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Evaluation of Bridge Replacement Alternatives for the County Bridge System

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Iowa Department of Transportation Highway Division,
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report

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ABSTRACT

Recent reports have indicated that 23.5 percent of the nation's highway bridges are structurally deficient and 17.7 percent are functionally obsolete. A significant number of these bridges are on the Iowa county road system. The objective of the investigation described in this report was to identify, review and evaluate replacement bridges currently being used by various counties in Iowa and surrounding states. Iowa county engineers, county engineers in neighboring states as well as private manufacturers of bridge components, and regional precast/prestressed concrete manufacturers were contacted to determine the most common replacement bridge types being used. Depending upon the findings of the review, possible improvements and/or new replacement bridge systems were to be proposed.

A questionnaire was developed and sent to county engineers in Iowa and several counties in surrounding states. The results of the questionnaire showed that the most common replacement bridges in Iowa are the continuous concrete slab and prestressed concrete bridges. The primary reason these types are used is because of the availability of standard designs and because of their ease of maintenance. Counties seldom construct these types of bridges using their own labor forces, but instead contract the work. However, county forces are used to construct steel stringer, precast reinforced concrete and timber bridges. In general, 69 percent of the counties indicate an ability and willingness to use their own forces to design and construct relatively short span bridges (i.e., 40 ft or less) provided the construction procedures are relatively simple.

Several unique replacement bridge types used in Iowa that are constructed by county forces are documented and presented in this report. Sufficient details are provided to allow county engineers to determine if some of these bridges could be used to resolve some of their own replacement bridge problems. Where possible, cost information has also been provided. Each of

these bridge types were evaluated for various criteria (e.g., cost effectiveness, conformance to AASHTO standards, range of sizes, etc.) by a panel of four Iowa county engineers; a summary of this critique is included.

After evaluating the questionnaire responses from the counties and evaluating the various bridge replacement concepts currently in use, one new bridge replacement concept and one modification of a current Iowa county bridge replacement concept were developed. Both of these concepts would utilize county labor forces.

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1. INTRODUCTION

A significant number of bridges on Iowa's county road system are in need of extensive rehabilitation/strengthening or replacement due to structural and functional deficiencies [1]. If replacement is determined to be more economical than rehabilitation/strengthening for certain sites, the right replacement alternative must be selected. To assist county engineers in making such decisions, there is a need for more information on available bridge replacement alternatives and criteria for determining the most economic alternative for a given location.

1.1 Need for study

Although there are numerous bridge replacement alternatives, the choice available to a county engineer is generally limited by various technical and economic constraints. In the past, there have been several investigations performed by various agencies on short span bridge replacement alternatives. However, some of problems unique to counties have not been addressed. The next chapter discusses the related literature in detail. Most counties must make difficult economic decisions when considering bridge replacement as an alternative. Their budgets severely limit the number of bridges that can be replaced in a given year. A large number of counties do not have "bridge crews" or the required equipment to replace and construct bridges [2,3]. This requires them to contract their replacement projects which adds to the project cost. Costs can be significantly reduced by selecting replacement alternatives that can be designed and constructed by local work forces. Thus, the available replacement alternatives need to be evaluated in terms of constructability, durability, and economics from the point of view of the county. This is of special interest to counties in Iowa because Iowa is one of the sixteen states in which the federal government has no bridge maintenance responsibilities [4]. Furthermore, Iowa also has the highest percentage of rural bridge maintenance responsibilities assigned to the county level, thus implying extensive participation of the county in maintenance functions [4]. A recent questionnaire sent to county engineers inquired about the need and interest in a study to evaluate replacement bridges. Over 76 percent of the respondents replied that such a study would be beneficial or very beneficial. Thus, there is a need to study not only the suitability of various bridge replacement alternatives for use on the county system but also to provide information to assist the county engineer in making the right choice.

1.2 Objective and scope

The primary objective of the study was to identify, review and evaluate replacement bridges currently being used on secondary roads in Iowa and surrounding states. County engineers in Iowa and surrounding states and manufacturers/fabricators of bridges/bridge components were to be contacted to obtain information on bridge replacement alternatives that are currently being used. Depending on the information obtained from the above sources, improvements to the existing alternatives and/or a totally new system may be proposed.

1.3 Research program

The research program is comprised of three distinct phases; data collection, data analysis, and presentation/summarization. To assist the research team with the various stages of the investigation, a project advisory committee (PAC) was formed. The advisory committee consisted of the following county engineers:

Del S. Jespersen :	Story County Engineer
Ed D. Tice :	Appanoose County Engineer
Mark J. Nahra :	Cedar County Engineer
Royce J. Fichtner :	Marshall County Engineer

The tasks performed in each phase of the project are briefly described in the following paragraphs.

1.3.1 Phase I: The initial phase consisted of gathering information and data on existing replacement systems. Since minimal information exists on replacement bridges that are currently being used in various parts of the state, it was decided to collect data through questionnaires and a literature review. The details of the literature review performed are presented in the next chapter. To obtain the desired information, two questionnaires were developed: Questionnaire 1 was for county engineers and Questionnaire 2 was for manufacturers and fabricators of replacement systems. Questionnaire 1 was sent to all county engineers in Iowa and to 49 counties in the neighboring states. Similarly, Questionnaire 2 was sent to 45 manufacturers and bridge fabricators in Iowa and surrounding states. The questionnaires were designed to obtain information on the structural, economic and constructability aspects of the substructure and superstructure of various replacement systems.

1.3.2 Phase II: Once the data from the various sources were obtained, criteria were developed to determine the effectiveness of the replacement systems. The various replacement systems were evaluated on the basis of the following items:

- Initial cost per square foot
- Ease of construction by county forces and equipment.
- Ease of construction by contractors.
- Ease of inspection.
- Conformance to AASHTO standards.
- Extent of maintenance required.
- Range of available spans and sizes.

The project advisory committee was consulted to assist in developing the above criteria for evaluation of the bridge types. Based on the findings of the first two phases of this investigation, one new system and one modification to an existing system have been proposed. These are presented in Chapter 5.

1.3.3 Phase III: The findings of this project have been summarized in this final report. Information on the structural and economic aspects of various replacement alternatives has been provided. Various conventional replacement systems are presented and the systems have been compared. General information on the proposed system and proposed modification have been included.

The remaining chapters of this report describe in detail the various phases of the research project. Chapter 2 details the literature survey conducted. The questionnaire survey and results are discussed in Chapter 3. Details of the various bridge replacement alternatives available for county use are described in Chapter 4. The following chapter (Chapter 5) describes the proposed replacement systems and discusses their relative advantages and disadvantages.

2. LITERATURE SURVEY

A literature search was conducted to gather data about various bridge replacement alternatives for low volume bridges. There have been quite a few articles and reports about the applicability of different types of bridge structures for low volume applications. However, compilations have seldom rated the various bridge types in terms comparative construction ease from the county's point of view.

The problem of replacement alternatives for low volume bridges was recognized and prestressed concrete alternatives were suggested by Tokerud [5] in 1979. The paper lists various precast prestressed bridge types ranging from solid/voided slabs to multi-stem tees and bulb tees. Each type is economical in a specific span range. Additional information on these alternatives is presented in Chapter 3. The paper also contends that work by in-house personnel works out considerably cheaper than contracting the project. Tokerud recommends using culverts for shorter spans wherever possible and the omission of curbs wherever possible. The average unit costs of these bridge types used in the Northwest range from $24 to $30 per sq.ft. Please note that these are 1979 values.

A study conducted by the University of West Virginia in 1980 (NCHRP Report 222) reports on the various bridge replacement alternatives available for low volume roads [6]. The study lists eight different concrete bridge replacement alternatives. Nine types of steel bridges and four types of timber bridges have also been documented along with other miscellaneous bridge elements such as abutments, piles, permanent deck forms and corrugated metal pipe systems. Most of the concrete bridge types are prestressed concrete. These are mostly repeats of those listed in Ref. 5. Precast reinforced concrete slabs were also presented. The various types of steel structures presented are listed below:

1. Prefabricated Steel Bridges
    a. Prefabricated Steel Tee-Shaped Units
    b. Prefabricated Steel Rectangular Units
    c. Steel Bridge Plank on Plate Girders
    d. Treated Timber Deck on Steel Stringers
2. Temporary Bridges
3. Precast Deck Slabs on Steel Beams
4. Laminated Timber Deck on Steel Beams
5. Timber Plank Deck on Steel Beams
6. Steel Grid Deck on Steel Beams
7. Bituminous Concrete Deck on Steel Planks
8. Orthotropic Steel Plate Deck
9. Site-Cast Deck on Steel Beams

All the above steel bridge types have been used in various parts of United States except (1.a.) and (1.b.). These two exceptions have been used satisfactorily in Europe. The timber structures documented are glulam timber bridges, nail laminated timber bridges, solid sawn timber beams and plywood decking surfaces. The report provides brief descriptions and drawings for each of the bridge types, however, no cost information is provided.

A follow up report to Ref. 6. (NCHRP Report 243) describes some additional bridge replacement alternatives [7]. One of the replacement systems suggested was a segmentally constructed concrete box girder bridge for short spans. These are full width concrete boxes that are match cast in convenient lengths and post-tensioned longitudinally. Precast concrete arch bridges, multiple culverts of aluminum, concrete and steel were also suggested. Field connected beams in both steel and prestressed concrete were also suggested as possible replacement alternatives. The construction procedure for the precast arches consists of erecting temporary steel arches on site, placing the standard size precast panels and welding the panels together with field welds. The system has been used extensively in Europe. One instance of use of the system in the United States is in Minneapolis, MN [8].

GangaRao and Zelina [9] have reported on the various replacement alternatives for low volume road bridges. These include prestressed and precast concrete slabs and beams. The prestressed beams include T-beams, bulb tees, I-beams and box beams. Steel systems including cast-in-place deck and steel stringers and steel stringers with timber decks have been suggested. The article recommends precast voided slabs and steel stringer/timber deck bridges for the 30 ft span range. Jointless bridges (integral abutments) have been recommended for the 60 ft and the 100 ft ranges. Cast-in-place reinforced concrete is not recommended as a suitable replacement alternative for low-volume roads, because it is very labor-intensive and therefore not as cost effective. In the short span range (30 ft), timber deck-steel stringer bridges and prestressed voided slabs are the most cost-effective, whereas glulam bridges are considerably more expensive. In the medium span range (60 ft), prestressed deck-steel stringer bridges are listed as the least expensive, while glulam bridges are considered the most expensive. In the medium span range, deck bulb tees and box beams are also reported to be cost-effective. In the 100 ft span range, prestressed deck-steel stringer bridges are reported to be more cost-effective than cast-in-place deck-steel stringer bridges. The unit costs of most of the suggested bridge types from Ref. 9 are presented in Table 2.1.

Table 2.1. List of bridge types and associated costs for the year 1988 as listed in Ref. 9.

Bridge Type	Span, ft	Number of beams	Weight, psf	Cost, $/sq.ft
Timber deck-steel stringer	30	4	31	35
Glulam deck-steel stringer	30	4	44	47
Glulam deck-glulam stringer	30	4	47	53
Prestressed voided slab	30	6	148	35
Cast-in-place deck-steel stringer	60	4	109	50
Glulam deck-glulam stringer	60	5	67	66
Prestressed panels-steel stringer	60	4	109	41
Grid deck-steel stringer	60	6	70	61
Cast-in-place deck-I beam	60	3	166	49
Decked bulb T	60	5	154	44
Box beam	60	6	196	46
Cast-in-place deck-steel stringer	100	5	149	80
Prestressed deck-steel stringer	100	5	149	69

Construction of a precast arch-culvert system for a 50 ft span (height of 10 ft) using in-house work forces reduced costs by one-half in a Litchfield Co., Connecticut replacement project[10]. The necessary equipment was rented for use by county personnel. Precast arch units similar to the Con-span system, and corresponding spandrel units made up the superstructure. These units were fabricated by a precaster. The bridge consisted of four precast arch units that were positioned on cast-in-place footings using a rented 140 ton crane. The total project cost was $235,000 (including equipment, in-house labor and overhead) versus the bid price of $450,000.

Albany County, NY has used prefabricated welded Warren truss systems as replacement alternatives [11] for low volume road applications. The system, designed by the US/Ohio Bridge Corporation of Cambridge, Ohio, was used when the time of construction had to be minimum. Rapid installation of the system was the most important reason for choosing the alternative. County forces prepare the existing substructure (if it is in good condition) for the new welded truss system, while the erection of the superstructure is contracted. Demolition of the existing structure, placing the backwalls, backfilling, and preparing the necessary approaches are also done by county forces. The bridge deck is made of timber with an optional asphalt overlay. The cost per square foot was $60.00 (1990 cost figure).

Non-prestressed 'double tee' sections developed by the Center of Local Technology, Oklahoma State University, has been extensively used as a replacement alternative of Daviess County, IN [12]. The county casts these bridge girders during the slack time of the year. Units are transported to site during summer and set on the abutments. Adjacent units are connected to each other at the third points using 1 in. diameter threaded rods. The design is expected to save the county one half-million tax dollars in the next ten years.

A study conducted in the northern New England region (New Hampshire, Vermont and Maine) compared the costs of timber bridge spans, steel stringer-concrete deck bridges, and prestressed concrete bridges [13]. Cost estimates were obtained from general contractors and from timber suppliers for 20 ft, 40 ft, and 60 ft spans. The data from the contractors indicated that timber was cost competitive with steel/concrete bridges and was less expensive than prestressed concrete bridges for all span ranges. However, data from the timber bridge suppliers showed initial cost advantages for timber over both steel stringer-concrete deck and prestressed concrete. The study dealt only with superstructure costs. Furthermore, lack of data regarding service lives and maintenance costs precluded a life-cycle cost analysis. Therefore only initial costs were compared.

A study conducted by Fereig and Smith [14] proposes a method for a preliminary economical design of prestressed concrete bridges. The method evaluates the most economical choice of superstructure (among prestressed sections, i.e., I-beams, voided slabs, box sections, etc.) for a particular span, width and deck thickness. Economical girder choices for different spans, ranging between 20 ft and 150 ft are presented.

The economic and structural performances of various types of short span bridge replacement structures that were built between 1973 and 1983 in the state of Minnesota were compared in a study by Shirole and Hill [15]. The study suggests a significant shift in preferences from labor-intensive and time consuming bridge types such as reinforced concrete bridges to timber and prestressed concrete prefabricated bridges. Steel structures have been used more on state trunk roads than on non-trunk highways. They also have been preferred in cases of large skew or curved spans. Prestressed concrete structures have also been used extensively. These are reported to cost 15 - 20 percent less than the corresponding steel structures. Double tees, bulb tees and quad tees have been very popular. Timber structures have been used on county and local road systems on short spans. These timber structures have been preferred mostly because of low maintenance problems. Timber slabs were found to be preferred over beam sections; these costs were found to be comparable to prestressed concrete sections.

Exodermic bridge decks have been used as a deck replacement alternatives even in short span bridges [16]. An exodermic deck is an unfilled, composite, steel grid deck, that utilizes a lower prefabricated steel grid with an upper reinforced concrete slab. Composite action is achieved by steel members that extend from the steel grid into the concrete slab. The decks are lightweight, can be erected rapidly and simplify construction staging. Using exodermic decks as the entire bridge for spans up to 40 ft has been suggested by Bettigole [16].

A literature compilation by Hegarty et. al [17] has reviewed cost and design scenarios among concrete, steel and timber bridges. Prestressed, precast concrete and precast deck bridges were among the recommended alternatives. Timber bridges, especially glulam timber is also recommended for low volume applications. The article notes that steel grid decks, although not recommended for high traffic and high speed applications, might be suitable for low volume applications. This is essentially because of less probability of failure of the diagonals of the steel grid in low volume applications. Furthermore, the problem due to low skid resistance of steel grids is mitigated by low speeds associated with low volume bridges.

A new folded plate bridge culvert system has been developed by the Department of Civil Engineering, University of Nebraska, Lincoln [18]. The system consists of a concrete folded plate structure spanning transverse to the roadway across two end walls. These end walls span longitudinally and are supported at the ends on cast-in-place concrete piers. Preliminary cost evaluations have indicated that the system will cost 20 percent less than a conventional twin box culvert. The efficiency of the system arises from the efficient increase in structural depth and reduced dead load. Other benefits include reduced construction time, economy and ease of construction.

A study conducted by the Bridge Engineering Center at Iowa State University, Ames, IA has compiled a list of various bridge types that are suitable for low volume applications [4]. The approximate costs of the various bridge types and brief descriptions of the bridge types are provided. The list of replacement types includes precast culverts (the Conspan system), Air formed arch culverts (briefly described in Chapter 3 of this report), Welded truss bridges and the Multiple tee-beam bridge developed by Oklahoma State University [8]. Various prestressed precast bridge types, the INVERSET system (described in Chapter 3 of this report), Corrugated metal pipe culverts and Low water stream crossings are also included, as are several types of Timber bridges-Stress laminated timber bridges, Glulam timber beam bridges and Glulam panel deck bridges. Spreadsheets for the design by AASHTO standards of the above three types of timber bridge types have also been included.

3. FINDINGS OF SURVEY

With the assistance of the PAC, questionnaires were developed, requesting information from county engineers and bridge manufacturers/fabricators on bridge replacement systems. The questionnaires were designed to obtain information on all the relevant criteria which were used to evaluate the alternatives. Questionnaire 1 was developed for the county engineers. Questionnaire 2, modified slightly from the one sent to the counties, was developed to obtain information from manufacturers/fabricators of bridge components. A sample of the cover letter sent to county engineers with the questionnaires and Questionnaire 1 are included in the Appendix. In an attempt to improve the response rate, the questionnaires sent to counties only requested information on two replacement projects which the respondent would consider representative of recent replacements. Thus, representative information was obtained rather than data and information on all recent replacements. After receiving the responses, in the opinion of the research team, the procedure did not statistically skew the data.

The questionnaire was sent to all the 99 counties in Iowa and to 49 surrounding counties in the neighboring states of South Dakota(2), Minnesota(9), Illinois(6), Nebraska(15), Missouri(6) and Wisconsin(11). The numbers in parentheses indicate the number of questionnaires sent to each state. Corresponding questionnaires (Questionnaire 2) were also sent to 45 fabricators of replacement alternatives. Reminders were also sent to 60 of the counties that did not respond by the first due date. The response from the counties in Iowa was 53 percent (i.e. 52 of the counties responded). There was poor response from the counties outside Iowa (11 responses) and from the manufacturers/fabricators (10 responses). The majority of the information was obtained from the questionnaires returned by the Iowa counties. In the following sections, the responses to the different parts of the questionnaires are summarized.

3.1 Reasons for bridge replacement

The questionnaire inquired about the reasons why various bridges had been replaced. The majority of the responses were in one or more of the following three categories: insufficient load capacity, excessive deterioration, or inadequate roadway width. In several of the responses received, more than one reason was given for replacing a given bridge. Some bridges however were replaced because of severe flood damage, and one response indicated severe channel erosion as the reason for replacement. Table 3.1 presents the number and percentage of responses for each of the categories. Percentages given in this table were determined by taking the number of a particular reason divided by the total number of responses received. For example, 41 of the 53 (77.3 percent) respondents indicated insufficient load capacity as a reason for replacing their bridges. As many respondents gave several reasons for replacing a given bridge, the percentages in Table 3.1 do not total 100 percent.

3.2 Bridge replacement types

The responses from counties in Iowa were analyzed to determine the various bridge replacement alternatives that have been used. Shown in Table 3.2 are the various replacement alternatives that were noted in the responses received. Also shown in this table are the number of applications of each alternative, the frequency each alternative was used (reported as a percentage), and the code used in this report for the various replacement alternatives. Continuous concrete slab bridges were found to be the most commonly used replacement alternative. Thirty six percent (33 responses) of the replaced bridges were found to be of this type. The next chapter discusses the characteristics of this type of bridge in detail. Prestressed concrete bridges were second with 31

Table 3.1. Reasons for replacing various bridges (questionnaire data).

Replacement reason	Number of responses	Percentage of responses
Insufficient load capacity	41	77.3
Excessive deterioration	36	69.8
Low roadway width	35	66.0
Severe floor damage	6	11.3
Severe channel erosion	1	1.9

Table 3.2. Breakdown of replacement bridge types - Iowa counties.

Bridge Type	Code	Number	Percentage
Continuous Concrete Slab	C R/C S	33	35.9
Prestressed Concrete Girder	P/C	29	31.5
Reinforced Concrete Culvert	R/C CU	16	17.4
Steel Stringer-Concrete Deck	STS	4	4.3
Timber Stringer	TIMB	4	4.3
Reinforced Concrete Girder	R/C G	3	3.3
Corrugated Metal Pipe Culvert	CMP	2	2.2
Low Water Stream Crossing	LWSC	1	1.1

percent (29 responses). These were all standard precast, pretensioned sections. A listing of the standard sections has been provided in Chapter 4 along with a brief description of the characteristics of this bridge type. Continuous concrete slabs and prestressed concrete bridges together account for the largest number of replaced bridges. Seventeen percent (16 responses) of the replaced bridges were reinforced concrete culverts. Eight one percent of the culverts were cast-in-place. It may be seen that the previously described bridge types account for approximately 85 percent (78 responses) of all replacements. A review of the bridge types chosen as replacement alternatives in the counties in neighboring states was also completed. Table 3.3 shows the breakdown of those responses. The most common replacement alternative was the prestressed concrete bridge. Data indicate that steel stringer bridges have been used more extensively in the counties in neighboring states than in Iowa.

3.3 Quoted costs of the bridge types

The average costs of the various replacement bridge types was calculated on a per square foot basis from the questionnaire data. The total quoted project costs were divided by the plan area of the bridge to arrive at these values. Therefore, they include substructure costs as well. Figure 3.1 presents the average costs of the various replacement types as evaluated from the questionnaire data. Prestressed concrete bridges were found to be the most expensive at an average cost of $58.00 per sq.ft. Continuous Concrete Slabs cost $50.00 per sq.ft. on the average. Reinforced concrete precast bridges averaged about $37.00 per sq.ft. Steel stringer bridges and timber bridges cost $29.00 and $25.00 per sq.ft., respectively. Concerns were raised about how the average cost really did not take into account the effect of the span length. However, our analysis regarding span length and average cost has indicated that the above quoted costs are sufficiently accurate in the span range in which

Table 3.3. Breakdown of replacement bridge types - Counties outside Iowa.

