BRIDGES ON SECONDARY HIGHWAYS
AND LOCAL ROADS
REHABILITATION AND REPLACEMENT

TRANSPORTATION RESEARCH BOARD
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REHABILITATION AND REPLACEMENT

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AREAS OF INTEREST:
STRUCTURES DESIGN AND PERFORMANCE
CONSTRUCTION
MAINTENANCE
(HIGHWAY TRANSPORTATION)
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TRANSPORTATION RESEARCH BOARD
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WASHINGTON, D.C. MAY 1980
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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

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Notice

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

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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Special Notice

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Printed in the United States of America.
This report contains the findings from an extensive evaluation of common bridge deficiencies along with repair procedures and replacement systems used to correct these deficiencies. These findings, in the form of a manual of recommended practice, are immediately applicable and will be of interest to engineers concerned with the design, construction, and maintenance of bridges, in particular those on secondary highways and local roads.

Many bridges on secondary highways and local roads are in need of replacement or major structural repair. Although most are not frequently traversed by heavily loaded vehicles, these structures are vital to the efficient movement of agricultural and other commodities and provide an important transportation link for rural America's population with centralized educational centers. It has been estimated that more than 110,000 bridges in the United States are inadequate for heavy loads or in need of major repairs and that another 51,000 have narrow widths, poor clearances, and dangerous approaches. Furthermore, it has been reported that about 150 bridge failures occur in the United States each year. Under the severe fiscal constraints that currently exist at the local level, most of these bridges cannot be replaced in the foreseeable future. Until recently, considerable effort had been devoted to the analysis and design of new structures, but little attention was given to problems associated with rehabilitation of older structures on the secondary and local road systems. Therefore, local agencies responsible for inspection, maintenance, and repair are required to make decisions without benefit of supporting information. Under these conditions, an urgent need exists for research that will provide tools for engineers to reach and carry out cost-effective decisions.

This report contains the findings of NCHRP Project 12-20, "Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement," which was intended to develop information that local highway agencies can apply immediately to the repair, improvement, or replacement of deficient bridges on secondary and local road systems. Project 12-20 had four major objectives: (1) to identify the common deficiencies found on bridges on secondary highways and local roads throughout the United States, (2) to evaluate feasible corrective procedures that have been successfully employed for these deficiencies, (3) to evaluate economical replacement systems for bridge structures for which repair or rehabilitation is not feasible, and (4) to develop a simple procedure to assist engineers in making decisions involving repair or replacement.

The major portion of this report consists of a manual of recommended practice—comprising 34 procedures for repair, rehabilitation, and retrofit of bridges and 27 systems that are available for use in replacing bridge components or complete structures. The manual is intended to be used by engineers responsible for bridges on secondary highways and local roads. In preparing the manual it was recognized that many of these engineers are not bridge specialists; therefore, the goal was to provide enough information to alert the engineer of his options in dealing with...
certain bridge deficiencies and to direct him to the proper sources for more detailed information required for a final design.

The research agency's complete, unedited final report on this study is included in the appendix. Background on the research approach and additional details are presented on the findings that led to the development of the manual.

In the middle of 1980 a follow-up phase of research is expected to be initiated with the purpose of expanding the manual to include repair procedures directed at problems such as fatigue cracking of steel bridge members, scour, bridge deck deterioration, and damage due to accidental impacts.
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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 12-20 jointly by the Civil Engineering Department, University of Virginia; the Virginia Department of Highways and Transportation; and the Virginia Highway and Transportation Research Council. Henry L. Kinnier served as the principal investigator and Furman W. Barton served as co-principal investigator. Both are professors of civil engineering for the University of Virginia and faculty research scientists for the Research Council. A major contribution was made by W. T. McKeel, Jr., Research Scientist, Virginia Highway and Transportation Research Council, to both the conduct of the research and the preparation of the manual of recommended practice. M. M. Sprinkel, Research Scientist, and H. E. Brown, Assistant Head, both of the Research Council, directed the preparation of the recommended replacement system section of the manual, and M. H. Hilton, Research Scientist, also of the Research Council, reviewed and supervised the synthesis of the repair procedure section of the manual. J. E. Andrews and C. L. Woodward, Bridge Design Engineer Supervisors; L. L. Misenheimer, District Bridge Engineer; and K. M. Smith, Bridge Design Engineer, all of the Bridge Division, Virginia Department of Highways and Transportation, assisted in the study by reviewing the drafts of the manual as well as by visiting the selected highway bridge offices throughout the United States. R. H. Bennett, P. G. Standiford, and M. D. Leinbach, all graduate civil engineering students, University of Virginia, provided important support to this study in many areas, but particularly in the preparation of the drawings and figures that illustrate the repair procedures and replacement systems.
SUMMARY

The primary results of this research project are (1) the identification of the types of structural deficiencies and problems involving functional obsolescence in bridges on secondary highways and local roads, (2) the identification of procedures that have been successfully used to correct a major portion of these deficiencies and problems, (3) the presentation of these corrective procedures in a manual of recommended practice, and (4) the development of a procedure to assist the engineer in making the decision as to whether a structure should be repaired or should be replaced.

