the structure will not be overloaded.

The lifting equipment should be large enough to handle the elements and it is better to have equipment that is too large than equipment that is too small. The boom distance, weight of the crane, weight of the elements, and crane cost should be taken into account when selecting a crane for a particular job.

Bearing areas should be properly prepared before the elements arrive. Once an element is placed, it is examined for fit. If acceptable bearing is not obtained when the element is placed, corrective measures must be taken. Neoprene bearing pads are usually adequate for providing acceptable bearing below large elements such as the I-beam. A variety of combinations of grouts and mortars of portland cement concrete, epoxy, and polymer concrete have also been used to obtain acceptable bearing for prefabricated elements. Usually temporary wooden shims or other devices must be used to support the element until the leveling mortar or grout has adequate strength. Elements that are fabricated accurately will fit together in the field easily and quickly and elements that do not bear properly will require additional time and attention. The best procedure is to try to achieve a properly prepared supporting surface and an accurately fabricated element and to be ready at the site to apply some suitable corrective measure. Typically, elements 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 elements and to otherwise connect the element into the structure (*6*). The development of high-early-strength epoxy and polymer mortars has minimized the time and problems associated with providing suitable bearing and connection between prefabricated elements.

TABLE 5

MAINTENANCE OF PREFABRICATED ELEMENTS

		Maintenance Required (No. of agencies)					
Element	Replies	None or Routine	Patching	Overlays	Joints	Connections	Other
Precast concrete slab span	20	8	5	3	3	1	4
Precast box beam	21	13	3	2	1	1	5
Prestressed I-beam	28	20	4	1	2	0	6
Precast deck panel	5	3	1	1	0	0	0
Permanent bridge-deck form	15	12	2	1	0	0	1
Precast parapet	5	4	0	0	0	1	0
Double-tee and channel	8	7	1	0	1	0	1

MAINTENANCE

Depending on the element, 83 to 100% of the replies to the questionnaire indicated that state or local forces maintain the bridges and 17 to 33% of the replies indicated maintenance is performed under contract.

Table 5 shows the replies to the questionnaire that noted that the indicated type of maintenance was performed on bridges containing the indicated element. It is apparent from the replies shown in Table 5 that bridges containing the elements are relatively maintenance free; the majority of the replies indicated that no maintenance or only routine maintenance is required. Only 25% or less of the replies, depending on the element, indicated that a particular type of maintenance was required. The most frequently cited types of maintenance were patching and maintenance of overlays and joints. Although connections are sometimes cited in the literature as a problem with prefabricated elements (*7, 11*), the response to the questionnaire did not support this conclusion.

CHAPTER FIVE

COSTS AND BENEFITS OF PREFABRICATED ELEMENTS AND SYSTEMS

CONSTRUCTION COSTS

In the responses to the questionnaire, reduced first cost was one of two principal reasons cited for the use of prefabricated elements and systems. Table 6 shows the average first cost based on the replies to questions that asked for the first cost in dollars per ft^2 of deck surface for the elements and the most frequently used alternative.

The most frequently used alternative to the box beam, I-beam, and double-tee and channel is steel beams with CIP concrete deck and, on average, the prefabricated elements cost less than the alternative. A CIP concrete superstructure costs slightly less than the box beam and I-beam and more than the double-tee and channel, but is not frequently used as an alternative evidently because it requires a larger section for the same span or because more spans are required, and consequently substructure costs are greater. A precast slab span typically costs less than a CIP slab and slightly more than steel beams and CIP concrete deck. Also, one reply indicated that a culvert costs less than a bridge with precast slabs. A CIP concrete deck on steel beams costs less than precast deck panels on steel beams, a CIP parapet costs about the same as a precast parapet, and the formwork for a CIP concrete deck costs slightly more than the cost of permanent bridge-deck forms.

Other values for first cost that were found in the literature are shown in Table 7. It is obvious from Tables 6 and 7 that the alternatives to the prefabricated elements are not necessarily cheaper or more expensive. Because of the many factors that affect first cost, either the prefabricated element or the alternative can have the lower first cost in a given situation.

Factors that affect cost include availability of one material relative to another, availability of forms and equipment for fabricating and handling one type of element relative to those for another, the qualifications and experience of the available labor force, and the characteristics desired in the finished bridge. In general, a bridge that utilizes elements that are a stock item, or can be cast in forms that are readily available and can be constructed with locally available labor, equipment, and expertise, will almost always have a lower first cost than a bridge that requires nonstandard elements, the purchase of special forms or equipment, and the use of specialized labor. Because the decision to use a prefabricated element is usually based on first cost, it is necessary to develop cost estimates for each site condition to ensure that the most economical alternative is selected; the values shown in Tables 6 and 7 are for illustrative purposes only.

Quantity can have a significant effect on cost. A precast concrete producer must foresee future demand for a prefabricated element or else will most certainly include the cost of forms in the bid for the first bridge that is advertised (*10, 78*). Consequently, the cost of the first bridge can far exceed the cost of a conventional alternative. For example, a research project by the Texas Department of Highways and Transportation developed five precast superstructure types, and arranged for the advertisement of two of them (box beam and double-tee) as alternative superstructures to a standard CIP concrete superstructure (*11*). The study concluded that the alternative superstructures with the prefabricated elements were not competitive with the standard CIP concrete superstructure because the precast producers were not willing to invest in new forms for only one job (*11*). It is likely that some transportation departments believed that prefabricated elements are more expensive than conventional bridges because they have had a similar experience. Clearly, when determining the cost of bridges with prefabricated elements that have not been previously used, the cost of the forms should be separated from the other costs so that a fair assessment of the costs of the new elements can be made. To minimize the cost of the forms for each bridge, the transportation departments should advertise a sufficient number of bridge spans with the same prefabricated element.

Other ways to minimize the cost of prefabricated elements are as follows. Use welded wire fabric rather than reinforcing bars (*11*). Work with local producers throughout the planning

TABLE 6

INSTALLED FIRST COST OF ELEMENTS AND ALTERNATIVES[a]

	Prefabricated Elements		Alternatives			
			CIP concrete		Steel Beam/ CIP Deck	
Element	Replies	Cost	Replies	Cost	Replies	Cost
Precast concrete slab span	13	26.11	5	28.69	5	25.02
Precast box beam	13	25.64	2	21.77	10	29.61
Prestressed I-beam	18	21.11	3	20.87	14	24.87
Precast deck panel	3	19.34	4	17.89	-	-
Permanent bridge-deck form	4	3.00	5	3.50	-	-
Precast parapet	3	2.67	4	2.54	-	-
Double-tee and channel	4	19.30	1	24.81	2	27.27

[a] $\$/\text{ft}^2$ of deck surface; based on 1984 survey.

stage, advertise a large number of identical spans, avoid diaphragms and other projections from the elements, avoid skews (limit the skew to 30° or less), avoid special details, minimize the quantity of reinforcing steel, and specify elastomeric bearing pads (*4*).

MAINTENANCE COSTS

Those responding to the questionnaire seldom provided estimates for life-cycle cost and maintenance cost and the few replies that were received seemed to indicate that maintenance costs were negligible for properly constructed structures, whether prefabricated or not, and therefore the life-cycle costs were the same as the first costs. The response from the Minnesota DOT indicated the life-cycle cost was 20% greater than the first cost for a concrete deck on steel beams and 5% greater for concrete deck on prestressed I-beams. Evidently 5% is for routine maintenance and 15% is for repainting the steel beams (*4*). Based on the response to the questionnaire, life-cycle costs and maintenance costs are not a factor in the selection of alternatives and all alternatives are considered to have a long life with near zero maintenance despite the fact that some maintenance, as cited in Chapter 4, is required for bridges containing all types of elements. Alexander (*79*) warns that it is possible to spend more on first cost than will ever be recovered in reduced maintenance costs. Bridges on low-volume roads should be designed to minimize first cost rather than maintenance cost, and bridges on high-volume roads should be designed to minimize maintenance so that it does not interfere with traffic. Clearly research should be directed at the development of estimates for maintenance cost and service life for all types of bridges, and bridge engineers should choose between alternatives based on life-cycle costs rather than first costs.

REDUCED CONSTRUCTION TIME

In the response to the questionnaire, a principal reason cited for the use of prefabricated elements and systems was to accelerate construction. However, almost no quantitative response was made to the question, "What is the lane closure time per square foot of deck surface for the installation of the elements and the alternatives?" Evidently, because of the many factors that affect construction time, it is difficult to provide estimates that would be applicable to the general case, but it should be possible to develop estimates for specific site conditions. Obviously there is strong feeling by the users of the prefabricated elements and systems that on-site construction time is less, but it would be helpful to direct research at the development of estimates. The information should be helpful when considering the use of alternative elements in the construction and replacement of bridges.

The response from the Kentucky DOT indicated that bridges with the precast slab spans, box beams, and I-beams could be constructed with 17% of the lane closure time required for bridges requiring CIP concrete. The Minnesota DOT noted that bridges with precast slab spans could be constructed with half the lane closure time required for bridges with CIP concrete decks. The New York DOT noted that less lane closure time was required for bridges with precast slab spans and box beams. The Wyoming DOT indicated that the same time was required for all bridges because a CIP substructure was used with all bridges. Alberta indicated a culvert bridge could be opened to traffic in 60% of the time required for a bridge with precast slab spans because a CIP substructure was required to support the slabs. The replies to the questionnaire somewhat support the theory that lane closure time can be reduced through the use of prefabricated elements.

Additional evidence is provided by the case studies of on-site construction time that were noted from the literature. For example, in Virginia state forces were able to install a precast slab span superstructure in 13% of the on-site time required for a CIP concrete superstructure and 24% of the on-site time required for a superstructure of steel stringers and timber plank deck (*6*). Similarly, it was estimated that in Virginia, a concrete deck on steel beams could be replaced with precast concrete deck panels in 21% of the on-site time required for a CIP concrete deck (*24*). Similarly, Berger (*25*) estimates that precast concrete deck panels can be installed in 26% of the time required for CIP concrete. Use of the prestressed subdeck panels on a new four-span prestressed concrete I-beam bridge in Indiana allowed the contractor to complete the job six weeks ahead of schedule (*28*).

On-site construction time and cost, the two principal reasons prefabricated elements are used, are somewhat interdependent. Construction can be accelerated by providing a cost incentive for rapid construction and a penalty for delays in situations where the contractor would otherwise not benefit economically by accelerating construction. For example, a small contractor, in particular, might have a considerable increase in overhead cost to accelerate construction because more investment in manpower and equipment would likely be required. Unless daily operating costs for items such as traffic control are adequate incentive to promote accelerated construction, it is likely that an incentive in the form of a bonus or penalty will be required to achieve a more rapid rate of construction.

An incentive of $5,000 per day, up to a maximum of 100 calendar days, was offered for early completion of the renovation of the Third Avenue Bridge over the Mississippi River and the work was completed almost one year ahead of schedule (*80*). Similarly, the contract for the rehabilitation of the deck of the Woodrow Wilson Bridge contained a clause that provided a bonus for each day the deck work was completed ahead of schedule and the work was completed seven months ahead of schedule (*17, 23, 27*). A number of DOTs have used incentives to accelerate repairs (*81, 82*).

VALUE TO TRAVELING PUBLIC

The traveling public is inconvenienced by almost any lane closure. The magnitude of the inconvenience is a function of the volume of traffic and the traffic capacity of the bridge being restricted, or the location of an alternative route and the volume of traffic and capacity of the alternative route (*22*). The higher the volume-to-capacity ratio, the greater the chance a motorist will be delayed. For example, an increase in the volume-to-capacity ratio from 0.5 to 1.0 can cause a decrease in the average speed of the motorist from 53 mph to 32 mph (85 to 51 km/h) (*83*). This could occur if one of two lanes of a bridge is closed or if one of two bridges is closed for construction and repair. The motorist can also be delayed if forced to take an

TABLE 7

LITERATURE SURVEY OF INSTALLED FIRST COST OF PREFABRICATED ELEMENTS AND ALTERNATIVES[a]

	Item Used for Cost Estimate and Source					
Element or alternative	Element (10)	Super-structure (9)	Element (11)	Super-structure (77)	Deck (24)	Deck (25)
Precast concrete slab span	-	9.39	-	-	-	-
Precast box beam	7.12	-	16.33	7.35	-	-
Prestressed I-beam	5.37	-	-	6.87	-	-
Precast deck panel	-	-	-	-	11.01	13.97
Permanent bridge-deck form	3.14	-	-	-	-	-
Precast parapet	2.42	-	-	-	-	-
Double-tee and channel	7.89	-	15.58	-	-	-
Single-tee	8.78	-	-	6.41	-	-
Cast-in-place deck	-	13.30	11.71	-	10.03	15.90
Steel beam with CIP deck	-	-	-	9.15	-	-

[a] $\$/ft^2$ of deck surface.

alternative route that is longer. Obviously, if travel time is assigned a dollar value, the use of prefabricated elements that reduce lane closure time would result in savings to the traveling public.

As an example of the magnitude of the dollar value to the traveling public, consider the replacement of a concrete deck with precast concrete deck panels as compared to CIP concrete. Assuming a lane closure during the day causes an average decrease in speed of 21 mph (34 km/h) over a 10-mile (16-km) segment of roadway, an average wage rate of $1 per hour per vehicle, and a traffic volume of 1,300 vehicles per hour, the cost of the reduction in speed is $161 per hour. The precast panels can be installed at night and opened to traffic in the day; therefore, the cost of the lane closure is negligible because it occurs when the traffic-to-capacity ratio is low. On the other hand the use of CIP concrete requires forming, rebar installation, concrete placement, and curing of the concrete to obtain sufficient strength. Even with the use of high-early-strength concrete mixtures, it is unlikely the lane could be opened to traffic in one day. If it is assumed that the delays associated with the lane closure last for 8 hours each day and 10 days are required to replace a deck 40 by 350 ft (12 × 107 m), the cost to the motorist is $12,880 or $0.92/ft^2 ($10/m^2) of deck surface. An increase in the average wage rate to $3 per hour per vehicle increases the cost to $2.76/ft^2 ($30/m^2).

The cost to the motorist would increase with increases in the number of days of lane closure, the volume of traffic, and the dollar value placed on driving time. Only a few examples of the dollar value to the traveling public of reduced lane closure time could be found in the literature (*72, 80, 84*). Research should be directed at quantifying the value to the traveling public of reduced lane closure time that results from the use of prefabricated elements and systems.

In many situations a lane closure during peak-hour traffic periods is out of the question because of the reduction in level of service owing to the inconvenience to the traveling public that would result. For example, in the replacement of the deck of the Woodrow Wilson Bridge, a lane closure during peak-hour traffic periods would require the motorist to choose between a major reduction in travel speed across the bridge or driving an extra 13 miles (21 km) or more over an alternative route that did not have the capacity to carry additional vehicles (*17, 27*). Most public agencies plan repairs to avoid this reduction in level of service to the public. A temporary bridge or ferry service would have been economically unfeasible. The deck replacement had to be done in stages that were restricted to the duration of the off-peak traffic period. The replacement of the deck of the Woodrow Wilson Bridge illustrates one of the principal benefits to be obtained from the use of prefabricated elements—the ability to construct or replace in stages. Most prefabricated elements (slab spans, box beams, deck panels, parapets, etc.) are suited for stage construction or construction during off-peak traffic periods. Research should be conducted to quantify the value to the traveling public of the stage construction that can be accomplished with prefabricated elements and systems.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Approximately 15% of the bridges in the United States and Alberta contain prefabricated elements and systems. The most frequently used elements are the prestressed concrete I-beam, precast and prestressed box beam, precast and prestressed and channel, and precast slab span. In recent years, steel stay-in-place forms, prestressed concrete subdeck panels, and the precast parapet have been used on a large number of bridges, and the decks of a small number of bridges with steel stringers have been replaced with precast deck panels.

The use of prefabricated elements has increased over the years and this trend is likely to continue. The elements are used on all types of roadways but the slab span and box beam are used most frequently on low-volume roads. The elements are used in new construction and in bridge replacement. The primary reasons the elements are used is to reduce first cost and to accelerate construction.

The elements are usually fabricated in forms that are suited for producing elements for many bridge spans. The elements are usually fabricated by a precast concrete producer and the precast plant is usually located within 200 miles (320 km) of the bridge site. The elements are usually transported by commercial truck and erected by a contractor. Sometimes the precast slab spans, and occasionally the other elements, are fabricated by a contractor or erected by the precast concrete producer. Also, state and local crews will occasionally fabricate and erect the elements, particularly the precast slab spans and box beams. Bridges containing the elements have required very little maintenance and that which was needed was usually done by state and local forces. The use of overlays, waterproof membranes, and sealers may have contributed to the low maintenance cost.

The cost of bridges containing the elements is usually not significantly different from the cost of alternative types of bridges and can be a function of local supply and demand.

On-site construction time can be significantly less for bridges containing the elements. Precast slab spans and box beam superstructures can be constructed in approximately 20% of the time required for CIP concrete superstructures. On-site construction time can be significantly affected by the procedures and decisions of the contractor and therefore a cost incentive may be needed to reduce on-site construction time.

Early problems with the use of prefabricated elements were usually caused by a lack of quality control and experience and have been largely eliminated. The most significant continuing problem is high first cost in some locations. The cost is usually a function of local supply and demand. By placing a dollar value on driving time, a higher cost can be justified on bridges subjected to high volumes of traffic because of the reduced lane closure time that can be achieved with prefabricated elements and because the prefabricated elements allow for stage construction and can be installed during off-peak traffic periods.

RECOMMENDATIONS

Special attention should be directed toward the resolution of the continuing problems cited in Chapter 3. Use of prefabricated elements and systems should be continued when cost savings can be achieved. The potential of prefabricated substructure elements should be developed. Research should be directed at the development of cost estimates for the value of the reduced lane closure time that can be achieved and the value of off-peak traffic period stage construction that can be accomplished when bridges are rehabilitated with prefabricated elements. Also, estimates for service life, first cost, and maintenance cost should be developed and bridge engineers should base decisions on the use of the elements on life-cycle costs, the value of lane closure time, and the value of the stage construction that can be accomplished. The role of sealers and epoxy-coated reinforcement in extending the life of prefabricated concrete elements should be evaluated.

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APPENDIX A

PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS

System	Description	Figure No.
C-Series - Concrete Structures		
C-1	Precast Concrete Slab Span	1
C-2	Precast Box Beam	2
C-3	Double-Tee and Channnel Beam	3
C-4	Inverted Channel Beam	4
C-5	Multistemmed Beam	5
C-6	Prestressed Single-Tee	6
C-7	Prestressed Bulb-Tee	7
C-8	Prestressed I-Beam	8
C-9	Short-Span Segmental Construction	47, 48
S-Series - Steel Structures		
S-1	Prefabricated Steel Bridges	9, 10, 11, 12
S-2	Temporary Bridges	13
S-3	Precast Deck Panel	14, 15, 16
S-4	Laminated Timber Deck on Steel Beams	17
S-5	Timber Plank Deck on Steel Beams	18
S-6	Steel Grid Deck on Steel Beams	19
S-7	Bituminous Concrete Deck on Steel Planks	20
S-8	Orthotropic Steel Plate Deck	21
S-9	Site-Cast Deck on Steel Beams	22
T-Series - Timber Structures		
T-1	Glued-Laminated Timber	23, 24, 25, 26
T-2	Nail Laminated Timber	27
T-3	Solid Sawn Timber Beams	28
T-4	Plywood Deck Surface	29
M-Series - Miscellaneous Bridge Elements		
M-1	Precast Abutment and Wingwall	30
M-2	Pile Substructures	31, 32, 33
M-3	Span-Shortening Substructures	34
M-4	Permanent Bridge-Deck Forms	35, 36, 37
M-5	Parapet and Rail Systems	38, 39, 40, 41, 42
M-6	Long-Span, Corrugated-Metal, Buried Conduits	43
M-7	Precast Concrete Arch Bridge	44
M-8	Single and Multiple Culverts of Aluminum, Concrete, and Steel	45
M-9	Field-Connected Beams	46

NAME OF SYSTEM:

PRECAST CONCRETE SLAB SPAN

SYSTEM NUMBER

C-1

PAGE 1 OF 2

DESCRIPTION

Precast and/or prestressed slabs. Solid or with voids.

PROMINENT FEATURES:

Slabs are modular and therefore precast in various lengths and widths to accommodate a range of spans and roadway widths. Solid slabs are frequently used for spans up to 30 ft. but prestressed or voided slabs are commonly used for longer spans. Slabs are very easy to transport and erect. Shear transfer between slabs is usually provided by a grouted keyway, weld plates, or tie rods placed in the transverse direction. See Figure 1. A wearing surface may be used.

Special consideration should be given to the connection details since premature cracking in the wearing surface and early failures of the system have been attributed to keyway and weld plate failures.

CASE EXAMPLES:

Widely used for short spans. Case examples can be found in many states including Arkansas, Louisiana, Mississippi, Virginia, West Virginia, and South Carolina.

MANUFACTURERS:

Most precast concrete plants should be properly equipped for production.