Bridge Type	Code	Number	Percentage
Continuous Concrete Slab	C R/C S	2	10.0
Prestressed Concrete Girder	P/C	7	35.0
Reinforced Concrete Culvert	R/C CU	3	15.0
Steel Stringer-Concrete deck	STS	3	15.0
Timber Stringer	TIMB	1	5.0
Reinforced Concrete Girder	R/C G	4	20.0

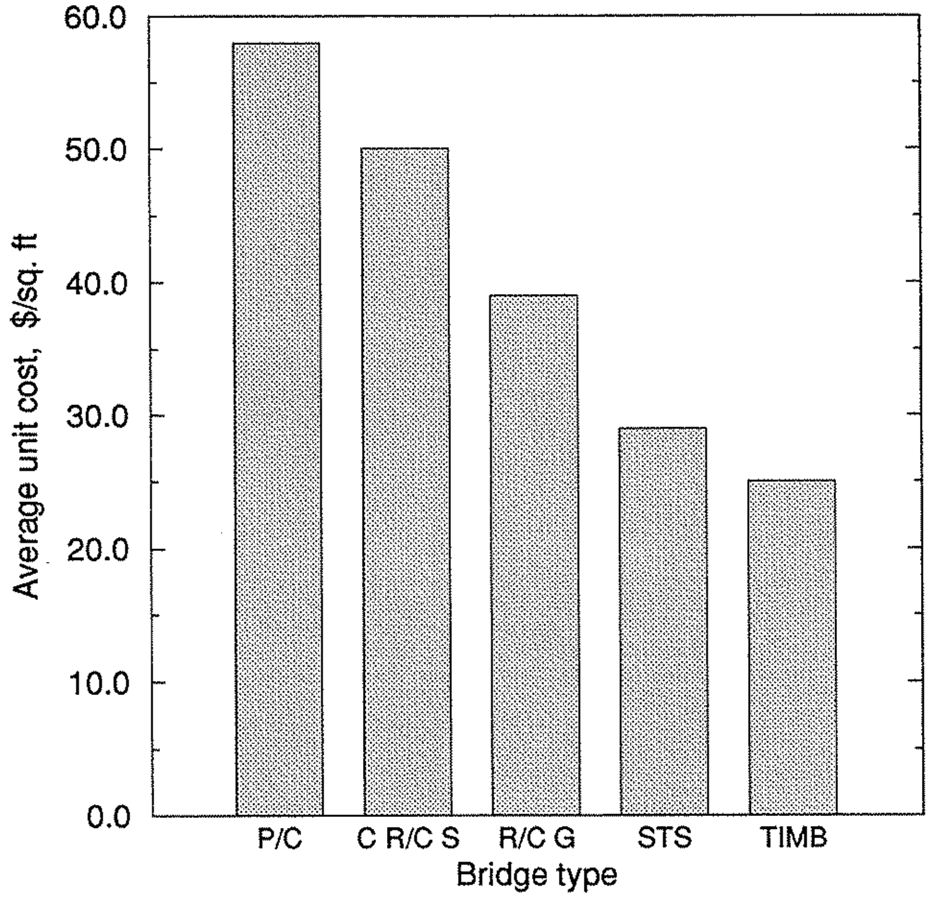


Fig. 3.1. Average cost of various replacement bridge types.

these replacement types are generally used. For example, prestressed concrete spans are used mostly in the 50 to 80 ft span range. Within this span range, the average unit cost is approximately $58.00 per sq.ft. Similarly, the applicable span ranges of each of the bridge types is shown in Table 3.4. The average costs of the other bridge types could not be determined because of lack of data combined with large deviations in available data.

3.4 County participation in construction

One of the more important factors investigated was the ease of construction of the various replacement alternatives. It was assumed that the extent of county participation in construction would represent the ease of construction of a particular bridge type with some degree of accuracy. The bridge projects handled completely by the county and the projects contracted were studied. It was found that only 14 percent (4 responses) of the prestressed concrete bridge replacements were handled by county forces entirely. Furthermore, only 12 percent (4 responses) of the continuous concrete slab bridge projects and 13 percent (2 responses) of the culvert projects were handled entirely by county forces. The rest were all contracted. On the other hand, it was seen that 67 percent (2 responses) of reinforced concrete precast bridges and 75 percent (3 responses) of steel stringer bridges were constructed by county forces. All the timber bridges built were constructed entirely by the counties. Figure 3.2 shows the percentage of county constructed projects for various bridge types. The reason most counties indicated for having a contractor construct a given bridge was the lack of heavy lifting equipment, or the requirement of extensive formwork and falsework.

Table 3.4. Applicable span ranges for average cost data.

Bridge type	Average span, ft	Span range, ft
Steel Stringer-Concrete Deck	49	35-60
Timber(Stringer and Panel Deck)	24	20-25
Continuous Concrete Slabs	39	28-58
Reinforced Concrete-Precast	32	25-40
Prestressed Concrete Bridges	65	35-100

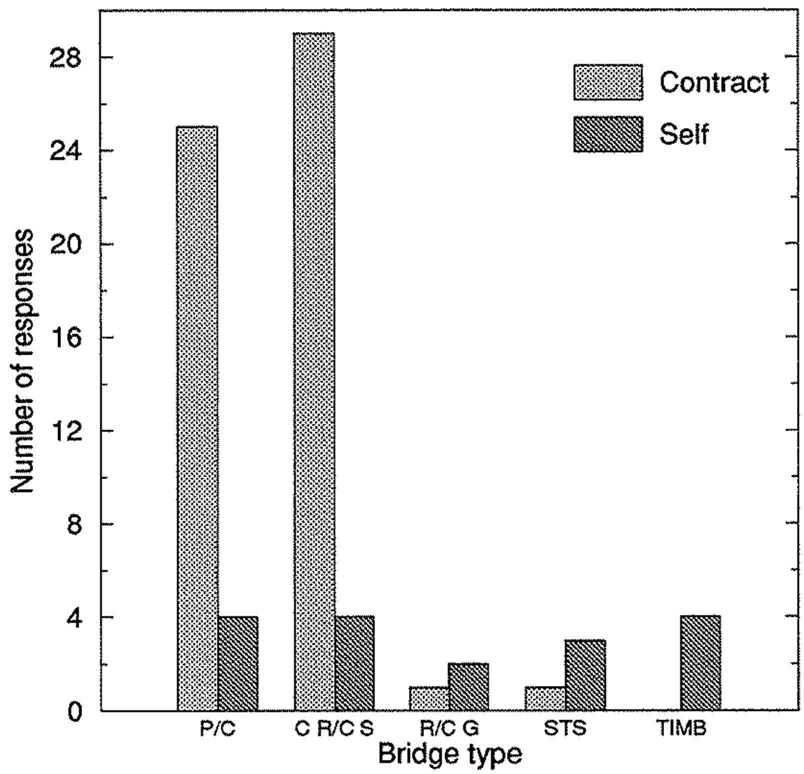


Fig. 3.2. County participation in construction.

3.5 Extent of external technical expertise required

The number of projects that required outside engineering design was studied. The responses indicate that for most bridge types, the design is either carried out by the county or standard plans are used. However, some of the prestressed concrete and continuous concrete slab bridges were designed by consultants. Table 3.5 displays the number of projects in which external expertise was required for design.

3.6 Expected lives of various bridge types

The expected design lives of the various bridge types was inquired about in the questionnaire and evaluated from the responses. However, the variation in the data for each bridge type was high. The average design life of a prestressed concrete bridge as estimated from the questionnaire data was 62 years, but the responses ranged from 30 years to 100 years. Similarly, the average design life of a continuous concrete slab bridge was 66 years but the responses ranged from 45 years to 100 years. The calculated average design lives of the various bridge types along with the maximum and minimum values from the questionnaire data are presented in Fig. 3.3.

3.7 Foundation types used

The study of foundation data from the questionnaire indicated that steel H piles were the most common foundation type. They were used in 47 percent (36 responses) of the span bridge cases (i.e., non-culverts). However, steel piles were usually used only in projects that were contracted. The second most common foundation type was timber piles. Timber piles were used in 41 percent (31 responses) of the cases. These were used on both projects that were contracted and on projects that were county constructed. However, all county constructed projects reported used only timber

Table 3.5. Number of bridges designed using external help.

Bridge type	County/Standard plans	External
Prestressed Concrete Girder	15	14
Continuous Concrete Slab	29	4
Reinforced Concrete Girder	3	0
Steel Stringer - Concrete Deck	4	0
Timber Stringer	4	0
Reinforced Concrete Culvert	15	1

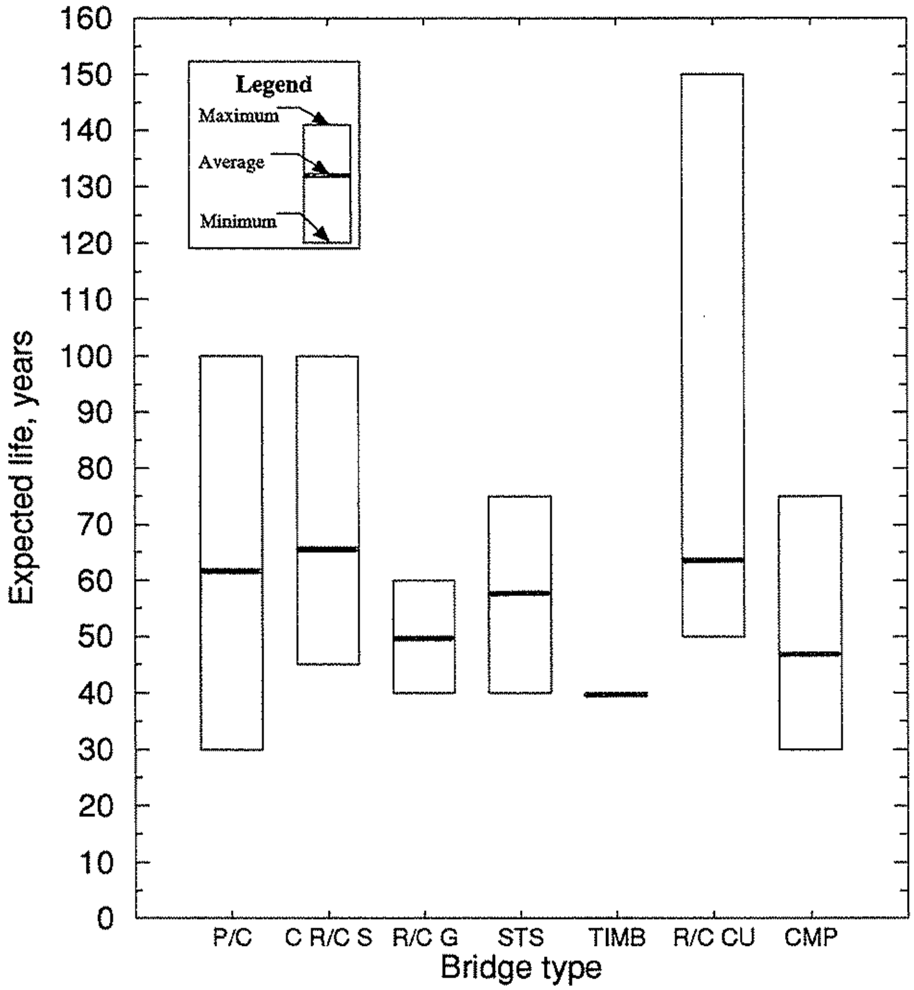


Fig. 3.3. Expected lives of various bridge types.

piles. The breakdown of the foundation types used with respect to bridge type is illustrated in Fig. 3.4. It can be seen that concrete piles and spread footings have seldom been used. Furthermore, the above two foundation types were never used on county-constructed projects.

3.8 Construction capabilities of counties

One of the questions addressed in the questionnaire was the construction capabilities of the county. The length of spans that the counties could lift into place and the type of piles they could drive was determined. A significant observation is that 69 percent of the respondents felt that county forces could handle entirely small sized bridge projects provided the construction procedure was simple.

The maximum span that could be replaced with county equipment by county forces ranged from 20 ft to 90 ft with the average being close to 38 ft. A histogram of the span replacement capacities of the counties with respect to span length is shown in Fig. 3.5a. It may be seen that a considerable number of counties have the capability to replace spans ranging from 20 ft to 50 ft. Some counties indicated capabilities to replace longer spans using rented equipment. Figure 3.5b is a histogram illustrating replacement capability of counties using rented equipment. The spans may be seen to range all the way from 24 ft to 100 ft.

A study of the pile-driving capability of the counties indicated that 64 percent (34 responses) were capable of driving timber piles using county owned equipment. It was seen that 38 percent (20 responses) could drive steel piles and 4 percent (2 responses) could drive concrete piles. Figure 3.6a shows the pile driving capabilities of counties using county equipment. Fifteen counties could drive

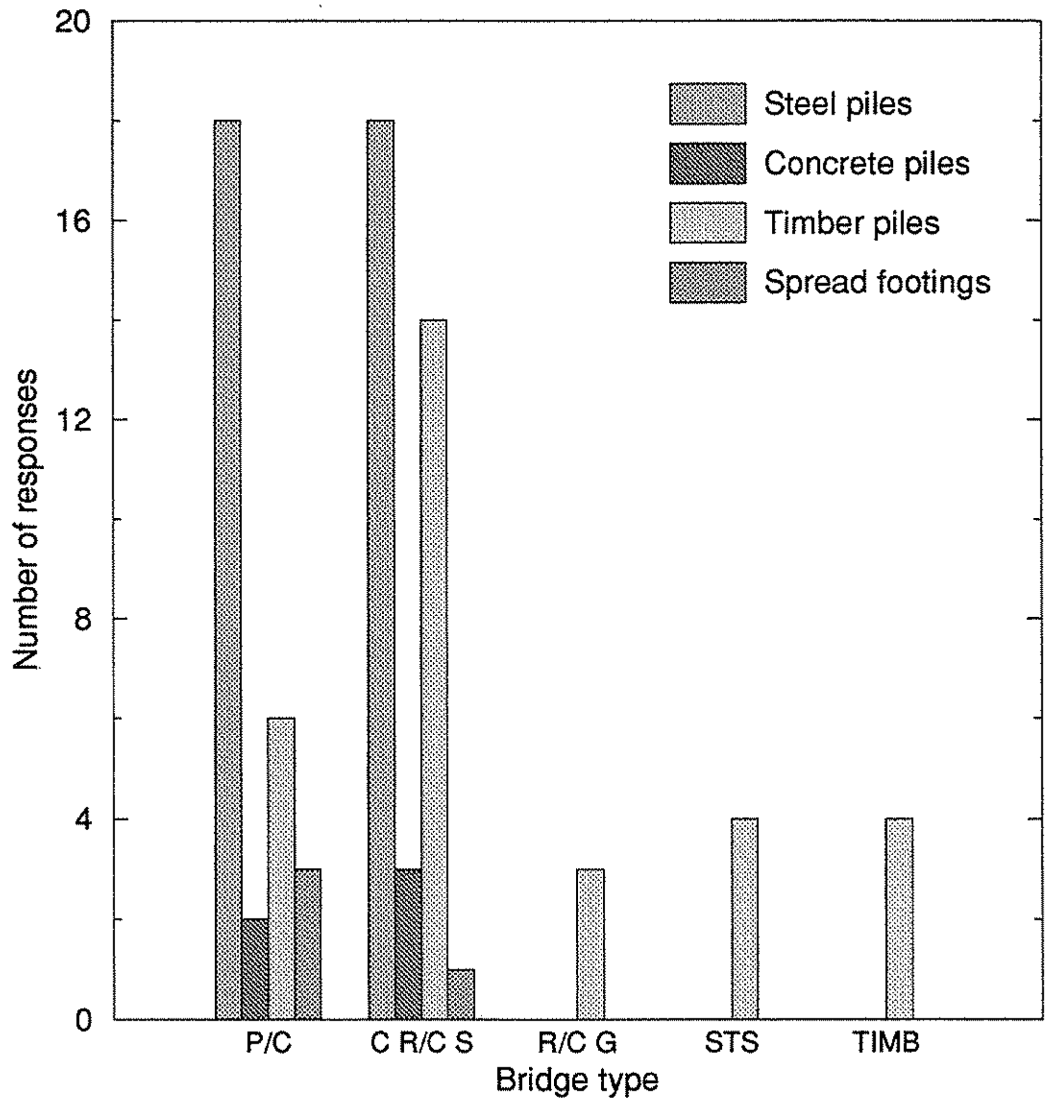
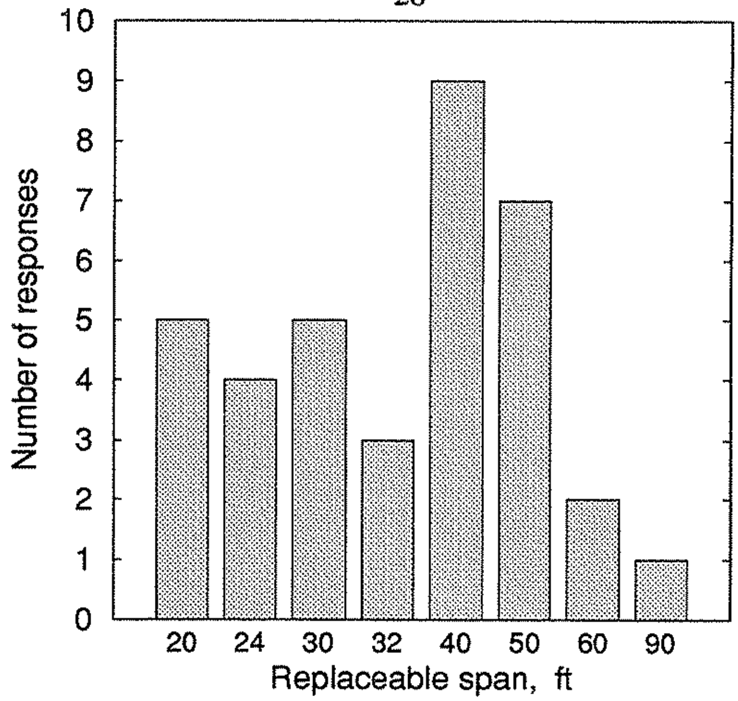
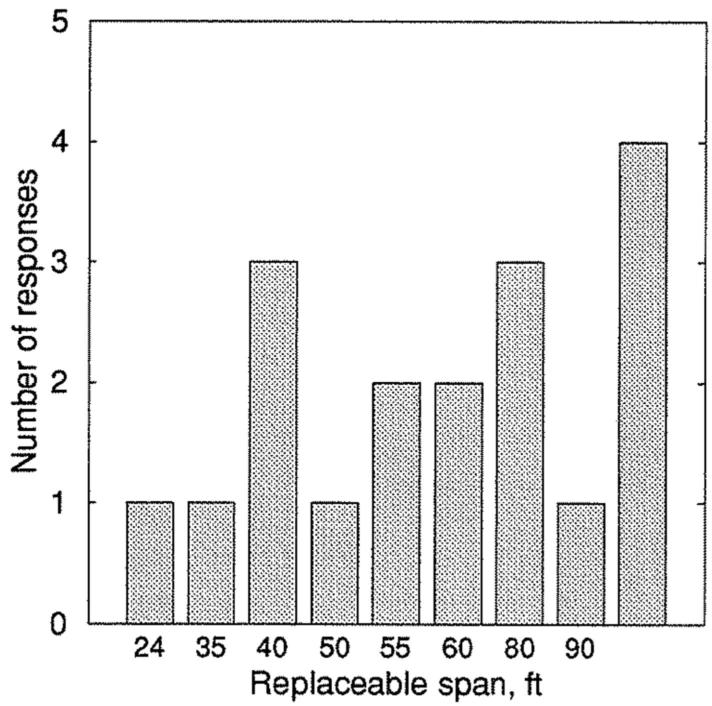


Fig. 3.4. Foundation types associated with various replacement alternatives.

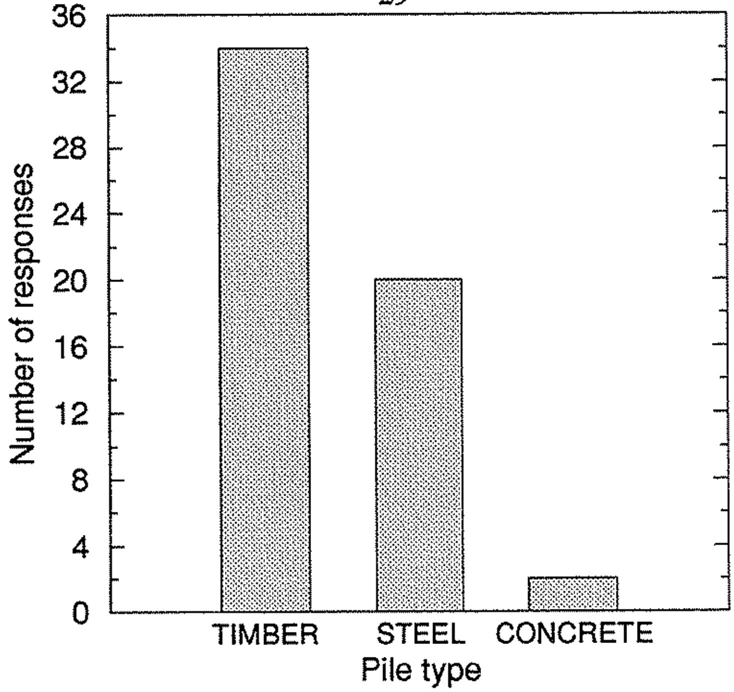


a. County owned equipment

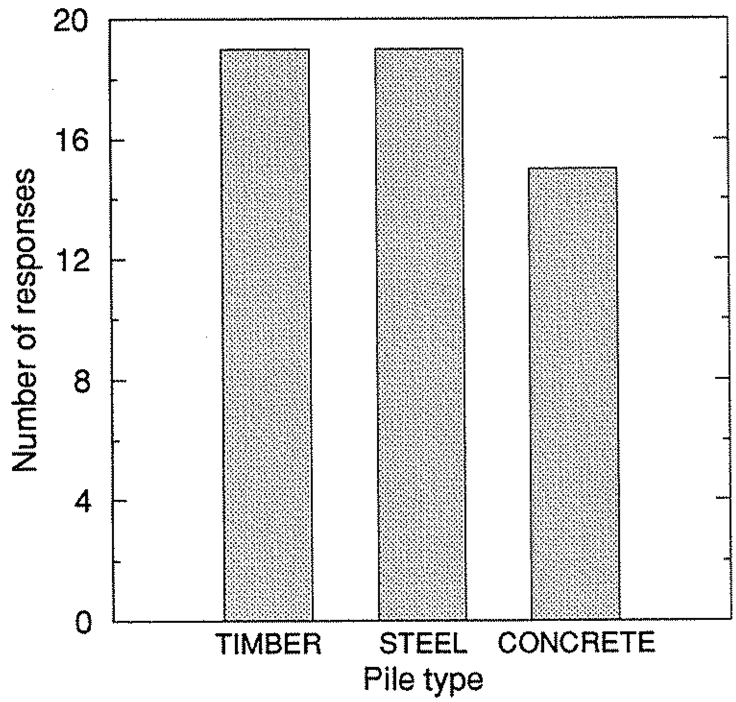


b. Rented equipment

Fig. 3.5. Span replacement capabilities of counties.



a. County owned equipment



b. Rented equipment

Fig. 3.6. Pile driving capabilities of counties.

concrete piles with rented equipment. The decrease in number of counties that can replace timber/steel piles is because of the fact that a smaller number of counties are willing to rent or have access to rented equipment. The pile driving capacities of counties using rented equipment is shown in Fig. 3.6b.