Because this research product is more a manual than a report, its organization differs from that of the usual NCHRP report. Chapter One commences with commentaries on bridge repair procedures and replacement systems and outlines a process for selecting between bridge repair and replacement. The material provided in Chapter Two consists of 34 repair procedures that have been successfully used in one or more states. The presentation contains a description of the procedure (including its limitations) and diagrams showing sufficient detail to allow an evaluation of the use of the procedure. Final plans will require additional engineering. Chapter Three includes 27 bridge replacement systems that are available for use in the United States. Details and dimensions are provided to show typical applications, but a well-qualified engineer must always be responsible for the design and construction of a specific structure.

Details of the research effort through which this manual of recommended practice was developed are published as submitted by the research agency in the appendix to this report. The reader is directed to this appendix for an overview of the project.
CHAPTER ONE

INTRODUCTION

ORGANIZATION OF MANUAL OF RECOMMENDED PRACTICE

This manual of recommended practice was developed under NCHRP Project 12-20, "Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement," and is intended to be used particularly by engineers at the local level. The material provided in subsequent chapters of this manual pertains to a collection of recommended repair procedures (Chapter Two), and descriptions of various replacement systems (Chapter Three). In addition, for convenience of the user, an index is provided at the beginning of each of these chapters for easily locating and using the material contained within. These lists are followed by pertinent references and a selected bibliography. Details of the research effort through which the manual was developed are contained in the appendix to this report.

The commentaries that follow pertain to the 34 repair procedures and the 27 replacement systems covered in Chapters Two and Three and include, as well, a rational process for selecting between repair and replacement of deficient bridges.

Every effort has been made to present proven repair procedures and replacement systems in a practical format to facilitate their use. However, it was not possible to completely detail the connections and member sizes to meet the wide range of span lengths and loadings encountered in the field. Sufficient dimensions are provided to enable the engineer to evaluate the applicability of a procedure or system to his needs and to weigh its benefits against those of alternatives, but additional engineering will be required to develop final design and construction plans for any particular bridge.

Only U.S. customary units are used in the manual; however, to obtain values in S.I. units, only the following six basic conversions are needed:

<table>
<thead>
<tr>
<th>U.S. Unit</th>
<th>S.I. Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 foot (ft) = 0.3048 meter (m)</td>
<td></td>
</tr>
<tr>
<td>1 inch (in.) = 25.4 millimeters (mm)</td>
<td></td>
</tr>
<tr>
<td>1 ounce (oz) = 0.02780 Newtons (N)</td>
<td></td>
</tr>
<tr>
<td>1 pound (lb) = 4.448 Newtons (N)</td>
<td></td>
</tr>
<tr>
<td>1 pound per square inch (psi) = 6895 Pascals (Pa)</td>
<td></td>
</tr>
<tr>
<td>1 mil = 0.00254 millimeters (mm)</td>
<td></td>
</tr>
</tbody>
</table>

COMMENTARY ON REPAIR PROCEDURES

The 34 repair and rehabilitation procedures included in Chapter Two are applicable to common structural and functional deficiencies in highway bridges. These procedures were developed by state bridge engineers and used on actual structures. The plans in this manual were generalized to meet the needs of a broad group of bridges and are presented in a standardized format. All procedures were reviewed by experienced bridge engineers on the research team in an effort to assure practicality.

Often, similar procedures were offered by several states as solutions to a common deficiency. In such cases the procedure that appeared most practical in the judgment of the research team was chosen for inclusion in the manual. If warranted, the best features of two or more procedures were combined in the interest of developing more refined details, and older procedures were modified on occasion to reflect current practice.

All procedures were considered workable by the agencies that submitted them. Several, not included in the manual, were eliminated for various reasons. In some cases a better technique had been developed in the years since the repair was first made. Other procedures were not included because the distress to be corrected was judged to be a minor or very localized problem.