REFERENCES:

Prestressed Concrete Institute (Reference 1)
Louisiana Department of Highways (Reference 2)
Federal Highway Administration (Reference 3)

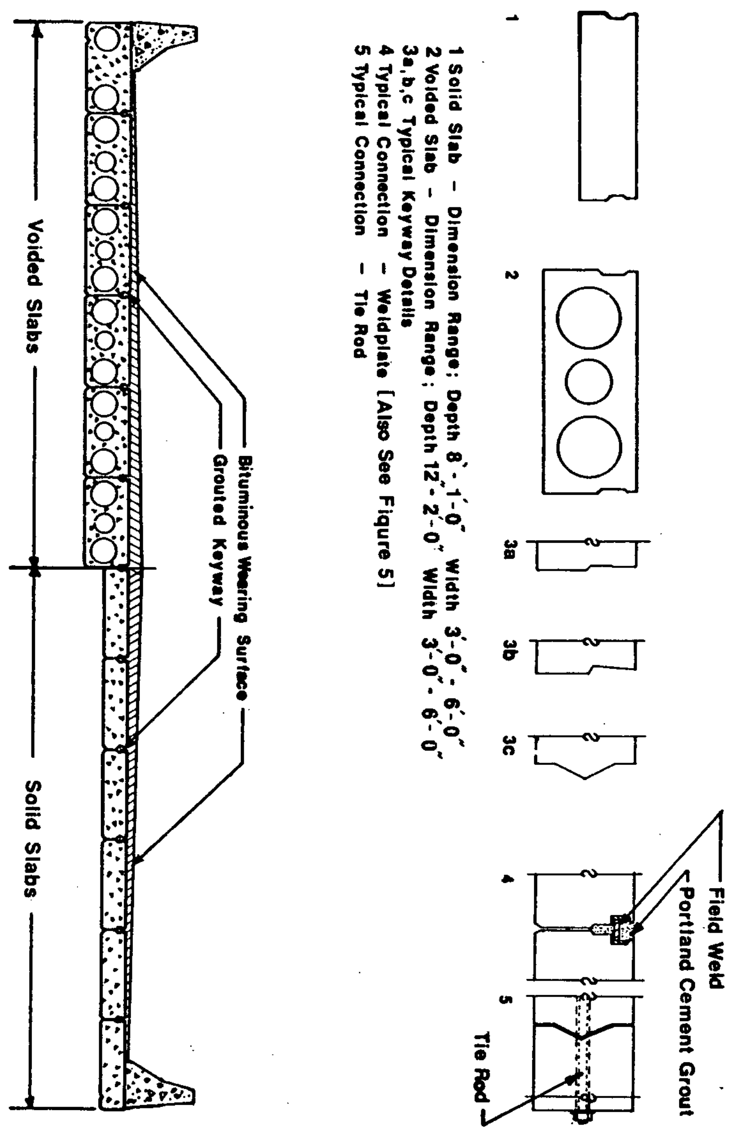


FIGURE 1. PRECAST CONCRETE SLAB SPAN

SYSTEM NUMBER C1

PAGE 2 OF 2

NAME OF SYSTEM: PRECAST BOX BEAM	SYSTEM NUMBER C-2
	PAGE 1 OF 2

DESCRIPTION:
Precast, pretensioned or posttensioned box beams with or without wearing surface.

PROMINENT FEATURES:
Boxes are modular and therefore may be precast in various lengths and widths to accommodate a range of spans and roadway widths. Box beams are generally used for spans of approximately 50 to 100 ft. Except for the longer spans, the boxes are very easy to transport and erect. Box beams which are placed adjacent to each other are usually connected in the same way slabs are connected. See System Number C-1. Box beams which are spaced apart (spread boxes) are tied together with diaphragms and a cast-in-place concrete overlay is added. A wearing surface may be used with the box beams. See Figure 2.

CASE EXAMPLES:
Widely used.

MANUFACTURERS:
Most prestressed concrete plants should be properly equipped for production.

REFERENCES:
Prestressed Concrete Institute (Reference 1)
Federal Highway Administration (Reference 3)
Virginia Prestressed Concrete Association (Reference 4)
Public Works (Reference 5)

SYSTEM NUMBER C2
PAGE 2 OF 2

1 Typical Box Beam – Dimension Range; Depth 2′ - 3′-6″ Width 3′ - 6′
2 Typical Longitudinal Section
3 Typical Keyway Detail

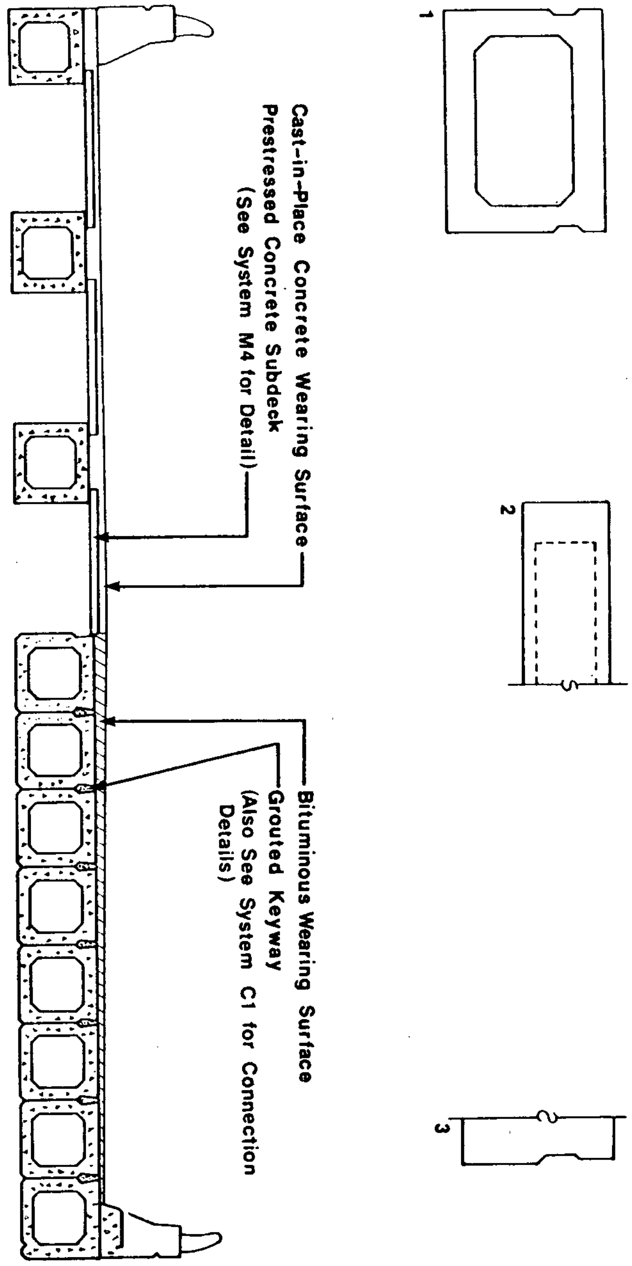


FIGURE 2. PRECAST BOX BEAM

NAME OF SYSTEM: DOUBLE-TEE AND CHANNEL BEAM	SYSTEM NUMBER C-3
	PAGE 1 OF 2

DESCRIPTION:

Precast, prestressed or posttensioned double-tee and channel beams.

PROMINENT FEATURES:

Forms are usually available at most prestress plants in several standard sizes to allow the production of beams for a range of span lengths. However, forms may not be available which are suitable for the fabrication of members which are heavy enough for bridge loadings. Post-tensioned beams may be fabricated at the bridge site or at a precasting plant. Channels are usually fabricated in double-tee forms by blocking off a portion of the exterior flanges. Both the channel and double tee may be fabricated for use with or without a topping. Both members are among the easiest to transport and erect. The members are typically used for spans of 20 ft. to 60 ft. Shear transfer between the beams may be achieved through the use of grouted keyways, transverse tie rods or weld plates.

CASE EXAMPLES:

Double tees have been used in California, Nebraska, Colorado, Washington, Idaho, Montana and several other states. Channel beams have been used in Mississippi, Arkansas, North Carolina, Kentucky, and several other states.

MANUFACTURERS:

If forms are available, most prestressed concrete plants should be capable of producing the members.

REFERENCES:

Virginia Prestressed Concrete Association (Reference 4)
Prestressed Concrete of Colorado (Reference 6)
Choctaw, Inc. (Reference 7)
Central Premix (Reference 8)
Mississippi Highway Department (Reference 9)
Kentucky Department of Transportation (Reference 10)

SYSTEM NUMBER C 3
PAGE 2 OF 2

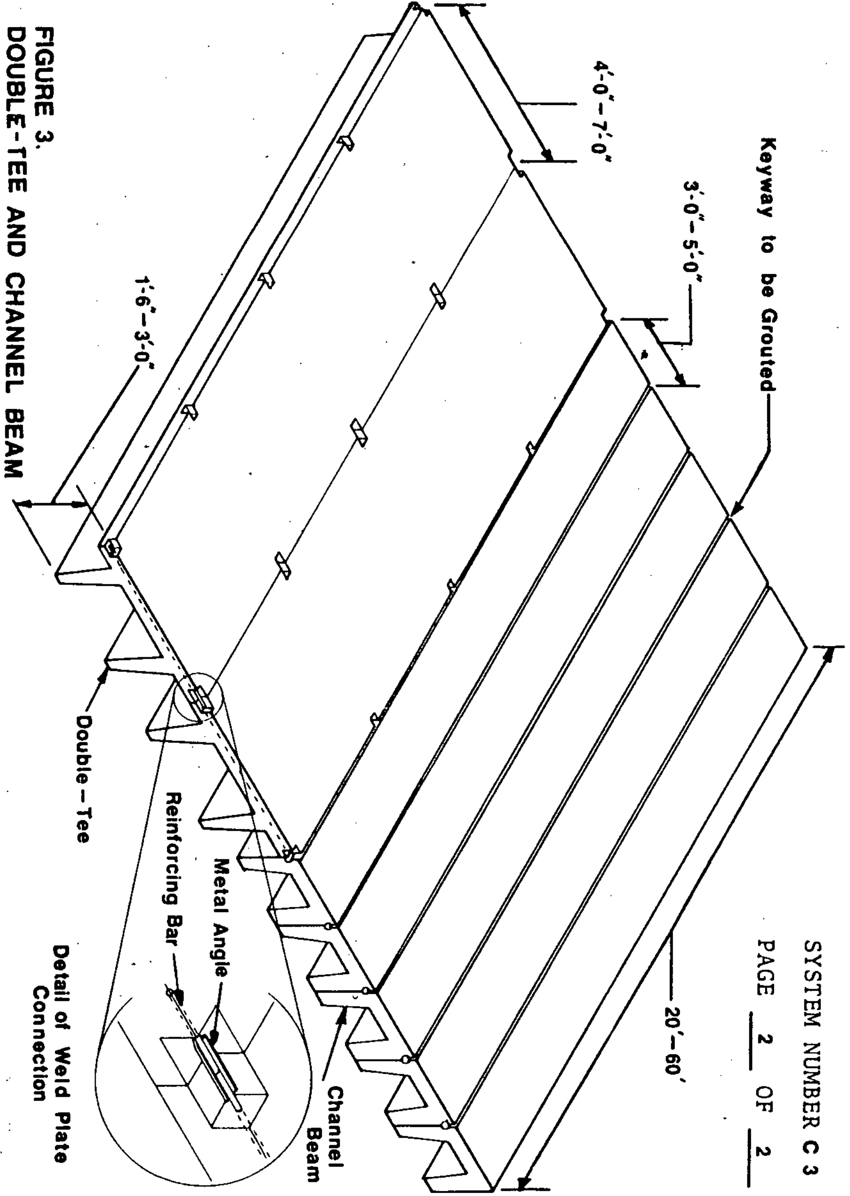


FIGURE 3.
DOUBLE-TEE AND CHANNEL BEAM

NAME OF SYSTEM:

INVERTED CHANNEL BEAM

SYSTEM NUMBER
C-4

PAGE 1 OF 2

DESCRIPTION:

Prestressed, inverted channel beams with cast-in-place concrete deck.

PROMINENT FEATURES:

Prestressed channel members may be precast in conventional or inverted position and in various lengths and depths to accommodate a range of spans between 30 and 80 ft. If precast in conventional position, the beams must be turned over before they are erected at the bridge site. A voided box beam is achieved by arching corrugated steel forms between the upright legs of the channel. The channels are tied together and the superstructure is completed with the installation of the cast-in-place concrete deck.

A precast trapezoidal beam which is reported to be economical for spans of 100 to 150 ft. has been developed in Ontario. The trapezoidal beam bridge is similar to the inverted channel beam bridge with the exception that the legs of the trapezoidal beam are slanted rather than vertical and the beams are much heavier than channel beams.

CASE EXAMPLES:

Several prototype inverted channel structures have been constructed in Missouri and trapezoidal beam bridges have been constructed in Canada.

MANUFACTURERS:

Ontario Precast Concrete Manufacturers Association
Local precast, prestressed concrete producers

REFERENCES:

Salmons, John R. (Reference 11)
Salmons, John R. (Reference 12)
Nairn, R. D. (Reference 13)

SYSTEM NUMBER C4
PAGE 2 OF 2

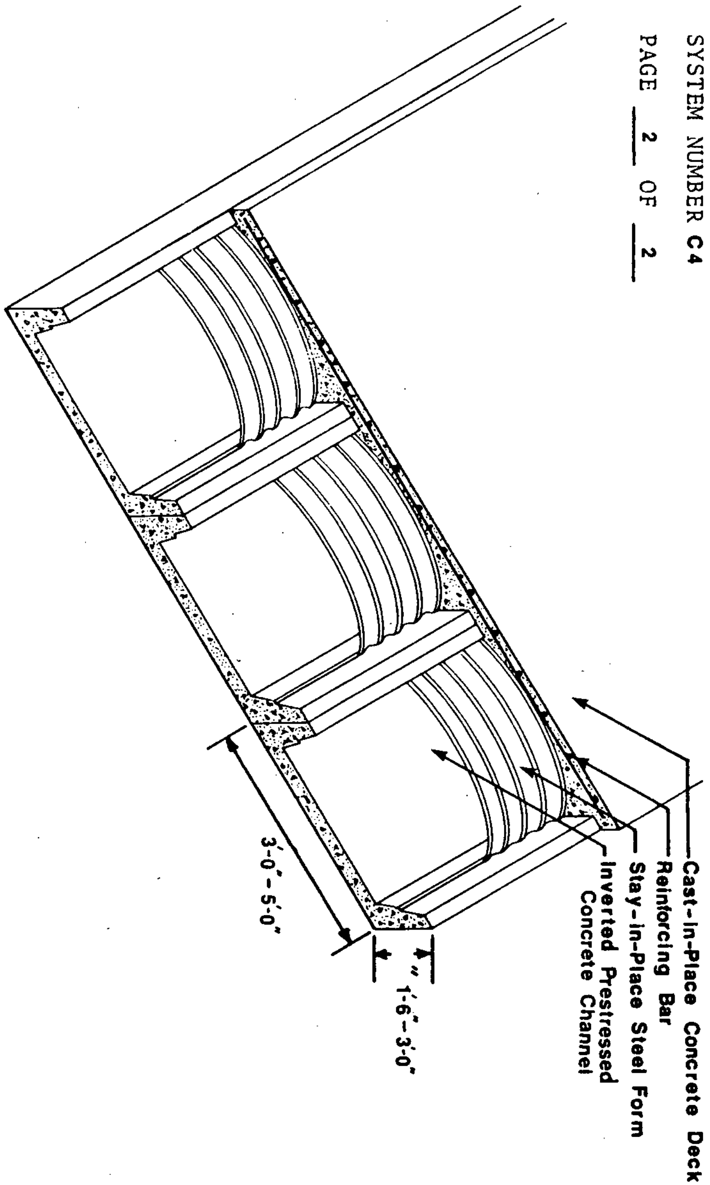


FIGURE 4. INVERTED CHANNEL BEAM

NAME OF SYSTEM:

MULTISTEMMED BEAM

SYSTEM NUMBER

C-5

PAGE 1 OF 2

DESCRIPTION:

Precast, prestressed multistemmed beams.

PROMINENT FEATURES:

Multistemmed beams are modular and therefore easily precast in various lengths and increments of width to accommodate a range of spans and roadway widths. The members are most suitable for spans of 25 ft. to 50 ft. The shape is particularly suited for low depth-to-span ratio installations. Shear transfer between the modular units is usually achieved with a grouted keyway and weld plates.

CASE EXAMPLES:

Several bridges have been constructed in the northwestern states.

MANUFACTURERS:

Central Premix Concrete Company of Spokane, Washington. If forms are available, most prestressed concrete producers should be capable of producing the member.

REFERENCES:

Prestressed Concrete Institute (Reference 1)
"Instant Bridges" (Reference 8)

SYSTEM NUMBER **C 5**

PAGE **2** OF **2**

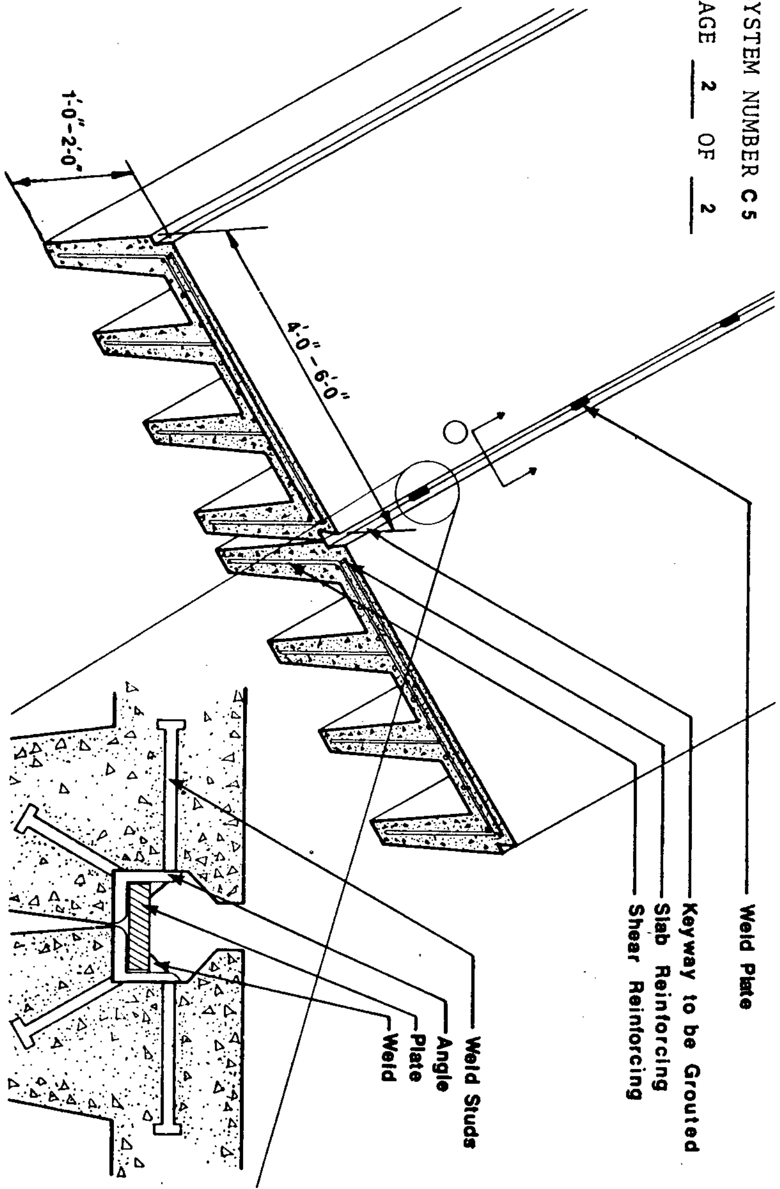


FIGURE 5. MULTISTEMMED BEAM

NAME OF SYSTEM:

PRESTRESSED SINGLE-TEE

SYSTEM NUMBER

C-6

PAGE 1 OF 2

DESCRIPTION:

Precast, prestressed single-tee beam.

PROMINENT FEATURES:

Single-tee beams are modular and therefore easily precast in various lengths, widths and depths to accommodate a range of spans and roadway widths. Single-tee beams are customarily used for spans between 30 ft. to 80 ft.; however, spans up to 130 ft. have been constructed. Transportation and erection difficulties may occur with longer spans. Temporary bracing is required during transportation and erection because of the unstable nature of the beam. Single-tee beams may be connected in several ways, but shear transfer between the tee beams is usually achieved through the use of grouted keyways and transverse tie rods or weld plates. End diaphragms and a cast-in-place concrete topping are also generally used in single-tee construction. When the full deck thickness is included in the tee flange, a bituminous surface is usually used as a leveling course.

CASE EXAMPLES:

Single-tee beams have been used in Washington, Connecticut, Virginia, West Virginia, Idaho, Montana and a number of other states.

MANUFACTURERS:

If forms are available, most prestressed concrete plants should be capable of producing the members.

REFERENCES:

Prestressed Concrete Institute (Reference 1)
Prestressed Concrete of Colorado (Reference 6)
"Instant Bridges" (Reference 8)
Virginia Department of Highways & Transportation (Reference 14)
Curtis, Robert B. (Reference 15)
Sprinkel, Michael M. (Reference 16)

SYSTEM NUMBER **C 6**

PAGE 2 OF 2

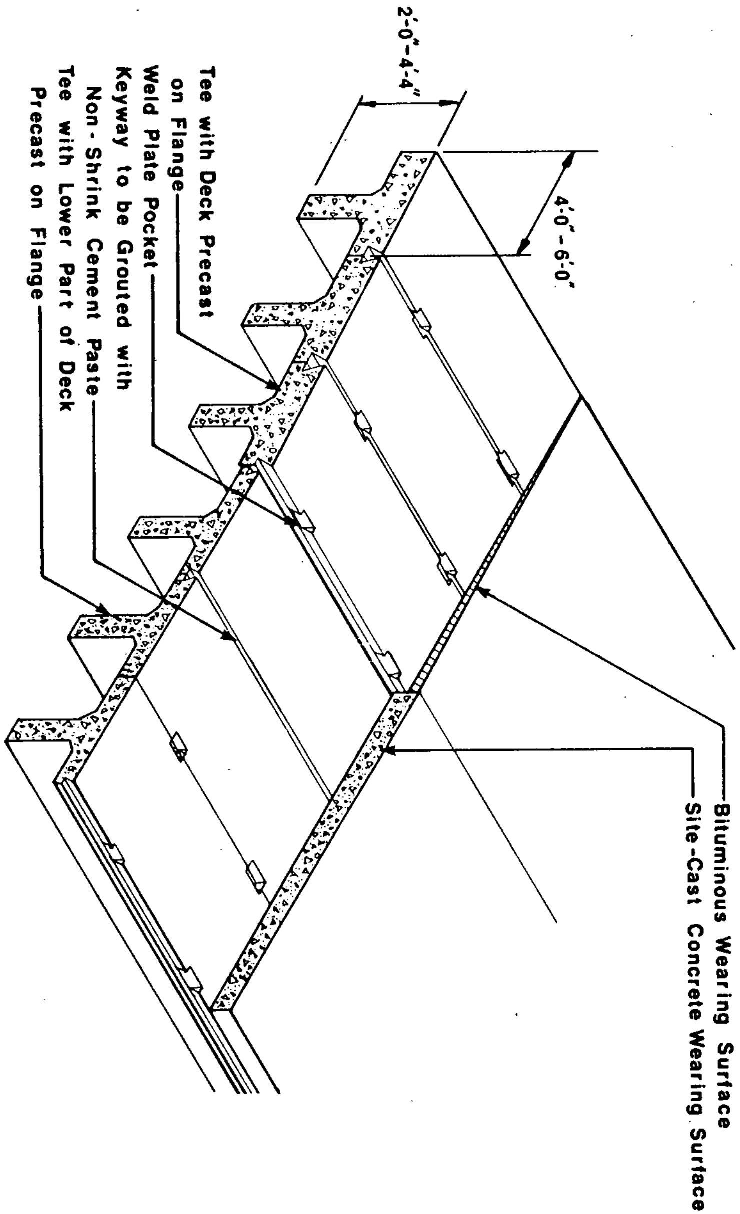


FIGURE 6. PRESTRESSED SINGLE-TEE

NAME OF SYSTEM: PRESTRESSED BULB-TEE	SYSTEM NUMBER C-7
	PAGE 1 OF 2

DESCRIPTION:

Precast, prestressed bulb-tee beams.