The above observations would indicate that most of the counties have the capability to replace short span bridges that are easily constructed. This has been shown to be the case for steel stringer bridges and timber bridges which have mostly been constructed by the county.

3.9 Degree of satisfaction with bridge types

The questionnaire requested the respondents to specify their degree of satisfaction with each bridge type on a scale of one to ten, with ten being the best. The counties were generally satisfied with the bridge types they use. Prestressed concrete bridges and continuous concrete slabs were ranked high with ratings of 9.7 and 9.65, respectively. Concrete culverts had a 9.55 rating. Steel stringer and reinforced concrete bridges were rated 9.0 while timber bridges had 8.0. The average degree of satisfaction with each bridge type is shown in Fig. 3.7.

3.10 General observations

Despite the popularity of continuous concrete slabs and prestressed concrete girders 23 percent of the respondents found continuous concrete slabs expensive and 27 percent found prestressed concrete bridges expensive. Both of these bridge types remain popular due to their easy maintainability and the availability of design standards. One of the most commonly quoted advantages of the continuous concrete slabs was their familiarity to contractors. Standard designs

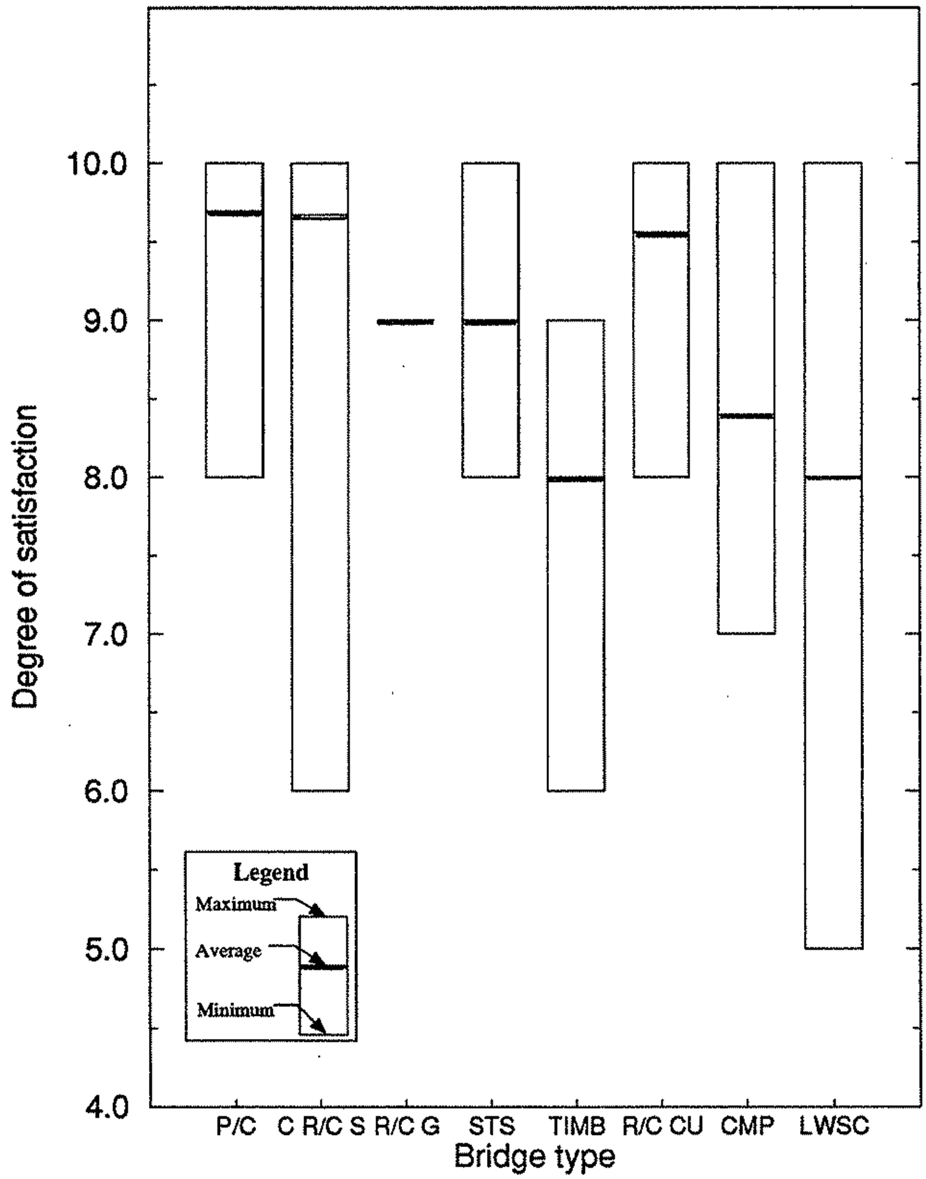


Fig. 3.7. Degree of satisfaction with various bridge types.

of continuous concrete slab bridges for specific spans are available and are used repeatedly. One of the respondents felt that these were generally conservative designs for the span lengths for which they were used, but that cost of a custom design would not result in enough savings. It was noticed that in 93 percent of the cases, no reason other than economy influenced the choice of replacement alternative. However, 23 percent of the respondents felt that lack of construction equipment affected their choice of replacement alternative. Furthermore, 21 percent of the respondents felt that lack of county labor affected the choice of replacement alternative. Some of the more interesting comments about continuous concrete slabs and prestressed concrete bridges are presented in Table 3.6.

3.11 Summary of survey

1. Continuous concrete slab bridges and prestressed concrete bridges are the most commonly used types of replacement bridges.
2. Continuous concrete slabs and prestressed concrete bridges are favored despite their higher initial costs because of their maintainability and the availability of standard designs. Familiarity of these bridge types to contractors is also an important factor.
3. Counties seldom construct continuous concrete slabs or prestressed concrete bridges. The construction is usually contracted. However, construction of steel-stringer bridges, reinforced concrete precast bridges and timber bridges was carried out in full by county forces in most of the cases.
4. Counties indicate an ability and willingness to replace short span bridges - 40 ft or less - using county forces, provided the construction procedures are simple.

Table 3.6. Comments from questionnaire survey.

PRESTRESSED CONCRETE BRIDGES "No expertise by county forces. Must be done by contract forces." "A large bridge like this needs outside design Engineering." "Expensive for a smaller county's budget." "County benefits by having a structure that meets state and Fed standards. There is not enough money in the off-system program to build more bridges." "Beams too deep for small spans." (3 responses)
CONTINUOUS CONCRETE SLABS "Standard Design. Familiar to contractors." "Overdesigned length, but cost of custom design not savings enough to use." "Falsework used for construction is effectively a temporary structure." "Contractors are familiar with Bridge standards and can quickly and effectively replace structures." "Major maintenance and repair are beyond in-house capability." "County forces could build a precast concrete for less money."
REINFORCED CONCRETE - PRECAST BRIDGES "Fast construction time. Can be erected by county forces." "Work done by County Crew - cost effective." "Can place and open to traffic a lot sooner than a normal bridge."

4. DESCRIPTION OF REPLACEMENT SYSTEMS

Some common replacement alternatives that are generally preferred by county engineers, in addition to some unconventional alternatives that have been used by a some Iowa counties are described in this chapter. The Inverset bridge system, which has not been extensively used in Iowa, but has been used extensively in Texas, is also discussed.

4.1 Prestressed beam bridges

The questionnaire survey discussed in the previous chapter has indicated that precast and prestressed beam bridges have been used extensively for low volume applications in various Iowa counties and on low volume roads in neighboring states. Standard bridge sections have been developed by both the Prestressed Concrete Institute (PCI) and AASHTO. However, most of these sections have been developed for long spans and can be slightly inefficient when used for short span applications. The Iowa DOT has standard plans for prestressed concrete bridges of various span lengths. There are also local plants that have designed non-standard sections suitable for low volume road applications. Many of these sections are precast with integral deck slabs which eliminates considerable on-site labor and also expedites the construction of a given bridge.

4.1.1 Bridge types: Prestressed beams are available in various shapes ranging from slabs to deck bulb tees. Some of the more common shapes are shown in Fig 4.1. Table 4.1 provides the cross section, size ranges and economical span lengths for the typical sections which are used in short-span

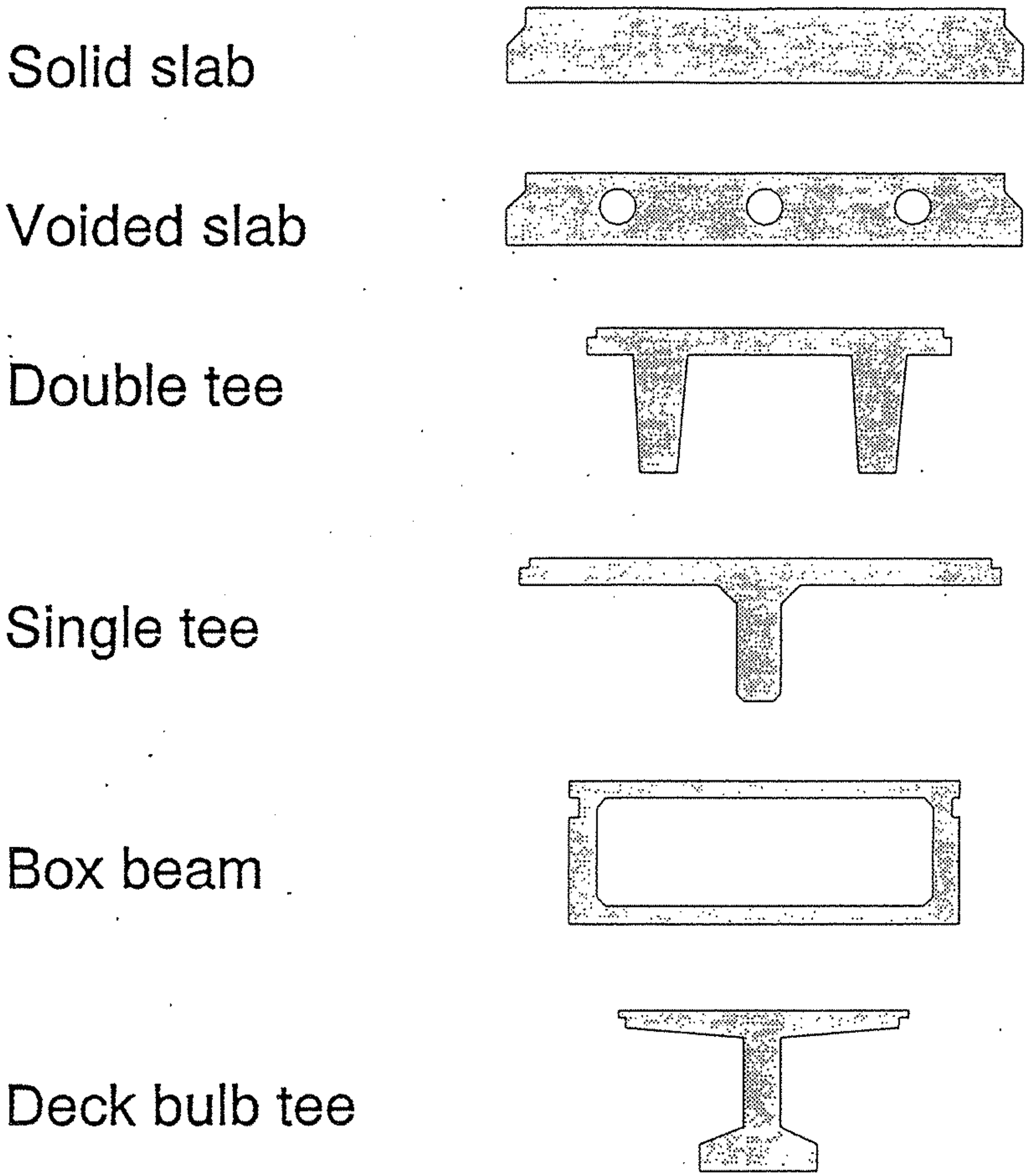


Fig. 4.1. Standard prestressed girder/slab sections.

Table 4.1. Standard sections and economical span lengths.

Section Type	Width	Depth	Economical Span (ft)
Solid Slab	3'-0" - 8'-0"	0'-10" - 1'-6"	up to 30
Voided Slab	3'-0" - 4'-0"	1'-3" - 1'-9"	25 to 50
Multistem Tee	4'-0"	1'-4" - 1'-11"	25 to 55
Double Tee	5'-0" - 8'-0"	1'-6" - 2'-8"	20 to 60
Single Tee	4'-0" - 6'-0"	2'-0" - 4'-0"	40 to 80
Box Beam	3'-0" - 4'-0"	2'-3" - 3'-6"	60 to 100
Deck Bulb Tee	4'-0" - 7'-0"	2'-5" - 3'-5"	60 or more
I Girder	1'-6" - 2'-2"	3'-0" - 4'-6"	40 to 100

bridge construction. The bulb tee is the most efficient of the more common shapes. However, double/multi stem tees and angles are preferred more often by contractors because of their stability during handling.

4.1.2 Design: Design of prestressed concrete girders follows the basic principles of designing a section to withstand both axial and bending forces. PCI has published a handbook detailing the standard sections available and the steps to be followed in design [5]. Another PCI publication dealing solely with bridge design [6], presents solved examples of bridge designs in which the various sections have been utilized. These examples greatly simplify the design of prestressed concrete bridges. Furthermore, most of the local fabricators have standard sections designed to Iowa DOT specifications.

4.1.3 Economics: The responses to the questionnaire indicate that this type of bridge has a high initial cost compared to other conventional types of bridges. The unit costs quoted in the responses ranged from $38.00 to $120.00 per sq.ft. Based on the costs provided, the average cost of these bridges is approximately $58.00 per sq.ft., which includes the substructure costs. As noted earlier, each of the precast sections has a specific span range within which it is the most economical. There are few maintenance problems reported with this bridge type and it has a long design life, which still makes it an economically feasible choice in some situations. Furthermore, prestressed concrete spans can be used for spans exceeding 100 ft. Thus, in medium span bridges, prestressed concrete spans are preferred.

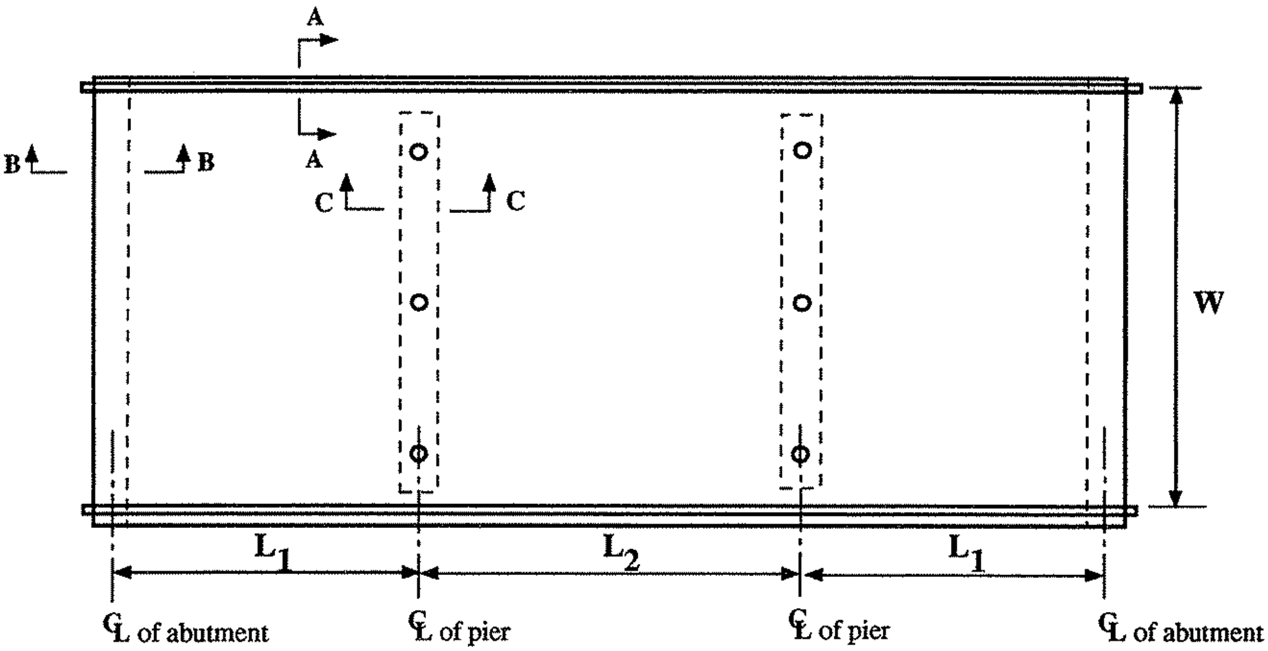
4.2 Continuous concrete slab bridges

Continuous concrete slab bridges are the most frequently chosen bridge replacement alternative in Iowa counties. These are generally three-span bridges, which have a longer central span. The ratio of end to central span is usually 1:1.25 to 1:1.35. Standard total spans of 75 ft, 87.5 ft, 100 ft, 112.5 ft and 125 ft. were most commonly used. Most of the responses from the questionnaire indicated bridges in one of these standard lengths.

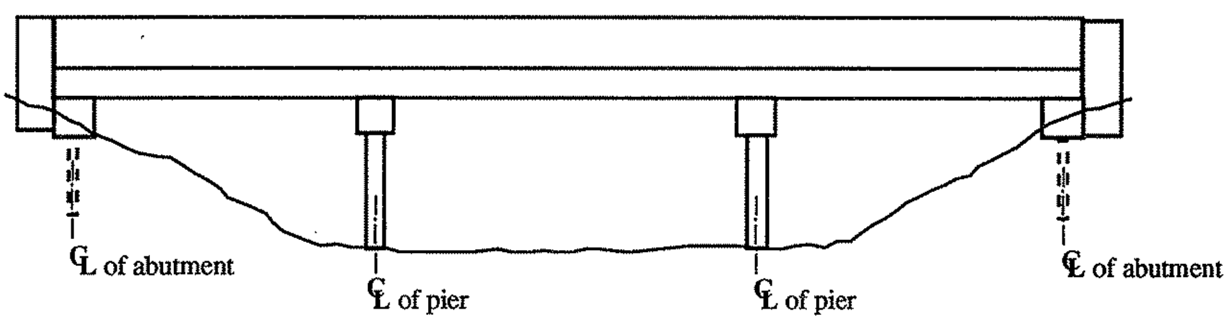
4.2.1 Construction: These slab bridges are usually cast-in-place. After the abutments and piers are constructed, the falsework and the formwork are erected; reinforcement is placed and the concrete is poured. In more than 85 percent of the cases, the construction of these bridge systems is carried out by contractors. The process of construction is relatively easy but requires extensive formwork and falsework and associated equipment. Most contractors are familiar with this type of bridge, thereby making it a preferred alternative.

4.2.2 Design: Standard designs for standard span lengths and configurations are available. Most designs follow one of the standard Iowa DOT designs. Standard designs are also available in the CRSI handbook [7] for reinforced concrete slabs. Figure 4.2 shows a generalized plan of a continuous slab bridge. Table 4.2 presents the various dimensions for three different span lengths (65 ft, 97.5 ft, and 130 ft) of continuous concrete slab bridges.

4.2.3 Economics: As explained in the previous chapter, county engineers have found continuous concrete slab bridges to be slightly high in initial cost. The unit costs quoted in the responses varied

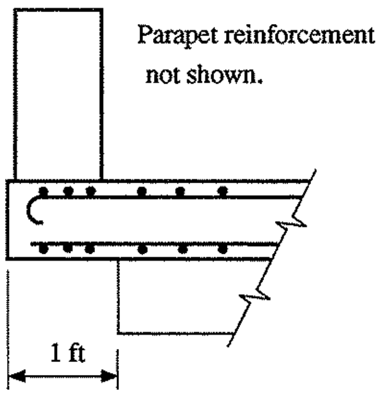


a. Plan

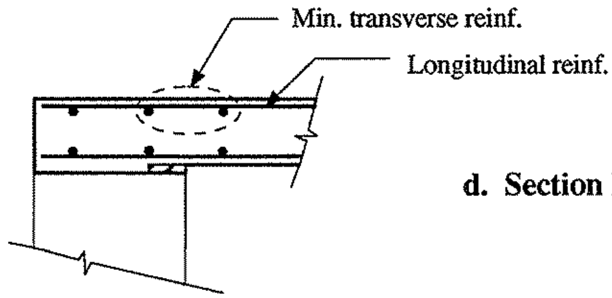


b. Elevation

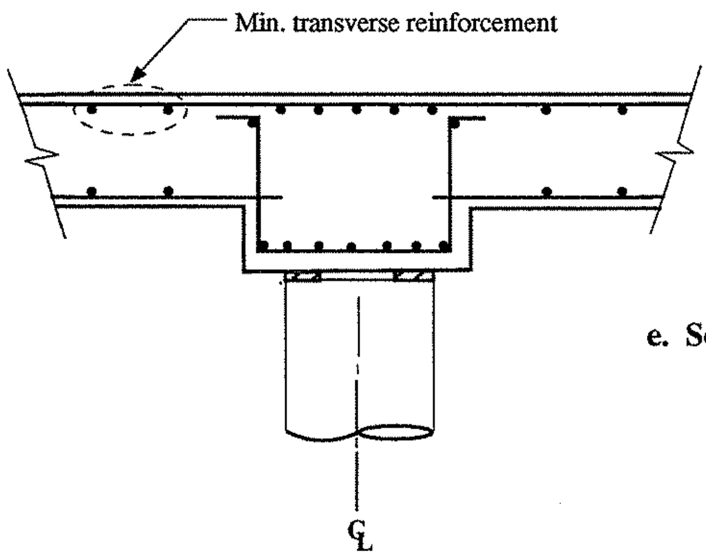
Fig. 4.2. General configuration of a continuous concrete slab bridge.



c. Section A-A



d. Section B-B



e. Section C-C

Fig. 4.2. Continued.

Table 4.2. General dimensions for continuous concrete slab bridges.

Individual Span Lengths (ft)	**20 - 25 - 20**	**30 - 37.5 - 30**	**40 - 50 - 40**
Total Bridge Length (ft)	65	97.5	130
Slab Thickness (in.)	12	16	21
Beam Depth (in.)	36	36	36
Beam Width (in.)	21	27	33

from \$33.00 to \$74.00 per sq.ft. The average cost of these bridges, based on the questionnaire responses, is approximately \$50.00 per sq.ft. The need for two intermediate piers is one reason for the slightly high cost. The other reasons include extensive falsework requirements and outside labor costs.