The repair procedures included in the manual do not cover all of the deficiencies to be found on bridges on secondary highways and local roads. It is expected that additional procedures will be developed through future research.

Each item in this manual includes a description of its use, a detailed construction procedure, a description of its limitations, and the resources in labor and equipment required. References, including, at least, the agency that developed and used the procedure, are listed to provide sources of more detailed information if needed.

For the convenience of the user, the repair procedures are indexed according to both the nature of the element or characteristic being improved and the type of distress. Often a single repair procedure is applicable to more than one deficiency. For example, the strengthening of a column pier or pile bent through the addition of a supplemental transverse "pony" bent (repair procedure F-3) can be useful when the original piles have deteriorated, when settlement has occurred, or when upgrading of the superstructure has increased the load on the pier beyond its design capacity. Conversely, more than one procedure may be applicable to a single deficiency, the extent of repair being left to the engineer. It is hoped that, by documenting the approaches of other agencies to common problems, the manual may lead engineers to devise their own creative solutions to problems.

Although the repair techniques presented in Chapter Two have proven successful and have wide applicability, some care in their use is advised. The engineer in charge of the repair should identify and eliminate the basic cause of the distress. For example, the repair of beam ends (repair procedures C-1 or S-4) might also call for the improvement of the deck expansion joint (C-4) to prevent deck drainage from reaching the beam end. The complete re-
pair of the end of a concrete beam that has cracked because of insufficient bearing area should include the enlargement of the bearing area through the use of procedures C-2 or C-3 to prevent recurrence of the distress.

Some of the procedures include steps that are expedient for field repairs, but do not reflect the best practice possible. For example, the use of welding in repair procedure S-3 simplified the procedure, but recent information reflected in current specifications would dictate a more complicated bolted connection to increase fatigue resistance. Similarly, although the bridge rails installed on a narrow through truss in repair procedure R-1 can be used to improve safety and to protect the truss members from impact, they do not meet AASHTO rail requirements, and if there is sufficient lateral clearance a more substantial rail system should be considered.

Some of the procedures call for a bituminous overlay on top of a concrete deck. It should be pointed out that conventional asphaltic concrete mixes are not impregnable, and a waterproofing membrane may be required between the overlay and the deck to inhibit intrusion of chloride ions that cause deck deterioration because of corrosion of the reinforcing steel. Corrosion protection is also essential for steel members embedded in soil, as in repair procedures F-1 and F-4.

**COMMENTARY ON REPLACEMENT SYSTEMS**

The information contained in Chapter Three is on typical bridge replacement systems available for use in the United States. Each system is briefly described and illustrated; prominent features are discussed; and one or more cases in which each system has been used are noted. The names and addresses of manufacturers who supply the materials used in each system are cited, except in a few cases where such information was not available. Reference documentation for each system is listed in the system description and in the references included at the beginning of the chapter.

To provide some degree of organization, most of the replacement systems are grouped according to the material used for the primary components of the superstructure. The groups are concrete, steel, and timber and are designated by prefixes of C, S, and T, respectively. The remaining replacement systems, such as substructure systems, parapets, and permanent bridge deck forms, were placed in a fourth, miscellaneous group designated by the prefix M.

The systems presented in Chapter Three are conceptual, and the designs and dimensions are intended for illustrative purposes only. Agencies or individuals cited in the references should be contacted for more specific details. A qualified engineer should always be consulted and be responsible for the design and construction of a specific structure.

Certain of the systems are proprietary. These were identified by manufacturers only for the convenience of the user. Inclusion of a proprietary system in this manual does not constitute a recommendation by the research team or by the Transportation Research Board.

Many factors must be considered when making a decision as to which system to use for a particular application. Significant factors include (1) the cost and availability of one material relative to those of another, (2) the cost and availability of forms and equipment for fabricating and handling one type of bridge component relative to those for another, (3) the qualifications and experience of the available labor force, and (4) the characteristics desired in the replacement system.

A replacement system utilizing a member that in the case of timber or steel is a stock item, or in the case of concrete can be cast in forms that are readily available, will almost always have a lower first cost than a system that requires nonstandard members or the purchase of special forms.