PROMINENT FEATURES:

Bulb-tee beams have a high section modulus-to-weight ratio and therefore are economical for longer spans and for precasting the deck on the beams. A curb is often precast on the exterior beam. The bulb tee is popular in the Northwest United States where it is commonly used for spans of 60 ft. to 80 ft. However, spans of up to 160 ft. have been reported in the literature. Special consideration must be given to transporting and erecting the larger beams. The beams are usually connected with weld plates and grouted keyways. As indicated by Figure 7 , the depth of the web and the width of the flange may be varied to provide the most economical beam for a given span.

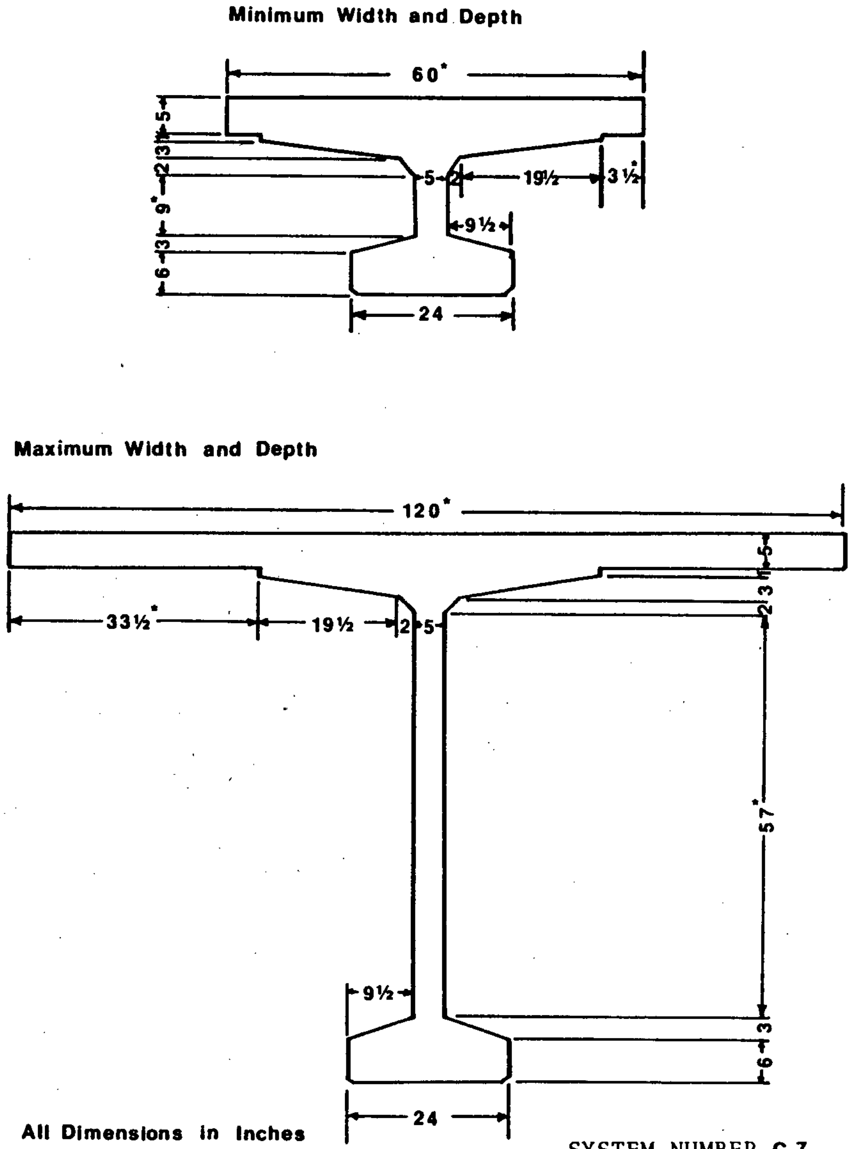
CASE EXAMPLES:

Many bridges have been constructed in Idaho, Washington and Montana.

MANUFACTURERS:

Concrete Technology, Central Premix, Ready-to-Pour Concrete, and other plants in the Northwest United States.

REFERENCES: Prestressed Concrete Institute (Reference 1)
"Instant Bridges" (Reference 8)
Anderson, Arthur R. (Reference 17)
"RTP Markets Instant Bridges" (Reference 18)
Prestressed Concrete Institute (Reference 19)



All Dimensions in Inches
*Variable Dimension

FIGURE 7. PRESTRESSED BULB-TEE

SYSTEM NUMBER C 7

PAGE 2 OF 2

NAME OF SYSTEM:	SYSTEM NUMBER
PRESTRESSED I-BEAM	C-8
	PAGE 1 OF 2

DESCRIPTION:

Precast, prestressed I-beams with cast-in-place concrete deck.

PROMINENT FEATURES:

The precast, prestressed I-beam is widely used since forms for precasting the member are readily available. The beams are usually used for spans of 40 ft. to 100 ft., but spans up to 140 ft. are reported in the literature. Because of the shape of the beam a cast-in-place concrete deck must be used. Although most decks are constructed with removable forms, the current trend is toward the use of permanent steel or prestressed concrete forms. See System M-4. Construction time and safety are improved through the use of permanent forms. Because of the large amount of cast-in-place concrete required, other systems better lend themselves to rapid bridge replacement.

CASE EXAMPLES:

Numerous examples can be found throughout the United States.

MANUFACTURERS:

Most producers of prestressed concrete.

REFERENCES: Federal Highway Administration (Reference 3)
Virginia Prestressed Concrete Association (Reference 4)
Anderson, Arthur R. (Reference 17)
Engineering News-Record (Reference 20)

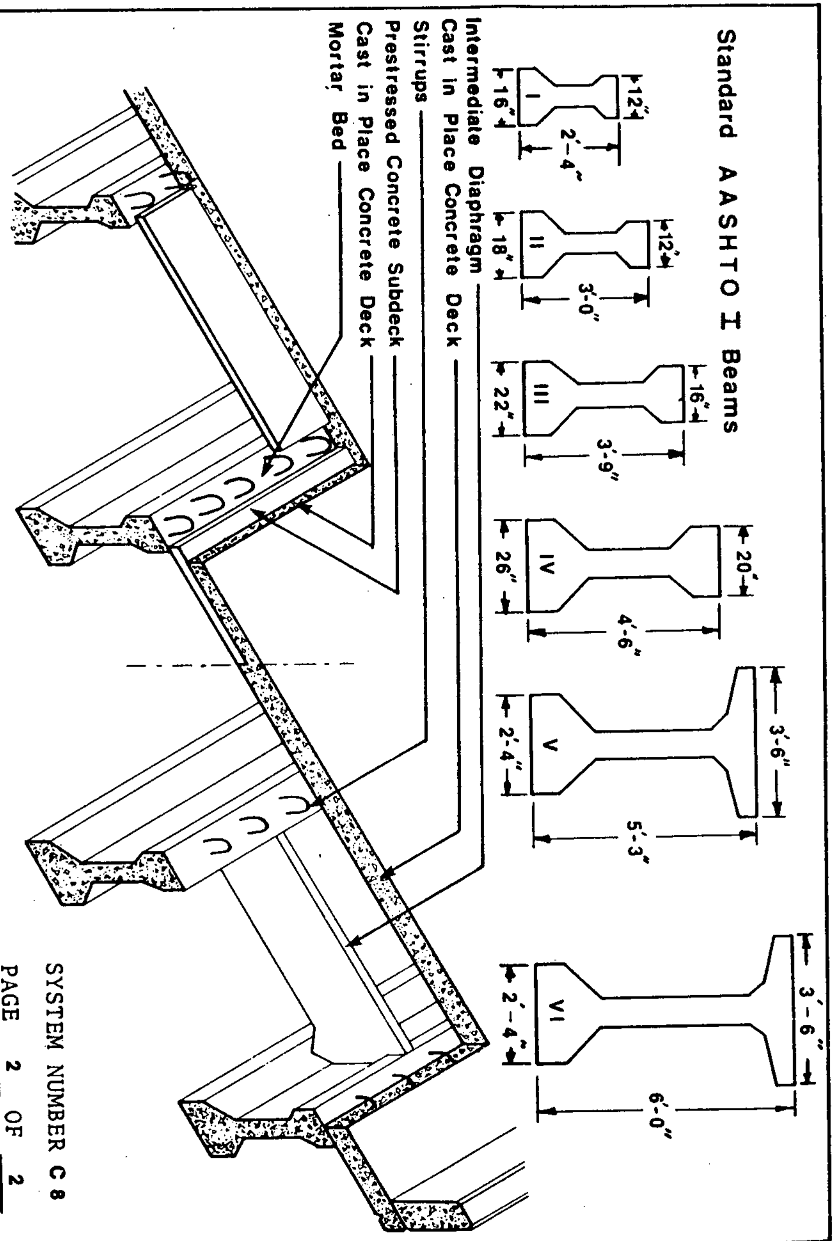


FIGURE 8. PRESTRESSED I-BEAM

SYSTEM NUMBER C 8
PAGE 2 OF 2

NAME OF SYSTEM: PREFABRICATED STEEL BRIDGES	SYSTEM NUMBER S-1
	PAGE 1 OF 6

DESCRIPTION:

Standard prefabricated steel superstructure components are connected and topped with a wearing surface to provide a fast-assembly bridge.

PROMINENT FEATURES:

Typically an orthotropic deck is prefabricated as an integral part of a standard steel superstructure component. The standard superstructure components are transported to the bridge site, connected together and covered with a wearing surface to provide a fast-assembly bridge. Several types of systems are available.

One system consists of prefabricated T-shaped units which are bolted together at the site. The units are 80 ft. long and 6 ft. wide and are suitable for multiple span situations requiring spans of 50 to 110 ft. See Figure 9.(21)

Another system consists of prefabricated rectangular units which are usually bolted together at the site. Four standard units are available which are interchangeable so that many site conditions can be accommodated. Two of the units are shown in Figure 10. One is a two-web main girder unit, and the other is a one-web unit which can be bolted to either side of a main girder unit or to another one-web unit to provide a range of roadway widths. The other two standard units are identical to the ones shown in Figure 10 with the exception that their length is only 19'-8" and their webs are tapered from a depth of 39-1/2" at one end to 19-3/4" at the other end.(22)

A third system is made up of prefabricated units which consist of several plate girders or rolled sections which are topped with steel bridge plank. The modular units with the plate girders can be used for spans up to 100 ft. and the units with the rolled sections are suited for spans up to 50 ft. See Figure 11.(23)

A fourth system consists of steel girders and a treated timber deck. Each prefabricated unit supports one line of wheels and the units are connected with diaphragms which are bolted to the units. The structures are presently designed for off-highway logging loadings and the typical span range is 30 to 80 feet. See Figure 12.(24)

Manufacturers who are known to have supplied these steel bridges are indicated below but it is likely that in most instances a local steel fabricator could supply comparable prefabricated units.

NAME OF SYSTEM: PREFABRICATED STEEL BRIDGES	SYSTEM NUMBER S-1
	PAGE 2 OF 6

CASE EXAMPLES:

Tee-shaped units fabricated by Nobels-Kline have been used in South America and Europe and are available in the United States. Rectangular units fabricated by Krupp Company have been used in Germany. Units consisting of bridge plank and plate girders are popular in the Northwest United States, and the units with the rolled sections are popular in the Midwest United States. The units with the treated timber deck are popular in the logging territories of Alaska.

MANUFACTURERS:

Nobels-Kline, Ltd., Columbia, South Carolina
Krupp Company, Rheinhausen, Germany
Spokane Culvert Company, Spokane, Washington
Armco Steel Company, Middletown, Ohio
Hamilton Construction Company, Springfield, Oregon

REFERENCES:

"Nobels-Kline, Ltd." (Reference 21)
Kroger, Elmer (Reference 22)
Godfrey, K. A., Jr. (Reference 23)
Muchmore, F. W. (Reference 24)

SYSTEM NUMBER S 1

PAGE 3 OF 6

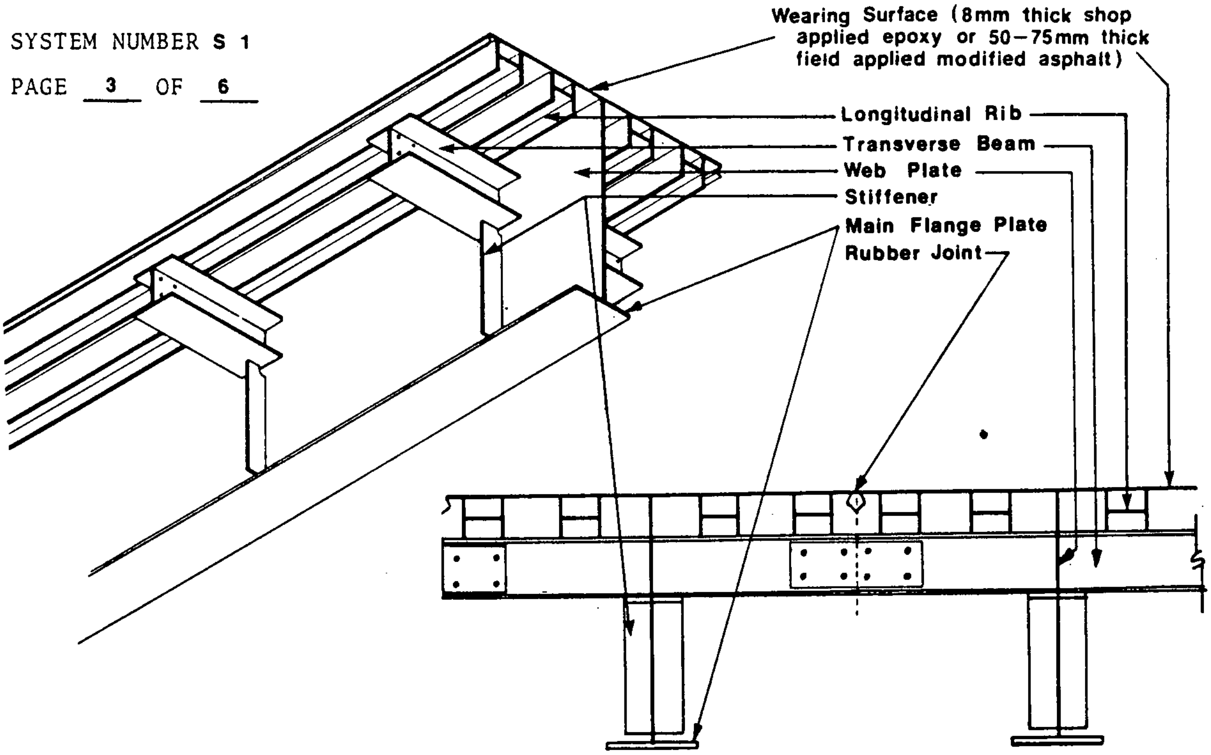


FIGURE 9. PREFABRICATED STEEL TEE-SHAPED UNITS

SYSTEM NUMBER S 1

PAGE 4 OF 6

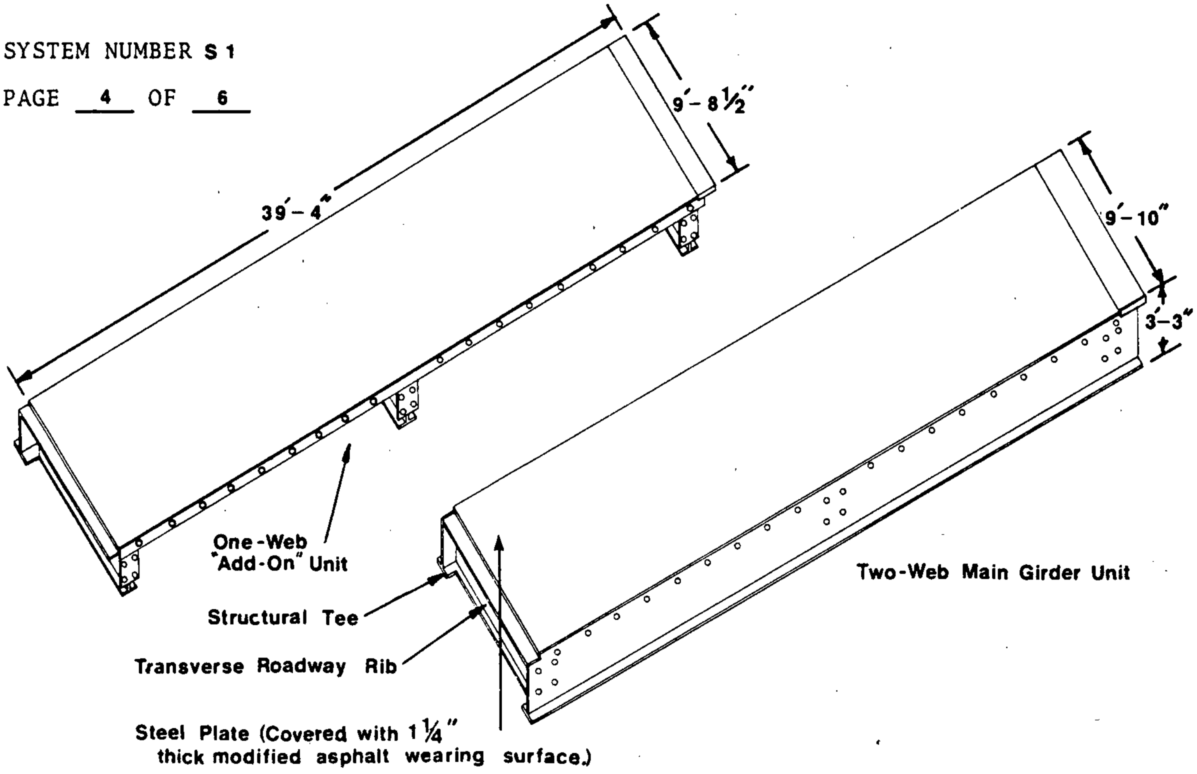


FIGURE 10. PREFABRICATED STEEL RECTANGULAR UNITS

SYSTEM NUMBER S 1

PAGE 5 OF 6

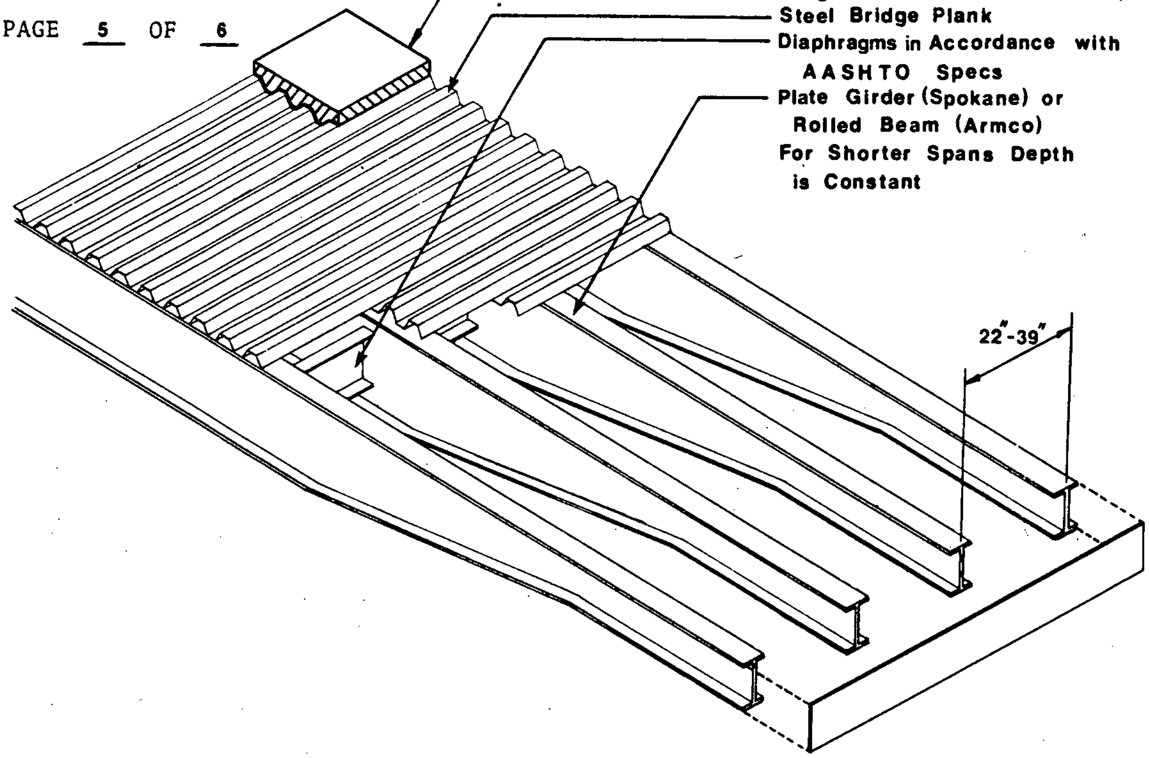


FIGURE 11. STEEL BRIDGE PLANK ON PLATE GIRDERS

SYSTEM NUMBER S1

PAGE 6 OF 6

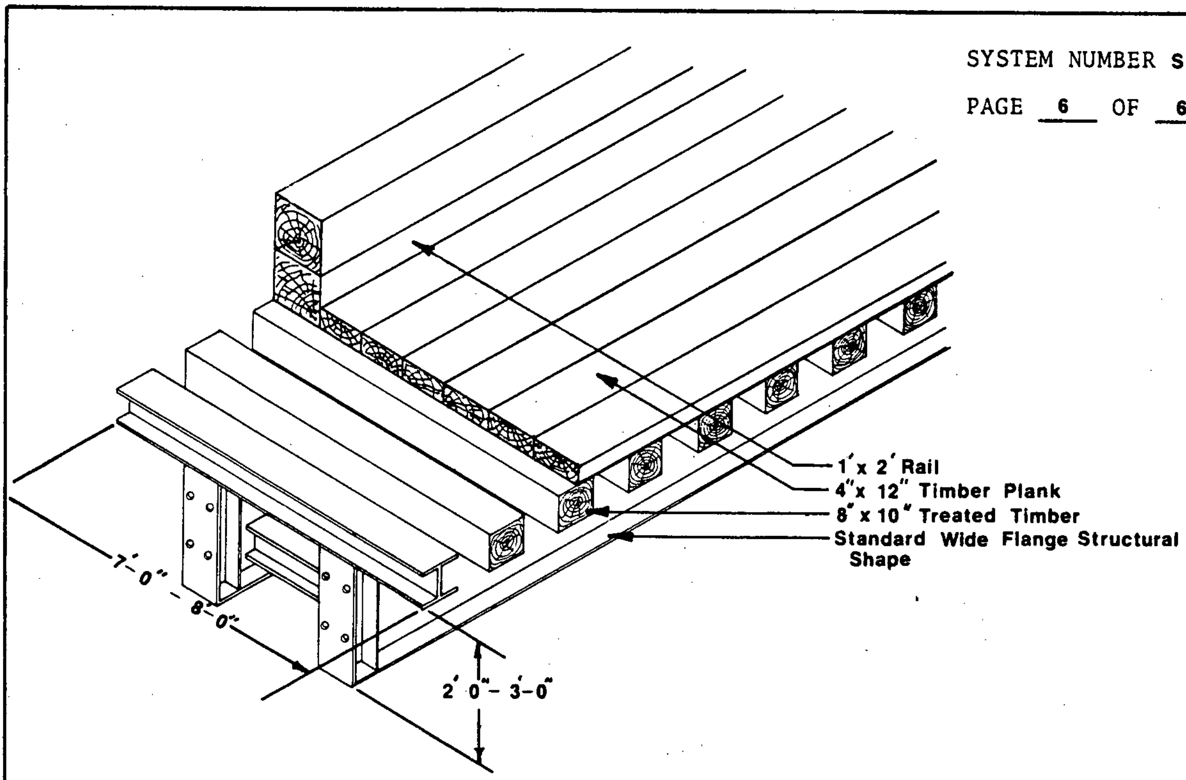


FIGURE 12. TREATED TIMBER DECK ON STEEL STRINGERS

NAME OF SYSTEM:

TEMPORARY BRIDGES

SYSTEM NUMBER

S-2

PAGE 1 OF 2

DESCRIPTION :

Steel truss bridges which are quickly assembled at the site from standard preassembled components.