4.3 Air formed arch culvert

This is a new method of culvert construction developed by Concepts in Concrete of Norman, OK [4]. The method, called the Air-O-Form process, uses an inflatable rubber membrane as the inner form for a reinforced concrete arch. The technique was proposed to be a viable alternative to single or multiple box culvert construction. By virtue of its shape, the arch offers several advantages over a box culvert. The arch is structurally more efficient than the box in that the stresses developed are essentially compressive thereby reducing the amount of reinforcement and concrete thickness. The arch is also hydraulically more efficient, in that the absence of center supports, which are found in multiple wall structures, eliminates obstruction to debris. Listed below are the six general steps required in the construction of the Air-O-Form Culvert after the site has been properly prepared:

- Construction of a reinforced concrete bottom slab or footing.
- Placement of flexible metal straps in the desired shape of the culvert followed by inflation of the balloon form.
- Placement of the required longitudinal and transverse steel reinforcement around the inflated form.
- Adjustment of the form air pressure to the desired magnitude.
- Application of the 6 in. of shotcrete in one lift.
- Deflation and removal of the form after the shotcrete has attained the required strength.

Demonstration projects were undertaken by the Iowa DOT in Washington Co., IA in 1988 and in Crawford Co., IA in 1991. In Washington Co., the culvert was 52 ft wide with a 12 ft radius cross-section. The cost of the project was $81,360 (unit cost $65 per sq.ft. of the plan area). Crawford Co. built a 52 ft wide culvert with a 9 ft radius cross-section. The project cost was $51,763 (unit cost $55 per sq.ft. of the plan area). Based on the two projects, the Iowa DOT notes that the Air-O-Form culvert system is better suited for longer and larger diameter culvert applications, where the economics are more favorable.

4.4 Concrete slab on steel girder bridges

Two different systems for concrete slab on steel girder bridges are currently being used in Appanoose Co., IA. The first system uses precast slabs on steel stringers. A schematic of the system on a specific bridge is shown in Fig. 4.3. Shown in Fig. 4.4 are photographs of a bridge on which the precast slabs have been used. As shown in Fig. 4.5, the precast slabs (18 ft long, 6 ft wide, and 6 in. thick) were cast with provisions for being attached to the top flanges of the girders. An overall view of the slabs is shown in Fig. 4.5a, and connection details are shown in Fig. 4.5b. Seven used steel beams (S15 x 42.9) were positioned to span 29 ft between the abutments. Two channels (of the same depth as the other beams) were positioned to serve as the exterior stringers. The precast slabs were then lifted into position and placed transversely on steel stringers, thus making a 18 ft wide bridge. Half inch cable clamps were then welded to the top flange of the steel girders. Adjacent precast sections were connected to the top flange of the girders by tightening the cable clamps (see Fig. 4.3c and Fig.4.3e). The connection voids were then grouted to ensure proper connectivity. Note, the hold down system is simply to hold the precast slabs on the steel stringers. Although the hold down system

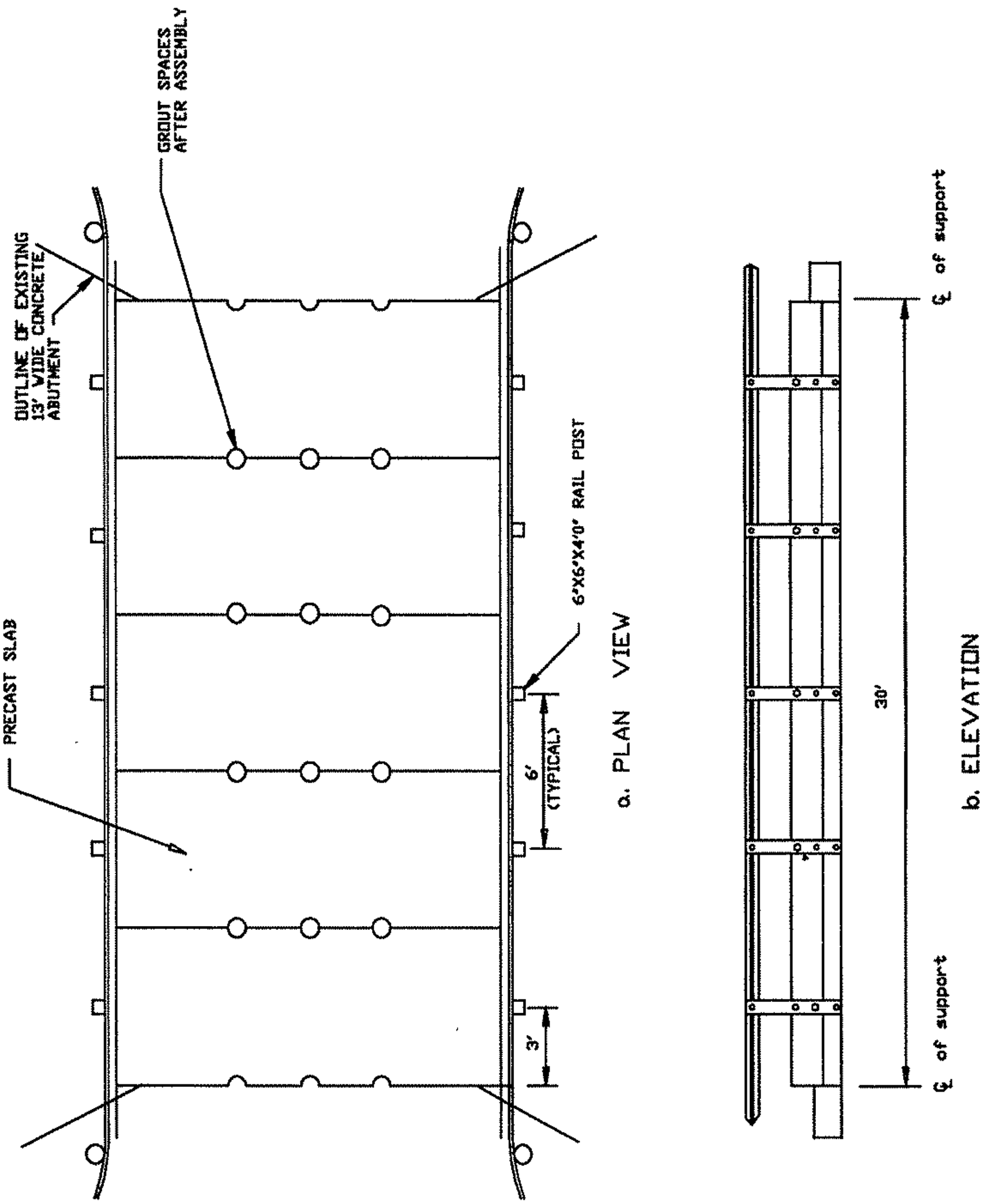
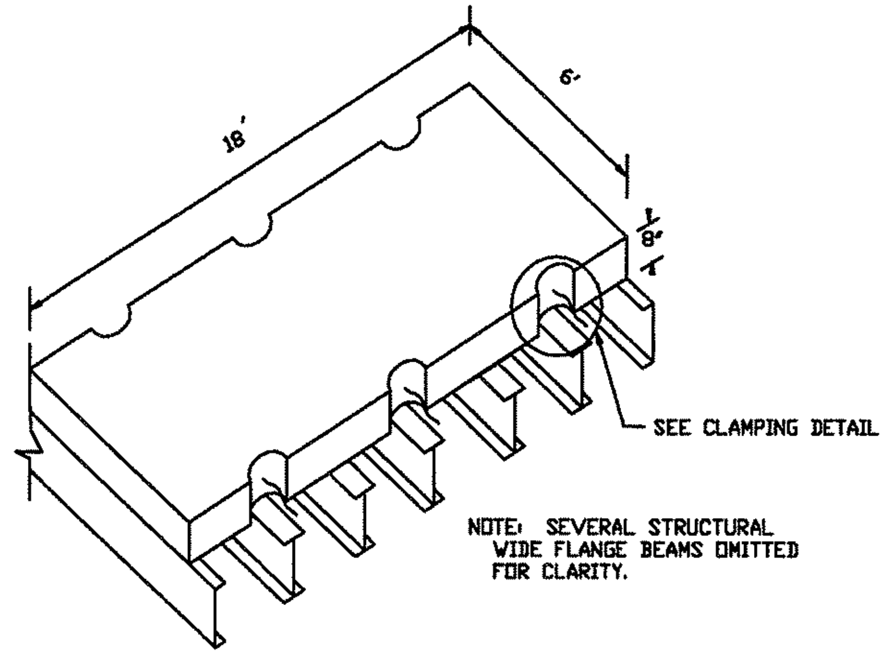
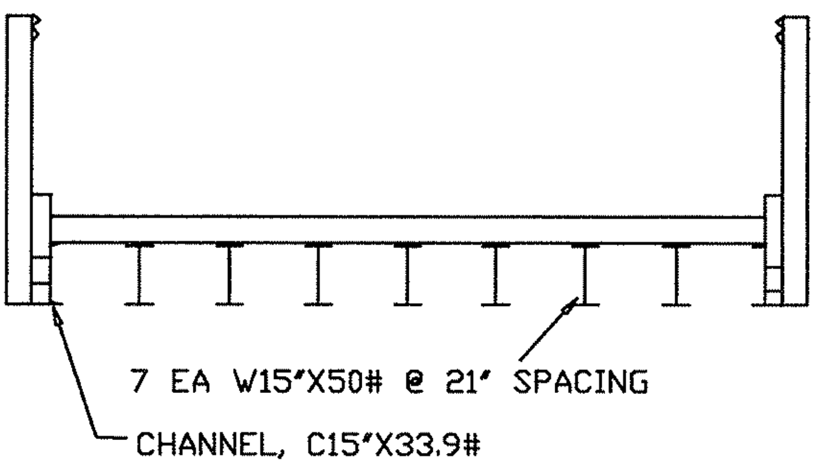


Fig. 4.3. Precast deck on steel stringers bridge system.

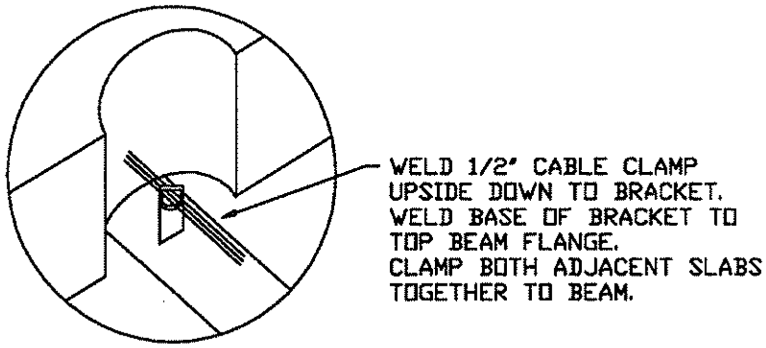


c. Dimensions of precast slabs

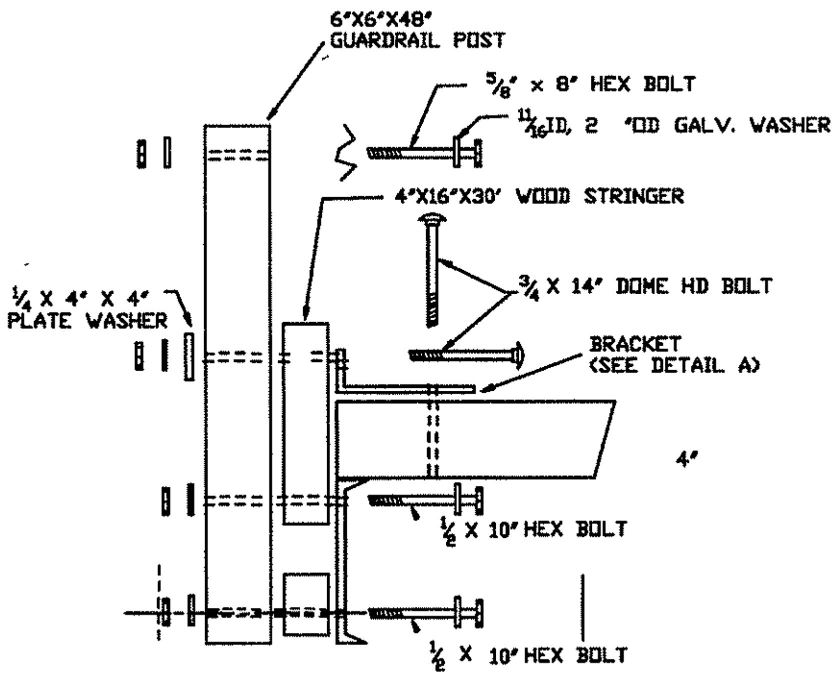


d. Cross-section

Fig. 4.3. Continued.



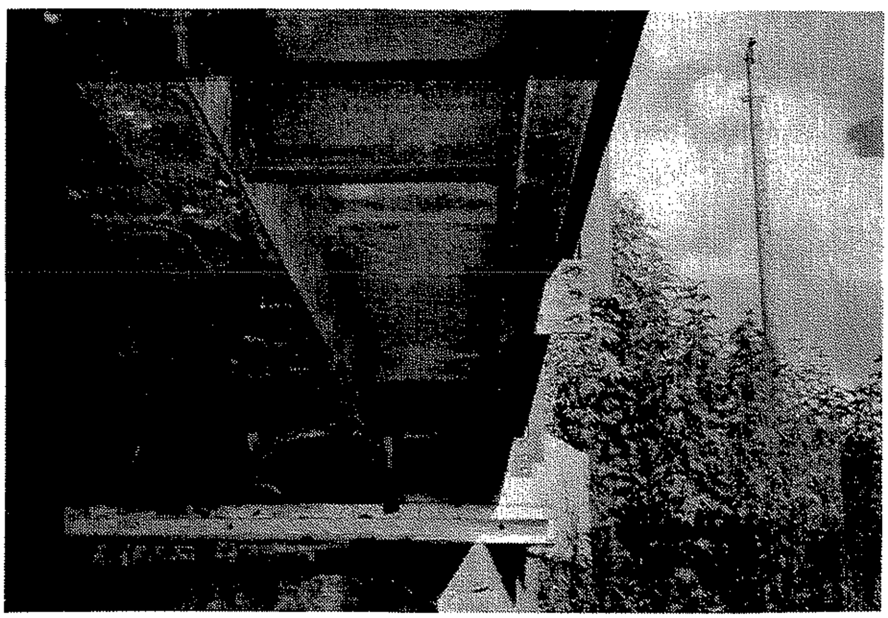
e. Clamping detail



f. Guardrail details

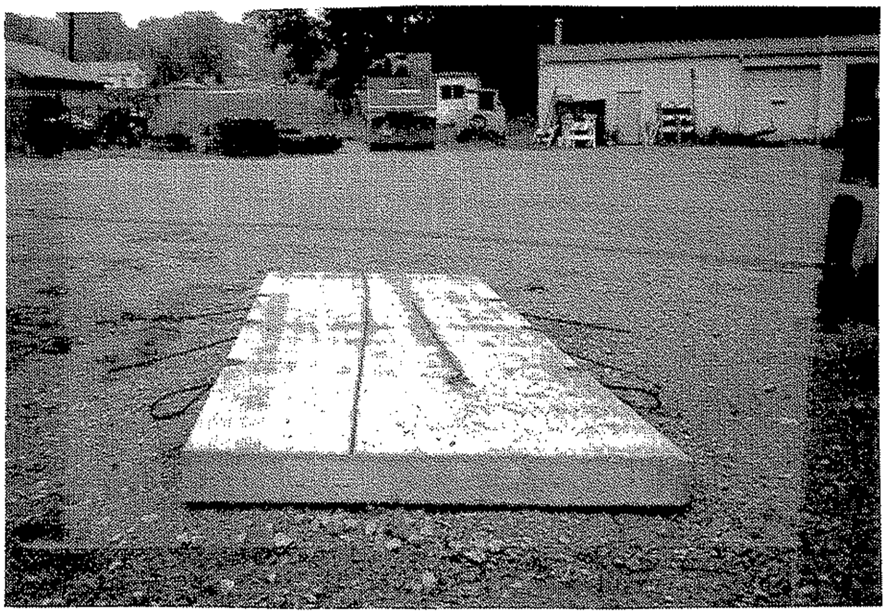
Fig. 4.3. Continued.

a. Sideview

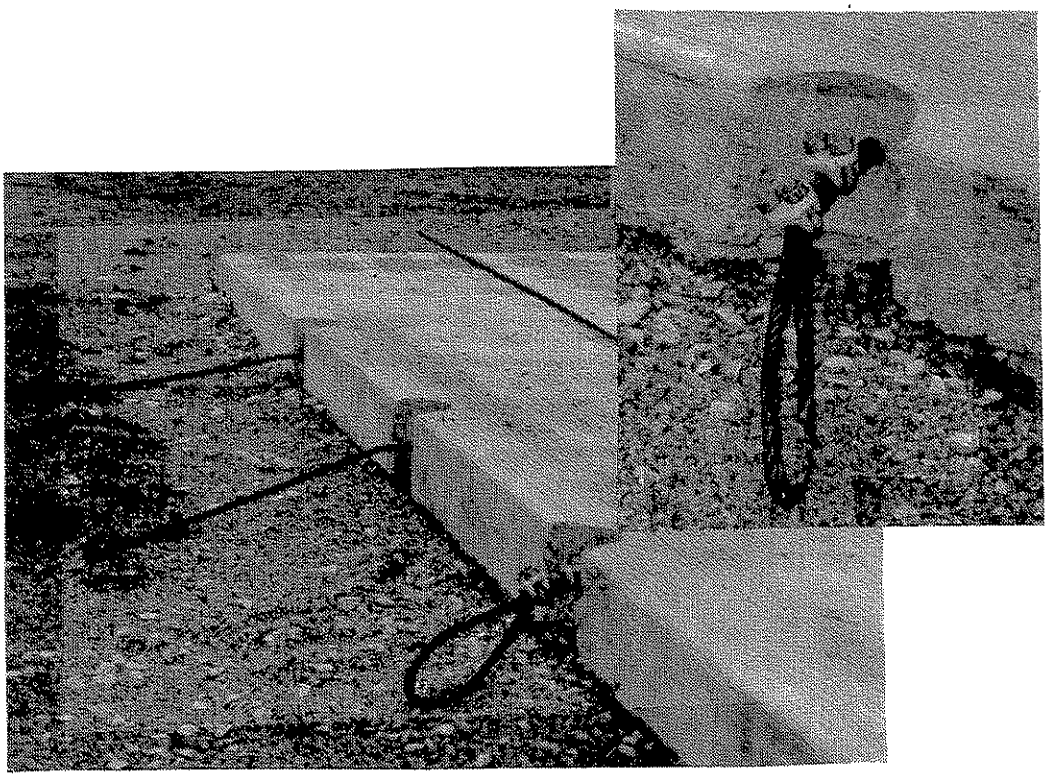


b. View of precast slabs from below

Fig. 4.4. Precast slabs on steel stringer bridge system (Appanoose Co.)



a. Overall view



b. Connection details

Fig. 4.5. Precast slabs.

does provide some horizontal shear restraint and thus some composite action, that is not the intended purpose of the cable ties. Timber guard-rail posts (6 in. x 6 in. x 48 in.) were then attached to the exterior channel sections (see Fig. 4.3f) and the slab by bolting before connecting the guardrails. The estimated costs (superstructure and substructure) are approximately $41.50 per sq.ft. (excluding the guardrail). A breakdown of the associated costs is presented in Table 4.3.

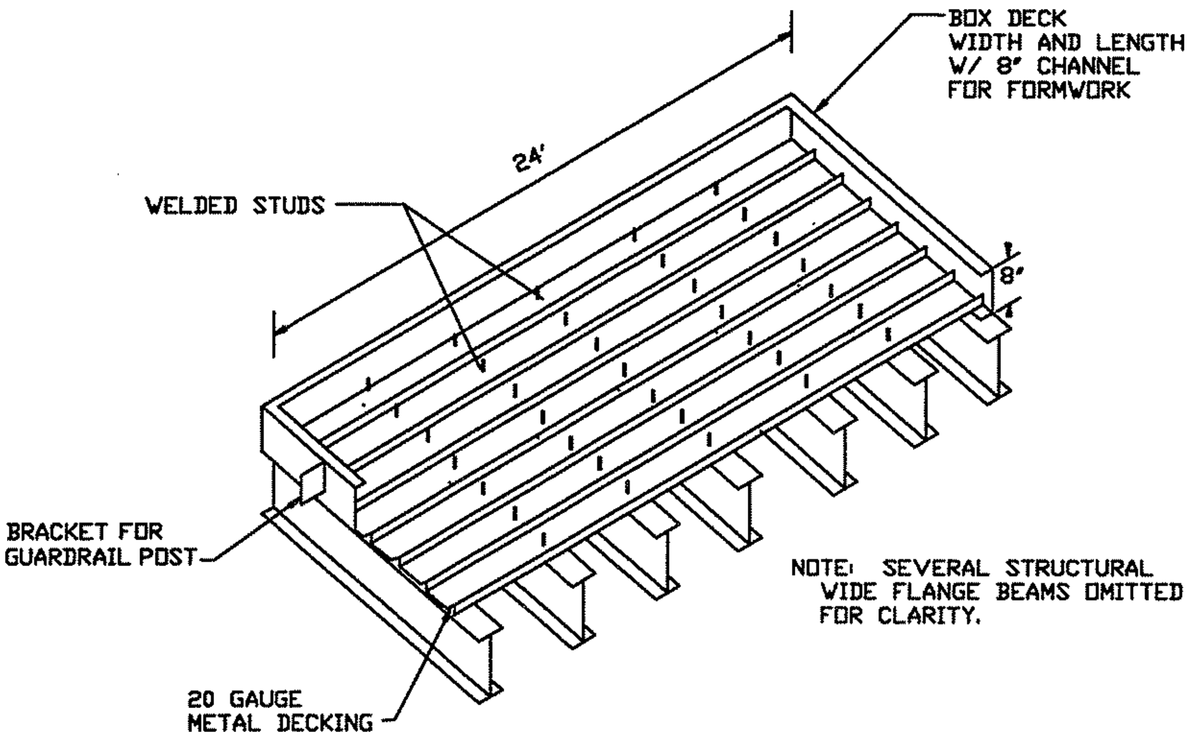
The other system used 20 gauge metal decking welded to wide flange steel stringers, on which an 8 in. concrete deck was cast. A schematic of the system is shown in Fig. 4.6. Photographs of a bridge of this type may be seen in Fig. 4.7. The bridge span was 25 ft with a width of 24 ft. In this case, the used steel beams (twelve S12 x 31.8 beams) were first positioned. The corrugated metal decking (20 or 22 gauge) was welded to the top flange of the stringers and 8 in. high channel sections were welded to the ends of the decking to serve as the side and end forms. Prior to casting the deck, reinforcement was placed in both the longitudinal and transverse directions. The metal decking serves as a stay-in-place bottom form. The guardrail posts and rails are then attached to the exterior channels through brackets. A variation of the above system is to use removable paving forms instead of welded channels. The estimated costs (superstructure and sub-structure) are approximately $39.00 per sq.ft. (excluding the guardrail). A breakdown of the costs is presented in Table 4.4.