Regardless of material type, the cross-sectional properties of the bridge components will influence the quantity of materials required and the relative ease with which the members can be fabricated and assembled, and, consequently, the cost of the bridge. For example, a precast slab is one of the easiest precast concrete members to fabricate and erect, but, for spans over 30 ft, the slab requires an excessive amount of concrete with its attendant dead load. For longer spans, box and tee-shaped members are preferable to a precast slab because the additional cost of fabrication is offset by savings in materials and substructure. Steel beams are popular for most span lengths, with the standard wide flange sections being used for spans of less than 90 ft and plate girders for longer spans. Primary supporting members of solid sawn timber are generally used for spans of 20 ft or less, but the development of glued laminated beams has resulted in the use of timber for much longer spans. The use of laminated panel decking allows the beams to be spaced further apart than is possible with conventional timber decking. Special consideration should be given to the lighter materials, such as timber or steel, when the weight of the new superstructure may be a factor as to whether or not the substructure will have to be modified or replaced. Although the lighter superstructure may be more expensive, economy may be realized if the existing substructure can be used.

The characteristics desired in the completed bridge will be a primary concern when choosing between alternative systems. A system should be selected that provides the best combination of first cost, maintenance cost, and service life. For a given system, service life is generally a function of the volume of traffic and the severity of the environment to which the bridge is subjected. The lower the traffic volume and the milder the climate, the more the emphasis should be on minimizing first cost rather than maintenance cost, and the higher the traffic volume and the more severe the climate the more the emphasis should be on minimizing the maintenance cost. For example, a very economical system with respect to first cost might be a steel stringer bridge incorporating timber or steel bridge plank and a bituminous wearing surface. This type system can usually be assembled economically with the use of locally available unskilled labor and with light equipment. Maintenance costs will be higher than for some other types; but, if the bridge is subjected to a mild environment, the maintenance cost may be negligible and the system represents a better use of funds than one with a higher first cost. In situations where traffic volumes are relatively heavy and the climate is severe, emphasis should be placed on bridge systems that provide...
maximum durability such as those incorporating high quality, properly air-entrained concrete.

The range of span lengths for which the replacement systems frequently have been used is indicated in the prominent features section for most of the replacement systems described in Chapter Three. Because many factors determine which system is used for a particular span length, there is no way to prioritize the systems with respect to span length and cost, and there is a lot of overlap in the applicable span ranges with many of the systems being used for the same span lengths. When choosing between alternatives the best advice might be to use what is available locally.

DEVELOPMENT OF A SELECTION PROCESS

In the conduct of their routine day-to-day activities, local bridge engineers are regularly faced with the need to make a multitude of decisions regarding the maintenance, repair, and replacement of bridge structures under their jurisdictions. In many cases, these decisions are routine and the choice so obvious they may be made almost instinctively. In certain other cases, the decision may be very difficult because of the number of complex factors that must be considered.

The selection process is simply a series of steps normally followed by bridge engineers in considering a variety of factors that may influence the final decision.

To discuss the details and steps that would enter into a decision on bridge repair or replacement, and to provide a framework within which the selection process can be described, it is appropriate to first outline the major phases in the decision-making process:

Phase 1. Prioritization—In this phase of the decision process, some procedure for assigning precedence to bridges requiring attention must be adopted.

Phase 2. Repair or Replace—This is clearly the most significant phase of the process and directs the engineer in one or the other of the distinctly different paths.

Phase 3. Choice of Repair Alternative—This is a phase in which a single repair procedure is selected to remedy the existing deficiency.

Phase 4. Choice of Replacement Alternative—In this phase, a system is chosen to replace the existing bridge.

To further clarify the decision process and to illustrate the procedures that might be followed, it is appropriate to discuss each phase in some detail.

Phase 1—Prioritization

In accordance with current practice, the sufficiency rating is suggested as the method of prioritization in Phase 1. Although other methods were considered, the familiar sufficiency rating required of all structures seemed the most practical. The Federal Highway Administration (FHWA) sufficiency rating is a method of evaluating 19 factors that are indicative of a bridge's adequacy to remain in service. In its most general form, the sufficiency rating can be represented by the equation used in the computer analysis:

\[
\text{Sufficiency Rating} = S_1 + S_2 + S_3 - S_4
\]

where:

- \( S_1 \) = structural adequacy and safety—55 percent;
- \( S_2 \) = serviceability and functional obsolescence—30 percent maximum;
- \( S_3 \) = essentiality for public use—15 percent maximum; and
- \( S_4 \) = special reductions (use only when \( S_1 + S_2 + S_3 \geq 50 \)).

The resulting sufficiency rating is reported as a numerical value between 1 and 100. Currently, structures with a sufficiency rating below 50 are eligible for replacement with federal funds.