PROMINENT FEATURES:

Standard preassembled steel components are easily assembled at the site by unskilled labor. The truss bridges come in a range of widths and can accommodate spans up to 300 ft. The standard components of the bridge are stocked by the manufacturers and can be easily transported to the site. Some of the bridges can be launched into place from one end. The bridges are over designed for most installations but are extremely versatile as they can be disassembled and used at other sites. Also, the bridges can be leased or purchased.

CASE EXAMPLES:

Bridges can be found all over the United States and other parts of the world.

MANUFACTURERS:

Bailey Bridges, Inc., San Luis Obispo, California
Acrow Corporation of America, Carlstadt, New Jersey

REFERENCES:

Acrow Panel Bridge,(Reference 25)
"Acrow Panel Bridge Replaces Two Spans Destroyed by Flood", ENR (Reference 26)

SYSTEM NUMBER S 2

PAGE 2 OF 2

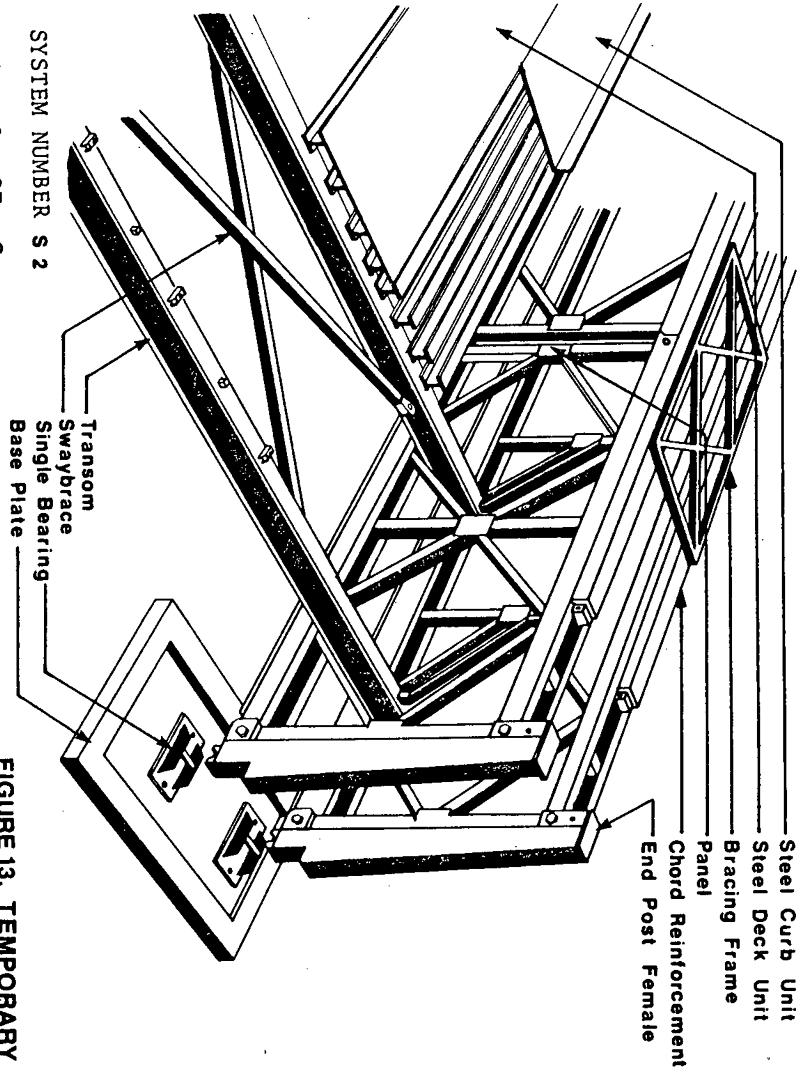


FIGURE 13. TEMPORARY BRIDGE

NAME OF SYSTEM:	SYSTEM NUMBER
PRECAST DECK PANEL	S-3
	PAGE 1 OF 4

DESCRIPTION:

Precast concrete panels are placed transversely or longitudinally on steel stringers.

PROMINENT FEATURES:

Precast concrete panels are placed transversely or longitudinally on steel stringers. Transverse panels may be prestressed in the transverse direction and are usually connected by a cast-in-place concrete joint, but examples are also cited in the literature where the panels are post-tensioned parallel to the direction of traffic or are connected with grouted keyways. Longitudinal panels are usually connected by a cast-in-place concrete joint which runs parallel to traffic. Composite action may be easily achieved with the longitudinal system if the deck panels are precast integrally with the stringers (Figure 14). Composite action is not usually achieved with the systems in which the panels are attached to the stringers at the site (Figure 15), but examples are cited in the literature where composite action was achieved through the use of studs or bolts and epoxy mortar (Figure 16). The systems eliminate most of the on-site formwork and concreting typically required for a steel stringer-concrete deck bridge.

CASE EXAMPLES:

New York, Alabama, Indiana, Pennsylvania

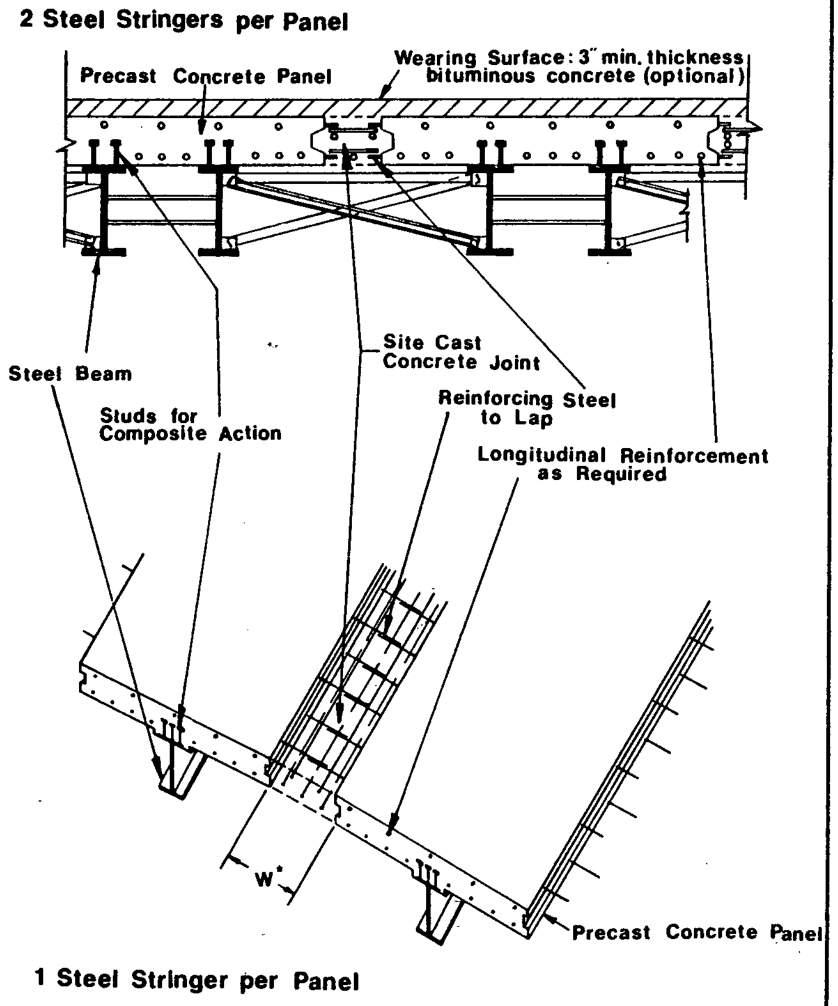
MANUFACTURERS:

Components can be secured from local precast concrete producers and steel fabricators.

REFERENCES: "Short-Span Steel Bridges, U. S. Steel Corp. (Reference 27)
Biswas, Mrinmay and others (Reference 28)
"Low-Cost, No-Care Bridge", Better Roads, (Reference 29)
NCHRP (Reference 30)

SYSTEM NUMBER S 3

PAGE 2 OF 4



*-Minimum W controlled by development length required for slab reinforcement

FIGURE 14.
PRECAST CONCRETE PANELS PLACED LONGITUDINALLY

SYSTEM NUMBER S 3

PAGE 4 OF 4

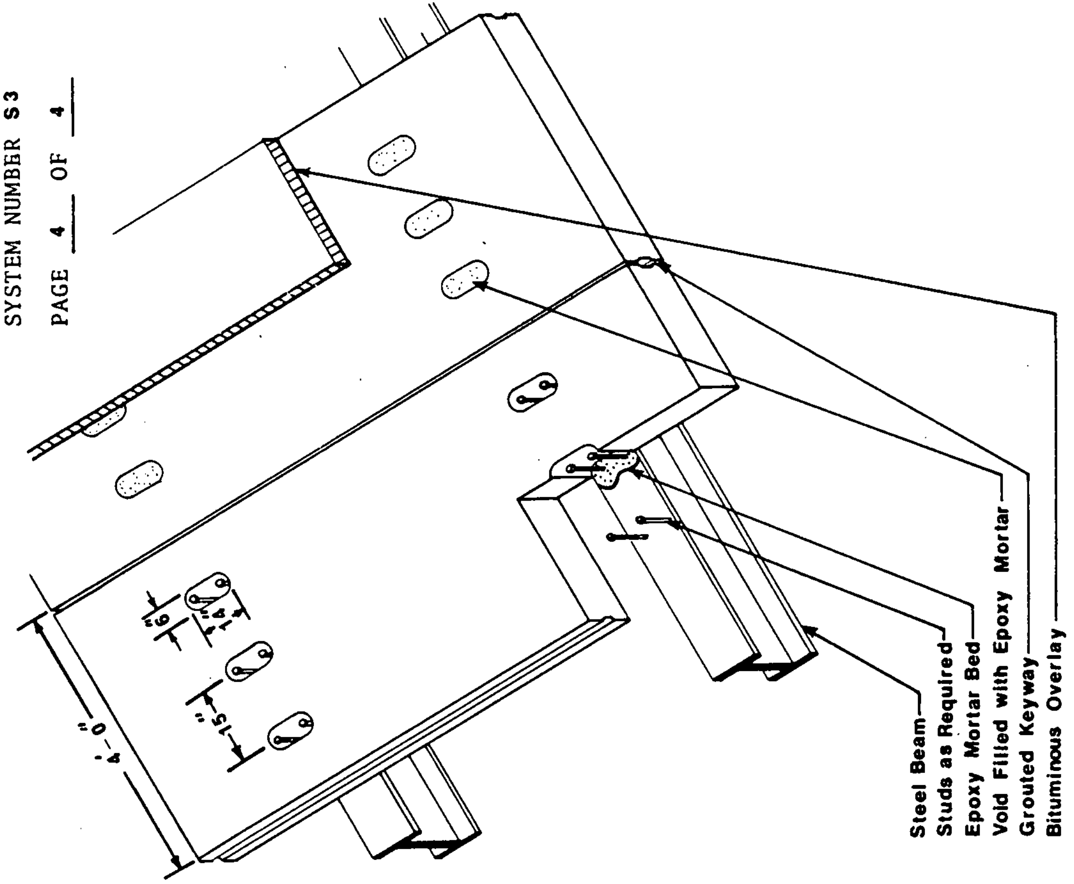
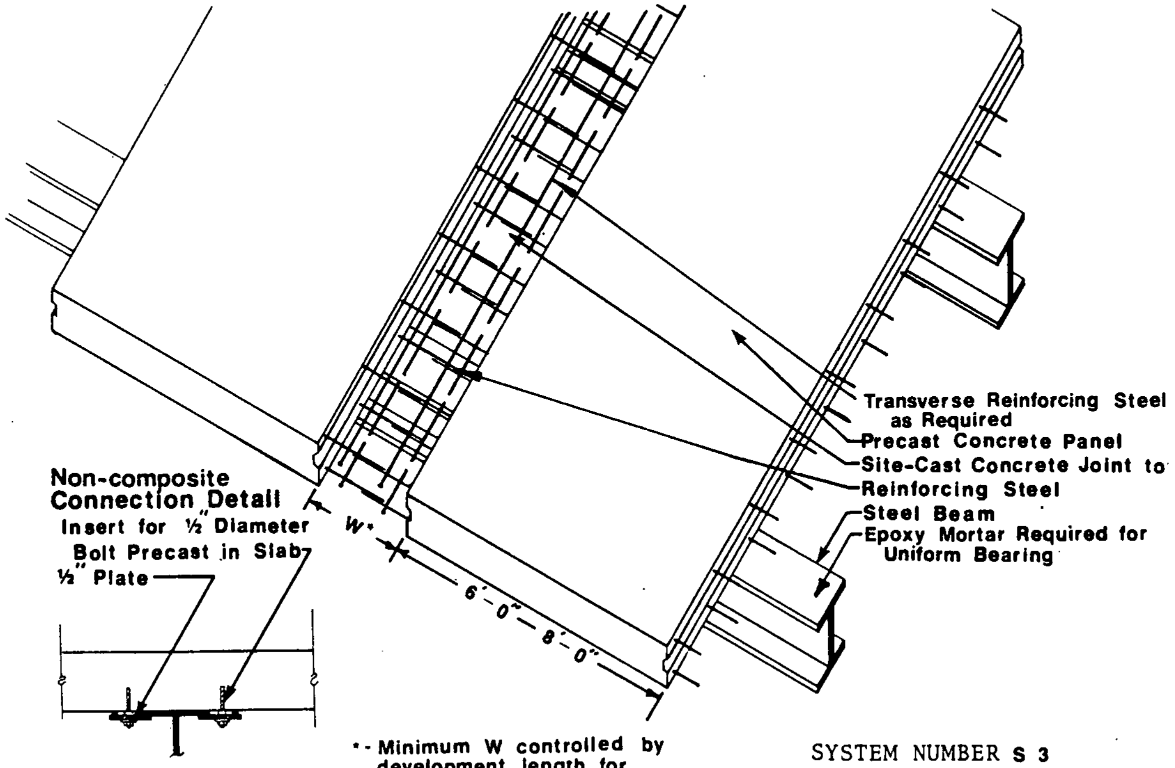


Figure 16.
Precast Concrete Panels Placed Transversely
(Composite Connection)



*- Minimum W controlled by development length for slab reinforcement

SYSTEM NUMBER S 3

PAGE 3 OF 4

FIGURE 15. PRECAST PANELS PLACED TRANSVERSELY (NON-COMPOSITE CONNECTION)

NAME OF SYSTEM:

LAMINATED TIMBER DECK ON STEEL BEAMS

SYSTEM NUMBER

S-4

PAGE 1 OF 2

DESCRIPTION:

Laminated timber deck is placed on steel stringers.

PROMINENT FEATURES:

The timber laminations may be connected with glue or nails. When the laminations are glued together (glulam) the deck is assembled from panels which are fabricated at a plant. Dowels are usually used to provide for load transfer between panels. When the laminations are nailed together, the deck is usually constructed at the site, in which case dowels are not used, however, panels could be nail laminated at a plant and assembled at the site. The deck is usually connected to a timber bolster with lag bolts as shown in Figure 17 or connected directly to the flange of the stringers with bolts and clips as shown in Figure 18. A surfacing material is generally used on the deck for increased resistance to skidding and weathering.

CASE EXAMPLES:

Virginia, Alaska and a number of other states.

MANUFACTURERS:

Supplies can be obtained from distributors located throughout the country.

REFERENCES:

U. S. Steel Corporation (Reference 31)
"Steel Beams with Glulam Flooring", VDHT (Reference 32)
Sprinkel, M. M. (Reference 33)

SYSTEM NUMBER S 4

PAGE 2 OF 2

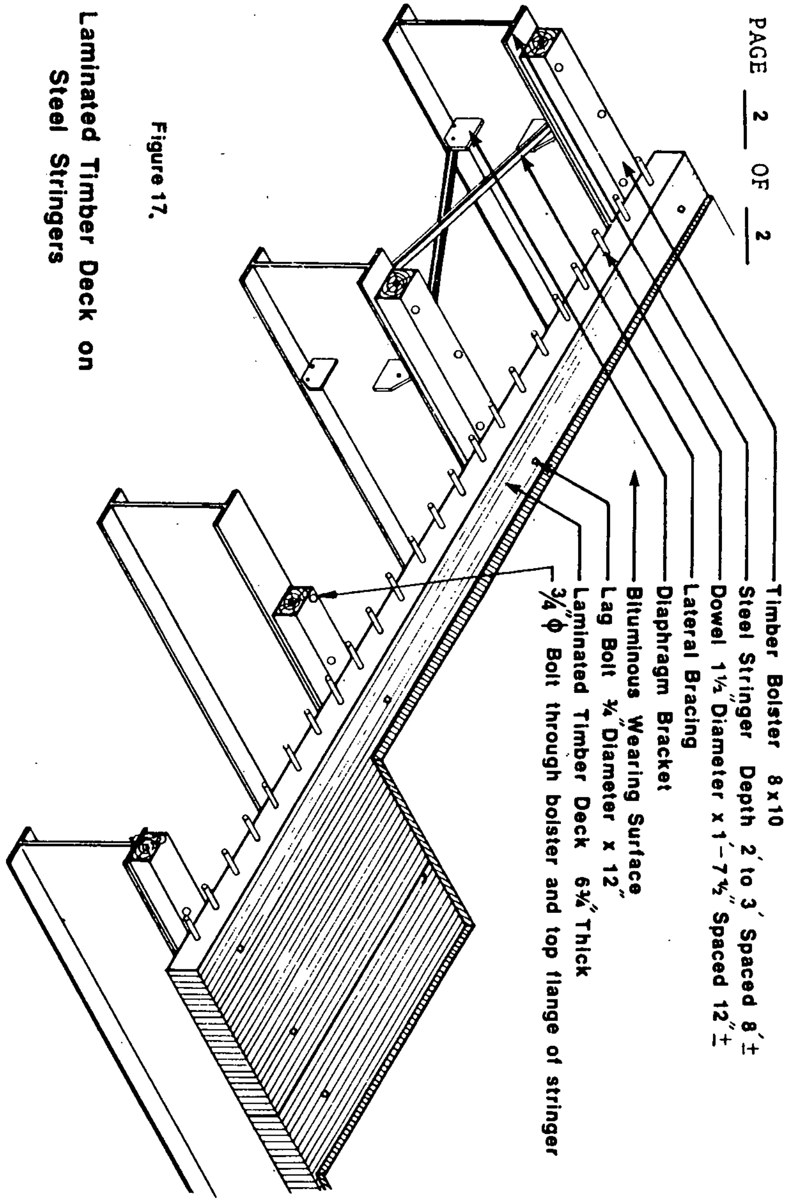


Figure 17.

Laminated Timber Deck on Steel Stringers

NAME OF SYSTEM	SYSTEM NUMBER
TIMBER PLANK DECK ON STEEL BEAMS	S-5
	PAGE 1 OF 2

DESCRIPTION:

Solid sawn timber planks are placed on steel stringers.

PROMINENT FEATURES:

Solid sawn timber planks are placed individually in the transverse direction and are secured to the steel stringers. Bolts and clips are commonly used to connect the planks to the stringers. The superstructure is easily assembled with light equipment and with relatively unskilled labor. Planks are easily replaced when damaged. A bituminous wearing surface is usually placed on the planks to protect the timber and to provide skid resistance. The system requires periodic maintenance because the planks tend to work loose and the wearing surface tends to spall. Because of the close stringer spacing, a relatively large quantity of structural steel is required for the system.

CASE EXAMPLES:

Numerous examples in Virginia and elsewhere.

MANUFACTURERS:

Materials are obtainable from local suppliers.