4.5 Inverset bridge system

A method of partially prestressing a steel stringer concrete deck bridge without the use of any expensive equipment has been developed by Grossman and Keith Engineering of Norman, OK [4]. The Inverset bridge is a proprietary system which is cast upsidedown to utilize the compressive

Table 4.3. Cost information: Precast deck slabs on steel stringers.

Item and quantity	Cost
Steel beams: 9 of S15 x 42.9 x 30 ft (used) = 11,583 lbs Diaphragms = 417 lbs @ $0.15 per lb	$1800
Precast concrete panels, concrete: 14 cu. yds @ $60 per cu. yd reinforcement: 2160 ft @ $0.15 per ft	$840 $320
80 ft of 1/2 in. cables per panel x 5 panels: 400 ft. Cable clamps	$200 $100
Labor: prepare 5 panels: 16 hrs. 4 persons: 68 hrs Weld beams, set panels: 160 hrs. Total 228 hrs @ $15 per hr.	$3420
Total (excluding guardrail and abutment costs):	$6680



NOTES:

1. Not shown for clarity, #4 rebar @ 12" spacing, both ways, on 2.5" and 5" chairs. (6" to 8" rebar spacing when beam spacing is greater than 12").

2. A variation of formwork includes removable paving forms instead of welded channels.

Fig. 4.6. Cast-in-place deck on steel stringer bridge system.

a. Sideview

b. View showing metal decking

Fig. 4.7. Photographs of metal deck plus steel stringer bridge.

Table 4.4. Cost information: Cast in place deck on steel stringers.

Item and quantity	Cost
Steel beams: 12 of S12 x 31.8 x 27 ft 1 in. = 10,303 lbs Diaphragms = 700 lbs @ $0.15 per lb	$1650
CIP deck: Concrete 15 cu. yd @ $60 per cu. yd Reinforcement 3460 ft @ $0.15 per ft	$900 $520
22 gage corrugated metal decking, 600 sq ft @ $0.45 Studs, weld rods	$270 $100
8 in. channel, 988 ft @ $4.37 per ft	$430
Labor: 256 hrs. @ $15 per hr.	$3540
Total (excluding guardrail and abutment costs)	$7400

strength of concrete and the tensile strength of structural steel. The casting procedure followed in fabricating the Inverset system is illustrated in Fig. 4.8 and detailed in the following section.

4.5.1 Fabrication: While precasting, the forms for the concrete deck are suspended from steel beams. In this configuration, the weight of the forms, steel W sections and wet concrete cause compressive stresses in the top flange of the steel section which will be the bottom flange of the stringer when the unit is inverted. When the concrete cures, the forms are stripped and the unit is inverted. This procedure results in the bottom flange of the unit having essentially zero stress under selfweight. The process also results in a longitudinal compressive stress in the deck, which makes it crack resistant and reduces its permeability. Stress induced during fabrication, combined with the increased moment of inertia of the composite section, allows the Inverset system to carry additional live load without overstresses.

4.5.2 Design: The design of an Inverset bridge system is similar to the design of a steel stringer concrete deck bridge with the addition that stresses have to checked during the various stages of construction. These include:

- Concrete - extreme compression fiber of the deck.
- Steel - top flange of girder when the unit is placed in service and when the unit is cast.
- Steel - bottom flange of steel girder once unit is erected. This flange is in compression during fabrication and is in tension when the bridge is in service.

Care should be taken to ensure that at no time during fabrication, installation, or service do the stresses in the Inverset cross-section exceed the allowable steel or concrete stresses. For a complete design example, see Ref. 4.

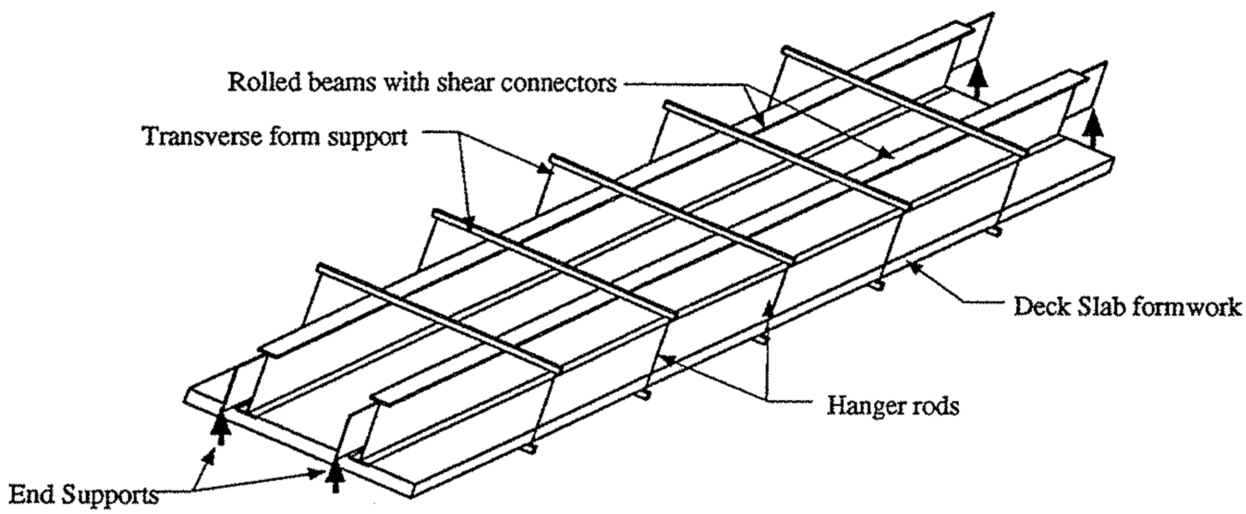


Fig. 4.8. Formwork and support system for fabrication of the Inverset units.

4.5.3 Economics: This bridge type has not been used by any of the respondents to the questionnaire. Hence direct economic details are not available. The following information is provided from Ref. 4 (1991 cost data) which listed some Inverset project costs. Several Inverset bridges have been installed in the state of Texas. The costs include the following items:

- Royalty fee paid to the designer
- Engineering with sealed plans
- Demolition of existing bridge
- Pile driving (16 in. square P/C piles)
- Pile caps (2 ft - 3 in. x 2 ft x 28 ft) and pile bents (3)
- Deck: 7 in. concrete deck
- Guardrail: Type T-6 with safety end treatments
- Embankment at ends of bridge (no deck overlay)
- Bonding
- Abutments: 2 ft - 3 in. x 2 ft x 28 ft (with backwall)

The summary of the project costs is provided in Table 4.5. Listed in the table are the span lengths, widths and cost information of seven Inverset bridge projects from Texas. The unit costs range from $31 to $45 per sq.ft. As may be seen, the cost for most of the bridges was approximately $34 per sq.ft. The cost of the project at Uncle Glen road is probably high because of the reduced width and longer piles.

Table 4.5. Inverset bridge installation costs.

Project Name	Span Lengths	Bridge Width	Pile Length (ft)	Project Cost ($)	Unit Cost ($/sq.ft)
Whippoorwill Road	3 x 30' - 0"	26' - 1"	40	79,730	34
Stidham Road	30' - 40' - 30'	26' - 1"	40	88,589	34
Nichol Road	4 x 42' - 10"	26' - 1"	45	150,961	34
Walnut Creek Road	4 x 37' - 10"	26' - 1"	45	148,775	38
Uncle Glen Road	4 x 45' - 3"	18' - 1"	50	147,000	45
Humble Pie Road	2 x 45' - 8"	28' - 1"	35	85,900	31
Brazos River	10 x 40' - 0"	16' - 0"	25	201,253	31

4.6 Timber deck bridge system

Nail laminated timber deck bridges have been used extensively in Linn Co., IA. These bridges are fabricated and erected by county crews. The typical dimensions of the panels are 6 ft x 24 ft; however, 4 ft and 4.5 ft wide panels have also been used. Generally, four such units make a 24 ft wide bridge. The bridges are also built in multiple units of 24 ft span lengths and a standard width of 24 ft.

4.6.1 Construction: Laminated bridge deck panels measuring 24 ft x 6 ft and with a thickness of 12 in. are prefabricated during the offseason by county crews. Each of these deck sections are made with 22 - 3 in. x 12 in. x 24 ft planks and four 3 in. x 6 in. x 24 ft planks. The planks are connected to each other with staggered nails to form the deck sections. These deck sections are connected through ship lap joints to adjacent sections. Each unit, which weighs approximately 3.5 tons, is built with provisions for being lifted into place. The piers consist of seven 12 in. diameter, 25 ft long timber piles that are driven by county forces. Piers are cross-braced using timber brace planks (3 in. x 12 in. x 17 ft). The pile cap is a 12 in. x 12 in. x 26 ft timber beam, which is attached to the piles with 5/8 in. dia. x 2 ft long drift pins. Abutments are similar but have backing planks that are nailed together instead of the cross-bracing. Once the substructures are completed, the prefabricated timber panels are lifted into place. Adjacent panels are connected to each other by drift pins at a spacing of 2 ft. Each panel sections is supported at the piers and/or abutments using two drift pins. Formed steel beam guardrail are then attached to the exterior deck panels using 5/8 in. dia. lag bolts. A suitable wearing surface is then applied.

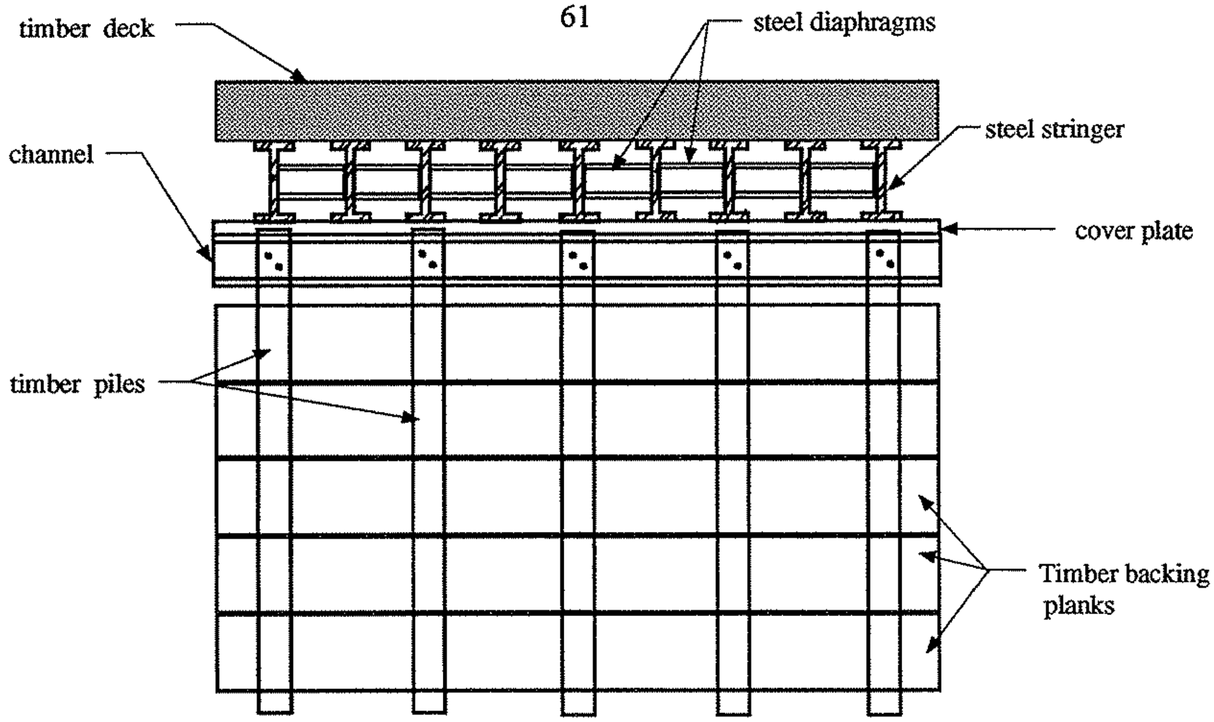
4.6.2. Economics: The economics of this bridge type are generally favorable to the county because of increased county participation in the design and construction of the system. A three span 72 ft x 24 ft structure was built on the Marion Airport Road in Linn Co., IA to replace a steel beam bridge at a total project cost of $63,390. The unit cost was $36.70 per sq.ft. On another project, a 24 ft x 24 ft deck bridge was used to replace a 24 ft x 19 ft timber beam bridge on the Linn-Benton road at Little Gannon Creek. The total cost of this project was $30,429.50, or a unit cost of $53.00 per sq.ft. The higher unit cost for the single span bridge is probably because of increased substructure costs.

4.7 Steel stringer-timber deck bridge system

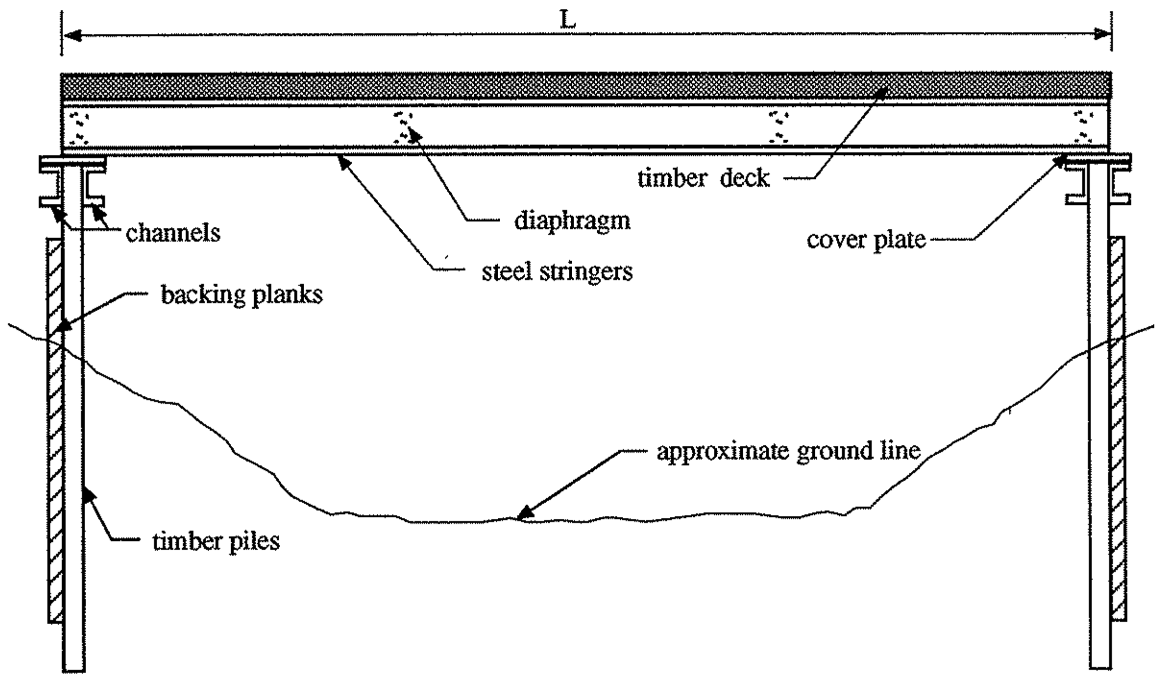
This system has been extensively used in Osceola Co., IA. The system uses old steel beams that are bolted onto abutments at a regular spacing as shown in Fig. 4.9. Timber decks are attached to the steel beams through special wood nailers which have been bolted to the beams. The abutments are timber piles with plank backing. Spans up to 34 ft have been constructed; this bridge is capable of carrying HS-20 loads.

4.7.1 Construction: The construction of the bridge system follows the steps described below:

- The timber piles are driven and wooden backing planks are attached to construct the abutments.
- A steel pile cap consisting of two channels (C10) and a welded-on cover plate is bolted to the piles.
- Ten used W21x62 beams are welded on to the cover plates at 30 in. spacing. Eight in. steel diaphragms are welded between the beams at the third points.



a. Cross-section of bridge system at the abutment



b. Elevation of bridge system

Fig. 4.9. Details of steel stringer-timber deck bridge system.

- Wooden nailers (4 in. x 12 in.) are bolted to the top flange of the beams to which a four in. wooden deck is nailed.
- Wooden guardrails are bolted to the outside beams.

4.7.2. Economics: The cost details of one such bridge constructed in Osceola Co. are as follows. The bridge was constructed entirely by using county forces. The total cost including materials, rented equipment and labor was $27,557.87 or $33.77 per sq.ft.

4.8 Con-Span culvert system

The Con-Span system is a precast arch-culvert system that is designed to provide a large hydraulic cross-section when vertical clearance is limited [4]. The system is proprietary and licensed by the Con-Span Culvert company of Dayton, OH. In Iowa, the Con-Span system is available through Iowa Concrete Products, West Des Moines. The system is available in spans of 16 ft, 20 ft, 24 ft and 36 ft and in rises of 5 ft to 10 ft. A general schematic of the system is shown in Fig 4.10. The arch-box shape gives a higher load carrying capacity than a reinforced concrete box culvert. The system also provides less obstruction to debris. The culvert consists of multiple units placed adjacently and bolted to each other to get the desired width. Precast wingwalls may be bolted on if desired. After backfilling is completed, the road can be constructed. In a load test performed on a Con-Span installation in Delaware, OH in 1986, the culvert failed at a load five times the service load; ultimate failure was gradual and predictable. The system is generally aesthetically pleasing and requires little maintenance.

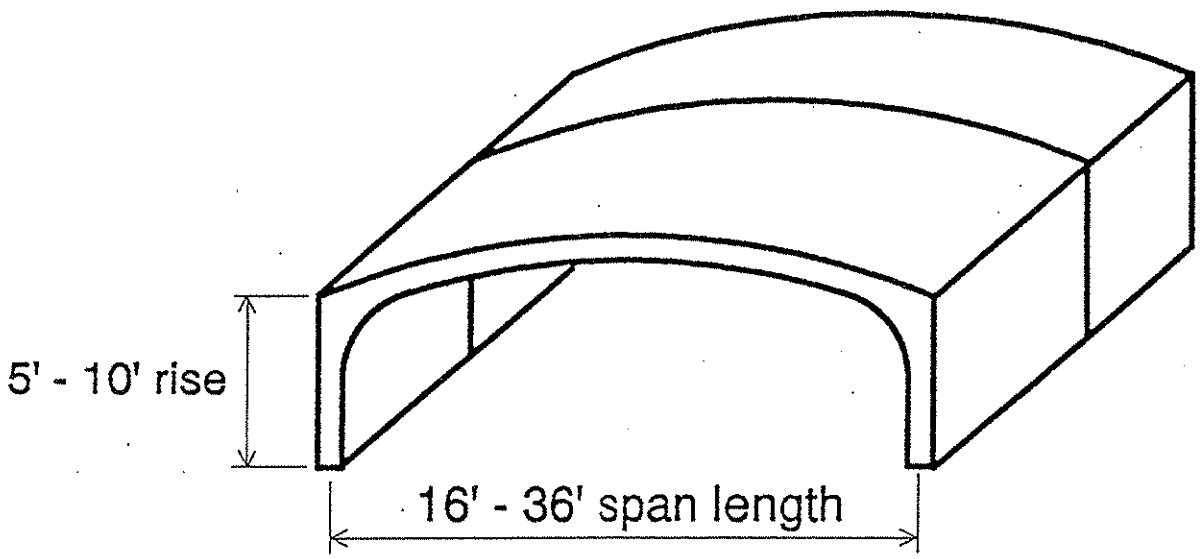


Fig. 4.10. General Schematic of Con-Span culvert system.

4.8.1. Construction: The installation of a Con-Span culvert system follows the basic steps outlined below:

- Pouring strip footings to support precast units.
- Set precast Con-Span units on the strip footings in a bed of cement grout.
- Spread engineering fabric over the joints to prevent the intrusion of backfill.
- Bolt units together on the vertical sides.
- Install precast wingwalls (if desired).

4.8.2 Design: Con-Span culverts are designed by the precasters to meet AASHTO specifications and loadings. When engineers desire to use the Con-Span system, they provide the supplier with information regarding the span length, height of rise, cover requirements and the design load. Hydraulic charts to assist the engineer in evaluating the required culvert size are also provided by the company.