The sufficiency rating appears to be an adequate procedure for prioritizing deficient bridges to be repaired or replaced, and it is suggested as the method of prioritization unless the local engineer has an alternative procedure which he prefers. (Complete information on the sufficiency rating procedure can be found in the "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, January 1979," Dept. of Transportation, FHWA, 400 Seventh Street, SW, Wash., D.C. 20590.)

Phase 2—Repair or Replace

The most significant decision to be made in the over-all selection process is the choice between the alternatives of repair and replace. In some situations, it is recognized that the decision to repair or replace may be an obvious one that will be made initially in any selection process; in other cases, the decision may be an extremely difficult one in which the proper choice may never be clear.

The repair or replace decision, then, is the one that will usually require the most thought and consideration, and it is here that a logical step-by-step process is recommended. Although a number of variations and approaches are possible, the one outlined here is defined in terms of the following steps within this phase:

Step 1. Identify factors and objectives.
Step 2. Judge how effectively "repair" or "replace" meets criteria of step 1.
Step 3. Estimate cost of "repair" and "replace" alternatives.
Step 4. Make preliminary decision: (a) repair, (b) replace, or (c) decision not clear—conduct further study.

These steps may provide the engineer with sufficient guidance to make the necessary decision in the majority of cases. Before step 4(c) is considered further, the basic concepts within these steps should be reviewed. The fundamental objective in this stage of Phase 2 is to examine explicitly the parameters that may influence the decision in the hope that such a structured consideration will result in either the repair or replace option being the clear choice.

Step 1: Here, the engineer should list the most signifi-
certain factors could affect the decision. These factors could be selected from the following:

1. Degree or extent of deficiency.
2. Functional obsolescence of structure.
3. Present and future traffic volumes.
4. Time out of service.
5. Acceptability of structure if repaired.
6. Availability of resources (in-house or contractor).
7. Anticipated length of service.
8. Permanence of possible repair.
9. Local factors (bus routes, funding, political, etc.).
10. Essentiality of structure.
11. Maintenance costs.
12. Environmental consideration.

This list should be extended by the engineer and his staff, and those factors most appropriate for the bridge under consideration should be selected for further scrutiny.

Step 2: In some subjective, arbitrary manner, the engineer should determine the degree to which either "repair" or "replace" would satisfy the criteria or meet the objectives implied by the list of factors. This could be done purely subjectively and abstractly or could be done by assigning weights from 0 to 10 for each factor under each alternative. At this stage, the intent is not to provide some numerical index on which to base a decision, but rather to provide a structured mechanism for clarifying the way in which "repair" or "replace" would meet the needs of the project. If the decision is made to repair a bridge, due consideration should be given to the ability of the repaired structure to meet the minimum standards for geometrics and load capacity of the AASHTO Standard Specifications for Highway Bridges.

Step 3: Based on the best information available to the engineer and his staff, approximate costs should be assigned to the "repair" and "replace" alternatives. These cost figures could be based on experience within the county or local agency or they could be obtained from the state highway department. Or, in extreme cases, they could even be a "best guess" on the part of the local engineer. Whatever the source, they will at least provide another relative measure on which to base the decision.

Step 4: At this stage, it is likely that a "repair" or "replace" decision that was not obvious before should now be. The engineer knows that he has taken the important factors into consideration and has even looked at a rough cost comparison. Certainly, if the cost of repair is, say, less than 30 percent of the replacement cost and if the repaired bridge will meet the service requirements, repair would be the choice. On the other hand, if bringing the bridge up to current standards would cost 70 percent of replacement, replace is probably the choice.

For those structures where the cost of repair is between 30 percent and 70 percent of replacement, the engineer must rely on his best judgment considering the factors tabulated in step 1 and the cost discussed in step 3. The decision between repair or replace in the many cases where the repair cost is in the proximity of 50 percent of the replacement cost will always be a subjective one.

Case Example

A two-span-deck truss bridge was designed for an HS15 live loading. Each span is 120 ft in length and has a clear roadway width of 24 ft. The bridge is over a river with a center pier in good condition as are the two abutments. A number of elements of the structure require repair and improvement. There is no provision for pedestrian traffic. The concrete deck shows signs of deterioration from corrosion of the reinforcing steel, and the bearing assemblies on the abutments and pier require overhaul or replacement. The concrete bearing pedestals on the abutments and piers have cracked and spalled from salt-water drainage from the deck. There has been loss of section in a number of main truss members and floor framing members from corrosion due to exposure to the environment.