REFERENCES:

"Standard Steel Beam Bridges", VDHT (Reference 34)

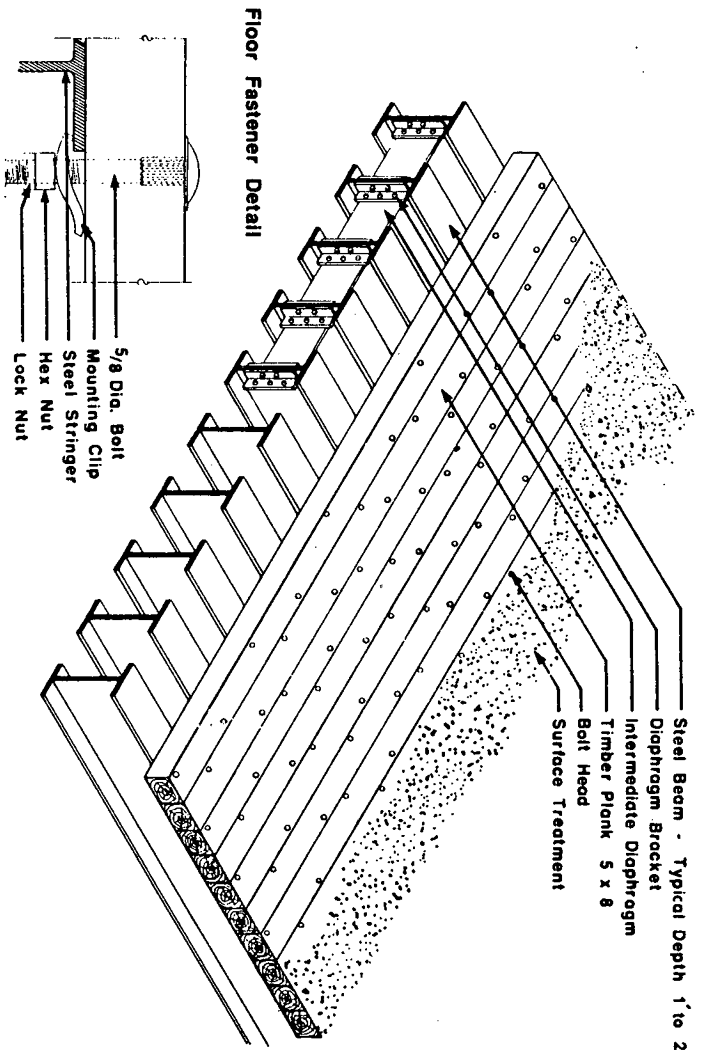


Figure 18. Timber Plank Deck On Steel Beams

SYSTEM NUMBER S 5

PAGE 2 OF 2

NAME OF SYSTEM:	SYSTEM NUMBER
STEEL GRID DECK ON STEEL BEAMS	S-6
	PAGE 1 OF 2

DESCRIPTION:

Modular steel grid units are placed on steel stringers.

PROMINENT FEATURES:

The system consists of steel stringers and modular open steel grids. The grids may or may not be filled with concrete. A variety of sizes and grid styles are available to suit the needs of a particular site. Typically the individual grids are 5 in. x 5 in. x 4 in. deep. The panels are usually prefabricated to meet the needs of a bridge. The grids are relatively light and modular and therefore lend themselves to rapid deck construction or replacement. The grids are unique in that they provide a relatively light and shallow deck system. Skid resistance characteristics can be improved by adding steel studs or roughening the top surface by other means. Filling the grid with concrete also improves the skid resistance.

CASE EXAMPLES:

Kansas, Pennsylvania and Virginia

MANUFACTURERS:

Greulich, Inc., specializes in grids. Other steel companies should be able to fabricate the grids.

REFERENCES:

Greulich, Inc. (Reference 35)
"Pittsburgh's Troubled Bridges: What To Do About Them?" (Ref. 36)

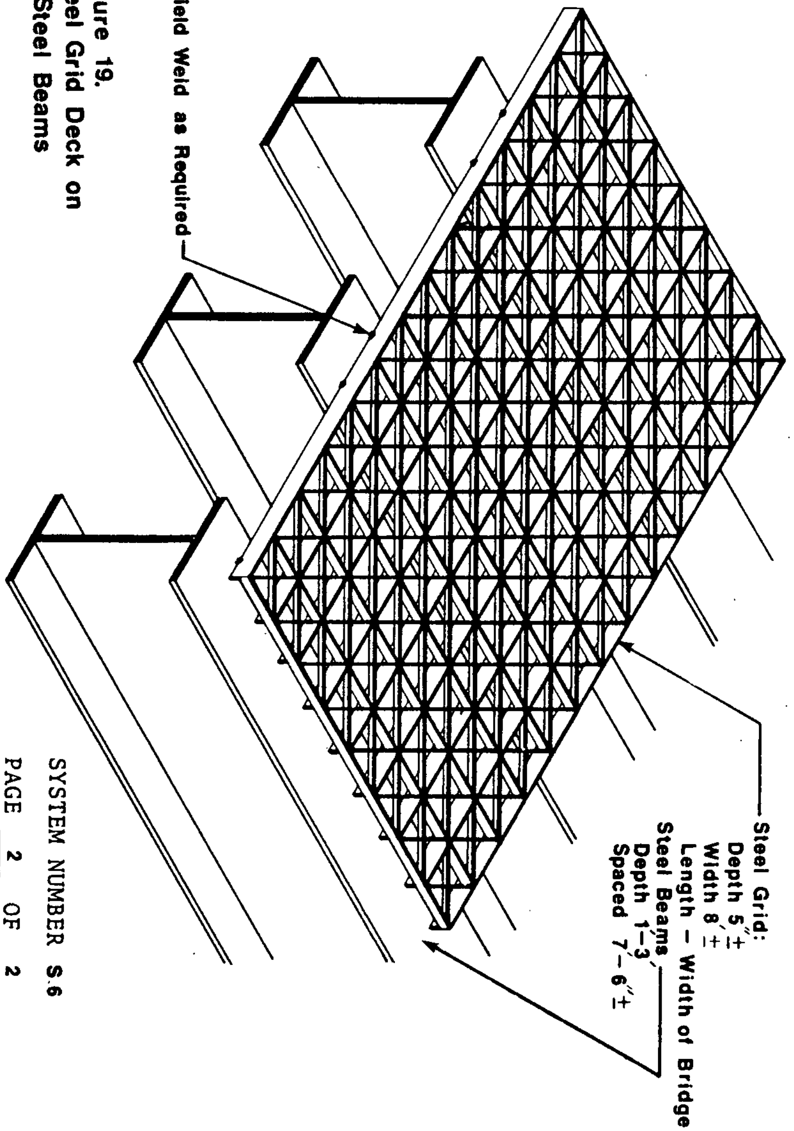


Figure 19.
Steel Grid Deck on
Steel Beams

SYSTEM NUMBER S.6
PAGE 2 OF 2

NAME OF SYSTEM:	SYSTEM NUMBER
BITUMINOUS CONCRETE DECK ON STEEL PLANKS	S-7 PAGE 1 OF 2

DESCRIPTION:

Steel stringers support corrugated steel plank which supports bituminous concrete wearing surface.

PROMINENT FEATURES:

Standard steel stringers are spaced approximately 2 ft. on center. Stringer spacing and size of beams are, of course, a function of the bridge span and live loading. Steel bridge plank is used on the stringers and connected by bolting or welding. Some authorities recommend bolting rather than welding on structures where the traffic count is high. A bituminous concrete wearing surface which is usually compacted to a thickness of about 3 inches is placed on the bridge plank. The system lends itself to rapid construction because of the absence of portland cement concrete. See Figure 20.

CASE EXAMPLES:

Used in Ohio, Colorado and Virginia.

MANUFACTURERS:

Materials and labor are usually available locally. Bridge plank may be obtained from Armco, Bethlehem and others.

REFERENCES:

Schukraft, Bernard (Reference 37)
Colorado Department of Highways (Reference 38)

SYSTEM NUMBER S 7
PAGE 2 OF 2

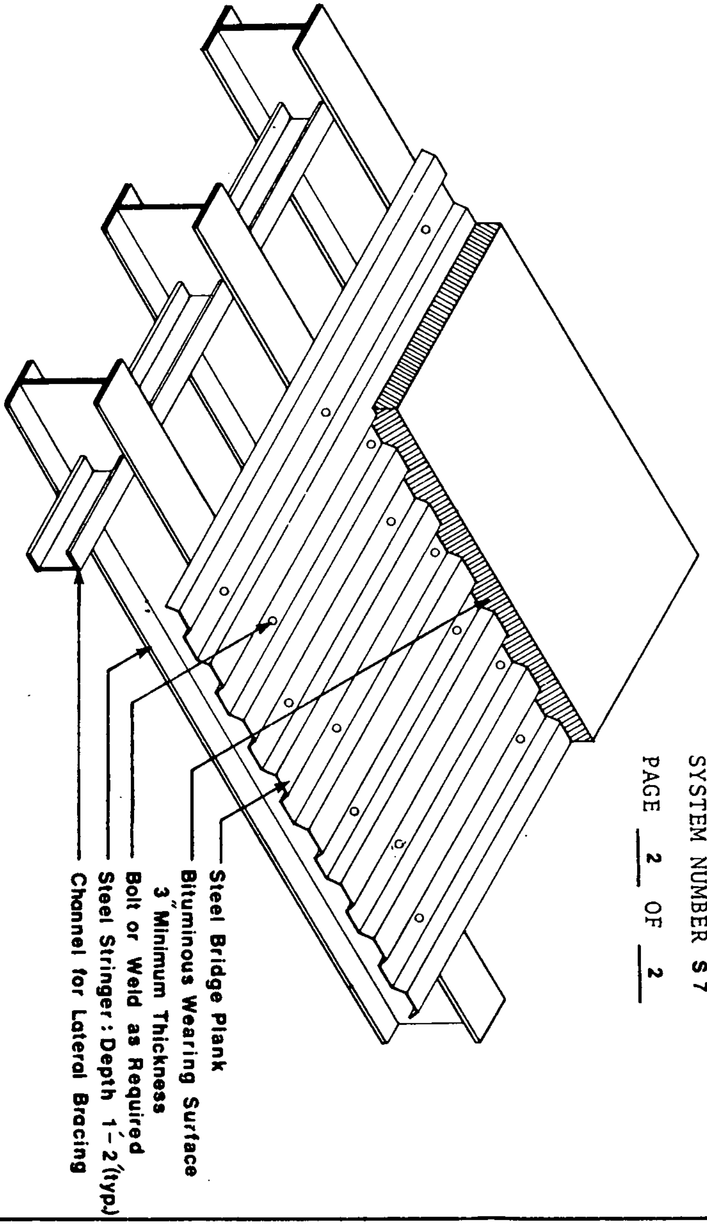


Figure 20.
Bituminous Wearing Surface and Steel Bridge Plank on Steel Stringers

NAME OF SYSTEM:

ORTHOTROPIC STEEL PLATE DECK

SYSTEM NUMBER

S-8

PAGE 1 OF 2

DESCRIPTION:

Steel I-beams support standard orthotropic steel plate bridge floor units.

PROMINENT FEATURES:

The system consists of steel stringers and standard orthotropic steel plate floor units as shown in Figure 21. The orthotropic plates may be placed parallel to the stringers in which case floor beams must support the plate. The orthotropic plate deck is available in a variety of sizes and shapes to accommodate a range of stringer or floor beam spacings typically between 7 to 20 ft. The top plate is typically 3/8 to 3/4" thick and the depth of the ribs is typically 8.0 to 14.0".

Although orthotropic steel plate decking has been used primarily on long span bridges to minimize the weight of the superstructure, the decking has seen occasional use on short span bridges where the major concern was to provide a bridge which could be installed in a very short time. Because the orthotropic plate decking is relatively light and easily handled, it is particularly suited for rapid deck construction and replacement. An epoxy grit or modified asphalt wearing surface is generally used to provide adequate skid resistance and to protect the steel from water and salt.

CASE EXAMPLES: An experimental bridge built by the Bethlehem Steel Corporation at its Sparrows Point, Md., plant in 1964. The bridge was built to explore the use of prefabricated, all-steel modular units for the construction of highway bridges in the span range of 20 to 100 ft.

MANUFACTURERS:
Bethlehem Steel Corporation and Reliance Steel Company. Other steel fabricators should be able to fabricate the orthotropic plate decks.

REFERENCES:

Orthotropic Plate Design for Steel Bridges (Reference 39)
Design Aid for Orthotropic Bridge Decks (Reference 40)

SYSTEM NUMBER S 8

PAGE 2 OF 2

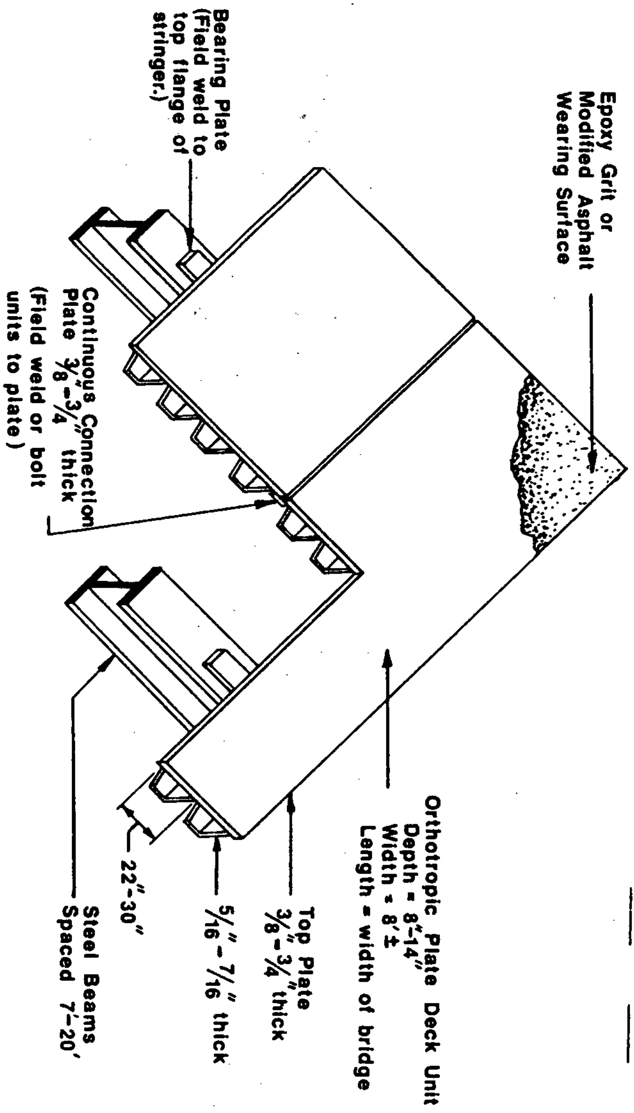


Figure 21. Orthotropic Steel Plate Deck On Steel Beams

NAME OF SYSTEM:	SYSTEM NUMBER
SITE-CAST DECK ON STEEL BEAMS	S-9
	PAGE 1 OF 2

DESCRIPTION:

Steel I-beams or welded plate girders support composite or non-composite cast-in-place concrete decks.

PROMINENT FEATURES:

This is a very common type of bridge. A wide range of standard wide-flange and I-beam shapes are available. The size and spacing of the beams may be adjusted from site to site to optimize the use of materials. The standard rolled shapes are typically used for spans which are less than 90 ft. Welded plate girders are commonly used for spans of 90 to 240 ft. and are usually custom fabricated for each site. Welded plate girder bridges usually require heavier equipment and more expertise than bridges utilizing standard rolled shapes. The cast-in-place concrete deck is traditionally formed with removable forms. However, permanent steel or prestressed concrete forms have become popular in recent years. See System M-4. Studs are generally used to achieve composite action except for very short spans where it may be economical to omit the studs. The system does not lend itself to rapid construction because of the cast-in-place concrete required for the deck.

CASE EXAMPLES:

This bridge system is widely used all over the world.

MANUFACTURERS:

Bridge materials may be purchased from local concrete and steel suppliers.

REFERENCES:

<u>Engineering News Record</u> (Reference 20)
U. S. Department of Transportation (Reference 41)
U. S. Steel Corporation (Reference 42)

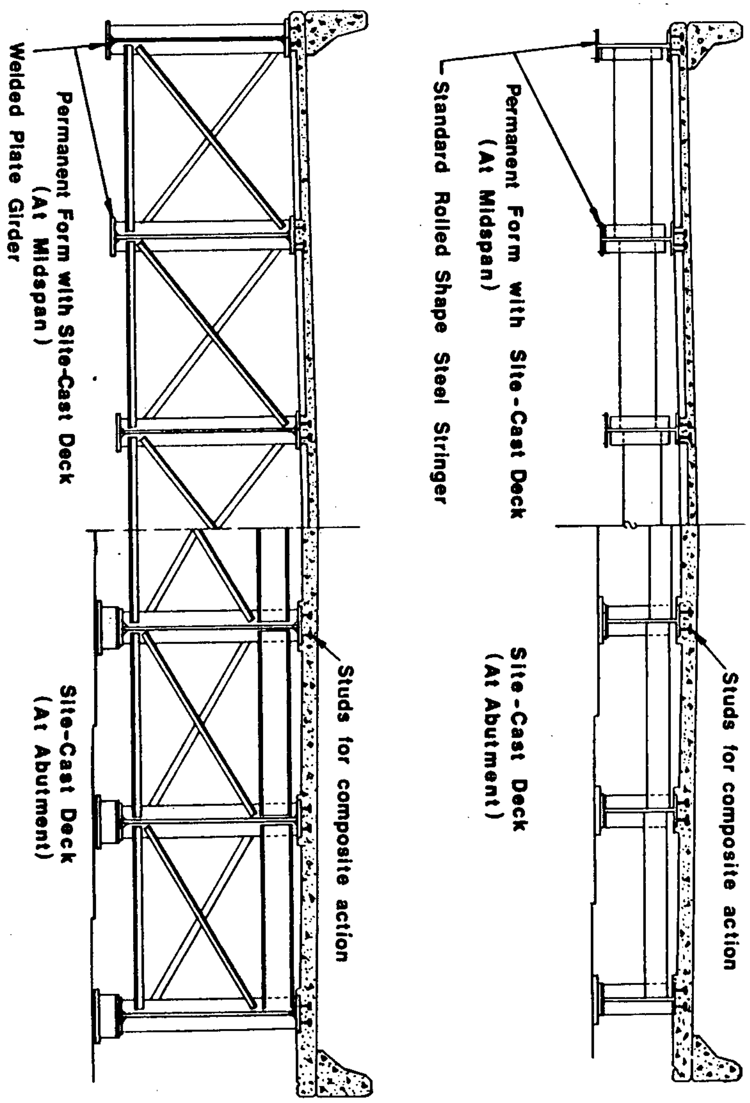


Figure 22. Site-Cast Concrete Deck On Steel Beams

SYSTEM NUMBER S 9
PAGE 2 OF 2

NAME OF SYSTEM:

GLUED-LAMINATED TIMBER

SYSTEM NUMBER

T-1

PAGE 1 OF 4

DESCRIPTION:

Glued laminated timber "Glulam" beams and deck panels.

PROMINENT FEATURES:

Modular beams and deck panels are plant manufactured by gluing together standard size lumber. Standard wood treating techniques are used to provide a long service life. The panels and beams may be erected and connected with relatively light equipment and carpentry oriented labor. Two connection details are commonly used. One consists of dowels which provide for shear transfer between panels and lag bolts which tie the panels to the beams. See Figures 22 and 24. The other detail requires patented deck brackets which connect the panels to the stringers and eliminate the need for the dowels between panels. See Figures 23 and 25. A bituminous wearing surface must be placed on the panels to protect the timber from wear and to provide skid resistance.

CASE EXAMPLES:

Case examples can be found in Virginia, Oregon, Washington, Alaska, New York, Colorado, and many other states. The bridges are most common in areas where timber is abundant.

MANUFACTURERS:

Contact AITC for a list of fabricators, which are located throughout the United States.