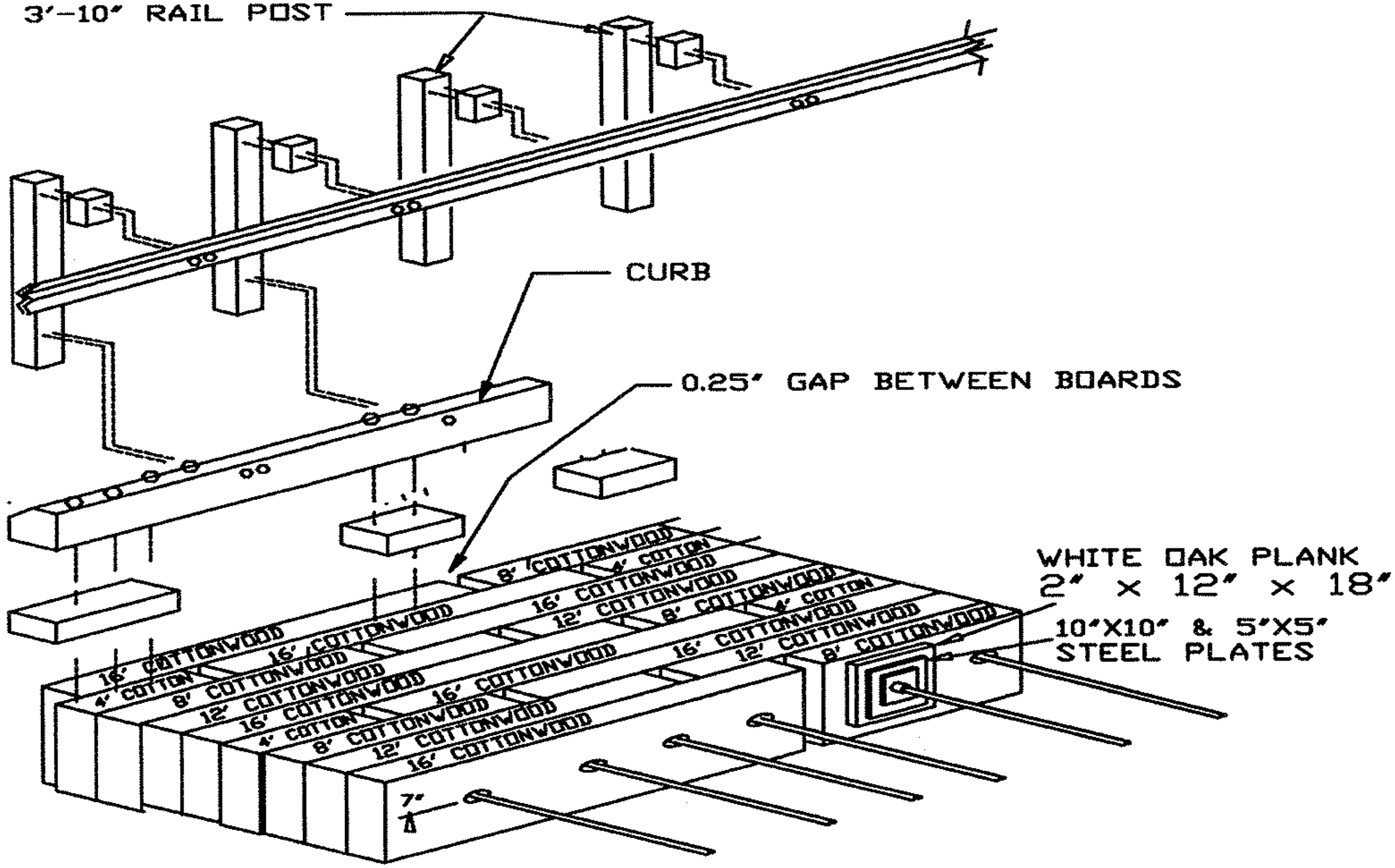
4.8.3. Economics: Specific cost information for each case may be obtained from Iowa Concrete Products, West Des Moines. The precast culvert system has been installed in Bremer Co. and Winnebago Co., IA. In Bremer Co., a laminated wooden box culvert was replaced with the Con-Span system. The total project cost for 20 ft x 9 ft x 64 ft system was $35,961 ($28.10 per sq.ft). In Winnebago Co., a timber bridge was replaced with a 16 ft x 5 ft x 136 ft Con-Span culvert. The project was completely by county forces with the exception of the substructure work. The total project cost was $86,057 ($39.55 per sq.ft). The higher unit costs may be due to a 45° skew in the structure. For more details on project costs and additional details on the product refer to Ref. 4.

4.9 Stress laminated deck bridge system

Some of the main problems affecting conventional nail-laminated panel deck bridges include excessive delamination, need for full length members and poor load distribution. With the stress laminated bridge system (Stresslam), these problems to a great extent are overcome. In the stress laminated bridge deck system, sawn lumber laminations are placed vertically and pressed together on their wide faces using high-strength steel prestressing tendons. This allows prefabrication of the deck in smaller panels which may be lifted into place more easily. Further delamination is greatly reduced if the prestressing force is properly maintained. Due to the fact that the load transfer between laminates in a stresslam system is by friction between adjacent wide faces, it is not necessary to have individual laminates span the entire length of the span. Butt joints of individual laminates are permitted with certain limitations.

Since most of the Stresslam bridges built to date have been constructed as a part of a national bridge initiative, very little useful cost data are available. Available cost data are indicative of high costs, essentially because of the experimental nature of the construction and the lack of a competitive bid process. A 34 ft x 24 ft Stresslam bridge built in Shelby Co., IA. through the US Forest Service Timber Bridge Initiative in 1990 cost $73,677 (unit cost $90.29 per sq.ft.).

Stresslam bridges using cottonwood lumber milled in Iowa have been constructed in Appanoose Co., IA., using county work forces and equipment. Figure 4.11 shows the schematic of one such cottonwood stresslam bridge. The bridge, spanning 24 ft between abutments, was constructed of 2 in. x 14 in. cottonwood lumber of different lengths (4 ft, 8 ft, 12 ft or 16 ft) placed longitudinally to obtain the desired bridge dimensions. These beams were prestressed transversely using prestressing tendons that were bolted on both sides through a series of three anchor plates. The



Note:
Timbers are 2" × 14" Curbs are 6" × 12"
Scuppers are 6" × 12"

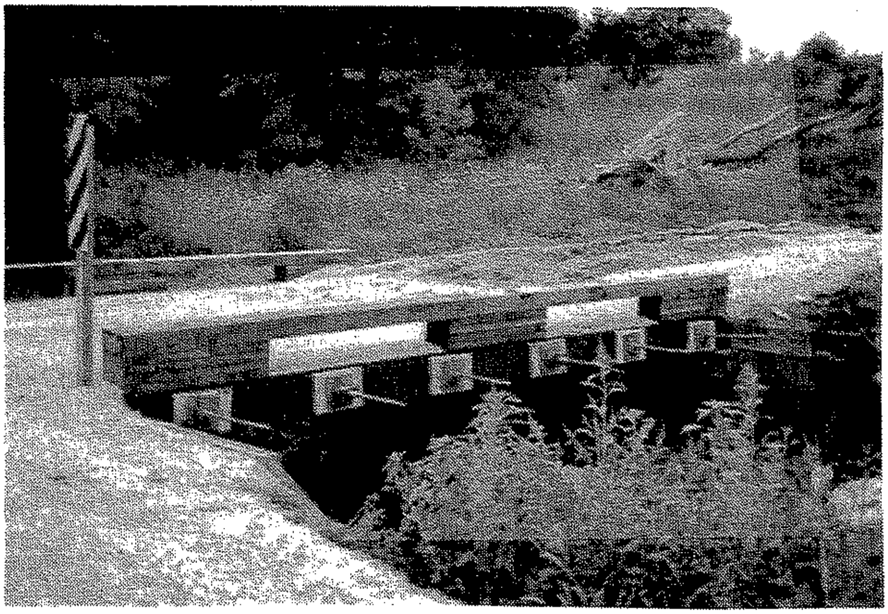
Fig. 4.11. Cottonwood deck system - typical 24 ft stress-laminated deck.

first anchor plate was a white oak plank, while the second and third were steel plates. Rail posts were attached to the curbs by bolting and a metal guardrail was attached. Photographs showing two views of a similar bridge built in Decatur Co., IA are presented in Fig. 4.12a. Figure 4.12b shows a two span cottonwood stresslam system constructed in Centerville, IA.

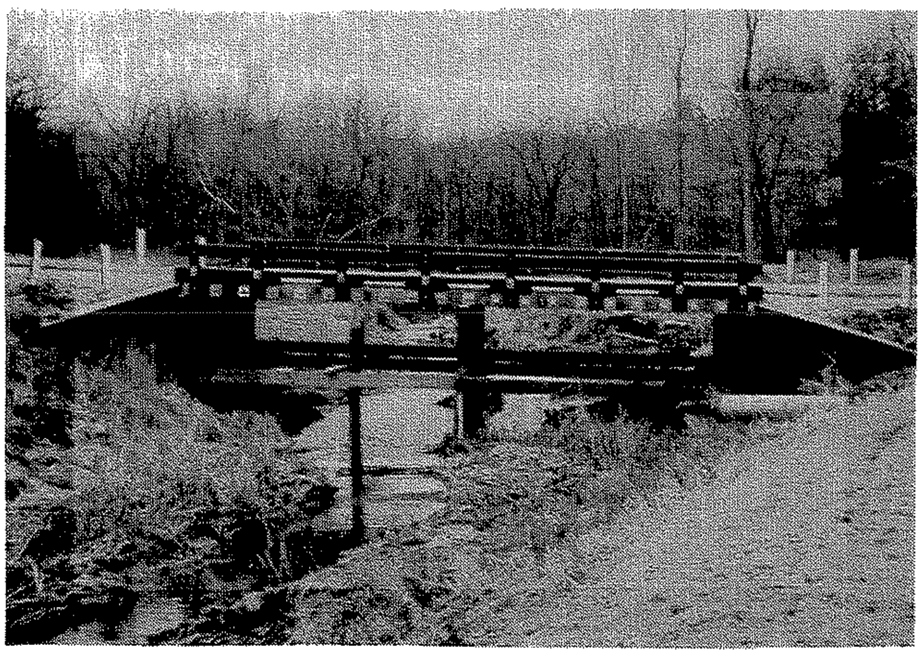
The superstructure cost of the two span bridge in Centerville was estimated to be approximately $32 per sq.ft. (including labor, asphalt and guardrail). A general unit cost for a single span bridge has been estimated to be $35 to $45 per sq.ft. (superstructure costs only).

4.10 Low water stream crossings

Low water stream crossings using a unique airplane wing profile with 15 in. dia. plastic pipes have been constructed in Appanoose Co., IA. These structures have been constructed entirely using county work forces and equipment. The crossings have been used on 18 ft wide roads. The system consists of two ft wide cast-in-place concrete strip footings which are cast 25 ft apart (on either side and parallel to the roadway) on which two 15 in. diameter plastic pipes are placed transversely. A schematic of this system is shown in Fig. 4.13; photographs of one installation are shown in Fig. 4.14. Concrete is cast around and above the pipes to make the roadway. The slope on the upstream side of the crossing is 1:1, and the slope on the downstream side is 4:1. Rumble strips made with a "2 x 4" board form are used on either side of the approach.

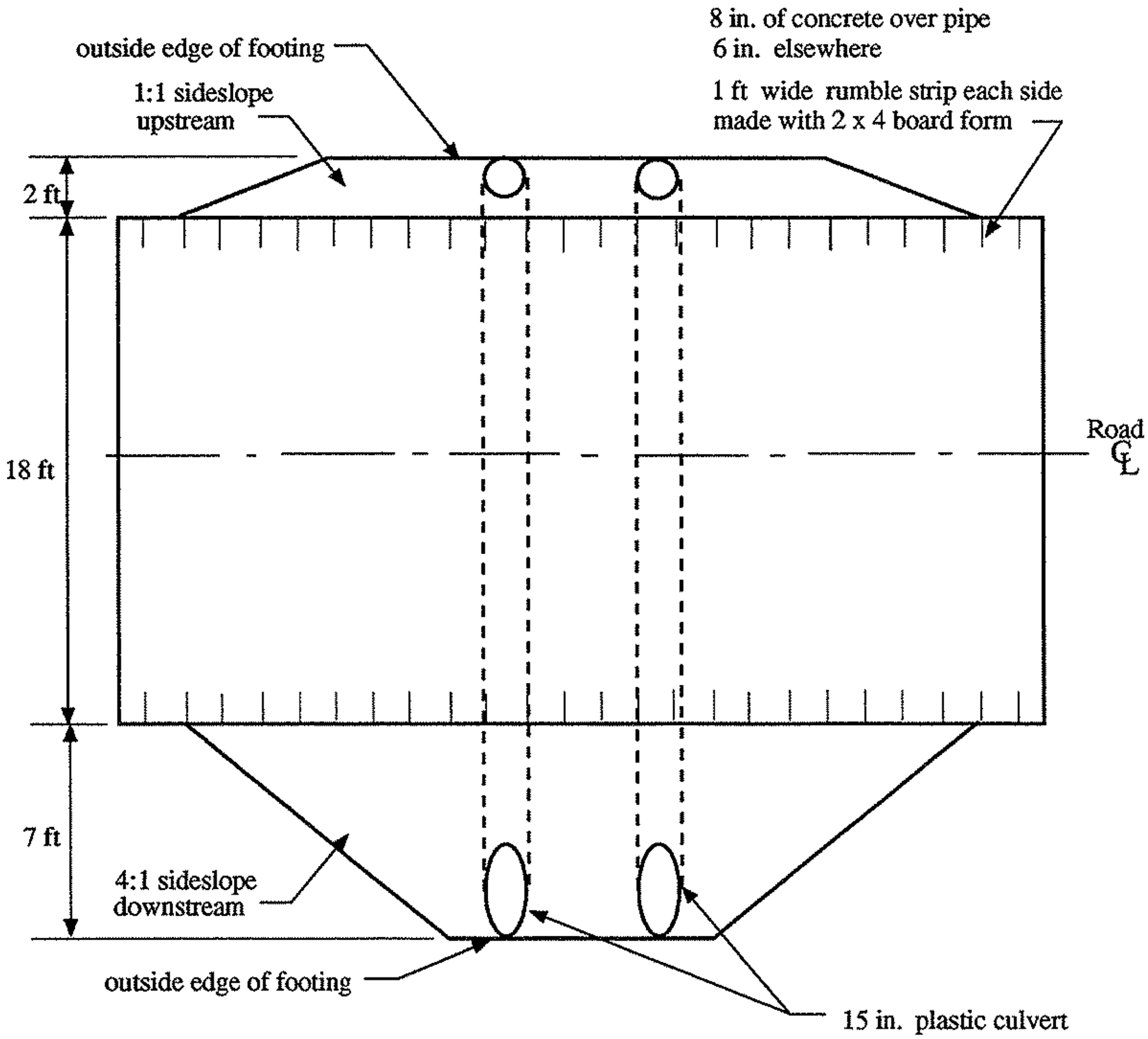


a. Single span bridge in Decatur Co., IA



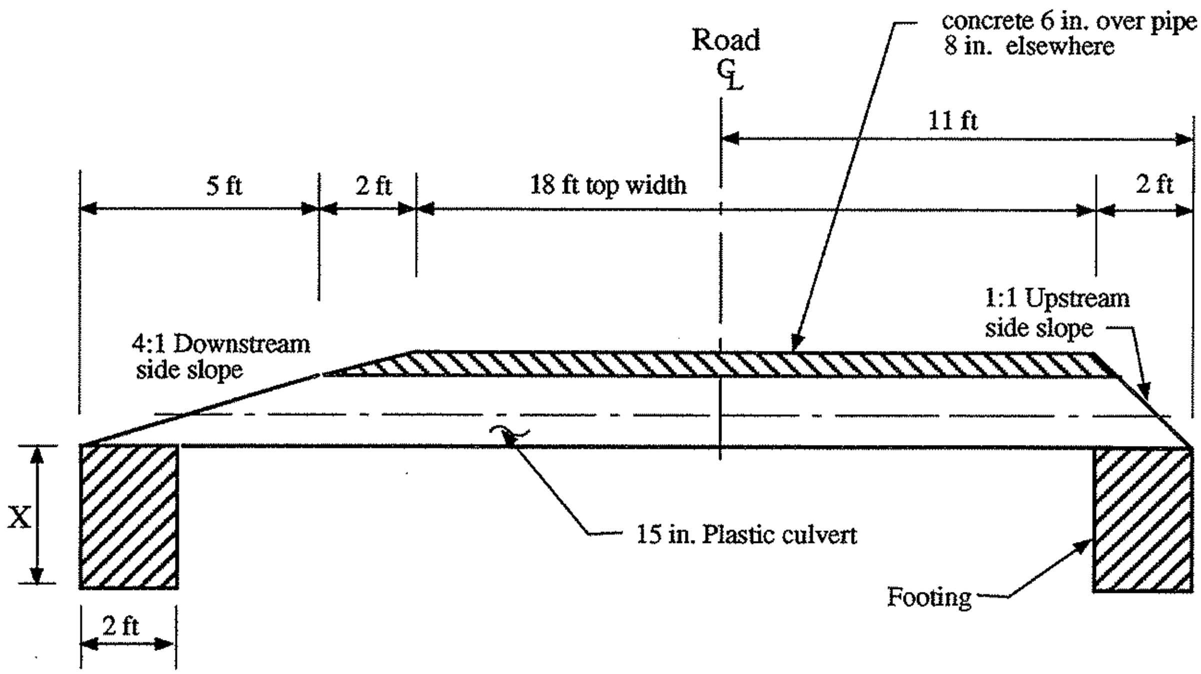
b. Two span bridge in Centerville, IA.

Fig. 4.12. Photographs of cottonwood bridges.



a. Plan

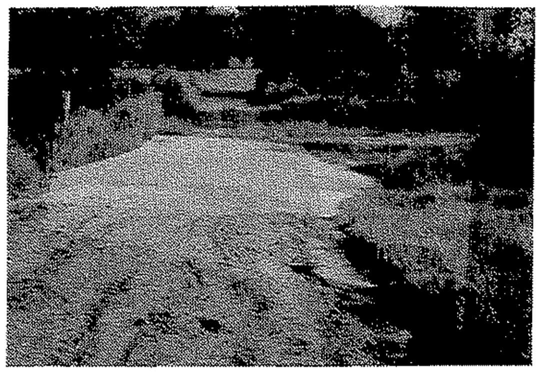
Fig. 4.13. Low water stream crossing.



* X varies with site conditions.

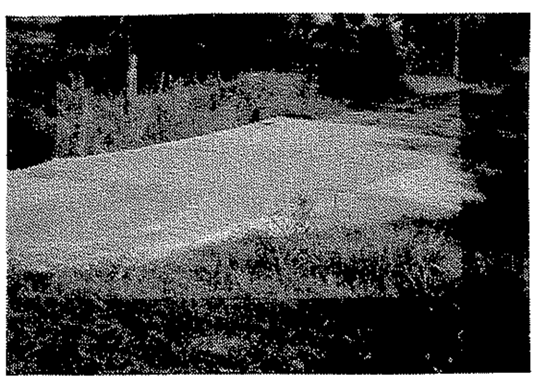
b. Cross-section

Fig. 4.13. Continued.



a. Overall view

b. Outlet view



c. Inlet view

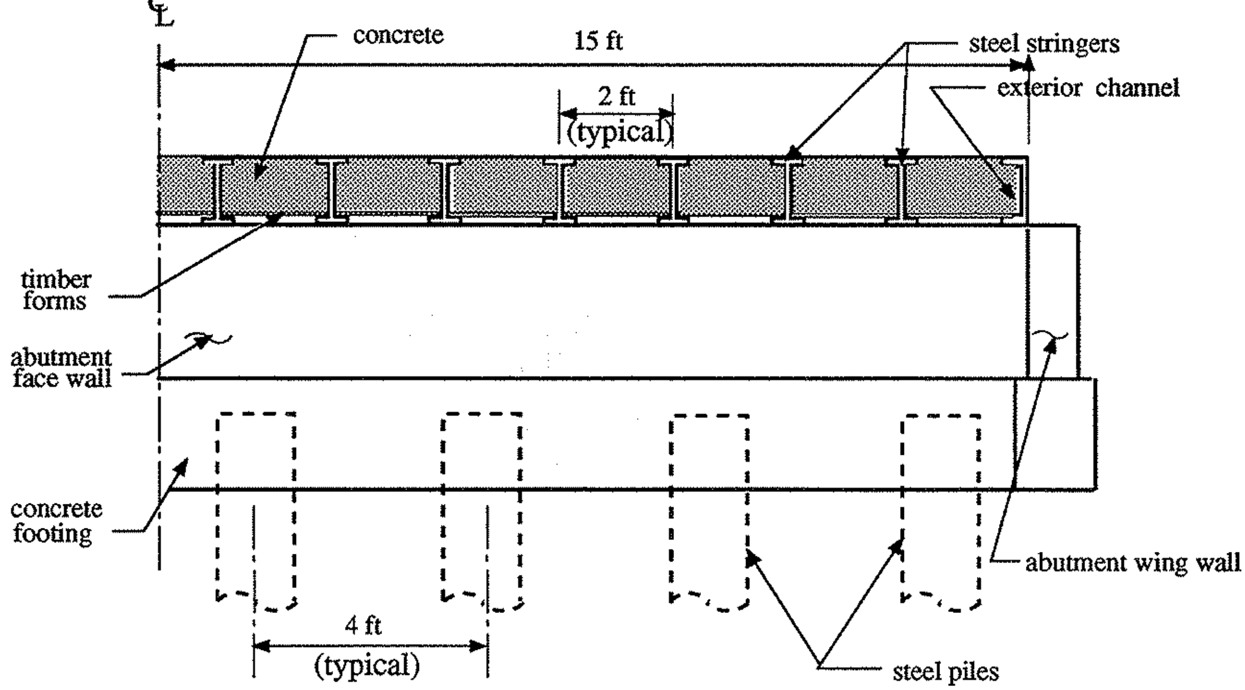
Fig. 4.14. Photographs of low water stream crossing.

4.11 Beam-in-slab bridge system

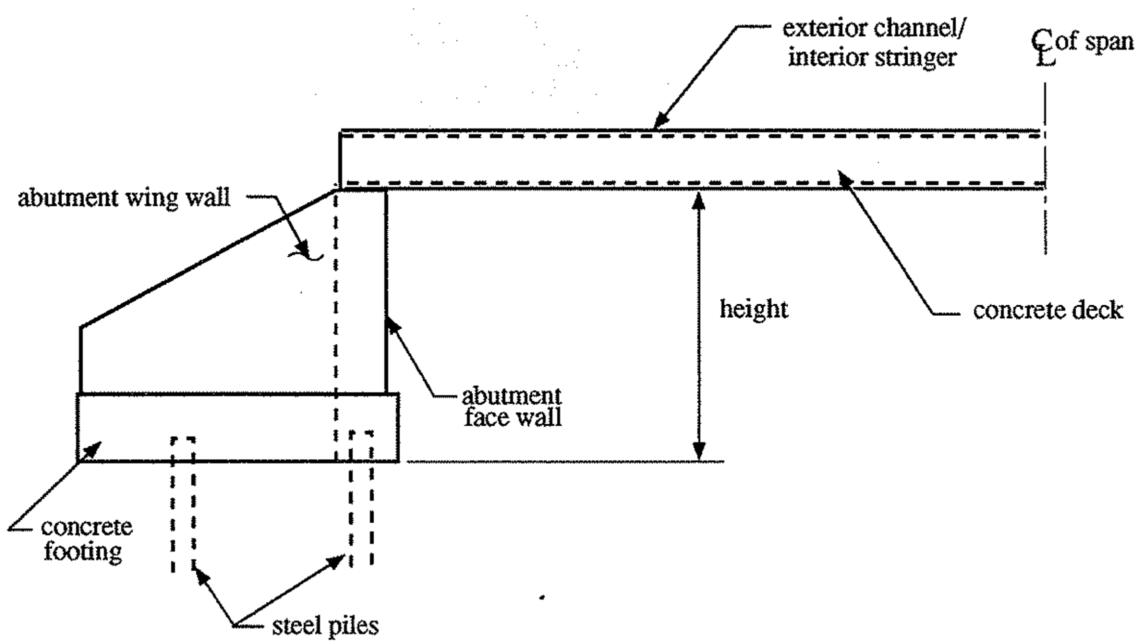
A significant number of beam-in-slab type bridge structures have been constructed in Benton Co., IA and Blackhawk Co., IA. As shown in Fig. 4.15, the structure uses a series of W sections spanning between abutments. Channel sections are used as the exterior stringers. Steel straps are welded to the bottom flanges to hold the steel beams in place while the concrete is placed. Plywood, placed between adjacent beams on the top surface of the bottom flanges, is used for formwork. The width of the forms is made a few inches less than the beam spacing so that the concrete is in contact with the bottom flange when placed. Thus, even when the formwork deteriorates there will be good bearing between the steel and the concrete. These structures have been used for spans varying from 20 ft to 40 ft and for heights varying from 5 ft to 12 ft (shown in Fig. 4.15b). Photographs of typical beam-in-slab bridges are shown in Figs. 4.16 and 4.17. The bridge in Fig. 4.16 is a typical installation for low water stream crossing applications in that no guardrail have been provided as is the case with the bridge shown in Fig. 4.17 which is at a higher elevation.