Step 1. Identify factors and objectives. In addition to the need for correcting the deteriorated elements of the structures described in the foregoing paragraph, the bridge must be upgraded to meet the requirements of new industries interested in locating plants in the immediate vicinity of the bridge. The live load capacity of the structure must be increased to an HS20 loading. Provision must be made for a 4-ft walkway on one side of the structure to accommodate greatly increased pedestrian traffic. The 24-ft clear roadway width, although narrow, is adequate to accommodate the anticipated traffic for the next 20 years. The structure's live load capacity is limited by upper and lower chords in the two center panels and the compressive diagonal at the ends of each truss.

Step 2. Judge how effectively "repair" or "replace" meets criteria of step 1. Repair of deteriorated elements and strengthening of the structural members to increase the live load capacity to an HS20 loading do not present a particular problem from the standpoint of capability of personnel available, availability of materials, or time out of service of the structure.

The replacement structure, which would be designed on anticipated traffic for a 50-year period, would be a 4-lane structure with a 54-ft clear roadway width and a 6-ft walkway on each side. It typically would be prestressed box girders and would require substantial alteration to the abutments and pier.

The replacement structure would accommodate the vehicular and pedestrian traffic in a much more adequate manner, would have less annual maintenance, and would lessen the number of accidents and fatalities that would undoubtedly result from the use of the existing structure.

Step 3. Estimate cost of "repair" or "replace." Considerable recent experience in repairing bridge structures and constructing new box girder bridges allows a reasonably approximate estimate of $125,000 for repairing the bridge and $432,000 for replacing the superstructure and altering the substructure. Annual maintenance costs for the existing steel deck truss is estimated at $3,000.

Step 4. Make preliminary decision. A logical decision here could be to repair the structure. The initial cost of repair is 29 percent of the replacement cost, and the re-
paired structure has an estimated service life of 20 years. Several experienced state bridge engineers regard 50 percent as the threshold figure when replacement becomes more cost-effective than repair.

These engineers make the point that in repairs and alterations, unforeseen costs and change orders inevitably develop which typically increase the cost of rehabilitating by 33 percent. Thus, rehabilitation, which originally was estimated to be 50 percent of the replacement cost, would more typically be 60 percent of the replacement cost.

Obviously, the 50 percent figure is a subjective one. However, as previously mentioned, if a structure can be placed in adequate condition for less than 30 percent of the replacement cost, the decision is more often toward repair. On the other hand, if it costs more than 70 percent to repair adequately a structure, the decision is more often to replace the structure.

**Phase 3—Choice of Repair Alternative**

Once the decision has been made to repair a deficient bridge rather than to replace it, the bridge engineer must select a particular bridge repair procedure that will effectively remedy an identified deficiency. A number of repair procedures are presented in this manual, which should provide local bridge engineers with the concepts necessary to correct the large majority of common deficiencies in bridges on secondary roads. In certain cases, only one repair procedure may be available for the deficiency. In other cases, however, more than one procedure may be available and it becomes necessary for the local engineer to select the most appropriate one. Numerous considerations may enter into the selection process. For example, the skilled trades required to perform a repair procedure may not be readily available to the repair site or the availability of special equipment may be an important influence. Frequently the initial cost of the repair is an important consideration, and in other cases the annual maintenance costs may be a major factor. In some cases, the engineer may simply prefer one procedure over another on purely subjective grounds.

However, the choice of a repair procedure for a particular deficiency may also be approached from a systematic comparative procedure as is illustrated in the following hypothetical situation.

**Case Example**

A concrete tee-beam bridge made up of three simple spans is located in a remote rural area. The ends of the girders have deteriorated badly, with the girder stems having cracked from unequal pier settlement. Further, considerable spalling has resulted from chlorides reaching the girders from drainage from the roadway slab.

In the selection of the most appropriate repair for this structure, five factors are to be considered; namely, (1) first cost, (2) annual maintenance, (3) time out of service, (4) equipment required, and (5) availability of necessary skilled trades. These factors may be conveniently compared and a repair selected by using the matrix in Table 1 in the manner described. Each factor is compared with each of the other four and possible scores are as follows: 1 = marginally more important, 2 = more important, and 3 = significantly more important.

In the matrix in column C and row A, the entry is A3, because “first cost” (A) is considered significantly more important than “time out of service” (C). In column E and row B, the entry is E1, because “availability of skilled trades” (E) is ranked marginally more important than “annual maintenance.”