REFERENCES: Bruesch, L. D. (Reference 43)
Virginia Department of Highways & Transportation (Reference 44)
Weyerhauser (Reference 45 and 46)
AITC (Reference 47), VDHT (Reference 48)

SYSTEM NUMBER T 1

PAGE 2 OF 4

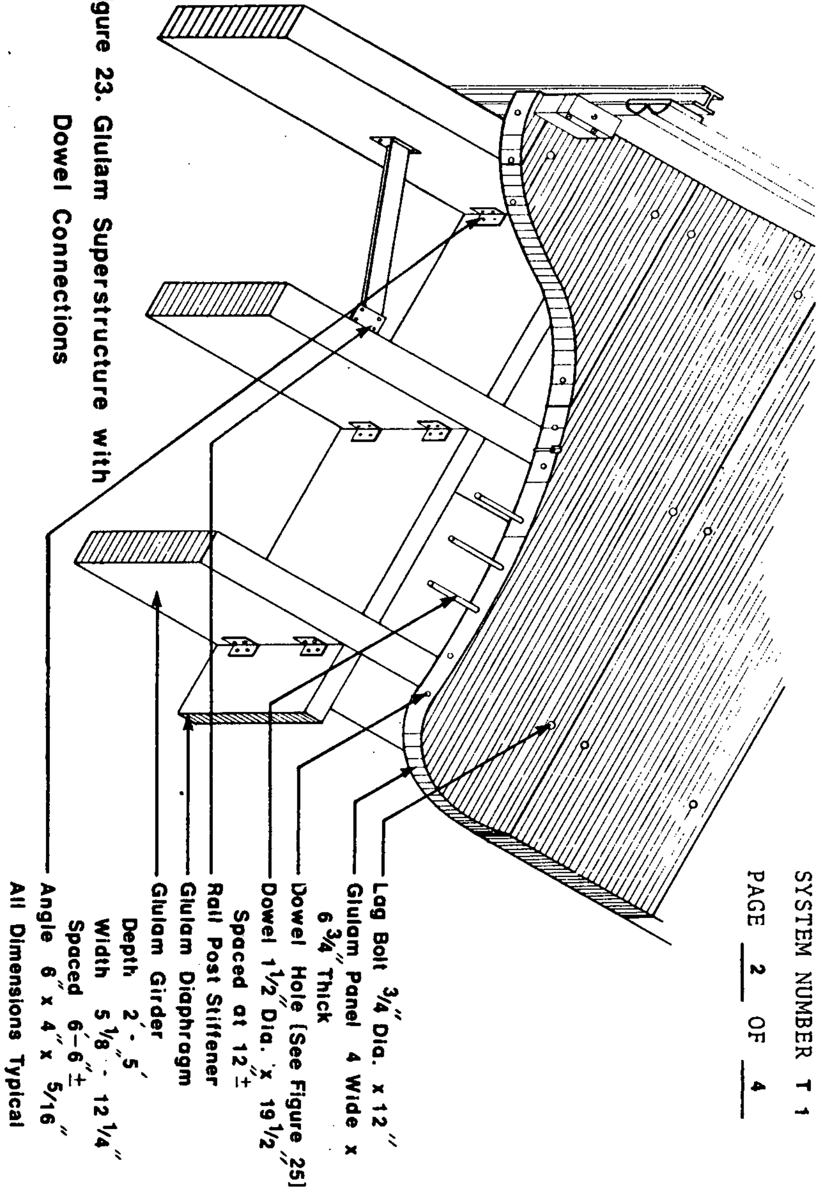
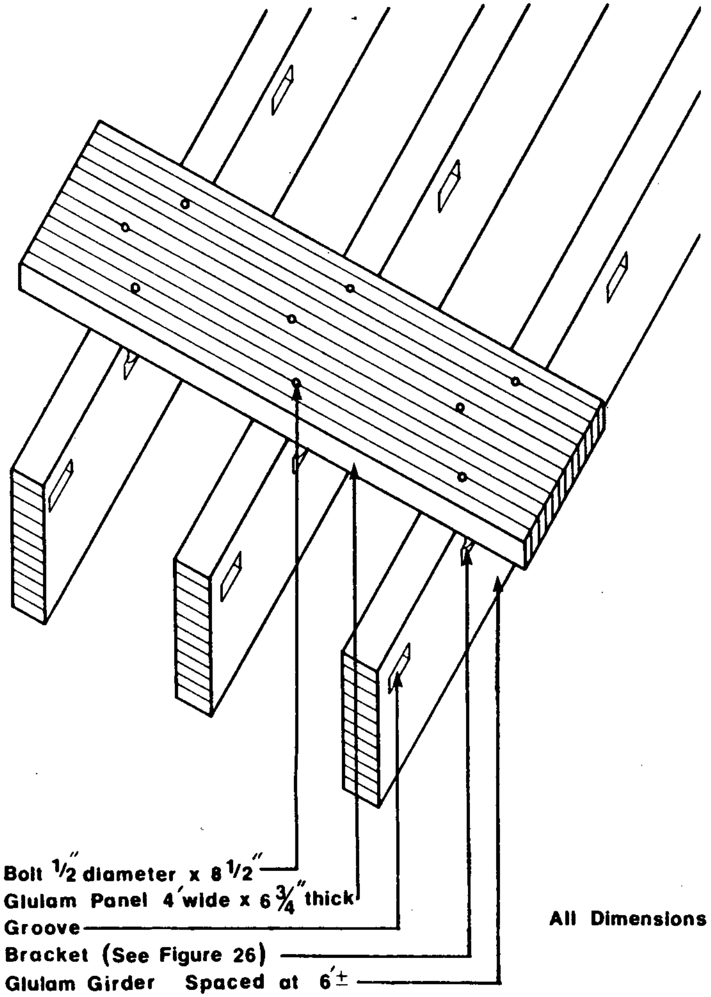


Figure 23. Glulam Superstructure with Dowel Connections



All Dimensions Typical

Figure 24.
Glulam Superstructure with Bracket Connections

SYSTEM NUMBER T 1

PAGE 3 OF 4

SYSTEM NUMBER T 1

PAGE 4 OF 4

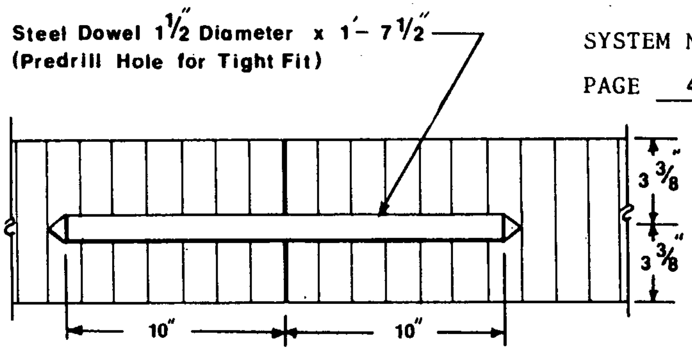


Figure 25.

Dowel Connection Detail

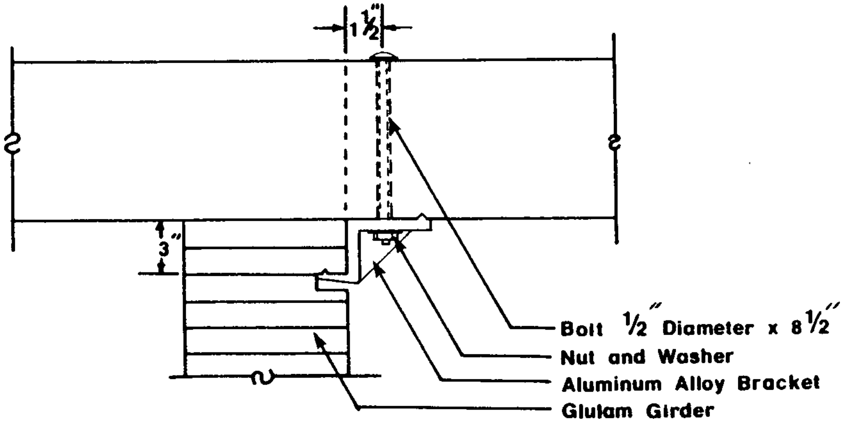


Figure 26.

Bracket Connection Detail

NAME OF SYSTEM: NAIL LAMINATED TIMBER	SYSTEM NUMBER T-2
	PAGE 1 OF 2

DESCRIPTION:

Treated lumber is nail laminated and topped with a wearing surface.

PROMINENT FEATURES:

The deck is easily constructed at the job site by carpentry oriented labor. Treated lumber is placed in the longitudinal direction and nailed to adjacent pieces and alternate pieces are toenailed to the pile cap. The deck is usually covered with a bituminous wearing surface. However, concrete may be placed on the timbers to provide a composite concrete-timber deck and in this case the laminations are of two or more depths to result in a corrugated effect. Both systems are suitable for spans of approximately 20 ft.

CASE EXAMPLES:

One example in Virginia.

MANUFACTURERS:

May be constructed with locally available materials.

REFERENCES:

Federal Highway Administration (Reference 49)

SYSTEM NUMBER T 2

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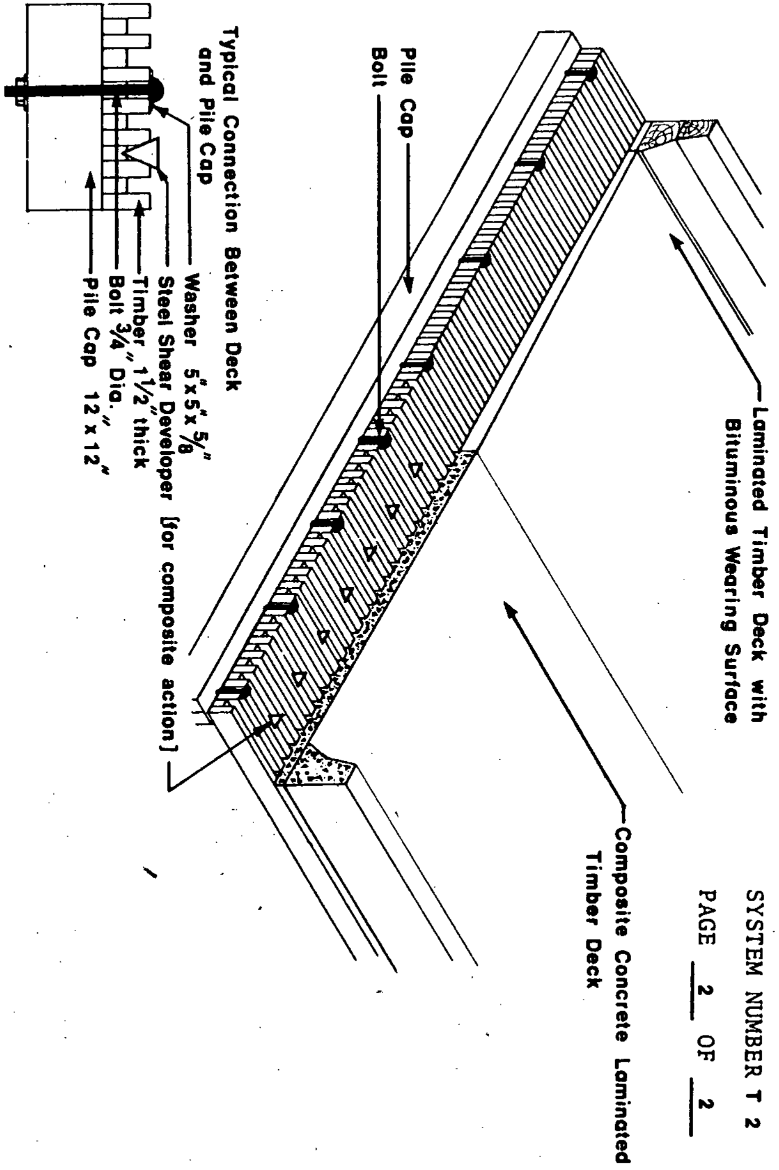


Figure 27. Nail Laminated Timber Superstructure

NAME OF SYSTEM:	SYSTEM NUMBER
SOLID SAWN TIMBER BEAMS	T-3
	PAGE 1 OF 2

DESCRIPTION:

Solid sawn timber beams support various types of decking material.

PROMINENT FEATURES:

The system consists of treated timber stringers approximately 6 in. x 18 in. deep and spaced approximately 2 to 4 ft. apart to accommodate spans of approximately 20 ft. The stringers may be covered with a timber and bituminous deck or a concrete deck. A timber deck is nailed to the stringers and a concrete deck is cast around the top edge of the stringers.

CASE EXAMPLES:

Several examples in rural Virginia

MANUFACTURERS:

Locally available materials and labor.

REFERENCES:

Federal Highway Administration (Reference 49)

SYSTEM NUMBER T 3

PAGE 2 OF 2

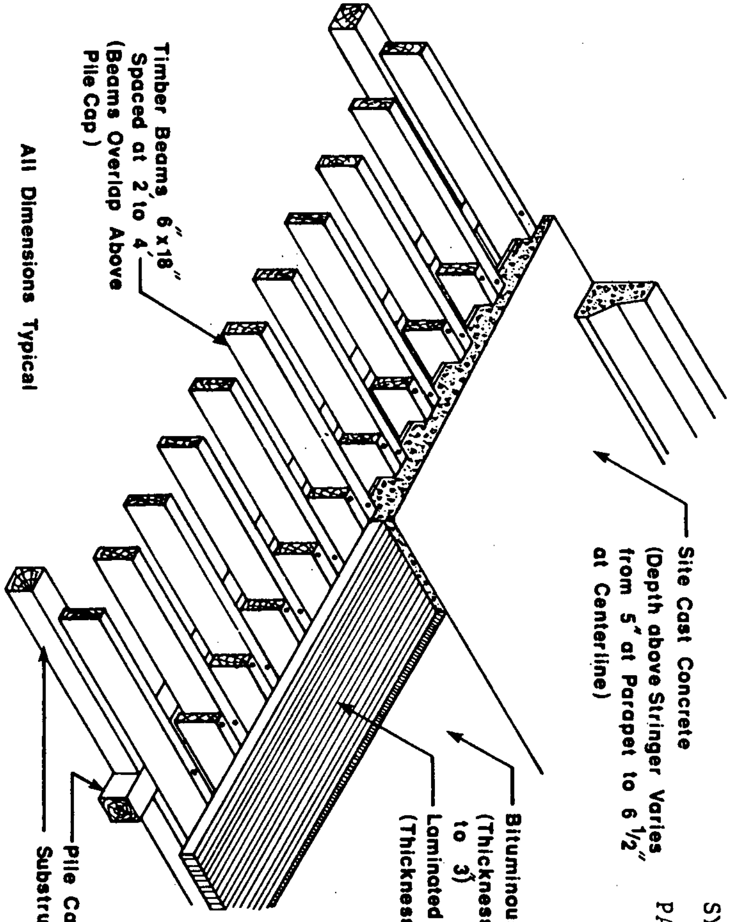


Figure 28. Solid Sawn Timber Beams

NAME OF SYSTEM:	SYSTEM NUMBER
PLYWOOD DECK SURFACE	T-4
	PAGE 1 OF 2

DESCRIPTION:

Polyurethane-resin-coated plywood serves as deck surface.

PROMINENT FEATURES:

Plywood sheets are supported by subflooring and stringers. The plywood sheets are usually 4 ft. x 8 ft. and are coated in the shop with polyurethane resin. The plywood sheets are secured to the subflooring with glue and spikes. The sheets are typically used to upgrade the wearing surface of a plank deck bridge so that the planks do not have to be replaced. This system should be considered for structures on low volume roads only.

CASE EXAMPLES:

New Hampshire

MANUFACTURERS:

Contact American Plywood Association

REFERENCES:

American Plywood Association (Reference 50)

SYSTEM NUMBER T 4

PAGE 2 OF 2

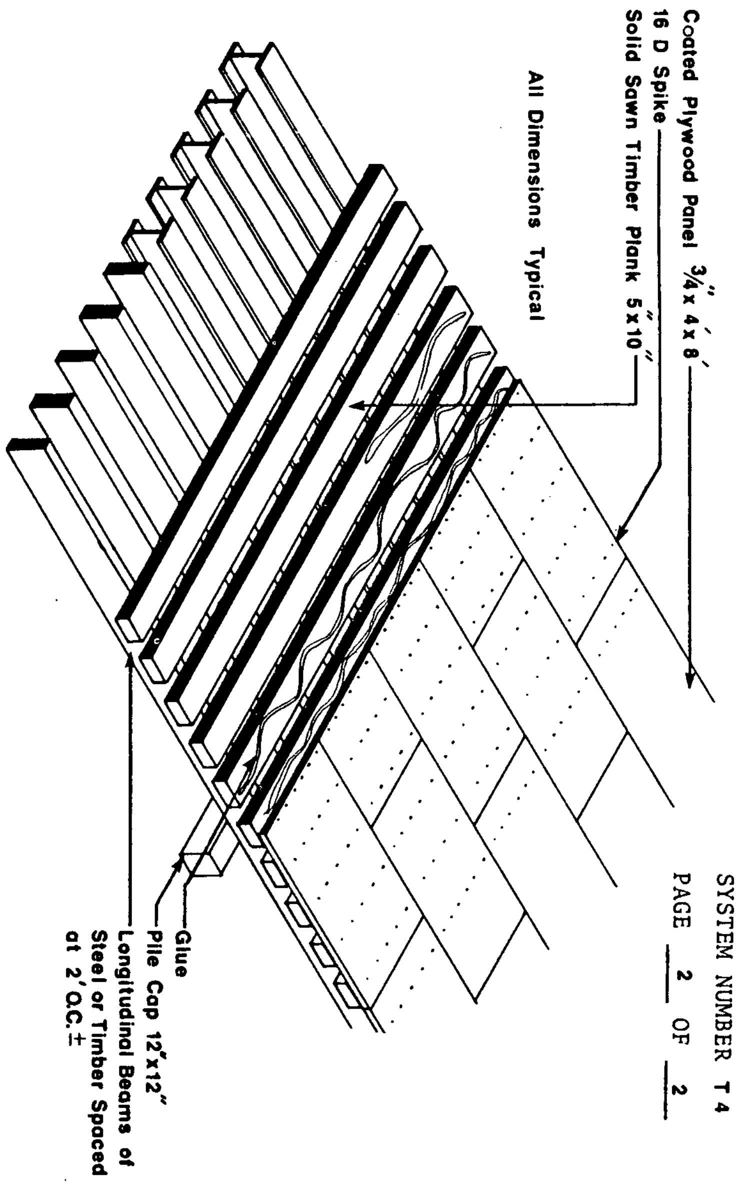


Figure 29. Plywood Deck Surface

NAME OF SYSTEM:	SYSTEM NUMBER
PRECAST ABUTMENT AND WINGWALL	M-1
	PAGE 1 OF 2

DESCRIPTION:

Precast concrete abutment and wingwall panels.

PROMINENT FEATURES:

Panels are modular and therefore easily precast in various lengths and widths to accommodate a range of abutment heights and roadway widths. Panels are set on cast-in-place concrete pads, and temporarily supported and then connected with weld plates and cast-in-place concrete footing (see Figure 30). Several other systems (both proprietary and non-proprietary) which utilize modular precast concrete units could be used to obtain a comparable abutment.

CASE EXAMPLES:

A prototype structure has been constructed in Garfield County, Washington, and proposed in Oklahoma.

MANUFACTURERS:

Central Pre-Mix Concrete Company, Spokane, Washington. Atlantic Pipe Corporation, Plainville, Conn. Most precast concrete plants should be properly equipped for production.

REFERENCES:

Prestressed Concrete Institute (Reference 1)
"Instant Bridges" (Reference 8)
Thompson, Pat (Reference 51)   Imel, K. Dean (Reference 52)

SYSTEM NUMBER M 1

PAGE 2 OF 2

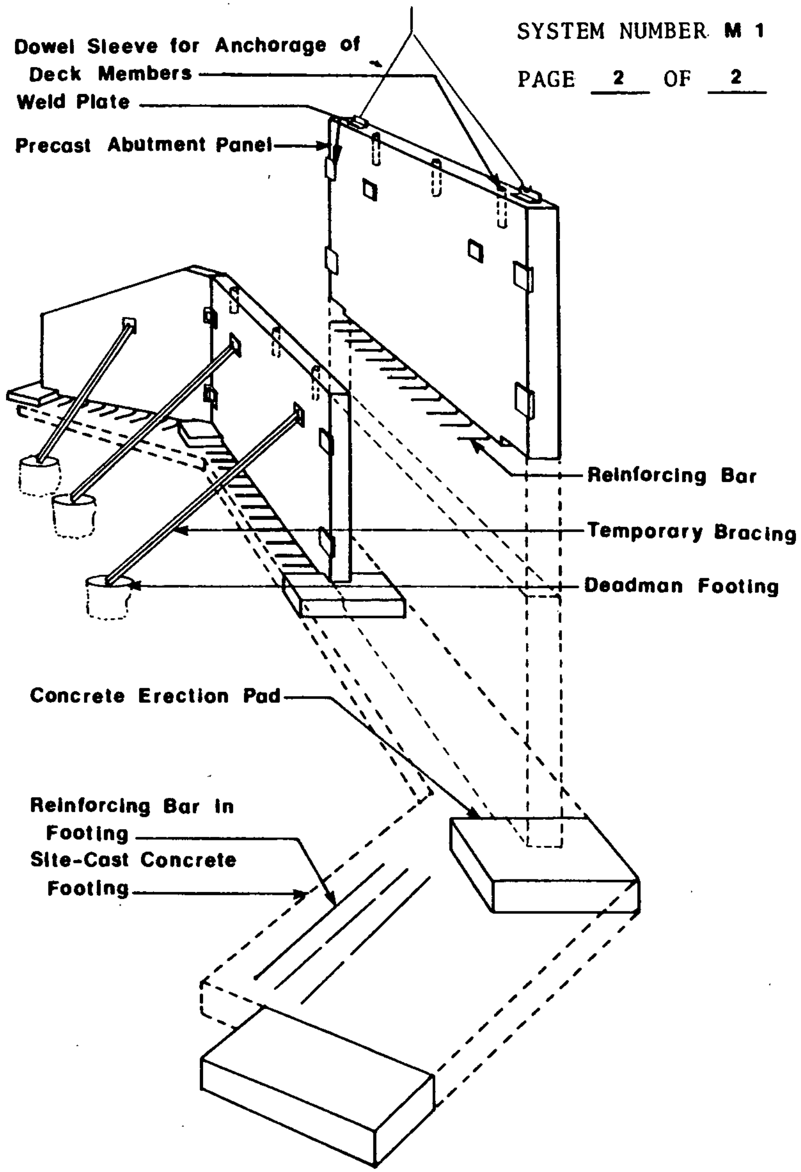


Figure 30. Precast Abutment and Wingwall

NAME OF SYSTEM:

PILE SUBSTRUCTURES

SYSTEM NUMBER

M-2

PAGE 1 OF 3

DESCRIPTION:

Prestressed concrete or steel H-piling with concrete or steel cap.

PROMINENT FEATURES:

Prestressed concrete or steel H-piles are driven to the required depth and cut to the required height. See Figures 31 and 32. The piles are capped with site-cast or precast concrete and the steel H-piles are sometimes capped with a steel section. Connections between the pile cap and piles are usually achieved with site-cast concrete or welds. See Figure 33. Steel angles are connected to the H-piles to stabilize the bent. For water crossings the H-piling is frequently jacketed in concrete or protected in an equivalent manner at the water line to inhibit corrosion. For abutments the piling may be backed with precast concrete plank, steel sheet piling, cold formed steel sections, steel bridge plank, or horizontal heavy timber planking. As an alternative concrete, steel or timber cribbing may be used to retain the soil or rip rap can be used for slope protection.

CASE EXAMPLES:

Steel H-pile bridges have been constructed in Alabama, Georgia and North Carolina, and proposed in Oklahoma.

MANUFACTURERS:

Materials should be readily available.