4.11.1 Construction: The beam-in-slab bridge system is simple to construct and has been built using county forces and equipment. The construction procedure is briefly described below:

Abutments: Drive 8 piles at 4 ft centers (for abutment face) and one pile for each of the wing walls. Place concrete for the abutment footing/pile cap with a keyway for the abutment wall. Next construct the abutment wall and wing walls to the desired height with necessary reinforcement. Provide dowels for connection between the abutment and the superstructure.

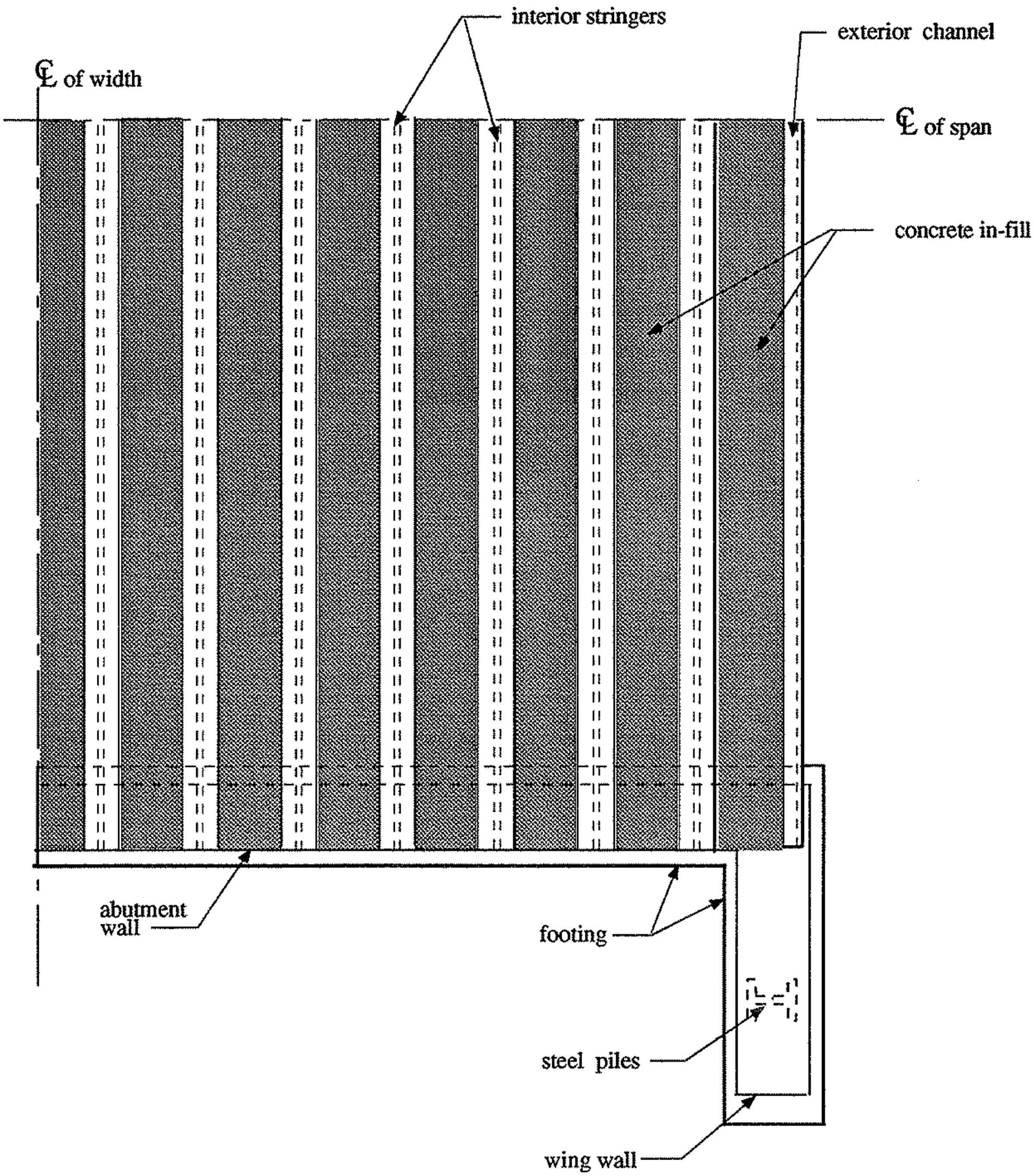


a. Half cross-section at abutment



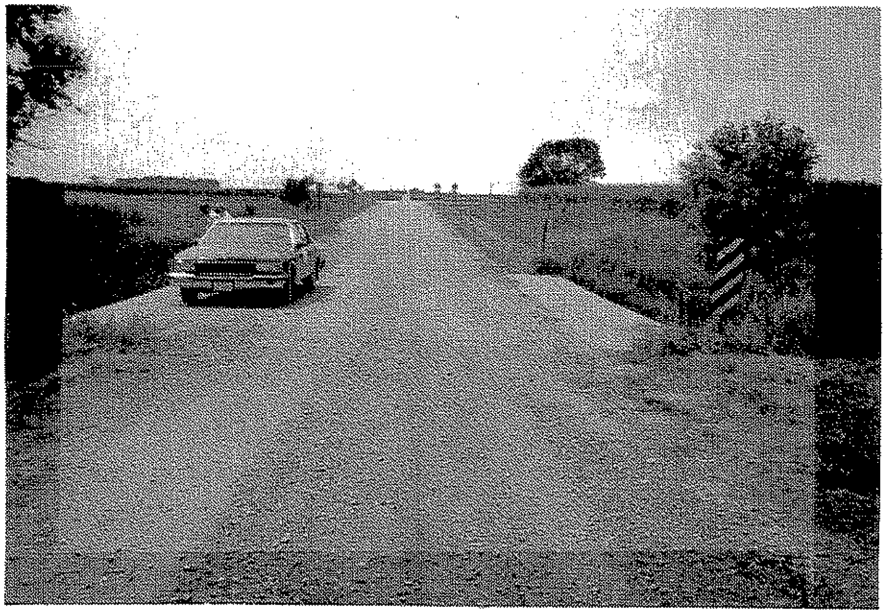
b. Half elevation of system

Fig. 4.15. "Benton County" bridge system.



C. Plan

Fig. 4.15. Continued.

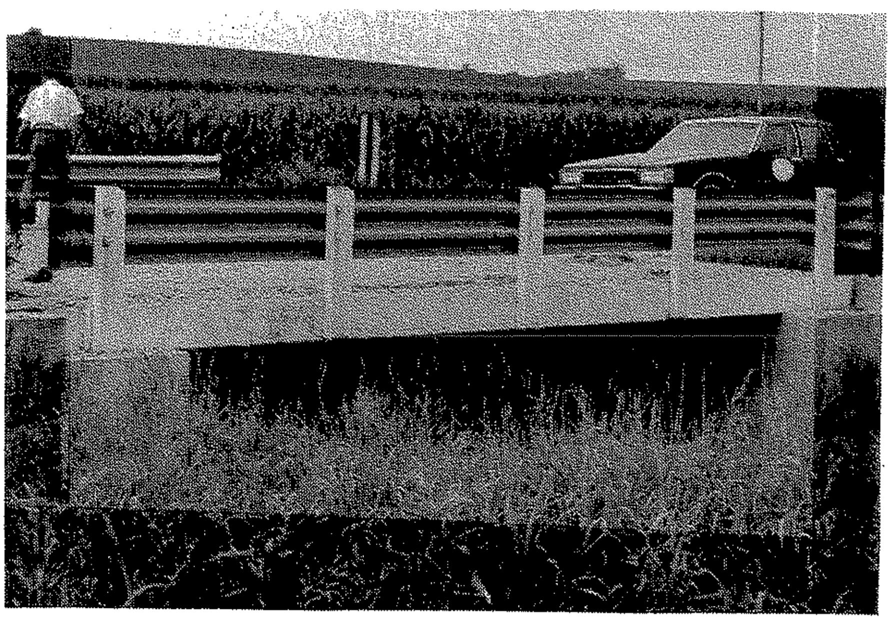


a. Overall view

b. Plywood forms in place

Fig. 4.16. Photographs of beam-in-slab bridge no. 1.

a. Overall view



b. Side view

Fig. 4.17. Photographs of beam-in-slab bridge no. 2.

Superstructure: Place the steel W sections in position, adjacent to each other (Note: The majority of bridges constructed to date in Benton Co. have used W12 and W10 sections on 2 ft centers). Place the two channel sections of same depth as the W sections at the exterior edges of the bridge. Position plywood forms between the bottom flanges of the adjacent W sections and the W sections and the channel sections. Pour concrete for the slab flush with the top flange of the beams. If guardrail are to be used, attach guardrail posts (TS 6 in. x 3 in. x 1/4 in. x 3 ft - 9 in.) to the exterior channel sections and the first interior W sections. Attach guardrail to the posts.

4.11.2 Economics: Cost studies for this bridge type suggest increased unit costs with decreasing spans. A low water stream crossing was constructed in Blackhawk Co., IA in 1993 with a width of 30 ft and a span of 34 ft at a cost $36,000 including guardrail, steel, labor and equipment (unit cost approximately $35 per sq.ft). The bridges in Benton Co. are built with a standard 30 ft width. A 25 ft span beam-in-slab system without Guardrail had a unit cost of $35 per sq.ft. A 21 ft span (30 ft width) costs $42.50 per sq.ft. The unit cost for a 40 ft beam-in-slab bridge has been estimated to be approximately $32 per sq.ft.

4.12 Evaluation of the alternatives

As noted earlier, the objective of this investigation was to identify possible replacement alternatives and to evaluate them on the basis of their appropriateness for use on the county road system. The twelve bridge replacement systems that were identified were evaluated using the criteria specified below:

- Initial unit cost
- Ease of construction by county forces
- Ease of construction by contractors
- Ease of inspection
- Conformance to AASHTO standards
- Extent of maintenance required
- Range of additional spans and sizes

These criteria were selected based on an active interaction and discussion between the members of PAC and the research team. The various replacement alternatives were rated by members of the PAC on evaluation sheets. Brief descriptions of the various replacement alternatives were provided to assist PAC members with their evaluations. The mean of the responses of all the evaluators in each category along with the overall rating of the replacement bridge systems is given in Table 4.6. Two overall ratings are given in the table for each bridge. Overall rating 1 is the mean of the ratings for a given type of bridge for all criteria except "Ease of construction-contractors"; in other words, this rating provides information on the various types of bridges as to their ease of construction by county forces. On the other hand, overall rating 2 - a mean of all criteria except "Ease of construction-county forces" - provides information on the

Table 4.6. Mean rating of listed bridge replacement alternatives.

Bridge Type \ Evaluation Criteria	Initial unit cost	Ease of construction-county forces	Ease of construction-contractors	Ease of inspection	Conformance to AASHTO Standards	Extent of maintenance required	Range of available spans and sizes	Overall rating	
								1	2
Prestressed concrete beam bridges	6	5.75	8.5	8.5	9.5	8.25	7.25	7.54	8.00
Continuous concrete slabs	7.67	3.33	8.67	8.67	9.33	9	8.33	7.72	8.61
Air-formed Arch culvert	3	1.5	5.5	4	5.5	6	5.5	4.25	4.92
Concrete slab - Steel girder - Precast deck	4.5	6	7	5	3	4	2.5	4.17	4.33
Concrete slab - Steel girder - CIP deck	5	6.5	7.5	6	3.5	5	2.5	4.75	4.92
Inverset bridge system	7	2	5	5	5	6	3	4.67	5.17
Timber panel deck system	5.5	8	8	8.5	8	8	6.33	7.39	7.39
Steel stringer - timber deck system	7	8.67	8	8	7	5.5	6.33	7.08	6.97
Con-span culvert system	5	5.5	7.5	7.67	8.33	8	7.67	7.03	7.36
Cottonwood stresslamdeck system	4	5.5	6.5	5.5	7	5	7	5.67	5.83
Low water stream crossings	6.5	7	7.5	7	4.5	5	3	5.50	5.58
Beam-in-slab bridge system	6	8	8	8	7	7.5	7.5	7.33	7.33

Note: Scale of 1 to 10 used, with 10 being the highest rating.
Some bridges were not given ratings by all evaluators.

ease of construction of the various types of bridges by contractors.

A brief summary of the ratings is provided below based on each criterion.

Initial Unit cost: Based on this criterion, continuous concrete slabs, Inverset bridge system, steel stringer-timber deck system and low water stream crossings had the most favorable ratings.

Ease of construction-county forces: The steel stringer-timber girder deck system, timber panel deck system, beam-in-slab bridge system, low water stream crossing, concrete slab-steel girder-CIP deck, and concrete slab-steel girder-precast deck were rated the highest when considering construction by county forces only.

Ease of construction-contractors: All of the bridges listed were rated high for this criterion except for the air-formed arch culvert and the Inverset bridge system.

Ease of inspection: Most of the bridges were perceived to be easy to inspect except for the air-formed arch culvert, concrete slab-steel girder-precast deck and the Inverset bridge system. The cottonwood system was given only a moderately acceptable rating.

Conformance to AASHTO Standards: The following bridges were rated poorly in terms of this criterion; concrete slab-steel girder-precast deck, concrete slab-steel girder-CIP deck, the

Inverset bridge system and low water stream crossing. The air-formed arch culvert was also given a low rating.

Extent of maintenance required: The bridges perceived to have the potential for maintenance problems were the concrete slab-steel girder-precast deck, concrete slab-steel girder-CIP deck, cottonwood stresslam deck system, and low water stream crossings. The steel stringer-timber deck system was also not rated very good.

Range of available spans and sizes: The bridges rated the least desirable based on this criterion are the concrete slab-steel girder-precast deck, concrete slab-steel girder-CIP deck, the Inverset bridge system, and low water stream crossings.

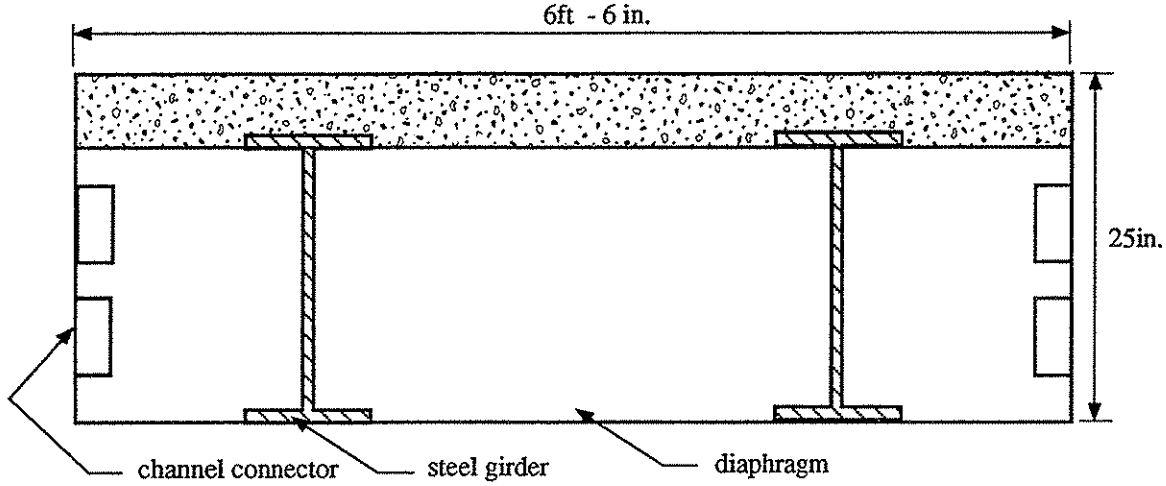
Summary of evaluations: If a bridge were to be constructed by county forces, the most desirable alternatives of those bridges with a high rating for the ease of construction-county forces criterion including all other criteria would be timber panel deck system, steel stringer-timber deck system, and the beam-in-slab bridge system. The cottonwood deck system and the Con-Span culvert system would be moderately desirable alternatives. Bridges that offer the most desirable alternative if constructed by contractors would be the continuous concrete slabs and the prestressed concrete beam bridges. This is consistent with the questionnaire responses received from county engineers which was discussed earlier in this report. The beam-in-slab bridge system, Con-Span culvert system, steel stringer-timber deck system, and timber panel deck system would also be rated high were they to be constructed by contract work forces.

5. POTENTIAL NEW BRIDGE SYSTEMS

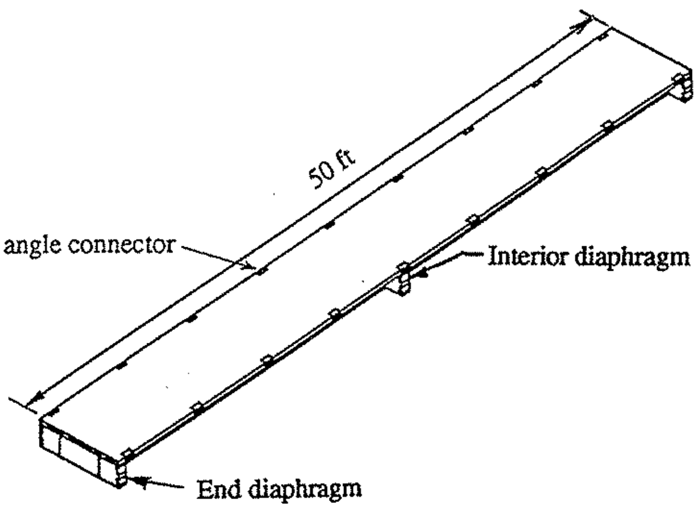
As was noted in the original proposal, depending on the findings of the initial tasks of this investigation, new systems may be proposed. In this section two such systems are presented. The proposed systems are economical and easy to construct. As was noted earlier, a majority (69 percent) of the respondents felt that the counties were capable of handling small replacement projects using county forces and equipment, provided the procedures were simple. The proposed systems meet this requirement. One of the proposed systems is a steel stringer-concrete composite deck bridge (System 1) while the other system (System 2) is a modification to the beam-in-slab system (see Sec 4.11). Both of the systems are designed for HS-20 loading and have the ability to carry all Iowa legal loads. These systems are briefly described in the following sections.

5.1 System 1

This bridge system is composed of repetitive units. Each unit would have two steel stringers (new or used); after appropriate shear connectors are installed on the beams, a concrete deck (4 in. thick) and diaphragms (see Fig 5.1) are poured and thus act compositely with the beams. The deck and the diaphragms could be cast in the county maintenance area (thus greatly simplifying their fabrication) prior to taking these units to the field. These units could then be transported to the site, lifted into place and connected to each other by simple connectors (see Sec. 5.1.2). With the units in place, a 5 in. thick concrete slab would be cast in situ using the precast deck as formwork. Guardrail and the wearing surface (if desired) could then be installed.



a. Cross-section of individual unit.



b. 3-D view of individual unit.

Fig. 5.1. Description of System 1.

5.1.1 Unit Details: Channel shear connectors (or other suitable shear connectors) welded to the top flange of each of the stringers would ensure complete composite action. In order to improve the load distribution between beams and to better resist lateral forces, concrete diaphragms would be cast along with the deck at the ends and at midspan. The width of each unit is 6.5 ft; thus, four such units would be required for a 2 lane bridge (total width = 26 ft). Each unit weighs about 11 tons, which would make it easy to lift into place by a county crew working with limited equipment.

5.1.2 Connection Details: Channel sections would be cast in the concrete diaphragms for the purpose of connecting the various units. Once the units were in place, plates (Plate A, in Fig. 5.2) would be welded to the channel sections to provide diaphragm continuity. Similarly, angle sections would be cast into the slab edges every 6 ft. Again, after the units are in place at the bridge sites, plates (Plate B, in Fig. 5.2) could be welded to these angles prior to casting the slab to ensure continuity. The load transfer capacities of the angle connections have been verified through a finite element analysis. The angle plus plate connection, with the 5 in. continuous slab, was found to be as efficient as a monolithic slab.

5.1.3 Construction procedure: The construction procedure for System 1 would consist of three distinct phases; fabrication of the units, erection of the units, and casting the deck. In the fabrication phase, the units could be built in the county maintenance area. This includes building formwork, placing reinforcement and casting the slab and diaphragms. In the erection phase, the units would be transported to the site, lifted into position, and connected through plates welded to angles and channels in the units. In the final phase, reinforcement for the deck slab would be placed and the deck cast. Guardrail and other details may then be installed.

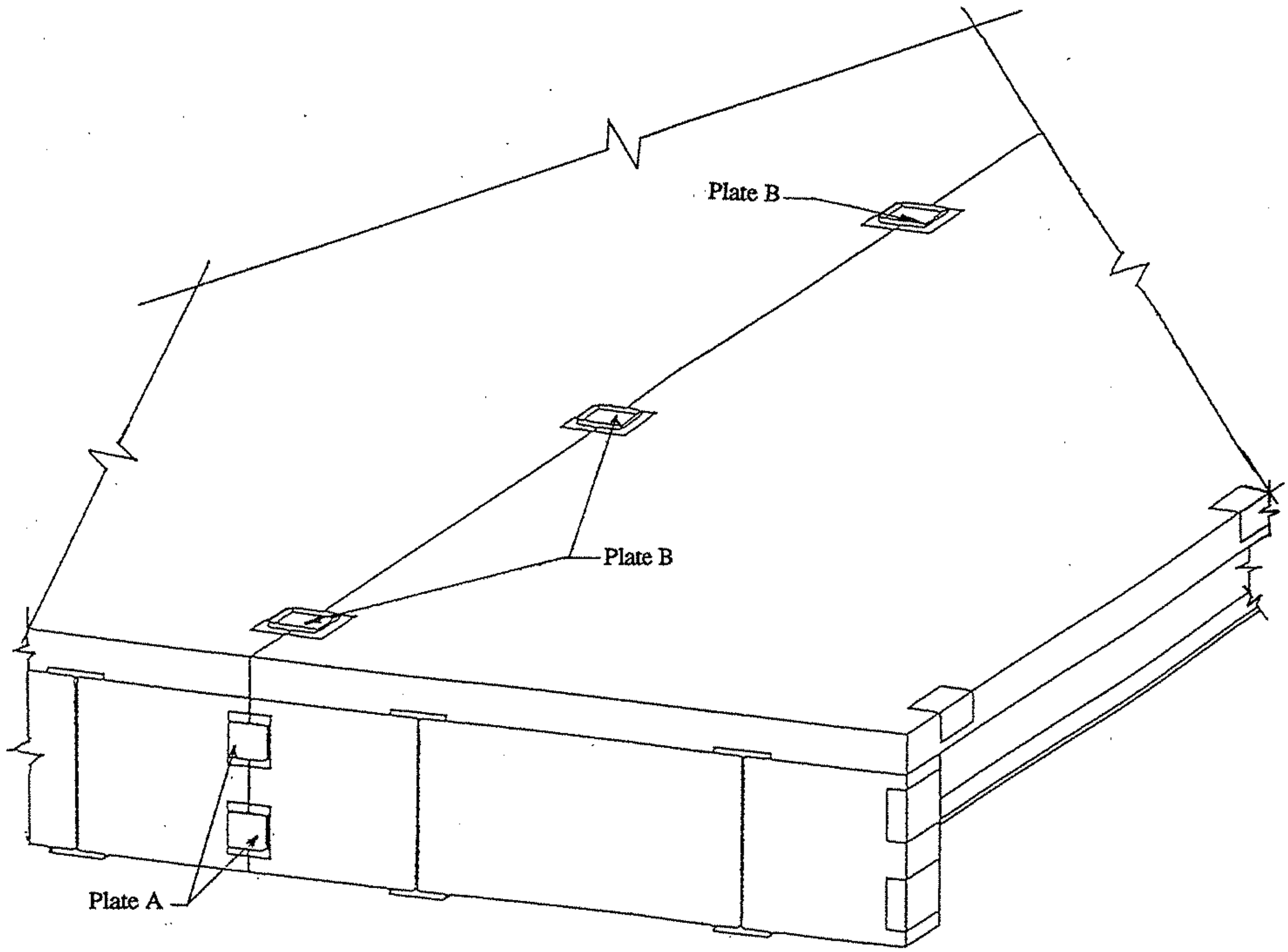


Fig. 5.2. 3-D view of both channel and angle connectors near end diaphragm.