The sums of all scores assigned to a matrix letter are listed in the column headed “Total Points.” In the case of factor B, for example, the scores are 3, 3, and 2, and the sum is 8. There are no scores in the matrix for factor C and a zero is entered. The total points are summed, a decimal proportion of the total is calculated for each factor, and the proportions are rounded off to percentages and used as weight factors.

The matrix indicates that, in selecting a repair procedure, the greatest emphasis should be placed on B, Annual Maintenance. Next in importance is A, First Cost; then E, Availability of Trades; then D, Equipment Required; and, last, C, Time Out of Service.

In this example, the selected repair procedure would probably be C-1 because that procedure would result in low annual maintenance costs; have a low first cost; require only basic carpentry and welding trades; and require readily available equipment, such as jacks, and perhaps portable welding gear. Procedure C-1 is compared with procedures C-2 and C-3.

Ordinarily, there are only two or three repair procedures applicable to a particular deficiency, and a selection of the most appropriate repair can be made by a simple inspection of the column headed Weight in the matrix.

If there are a large number of possible solutions, corresponding “factor” weights should be assigned to each possible repair and totals should be listed for comparison. This extension of the use of this matrix approach is illustrated next (in Phase 4), where seven replacement systems are compared and a “best” system selected.

**Phase 4—Choice of Replacement Alternative**

Various factors may influence the decision to completely replace rather than repair a deficient bridge structure. As was discussed in Phase 2, cost may be the primary determining factor in the decision to replace an existing structure. But, whatever the reason for the replace decision, the bridge engineer must decide the type of replacement system that will best satisfy the requirements. This manual provides 27 replacement systems that have been successfully used in various situations. These systems include replacement bridges primarily of concrete, steel, and timber. This collection of replacement systems has been carefully selected and evaluated. Thus, the local bridge engineer will likely find adequate guidance and suggestions in the replacement systems presented in the manual. Slight variations of these systems may be advantageous under certain circumstances, but the best basic system for a particular application can probably be found in the manual. As discussed earlier, each of the classes of systems has certain advantages over the others, and consideration of the particular requirements of the system will usually indicate not
TABLE 1
REPAIR PROCEDURES MATRIX FOR ASSIGNMENT OF WEIGHTING VALUES

<table>
<thead>
<tr>
<th>Matrix Letter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
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<tr>
<td>Factor</td>
<td>First Cost</td>
<td>Annual Maintenance</td>
<td>Time Out of Service</td>
<td>Equipment Required</td>
<td>Availability of Trades</td>
</tr>
<tr>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
<td>A5</td>
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<tr>
<td>0.364</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>A3</td>
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<td>C3</td>
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<td>A5</td>
<td>E1</td>
<td>E2</td>
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<tr>
<td>0.227</td>
<td>23</td>
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In the selection of the most appropriate replacement system for this bridge, six factors will be considered; namely, (1) first cost, (2) annual maintenance, (3) time out of service, (4) special substructure repair, (5) availability of labor and equipment, and (6) appearance of the bridge. These factors may be subjectively compared using the matrix in Table 2.

Although there might be two or more systems that would meet the engineering needs of the project, the requirement to meet local needs will occasionally identify a single replacement system that seems best. And where two or more systems seem equally acceptable, the factor of cost can always be used as the final decision criterion. The choice of a replacement system may also be approached from a systematic comparative procedure similar to that explained in Phase 3 and as illustrated in the following hypothetical situation.

Case Example

A 40 ft long, one lane, steel stringer timber plank deck bridge requires widening to two lanes and strengthening to carry an HS20 loading. The bridge is subjected to about 90 freeze-thaw cycles per year and approximately 100 vehicles per day (vpd) of primarily lightweight vehicles. A Phase 2 analysis indicated that the bridge should be replaced rather than repaired. The local jurisdiction, a county, has a small bridge crew that is capable of minor repairs and limited replacement work. Potential bridge contractors and suitable suppliers of ready-mix concrete, precast concrete, steel, and timber are located more than 100 miles from the bridge site.

In the selection of the most appropriate replacement system for this bridge, six factors will be considered; namely, (1) first cost, (2) annual maintenance, (3) time out of service, (4) special substructure repair, (5) availability of labor and equipment, and (6) appearance of the bridge. These factors may be subjectively compared using the matrix in Table 2.