REFERENCES:

U. S. Steel Corporation (Reference 27)

Imel, K. Dean (Reference 52)

Engineering News-Record (Reference 53)

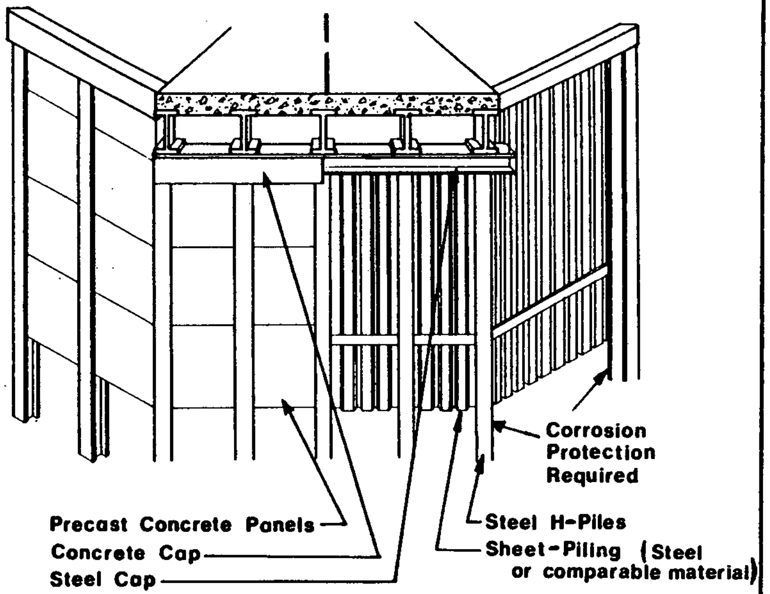


Figure 31. Pile Substructures—Abutment Details

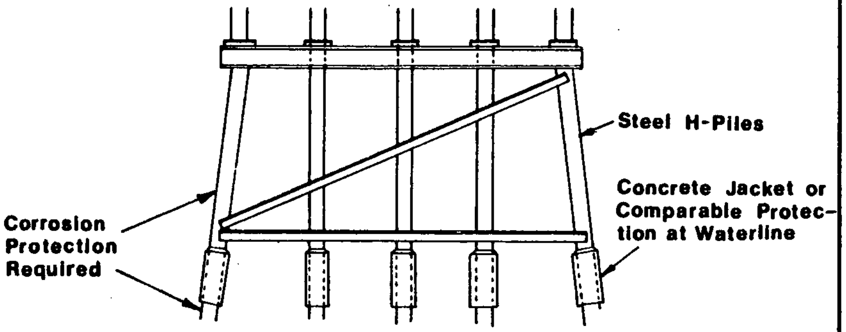
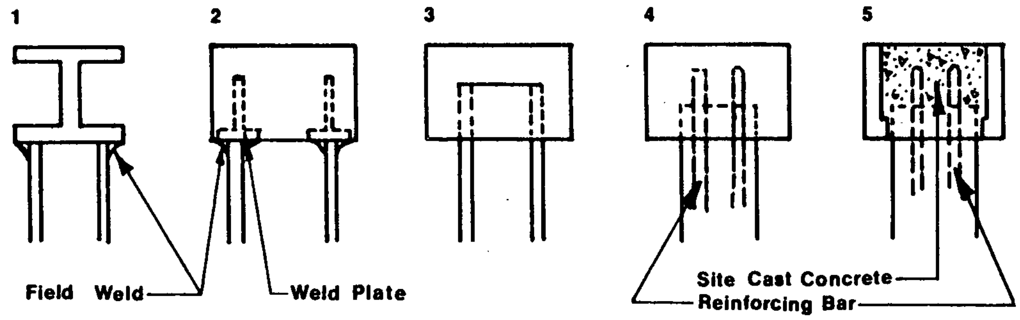


Figure 32. Pile Substructures—Pier Details

SYSTEM NUMBER M 2

PAGE 2 OF 3



1 Steel Cap on Steel Pile
2 Precast Concrete Cap on Steel Pile
3 Site-cast Concrete Cap on Steel Pile
4 Site-cast Concrete Cap on Prestressed Concrete Pile
5 Precast Concrete Cap on Prestressed Concrete Pile

Figure 33.
Connection Details for Pile Substructures

SYSTEM NUMBER **M 2**

PAGE 3 OF 3

NAME OF SYSTEM: SPAN-SHORTENING SUBSTRUCTURES	SYSTEM NUMBER M-3 PAGE 1 OF 2

DESCRIPTION:

Slanted leg piers serve as supporting members.

PROMINENT FEATURES:

Several slanted leg substructure systems are available which increase the clear span that can be achieved with conventional superstructure members. These are the inverted A-frame center pier, the cantilevered center girder and the slanted leg bridge. The legs may be steel or precast concrete. In most cases the legs must be temporarily supported during erection. Relatively short on-site time should be expected since the substructure components are prefabricated. See Figure 34.

CASE EXAMPLES:

Several bridges with precast concrete legs have been constructed in Alberta, Canada, and Washington. Steel slanted leg bridges can be found in Virginia.

MANUFACTURERS:

Local precast concrete producers or steel fabricators.

REFERENCES:

"Ardrossan Bridge Employs Precast, Prestressed Components" (Ref. 54)
Jacques, F. J. (Reference 55)
Casad, D. D. and H. W. Birkeland (Reference 56)

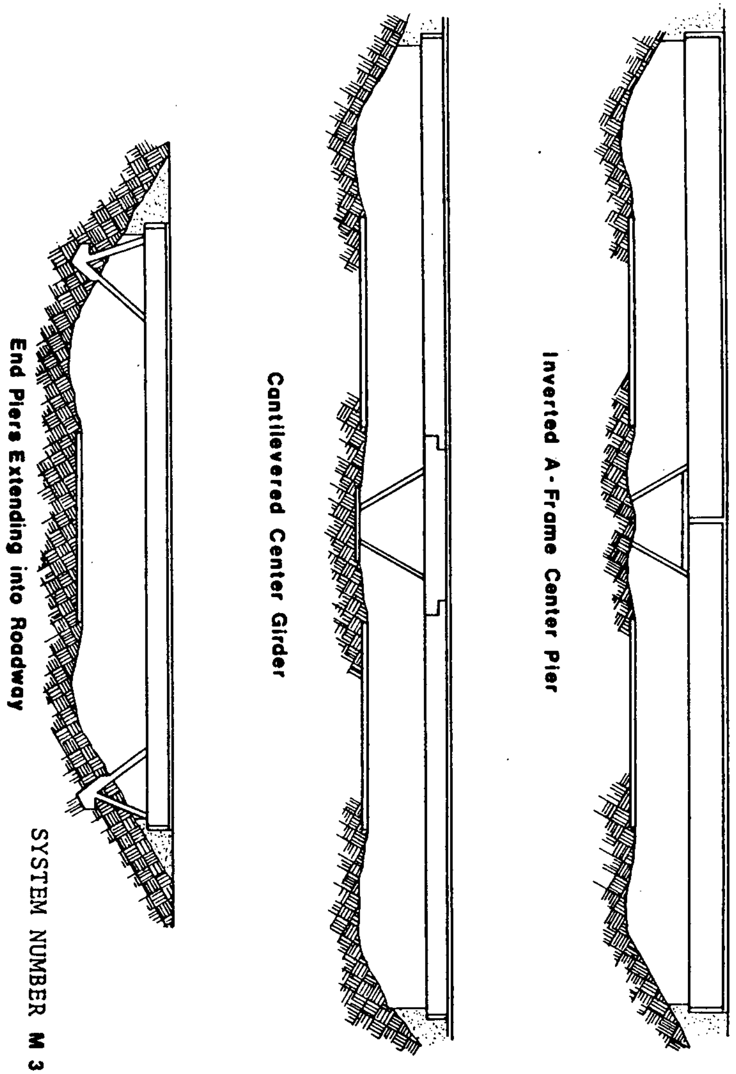


Figure 34. Span-Shortening Substructures

SYSTEM NUMBER M 3
PAGE 2 OF 2

NAME OF SYSTEM:

PERMANENT BRIDGE-DECK FORMS

SYSTEM NUMBER

M-4

PAGE 1 OF 3

DESCRIPTION:

Permanent steel forming or prestressed concrete subdeck panels support site-cast concrete deck.

PROMINENT FEATURES:

The ready-mix concrete required for site-cast concrete bridge decks must be formed with temporary or permanent bridge deck forms. In recent years permanent deck forms of steel or subdeck panels of prestressed concrete have become popular because the high cost of the form removal is eliminated. Prestressed concrete subdecks provide an added advantage in that less concrete and reinforcing steel must be placed at the bridge site since the form becomes an integral part of the deck.

CASE EXAMPLES:

Case examples can be found throughout the United States.

MANUFACTURERS:

Local steel fabricators and prestress concrete producers.

REFERENCES:

Engineering News-Record (Reference 20)
Hilton, Marvin H. (Reference 57 and 58)
Transportation Research Circular 181 (Reference 59)

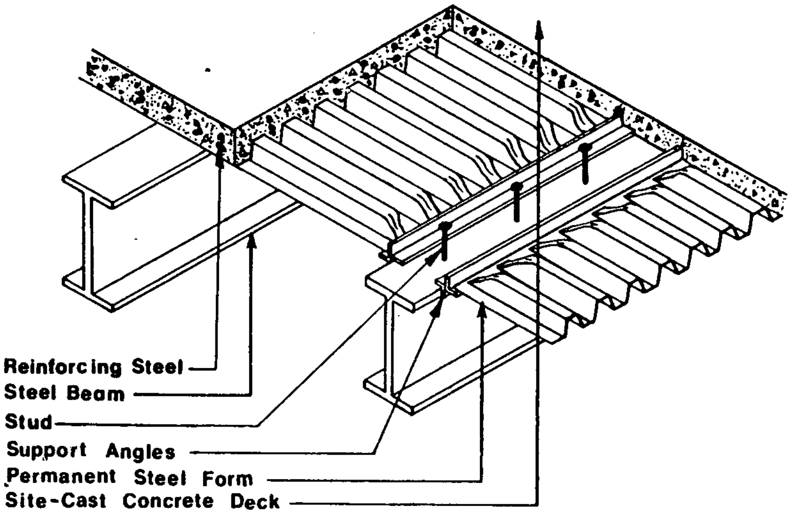
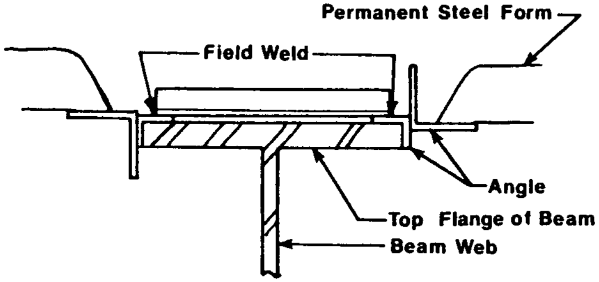


Figure 35. Permanent Steel Forms

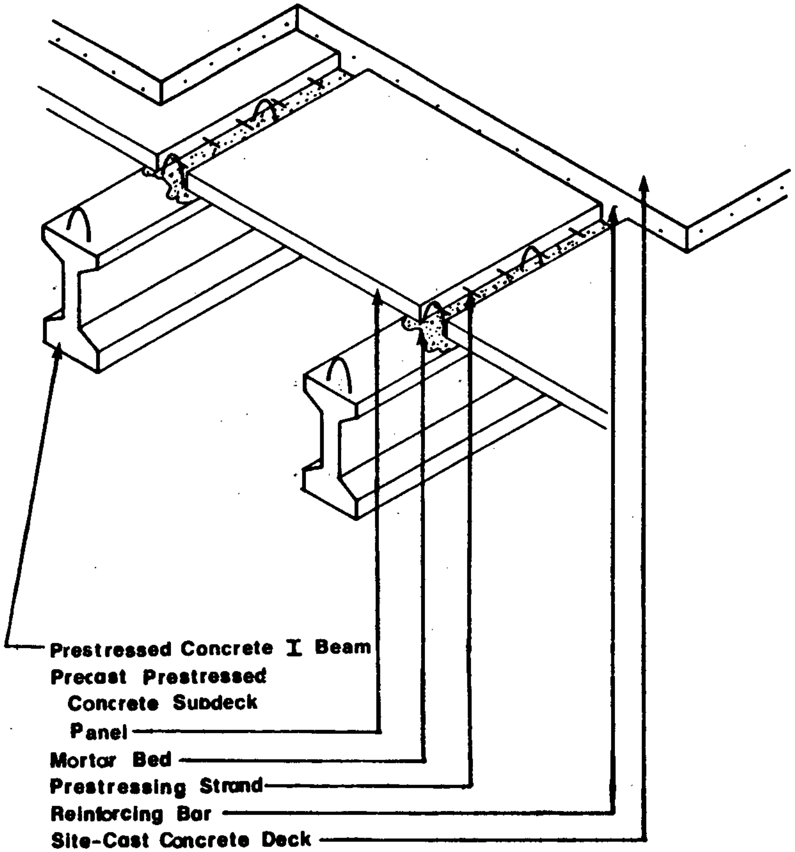


NOTE: Vertical leg downward allows for higher form support elevations. Vertical leg upward allows for lower form support elevations.

Figure 36. Steel Form Connection Detail

SYSTEM NUMBER M4

PAGE 2 OF 3



Prestressed Concrete Subdeck Panels

Figure 37.

NAME OF SYSTEM:

PARAPET AND RAIL SYSTEMS

SYSTEM NUMBER
M-5

PAGE 1 OF 3

DESCRIPTION:

Typical parapet and rail systems suitable for use with most concrete, steel or timber replacement systems.

PROMINENT FEATURES:

A parapet or rail is generally designed to meet Section 1.2.11 of the AASHTO Standard Specifications for Highway Bridges. The post sizes and gauge of bridge rails shown in the following figures are typical. The parapet or rail is in most cases constructed from concrete, steel or timber or some combination of these materials. Aesthetics usually play a role in the choice of materials and the design.

A concrete parapet is generally constructed on a bridge having a concrete deck. The parapet is usually formed and constructed with ready-mix concrete at the site but precast parapets have begun to see limited use in recent years. Steel reinforcement is typically used to anchor the parapet to the concrete deck. See Figures 38 and 39.

Steel and/or timber rails and posts are generally used with bridges having a timber deck. The rail posts may be anchored to the exterior stringer, to the deck, or to both. See Figures 40, 41, and 42.

CASE EXAMPLES:

Examples can be found throughout the United States.

MANUFACTURERS:

Materials are usually available locally.

REFERENCES:

Virginia Department of Highways and Transportation (Reference 32)
Weyerhaeuser Company (Reference 43)
American Institute of Timber Construction (Reference 45)
Virginia Department of Highways and Transportation (Reference 60)
FHWA Report No. RD-77-40 (Reference 61)

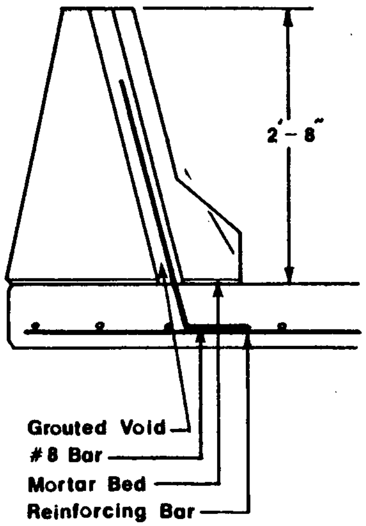


Figure 38. Precast Concrete Parapet

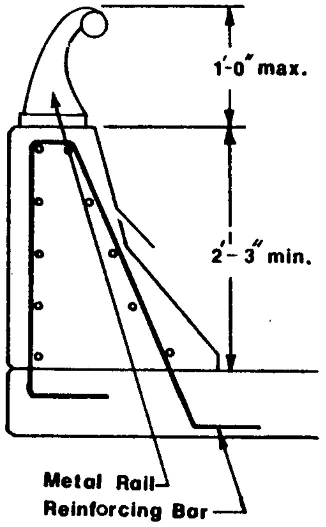
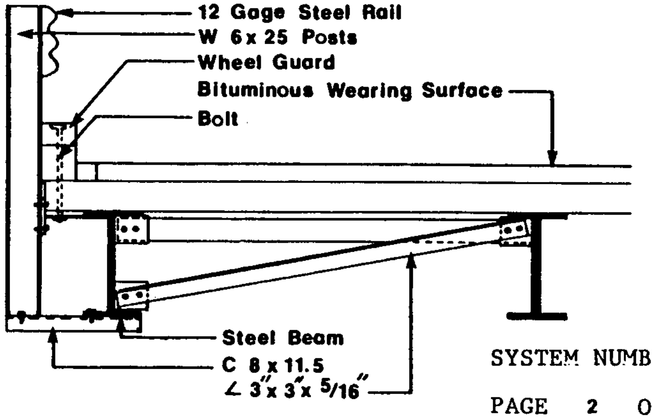


Figure 39. Site Cast Concrete Parapet



SYSTEM NUMBER M 5

PAGE 2 OF 3

Figure 40. Steel Rail and Post Connected to Deck and Exterior Beam

SYSTEM NUMBER **M 5**

PAGE **3** OF **3**

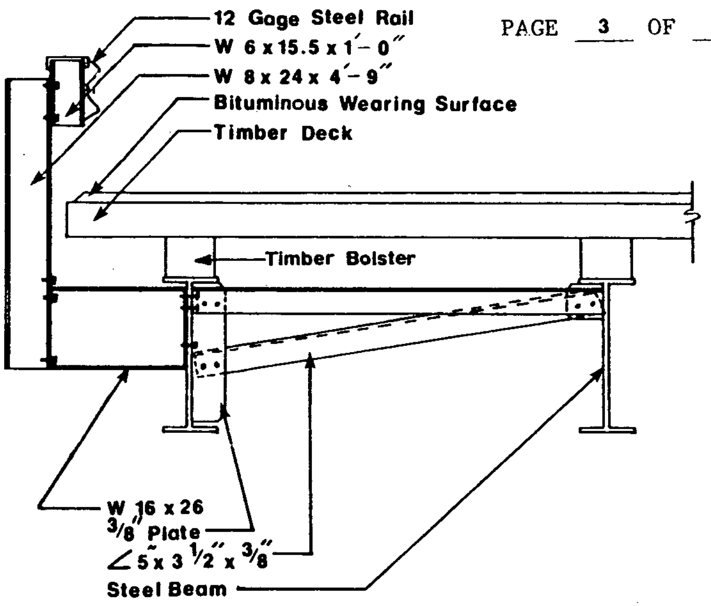


Figure 41. Steel Rail and Post Connected to Exterior Beam

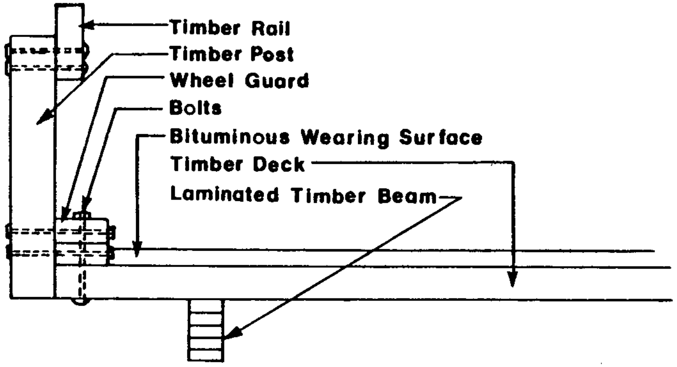


Figure 42. Timber Rail and Post Connected to Deck

NAME OF SYSTEM:	SYSTEM NUMBER
LONG-SPAN, CORRUGATED-METAL, BURIED CONDUITS	M-6
	PAGE 1 OF 2

DESCRIPTION:

Structures are made of corrugated-metal structural plate sections, field assembled in various closed or arch configurations to serve as large culverts or grade separation structures.

PROMINENT FEATURES:

Long span structural plate culverts or grade separation structures made of steel or aluminum are frequently suitable alternatives for small bridges. Maximum span lengths available from the various manufacturers currently range from just under 40 to just over 50 ft., and multiple lines have been used where great waterway openings have been required. These buried structures are covered in Sections 1.9.10 and 2.23 of the current (1977) AASHTO Standard Specifications for Highway Bridges, and an excellent, comprehensive report on them has been published by the FHWA (referenced below). No design capability is usually required of the purchaser beyond the determination of the waterway opening, as the manufacturers commonly check standard designs or design critical structures. Similarly, the presence of a representative of the manufacturer is usually required during construction. Experience on the part of the contractor or agency forces is desirable but not mandatory, as only normal earth moving and compaction procedures and equipment are used.

The AASHTO Specifications require certain minimum geometric and sectional properties and the use of special features such as thrust beams or compaction wings along the edge of the top arch section, soil bins on top of the structure, or transverse ribs. These special features, which are included in the designs of the six major fabricators, aid in compaction during construction and prevent unwanted distortion of the structure.

As is the case with all large, flexible, buried structures proper construction procedures must be followed. Compaction during backfilling is most important in attaining the desired load carrying capacity, and the configuration of the barrel must be held within specified limits.

Assuming that a site will accept a culvert configuration with at least the minimum required cover and that acceptable backfill material is available nearby, considerable economy may be realized. Among the advantages cited by manufacturers are relative ease of delivery in rural areas, savings when the bearing capacity of the subgrade is too poor for economical bridge foundations, and the elimination of deck distress from deicing salts.

NAME OF SYSTEM:	SYSTEM NUMBER
LONG-SPAN, CORRUGATED-METAL, BURIED CONDUITS	M-6
	PAGE 2 OF 2

CASE EXAMPLES:

Over 600 long span, corrugated-metal, buried structures have been built in the United States and Canada since 1960.

MANUFACTURERS:

Armco Steel Corporation, Kaiser Aluminum Company, Republic Steel Corporation, Syro Steel Company, U. S. Steel Corporation, Westeel-Rosco, Ltd. (Canada)

REFERENCES:

Federal Highway Administration Report FHWA-RD-77-131 (Reference 62).

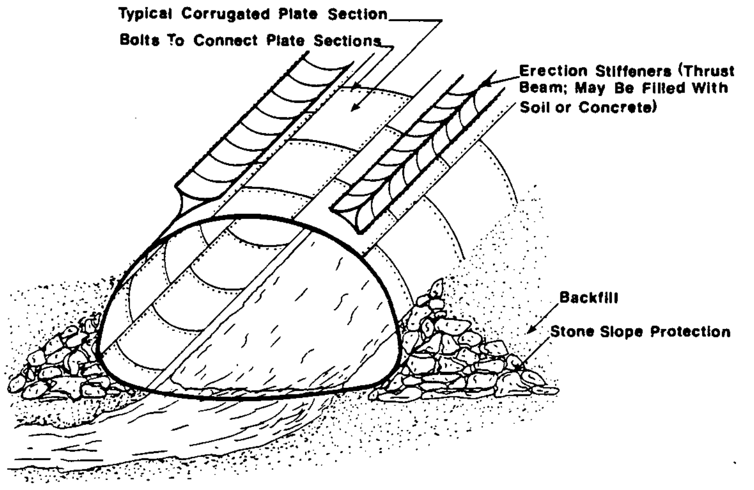


FIGURE 43. Long-Span, Corrugated-Metal, Buried Conduits

NAME OF SYSTEM:

Precast Concrete Arch Bridge

SYSTEM NUMBER

M-7

PAGE 1 OF 2

DESCRIPTION:

Modular precast concrete panels are connected with cast-in-place concrete to form an arched bridge.