5.1.4 Ease of construction: System 1 would be easier or as easy to construct and erect than most conventional systems such as the Inverset system or continuous concrete slabs. Unlike the Inverset system, there are no complications with suspended forms, inversion of whole unit after the concrete is placed, etc. The beams could set on a concrete floor (or even the ground surface if the units are fabricated outside), simple formwork for the slab built and the deck cast. The individual units of System 1 weigh considerably less than the units of the Inverset system thus making transportation and placement much easier. The continuous concrete slab bridge is cast in place, thereby requiring extensive falsework and formwork for the concrete. System 1 could be erected without falsework or formwork, since the unit itself becomes the formwork.

When compared to prestressed precast girders of comparable span, it may be seen that System 1 weighs less which gives it a considerable advantage when it comes to construction ease. Furthermore, System 1 does not need extensive equipment (jacks, anchorages, tendons, bulkheads etc.) or the extensive formwork, that are needed for prestressed, precast construction.

5.1.5 Comparative economics: The economics of System 1 compare favorably with that of conventional systems because of efficient use of county forces and equipment. Additional savings could be achieved if surplus steel beams were used. A comparison of the costs of System 1 are made with the Inverset system, prestressed precast girder systems, and continuous concrete slab systems. The estimated average superstructure costs are listed along with unit costs in Table 5.1. The unit costs provided are for 100 ft spans. Two spans were assumed for the Inverset, prestressed concrete girder system and System 1, whereas three spans were assumed for the continuous concrete slab system. Unit costs include estimated foundation costs. The foundation costs have been approximated as $21,000 for two spans and $30,000 for three spans. For the fabrication of System 1 reusable steel forms and some basic equipment are a one time cost; if desired, formwork could possibly be shared by counties which are in close proximity to each other. Comparing cost figures in Table 5.1, one observes that the cost of System 1 (assuming new beams are used) is approximately 65 percent of that for the Inverset system, 56 percent of that for the prestressed precast girder system, and 61 percent of that for the continuous concrete slab systems. Savings would obviously be more if surplus beams were used other than new beams.

5.1.6 Advantages of System 1

- Simple design and construction procedures.
- Provides more economical solutions than conventional replacement systems for corresponding spans even when new beams are used.
- Can be entirely constructed with county equipment and work forces.
- Lightweight units can be easily lifted into place.
- Can be fabricated by county forces during the winter months of the year (if indoor facilities are available) and erected during better weather. If indoor facilities are not available, the units can be fabricated outdoors (except for a few months of the year) in the maintenance area.
- Units do not require any special forms or other equipment for fabrication; forms are reusable.
- Maintenance of the System 1 bridge should be essentially the same as for existing bridges. Thus, no additional equipment would be required or new procedures learned.

Table 5.1. Comparison of costs of various bridge types.

System	Superstructure costs ($)	Unit cost ($/sq.ft)
System 1 (new beams)	34,380	23.10
System 1 (surplus beams)	25,260	19.30
Inverset	65,000	35.80
P/C	77,870	41.20
C R/C S	61,000	37.90

Note: Unit costs include substructure cost.

5.1.7 Using System 1 with narrow abutments: The feasibility of using System 1 for narrow abutment applications was also investigated. It was seen from the responses to the questionnaire discussed earlier in the report that, on the average 30 percent of the cost on a given project is for the substructure. It was therefore considered appropriate to investigate the possibility of using System 1 on existing abutments. Existing abutments, however, are usually too narrow for 24 ft wide bridges, and hence System 1 would require modification. It was previously stated that four units are required for a normal width bridge which would require an abutment width of at least 23.5 ft. However, most abutments which were built for 18 ft wide bridges are significantly narrower. Hence, the possibility of using three units with extended cantilevering portions to make up the required 24 ft of roadway was reviewed. Three units require a minimum abutment width of 17 ft. Shown in Fig. 5.3 is the cross-section of a modified bridge on a narrow abutment. Diaphragms have been provided at more locations (fourth points) to stiffen the cantilever slab. The beam sizes are increased, so the increased moment per beam can be accommodated. As was previously noted, the top 5 in. of the deck would be cast-in-place at the site. Preliminary model studies comparing stresses between bridges on normal width abutments and narrow abutments, indicate an increase in exterior girder stresses of approximately 15 to 20 percent; the increase in stringer reactions was approximately 20 to 25 percent. Extensive overhangs necessitated the use of method specified by Bahkt et.al [24] for the evaluation of the cantilever moments. However, the AASHTO specified moments govern. Overall, the use of three units per bridge with increased beam sizes seems to be a feasible option.

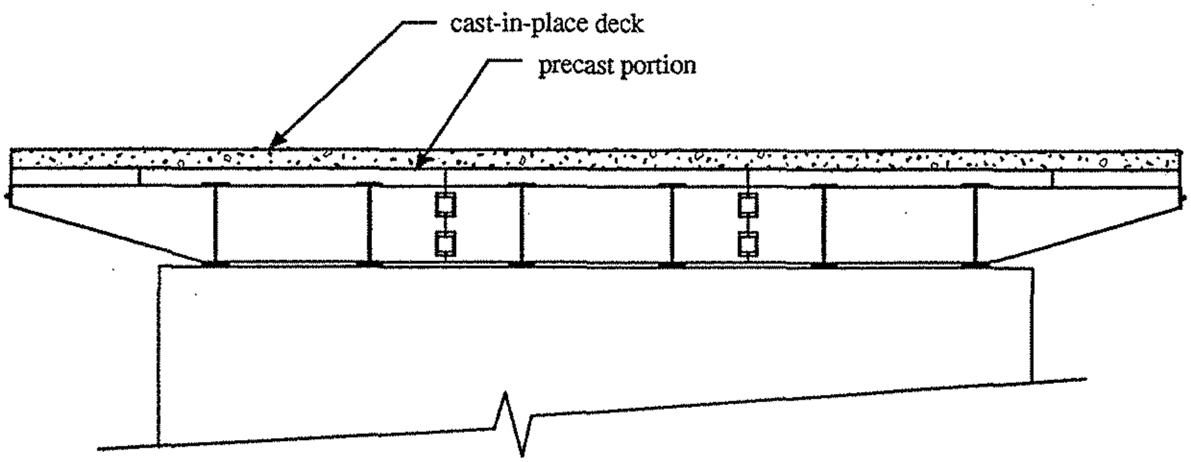


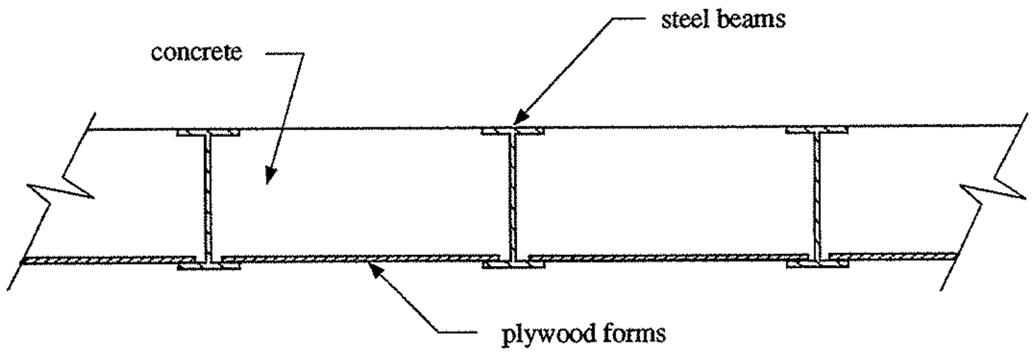
Fig. 5.3. Sectional view of System 1 modified for narrow abutments.

5.2 System 2

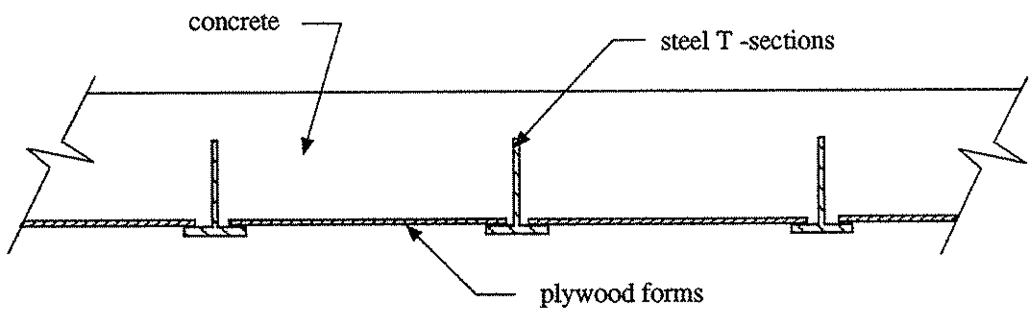
The research team, as well as numerous other county engineers, are impressed with the beam-in-slab system used in Benton Co., IA (see Fig. 5.4a). Many of the applications of this system in Benton Co. have been in place for numerous years; thus the system does have a "proven-track-record". The research team is aware of two different concepts that if incorporated in the beam-in-slab system, would increase its strength and thus make it possible to use it on longer spans. Also, since the modifications to the current system would eliminate the top flanges of the beams from the riding surface, the skid resistance of the bridge surface would be improved.

Research is currently in progress at the Technical University of Nova Scotia on composite slabs reinforced only with polypropylene fibers and no internal steel reinforcement [28]. The fiber reinforcing provides crack control in the slab, while the elimination of steel reinforcing significantly reduces maintenance concerns. If lateral restraint is provided between the beams to anchor the slab arching forces, the system is only limited by punching forces.

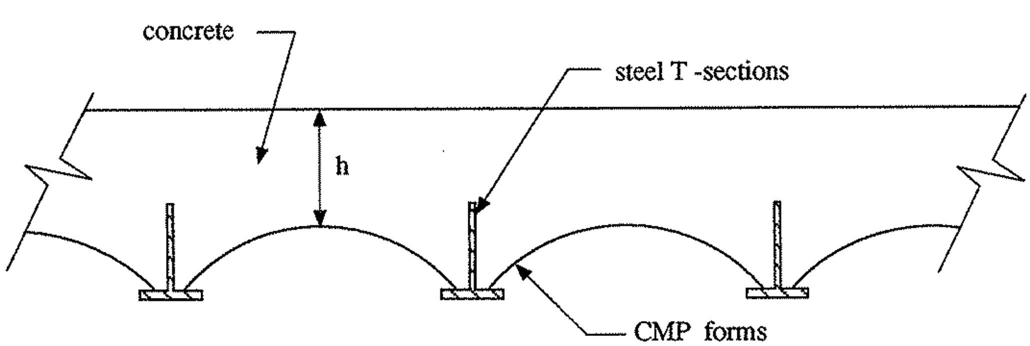
In the beam-in-slab system, there is sufficient concrete to carry compressive forces without the contribution of the top flange to the steel beams. Elimination of the top flange would modify the beam-in-slab system to a slab plus T-beam section as shown in Fig. 5.4b. Leonhardt, et. al. [29] has shown that by punching holes in the web of the T-section composite action between the concrete and steel can be developed. The T-beams could obviously be fabricated from existing surplus beams. If the surplus beams were of sufficient depth, two T-beams could be fabricated from one surplus beam.



a. Benton county bridge system



b. Modification no. 1



c. Modification no. 2

Fig. 5.4. Description of System 2.

Concrete on the tension side of the beam-in-slab system is obviously making little, if any, strength contribution and thus is essentially only adding to the dead load of the system. By replacing the plywood forms with sections of CMP, (see Fig. 5.4c) the amount of concrete on the tension side could be significantly reduced. By using the appropriate diameter of CMP the desired slab thickness (dimension "h" in Fig. 5.4c) could be obtained.

Incorporating these three modifications - fiber reinforced concrete, T-sections, and CMP forms - to the beam-in-slab system would make it possible to use this system on significantly longer spans and reduce the costs. Even with these modifications, the beam-in-slab system could still be constructed with county work forces.

6. CONCLUSIONS AND RECOMMENDATIONS

The above research effort has culminated in the identification and evaluation of various bridge replacement alternatives available to county engineers. The capability of counties to construct their own bridges has also been evaluated. Potential new replacement alternatives for use on county roads have been proposed. The study has led to the following conclusions:

- Continuous concrete slab bridges and prestressed concrete bridges are the most commonly used replacement alternatives. However, counties seldom construct these bridge types with county forces which leads to slightly higher costs.

- Counties are willing, and in a majority of the cases, seem to have the capability to replace bridges in the short span range (40 ft or less), provided the construction procedures are relatively simple. Need for extensive or complicated construction equipment has proven to be a deterrent.

- Potential replacement systems, System 1 and System 2, promise to be economically viable alternatives. These systems would meet all AASHTO requirements. They also are simple to construct, which allows construction using county work forces.

On the basis of the above investigation, the following recommendations for future research work in this and related areas include:

- An analytical study of other bridge types to evaluate the structural and economic feasibility of their use in the county bridge system. Bridge types showing promise of use on county systems to be field tested to confirm structural integrity and economic advantage.

- Laboratory tests of potential replacement bridges, System 1 and System 2.

- Based on the results of the laboratory tests, prototypes of the proposed systems (System 1 and System 2) should be fabricated and erected in the field as demonstration projects. The construction procedures should be fully documented (with video recordings, if desired) including structural and economic performance data.

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8. ACKNOWLEDGEMENTS

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APPENDIX

COVER LETTER AND QUESTIONNAIRE

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bridge Engineering Center
Department of Civil and
Construction Engineering
Ames, Iowa 50011-3232
515 294-7457
FAX 515 294-8216

September 23, 1993

Dear County Engineer,

Iowa State University, through the Department of Civil and Construction Engineering, is conducting a research project: "Bridge Replacement Alternatives for the County Bridge System", HR 365 which is sponsored by the Iowa DOT, Highway Division and the Iowa Highway Research Board.

Although there are numerous bridge replacement alternatives, the choice available to a county engineer is generally limited by various technical and economic constraints. The primary objective of this project is to identify, review, and evaluate replacement bridges currently being used by various counties in Iowa and surrounding states. The findings of this review and evaluation will be made available to the county engineers at the completion of the project. Hopefully the results of this project will help county engineers identify the most applicable replacement system. Depending on the results, improvements to existing replacement bridges or an entirely new system may be proposed.

The initial phase of the project involves collection of information and data on replacement bridges used in various Iowa counties. The enclosed questionnaire requests information on various alternatives that are being used to replace bridges; questionnaire data will then be reviewed, evaluated, etc., as previously noted. The questionnaire has been designed to obtain information about at least two typical types of replacement bridges that have been used in your county. If you have used more than two types of replacement bridges, we would appreciate your photocopying the necessary pages of this questionnaire and providing information on those bridges also. If you need clarification or desire more information on some of the questions, please contact Prof. T. J. Wipf [515-294-6979], or Prof. F. W. Klaiber [515-294-8763], [Fax no: 515-294-8216].

We understand that you receive many inquiries requesting your participation. Hopefully you will find this study of interest and can see some personal benefit from its final report. Your effort and time in responding to this questionnaire are greatly appreciated. Thank you very much for your help. If at all possible, we would like the completed questionnaire returned by Oct. 8, 1993.

Sincerely,

Terry J. Wipf, P.E.
Associate Professor of Civil Engineering
Project Co-Principal Investigator

Iowa Department of Transportation
Highway Division
Research Project HR 365
Bridge Replacement Alternatives for the County Bridge System
QUESTIONNAIRE

Please answer all of the questions. If you wish to comment on any questions or qualify your answers, please use the margins or a separate sheet of paper.

QUESTIONNAIRE COMPLETED BY ____________________

TITLE ____________________

ADDRESS ____________________ COUNTY ____________________

CITY ____________________ STATE __________ PHONE ____________________

FAX ____________________

Please return the questionnaire by Nov. 8, 1993 using the enclosed stamped envelope or fax to:

Prof. Terry J. Wipf
Dept. of Civil and Construction Engr.
Iowa State University
Ames, Iowa 50011
Fax No.: 515-294-8216

Q-1 Has your county replaced any bridge(s) during the last ten years?

Yes __________ No __________

If yes, please complete the rest of the questionnaire for *two* typical bridge replacements. If no, please return this page of the questionnaire.

Q-2 What were the reason(s) for replacing the bridge(s)? Check all that apply. Indicate most common reason by an asterisk (*).

Insufficient load carrying capacity ______

Excessive deterioration ______

Wider roadway requirements ______

Severe flood damage ______

Other (please describe) ______________________________

____

Q-3 Please furnish the following details on the original and replacement bridge(s).

	ORIGINAL BRIDGE		REPLACEMENT BRIDGE	
Bridge Number	1	2	1	2
Number of Spans				
Span Length(s)				
Type of Bridge*				
Bridge Width Curb to Curb				

* Identification numbers are available in the table on following page. If the type of replacement bridge is not in this table, indicate No.14. If the type of original bridge is not in this table, indicate No.15.

Number	Bridge Type (FHWA Number)
1	Precast Culvert/Bridge (119)
2	Cast In Place Culvert (119)
3	Air Formed Arch Culvert
4	Welded Steel Truss Bridge (309)
5	Prestressed Concrete Beam Bridge With Precast Deck (502)
6	Prestressed Concrete Beam Bridge With Cast In Place Deck (502)
7	Inverset Bridge System
8	Precast Multiple Tee Beam Bridge (104)
9	Low Water Stream Crossing
10	Corrugated Metal Pipe Culvert (319)
11	Stress Laminated Timber Bridge
12	Glue Laminated Timber Beam Bridge (702)
13	Glue Laminated Panel Deck Bridge
14	Other(Replacement), please specify:_______________ ____
15	Other(Original), please specify:_______________ ____

Q-4 Please provide your best estimate of the following cost information. In part 4.1 provide information using either a or b, whichever is more convenient.

COST INFORMATION	BRIDGE 1	BRIDGE 2
4.1 a. Initial cost of replacement/ sq. ft.	$	$
--- or ---- b. Total cost of replacement	$	$
4.2 Expected maintenance costs/ yr.		

Q-5 Estimate the expected life of the new bridges.

	BRIDGE 1	BRIDGE 2
Estimated Life		

Q-6 Was the substructure replaced or altered significantly?

Bridge 1 : Yes ____________ No ____________

Bridge 2 : Yes ____________ No ____________

If yes, what percentage of the total cost (given in Q-4) was spent on the substructure?

Bridge 1 : __________% Bridge 2 : __________%

Q-7 Please furnish the following details of the present substructure (replaced or original). Check all that apply.

ELEMENT	BRIDGE 1	BRIDGE 2
TYPE OF ABUTMENT		
Precast		
Cast in place		
Timber piles		
Steel piles		
Other (describe)		
TYPE OF PIER (if any)		
Precast piles		
Cast in place		
Timber piles		
Other (describe)		

* Continued on next page

TYPE OF FOUNDATION	BRIDGE 1	BRIDGE 2
Reinforced concrete spread footing		
Precast piles		
Cast in place piles		
Steel piles		
Timber piles		
Other(describe)		

Q-8 What was the extent of external technical expertise required to design and/or erect the replacement bridge?

	BRIDGE 1	BRIDGE 2
Project was handled in full by county forces		
Non-County forces were hired for structural design		
bridge erection		
both		

Q-9 The main structural(load carrying) bridge components were

	Bridge 1	Bridge 2
Purchased from suppliers		
Fabricated on site by non-county forces		
Fabricated by county work forces		
Other (please describe)		

If components were purchased, please provide name(s) and address(es) of supplier(s).

a.____

b.____

c.____

Q-10 Please list what you consider to be the specific advantages and disadvantages of the replacement system(s).

BRIDGE 1 :

Advantages ____________________________________

____

Disadvantages _________________________________

____

BRIDGE 2 :

Advantages____

____

Disadvantages____

____

Q-11 Did reasons other than economy affect the choice of replacement alternative? e.g. aesthetics, environmental considerations, urgency of replacement, etc.

Bridge 1 : Yes __________ No __________

Bridge 2 : Yes __________ No __________

If you have answered yes for either bridge, please elaborate.

____

____

____

Q-12 Did lack of construction equipment, labor, etc., limit choice of replacement alternatives? Yes __________ No __________

If yes, please indicate the items that restricted the choice of replacement. Check all that apply.

Construction equipment __________

Computers __________

Day Labor __________

Other (please describe) ____________________

____

Q-13 What is the largest span your county can replace with

a. existing equipment ____________________

b. rented equipment ____________________

Q-14 Indicate the types of piles that your county can drive using

Pile Type	Existing Equipment	Rented Equipment
Steel		
Timber		
Concrete		

Q-15 What is your degree of satisfaction with the replacement bridge systems? Did it perform as required? Rank on a scale of 1-10, with 10 representing excellent performance and 1 representing poor performance.

Bridge 1 : __________

Bridge 2 : __________

If necessary, please qualify your ranking. ____________________

____

____

Q-16 Is documentation (photographs, video recordings of construction sequences, information about construction equipment required, detailed drawings, etc.) of the replacement bridge(s) available?

Yes __________ No __________