PROMINENT FEATURES:

The system is proprietary and marketed under the name "BEBO." Steel arches are temporarily erected at the bridge site to support the standard size precast concrete panels, which are joined together with field welds and cast-in-place concrete. On some occasions, particularly where the arch is wide and therefore many segments are required, it may be economical to cast full length segments so as to eliminate the need for the temporary supports. Conventionaly fill material is compacted over the arch. The system is typically used for spans of less than approximately 50 ft.

CASE EXAMPLES:

The structures have been principally used in West Germany and Switzerland but one bridge has been constructed in Minnesota and others are being considered elsewhere in the United States

MANUFACTURERS:

BEBO - International Heierli & Company, Zurich, Switzerland
Hancock Concrete Products Company, Minneapolis, Minnesota

REFERENCES:

"The Reinforced Concrete Arched Bridge— BEBO System" (Reference 63)
Civil Engineering (Refernece 64)

SYSTEM NUMBER M-7 PAGE 2 OF 2

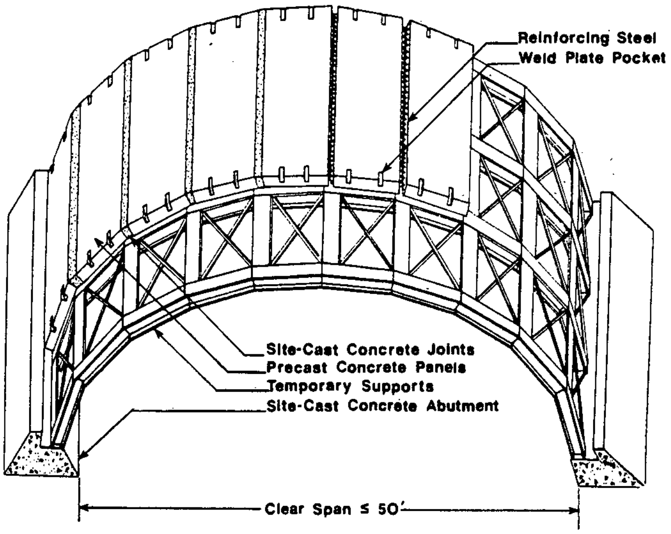


FIGURE 44. Precast Concrete Arch Bridge

NAME OF SYSTEM:

Single and Multiple Culverts of
Aluminum, Concrete, and Steel

SYSTEM NUMBER

M-8

PAGE 1 OF 2

DESCRIPTION:
One or more pipes of aluminum, concrete, or steel are placed so as to provide adequate drainage beneath a roadway.

PROMINENT FEATURES: Being prefabricated, culverts can be installed in a roadway in a short period of time. Metal culverts having a diameter less than about 5 ft differ from the long-span structural plate culverts (see System M-6) in that little on-site assembly is required and no special bracing is required in backfilling operations. Sections of metal culvert are usually laid end to end and coupled in a variety of ways, usually with bolted bands, hugger connections, or sleeve joints. A tongue and groove joint or sleeve is typically used to connect adjacent sections of concrete pipe or culvert. For diameters greater than about 10 ft, the metal culverts are usually assembled at the site from structural plate sections. Precast concrete U-shaped sections (no bottom) have been fabricated to accommodate spans up to about 16 ft. The precast concrete units are placed end to end on site-cast footings or floors (see Fig. 45). End walls that provide added stability and help prevent erosion are usually constructed from site-cast concrete, metal sheeting, or stone. The culverts are covered with fill material in a manner prescribed by the manufacturer. The roadway is constructed over the fill material.

Culverts have an advantage over bridges in that construction plans are seldom required, there is no deck to deteriorate, and installation is relatively rapid. The principal disadvantages are that they can restrict flow, they cannot be used on navigable streams, and they deteriorate prematurely in some corrosive environments. Steel culverts can be galvanized or coated with a bituminous material to prevent corrosion.

CASE EXAMPLES:

Numerous case studies of the use of culverts can be found throughout the United States.

MANUFACTURERS:

Manufacturers are located throughout the United States.

REFERENCES:
"RTP Markets Instant Bridges" (Reference 18)
Armco Multi-Plate (Reference 65)
Corrugated Steel Pipe (Reference 66)
American Concrete Pipe Association (Reference 67)
Aluminum Storm Sewers (Reference 68)

NAME OF SYSTEM:

Field-Connected Beams

SYSTEM NUMBER

M-9

PAGE 1 OF 2

DESCRIPTION: Standard, precast, prestressed I-beams or steel beams are connected end to end in the field so as to allow the construction of a bridge with a longer span or larger deck joint spacing than is possible without the field-made connections.

PROMINENT FEATURES:

Without field-made connections the maximum bridge span length and, quite often, the maximum deck joint spacing that can be achieved is controlled by the maximum length or weight of the primary supporting beams that can be transported to the bridge site. For steel I-beams or plate girders used in the construction of a bridge superstructure (see System S-9), it has been common practice in most states for many years to use bolted or welded splice plates to connect the beams end to end so as to provide the desired span length or deck joint spacing (see Fig. 46). Long-span concrete beams could be constructed by providing forms and site casting the concrete beams to achieve the desired span length or deck joint spacings. However, the most popular concrete beams to be used in recent years are precast and prestressed ones such as the standard AASHTO I-beam (see System C-8), and these beams have not been routinely connected end to end in the field. A field-made connection which shows promise has been developed and tested at the University of Illinois (see Fig. 46). The field connection of the I-beam is achieved by supporting the I-beam segments on falsework, splicing the reinforcement between the segments, filling the joint with site-cast concrete, and posttensioning the segments.

CASE EXAMPLES: Numerous case examples of steel beams that have been connected end to end can be found throughout the United States. A prototype two-span bridge incorporating three precast, prestressed I-beam segments was constructed in Illinois in 1973.

MANUFACTURERS:
Steel connections—most steel fabricators
Concrete connections—most precast, prestressed concrete producers that can provide on-site posttensioning

REFERENCES:
U.S. Department of Transportation (Reference 3)
U.S. Department of Transportation (Reference 41)
Fadl, A. I., Gamble, W. L., and Mohraz, B. (Reference 69)

SYSTEM NUMBER

M-8

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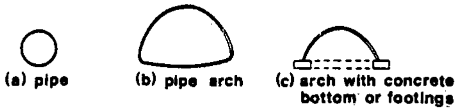
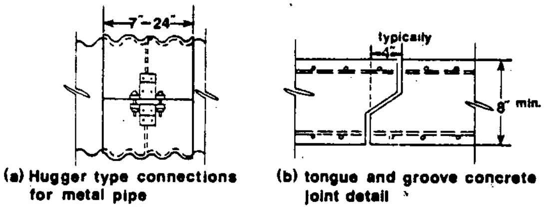
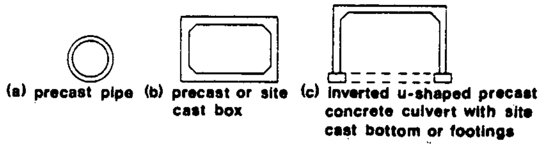


Typical Corrugated Metal Configurations



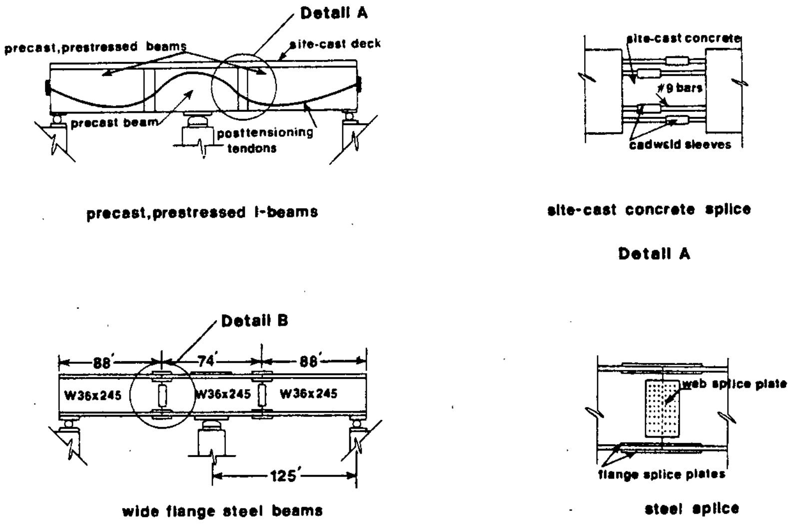
Typical Connections For Culverts



Typical Concrete Configurations

FIGURE 45. Single Culverts

SYSTEM NUMBER M-9 PAGE 2 OF 2



precast,prestressed I-beams

site-cast concrete splice

Detail A

wide flange steel beams

steel splice

Detail B

FIGURE 46. Field-Connected Beams

NAME OF SYSTEM: Short-Span Segmental Construction	SYSTEM NUMBER C-9
	PAGE 1 OF 3

DESCRIPTION:

Precast or site-cast concrete segments are tied together by posttensioning.

PROMINENT FEATURES:

Standard concrete boxes incorporating the full roadway width are precast or site-cast in a convenient length and posttensioned in the longitudinal direction to provide a continuous monolithic concrete superstructure. Although segmental construction has been popular in Europe for two decades, it began to gain popularity in the U.S. only in the late 1970's. It has been used primarily for medium to long (150 x 400 - ft spans) multiple-span bridges,but recent studies have indicated that the concept can be economical for use in constructing a typical three-span grade crossing (73). Economy requires that all the segments be cast in the same form and, if precast, that match casting generally be required. For short-span construction, the segments would probably be erected on falsework or constructed span by span on a supporting truss as shown in Figure 47. For longer span bridges, the most popular method of erection is the balanced cantilever method, but the incremental launching method and the progressive placing method have also been used. Posttensioning requirements are much simpler for short spans. A completed bridge constructed by segmental construction is shown in Figure 48.

The advantage of the system is that the shapes of the segments lend themselves to use in a variety of span lengths. Economy favors use of the same form to construct segments for many bridges. The basic disadvantages of the system are the investment in forms, the large equipment required for erection, and the engineering expertise required for a satisfactory job.

CASE EXAMPLES: Examples of medium- to long-span segmental construction can be found in Texas, Indiana, Colorado, Pennsylvania, Washington, Illionis, and Kentucky. The best example of what might be considered short-span construction is the bridge being constructed in Long Key, Florida, which will have 101 spans 118 ft in length.

MANUFACTURERS:

Some specialized contractors and consultants should be able to provide a satisfactory structure.

REFERENCES:
PCI Journal (Reference 70)
Long Key Bridge (Reference 71)
Bridge Report (Reference 72)
Precast Segmental Box Girder Bridge Manual (Reference 73)

SYSTEM NUMBER
C-9

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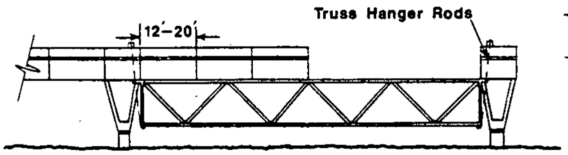
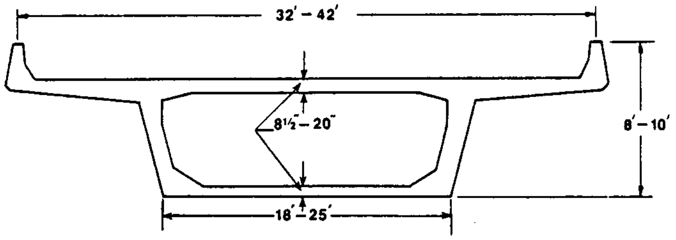


ASSEMBLY TRUSS



TYPICAL SEGMENT

FIGURE 47. Short-Span Segmental Construction

SYSTEM NUMBER
C-9

PAGE 3 OF 3

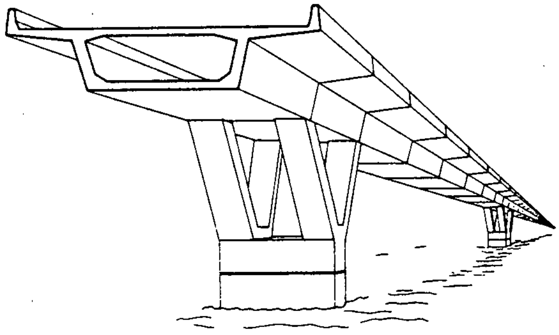


FIGURE 48. Segmental Construction – Long Key Bridge, Florida

APPENDIX A REFERENCES

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2. Louisiana Dept. of Hwys., "Standard Plans for Precast Concrete Slab Units" (1974).
3. Federal Highway Administration, "Standard Plans for Highway Bridges—Vol. 1, Concrete Superstructures" (Aug. 1968).
4. Virginia Prestressed Concrete Association, "New Approaches in Prestressed, Precast Concrete for Bridge Superstructure Construction in Virginia" (Aug. 1973).
5. "County Highway Department Casts Its Own Prestressed Bridge Beams." *Public Works* (June 1975) pp. 84-85.
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8. Central Premix Concrete Company, "Instant Bridges." Spokane, Wash.
9. Mississippi State Highway Department, "Standard Plans for Precast Posttensioned Channel Bridge Spans." Jackson, Miss. (June 1969).
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11. SALMONS, J. R., "Design and Construction of a Precast-Prestressed Composite Bridge System." FCP Conference, Atlanta, Ga. (Oct. 1977).
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13. NAIRN, R. D., "Precast Trapezoidal Beams for Bridges." Ontario Precast Concrete Manufacturers Association.
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APPENDIX B

SUMMARY OF RESPONSE TO QUESTIONNAIRE

QUESTIONNAIRE
on
Prefabricated Bridge Elements and Systems

1) Transportation Department 36

2) Name of individual completing questionnaire

3) Position of individual

4) Telephone number

5) How many bridges are under your jurisdiction? 228,677

For Questions 6 to 16, answers in terms of numbers of bridges are requested but approximate percentages in terms of total number of bridges or total deck surface area may be used if numbers are not known.

6) How many bridges contain prefabricated components? 34,983

7) How many bridges are completely prefabricated? 1,197

For questions 8 to 23, use the spaces g), h), i), and j) to note other types of prefabricated bridges that are frequently used.

8) How many bridges contain the indicated type of prefabricated element?

Type of Element	Number of Bridges
a) Precast concrete slab span (Fig. 1)	3,002
b) Precast box beam (Fig. 2)	5,948
c) Prestressed I-beam (Fig. 8)	18,299
d) Precast deck panel (Fig. 16)	8
e) Permanent bridge-deck form (Fig. 35 & 37)	2,628
f) Precast parapet (Fig. 38)	331
g) Double-tee and channel	4,482
h) Other	97
i)	
j)	

9) How were the prefabricated elements noted in Question 8 used?

(Percent)

Element	To Provide a New Bridge	To Widen a Bridge	To Replace a Bridge	Other
a) Slab span	78	41	70	4
b) Box beam	92	64	72	0
c) I-beam	100	56	74	0
d) Deck panel	17	0	33	50
e) Deck form	85	27	42	8
f) Parapet	80	20	40	30
g) Double-tee & channel	78	11	67	0
h) Other	86	29	43	21
i)				
j)				

10) When were the elements used and what use do you anticipate for the next decade?

(Percent)

Element	Before 1965	1965 through 1974	1975 through 1984	1985 through 1994
a) Slab span	56	74	74	67
b) Box beam	56	80	88	72
c) I-beam	67	97	91	82
d) Deck panel	0	0	86	100
e) Deck form	14	36	91	73
f) Parapet	0	11	89	67
g) Double-tee & channel	11	56	100	78
h) Other	50	36	79	36
i)				
j)				

11) Where were the elements used?

(Percent)

Element	Interstate		Primary		Secondary		Other
	High Volume Traffic	Low or Medium Volume Traffic	High Volume Traffic	Low or Medium Volume Traffic	High Volume Traffic	Low or Medium Volume Traffic	
a) Slab span	27	23	42	65	42	77	
b) Box beam	50	36	59	64	50	86	
c) I-beam	72	66	72	88	50	69	
d) Deck panel	25	0	25	50	0	0	
e) Deck form	60	45	65	85	50	65	
f) Parapet	63	38	13	25	25	38	
g) Double-tee & ch.	38	25	50	75	50	88	
h) Other	42	33	50	75	17	67	
i)							
j)							

12) Why were the elements used?

(Percent)

Element	To Accelerate Construction	To Improve Quality	To Reduce First Cost	To Reduce Life-Cycle Cost	Other
a) Slab span	70	11	67	7	30
b) Box beam	65	15	81	8	19
c) I-beam	39	9	79	27	15
d) Deck panel	67	0	33	0	0
e) Deck form	71	14	90	14	14
f) Parapet	80	10	80	10	10
g) Double-tee & channel	89	33	56	44	33
h) Other	60	13	80	20	47
i)					
j)					

13) How far from the bridge were the elements fabricated?

(Percent)

Element	< 1 mile	1 to 50 miles	51 to 200 miles	>200 miles
a) Slab span	13	79	75	25
b) Box beam	10	67	90	29
c) I-beam	10	65	90	32
d) Deck panel	0	50	75	0
e) Deck form	6	65	59	47
f) Parapet	0	71	86	14
g) Double-tee & ch.	13	75	100	50
h) Other	15	38	46	46
i)				
j)				

14) What type of forms or equipment were required?

(Percent)

Element	Special, One-Time Use	Versatile, Multiple-Project Use	More Versatile, Multiple Purpose	Other
a) Slab span	22	72	22	0
b) Box beam	11	84	26	0
c) I-beam	4	78	30	0
d) Deck panel	67	0	33	0
e) Deck form	23	69	38	0
f) Parapet	0	100	17	0
g) Double-tee & channel	0	75	25	0
h) Other	38	75	13	13
i)				
j)				

15) What type of labor was used for the fabrication of the elements? (Percent)

Element	Precast Concrete Producer	Steel Fabricator	Contractor	State or Local Crews	Other
a) Slab span	92	0	24	12	0
b) Box beam	100	0	13	4	0
c) I-beam	100	0	9	0	0
d) Deck panel	100	0	17	0	0
e) Deck form	55	59	5	0	0
f) Parapet	100	0	13	0	0
g) Double-tee & ch.	100	0	11	0	0
h) Other	64	7	21	0	14
i)					
j)					

16) What type of labor was used for the installation of the elements? (Percent)

Element	Precast Concrete Producer	Steel Fabricator	Contractor	State or Local Crews	Other
a) Slab span	30	0	96	26	0
b) Box beam	33	5	95	24	0
c) I-beam	23	0	97	3	0
d) Deck panel	0	0	100	0	0
e) Deck form	10	10	100	5	0
f) Parapet	13	0	100	13	0
g) Double-tee & ch.	50	0	88	38	0
h) Other	23	0	92	0	0
i)					
j)					

17) How were the elements transported from the plant to the site?

(Percent)

Element	Description of Transportation			
	Truck	Rail	Barge	Other
a) Slab span	96	4	8	4
b) Box beam	95	9	5	5
c) I-beam	94	14	9	3
d) Deck panel	83	0	17	0
e) Deck form	95	10	5	5
f) Parapet	100	13	13	0
g) Double-tee & ch.	100	0	0	0
h) Other	92	8	23	8
i)				
j)				

18) Who does the maintenance and what type of maintenance is required for the elements?

(Percent)

Element	Type of Labor		Type of Maintenance					
	State Force	Contract	None	Patch	Overlay	Joint	Connection	Other
a) Slab span	95	20	40	25	15	15	5	20
b) Box beam	94	22	62	14	10	5	5	24
c) I-beam	95	18	71	14	4	7	0	21
d) Deck panel	83	33	60	20	20	0	0	0
e) Deck form	92	17	80	13	7	0	0	7
f) Parapet	86	29	80	0	0	0	20	0
g) Double-tee & ch.	100	20	88	13	0	13	0	13
h) Other	63	50	43	14	14	14	29	14
i)								
j)								

19) What is the cost in dollars per ft^2 of deck surface for the elements?

Element	First Cost	Life-Cycle Cost	Annual Maintenance Cost	Other
a) Slab span	$ 26.11	26.11	-	-
b) Box beam	25.64	-	0	-
c) I-beam	21.11	21.81	0	-
d) Deck panel	19.34	-	-	-
e) Deck form	3.00	-	-	-
f) Parapet	2.67	-	-	-
g) Double-tee & ch.	19.30	19.30	-	-
h) Other	23.40	-	0	-
i)				
j)				

20) What is the cost in dollars per ft^2 of deck surface for the most commonly used alternative to the elements?

Element	Alternative	First Cost	Life-Cycle Cost	Annual Maintenance Cost
a) Slab span	S.B., CIP Deck	$ 25.02	-	-
b) Box beam	S.B., CIP Deck	29.61	-	-
c) I-beam	S.B., CIP Deck	24.87	-	-
d) Deck panel	CIP Concrete	17.89	-	-
e) Deck form	CIP Concrete	3.50	-	-
f) Parapet	CIP Concrete	2.54	-	-
g) Double-tee & channel	S.B., CIP Deck	27.27	-	-
h)				
i)				
j)				

21) What is the lane-closure time in days per ft of lane required for the installation of elements and alternatives noted in Question 20?

Element	Lane Closure Time	Alternative Lane Closure Time
a) Slab span	17 to 100% of alternative	
b) Box beam	17 to 100% of alternative	
c) I-beam	Same because CIP deck required	
d) Deck panel	—	
e) Deck form	Same because CIP deck required	
f) Parapet	—	
g) Double-tee & ch.	Faster than CIP concrete	
h) Other	—	
i)		
j)		

22) What problems have been eliminated so that the elements have been used more frequently?

Element	Problem						Solution
	None	Quality	First Cost	Experience	Std.	Other	
a) Slab span	36	21	7	7	7	21	(See text)
b) Box beam	30	20	20	6	10	20	" "
c) I-beam	33	27	13	7	7	20	" "
d) Deck panel	0	0	50	50	0	0	" "
e) Deck form	33	33	11	11	11	0	" "
f) Parapet	0	0	33	67	33	0	" "
g) Double-tee/ch.	40	20	20	20	0	0	" "
h)							
i)							
j)							

23) What problems have continued such that the elements have not been used extensively?

Element	Unresolved Problems					
	First Cost	None	Length/Weight	Deterioration/Corrosion	Supply	Connections
a) Slab span	50	20	10	15	10	5
b) Box beam	47	21	11	16	11	0
c) I-beam	43	35	17	0	9	0
d) Deck panel	40	20	20	0	0	0
e) Deck form	38	38	0	0	8	0
f) Parapet	17	17	0	17	0	83
g) Double-tee & ch.	40	40	0	20	0	0
h)						
i)						
j)						

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