In the matrix, the entry in row A, column B is A3, because first cost is significantly more important than annual maintenance. The jurisdiction has a certain amount of money appropriated each year for maintenance but has difficulty coming up with large sums of money for special situations. In row A, column C, the entry is A1, because first cost is marginally more important than time out of service, but not significantly more important because approximately 100 vpd will have to drive a considerable distance if the bridge is closed. First cost is marginally more important (A1) than special substructure repairs, because at least one-half of the substructure will have to be newly constructed to accommodate the second lane of traffic. With similar logic, the remaining factors can be compared and the matrix completed.
TABLE 2
REPLACEMENT SYSTEMS MATRIX FOR ASSIGNMENT OF WEIGHTING VALUES

<table>
<thead>
<tr>
<th>Matrix Letter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Total Points</th>
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<tr>
<td>A3</td>
<td>34</td>
<td>9</td>
<td>16</td>
<td>6</td>
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<td>75</td>
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<td>A1</td>
<td>24</td>
<td>7</td>
<td>20</td>
<td>9</td>
<td>22</td>
<td>0</td>
<td>82</td>
</tr>
<tr>
<td>A1</td>
<td>27</td>
<td>6</td>
<td>19</td>
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<td>20</td>
<td>8</td>
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<td>12</td>
<td>22</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>F</td>
<td>26</td>
<td>9</td>
<td>21</td>
<td>13</td>
<td>15</td>
<td>0</td>
<td>84</td>
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</table>

The matrix for this particular county situation indicates that first cost should have a weight of 34 percent, availability of labor and equipment and time out of service should have a weight of 22 percent each, special substructure repairs should have a weight of 13 percent, and annual maintenance should have a weight of 9 percent. The appearance of the bridge is a relatively unimportant factor in the decision.

In this example the most likely concrete replacement system would be system C-3, a prestressed double-tee beam bridge, because several of the closest precast concrete producers have forms for this type member and because the double-tee is economical for 40-ft spans. Ready-mix concrete is ruled out because the nearest plant is too far away and site batching would not be feasible. The most likely steel replacement systems would be system S-4, a laminated timber deck on steel beams; system S-5, timber plank deck on steel beams; system S-6, steel grid deck on steel beams; and system S-7, bituminous concrete deck on steel bridge plank on steel beams. Of the timber systems only system T-1, glued laminated timber, is considered practical because of the span length involved. System M-6, long span, corrugated metal culvert, is considered a practical candidate from the miscellaneous group of systems.

Possible alternatives have now been narrowed from 27 systems to 7 systems. These systems can be compared using the relative weights of the factors determined from the matrix as shown in Table 3. For example, system C-3 is expected to have the lowest first cost (factor A) and, therefore, is assigned all 34 of the 34 possible points for fac-

TABLE 3
TABLE OF POINT COMPARISONS

<table>
<thead>
<tr>
<th>System No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Total Points</th>
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<tr>
<td>C-3</td>
<td>34</td>
<td>9</td>
<td>16</td>
<td>6</td>
<td>10</td>
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<td>75</td>
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<td>0</td>
<td>82</td>
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<td>S-5</td>
<td>27</td>
<td>6</td>
<td>19</td>
<td>9</td>
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<td>18</td>
<td>9</td>
<td>22</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>T-1</td>
<td>20</td>
<td>8</td>
<td>21</td>
<td>12</td>
<td>22</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>M-6</td>
<td>26</td>
<td>9</td>
<td>21</td>
<td>13</td>
<td>15</td>
<td>0</td>
<td>84</td>
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</table>
tor A. However, the county bridge crew does not have a crane large enough to handle the double-tee beams but could rent one and, therefore, system C-3 is allotted only 10 of the possible 22 points for factor E, which is the availability of labor and equipment. On the other hand, system T-1 is assigned 20 of the 34 possible points for factor A, but gets all 22 points for factor E. After all points are assigned and totaled, it appears that system S-7 with a total of 85 points is the best system given the relative weights assigned for this particular local situation. The choice could not have been made easily without the use of the matrix because six of the seven systems had a point total between 82 and 85. The result obtained with this method depends heavily on the judgment and experience of the person making the subjective comparisons, but it does provide a mechanism for choosing between alternatives and may be the most useful in situations similar to the one described.

CHAPTER TWO

RECOMMENDED REPAIR PROCEDURES

LIST OF REPAIR PROCEDURES

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<td>C-2</td>
<td>Side Elevation of Saddle in Place</td>
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<td>C-3</td>
<td>Side Elevation of Pier Saddle (Technique B)</td>
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REPAIR PROCEDURES CLASSIFIED BY BRIDGE ELEMENTS AND AREAS OF DEFICIENCIES

I. Concrete Girders
(a) End areas cracked; bearing areas deteriorated ............... C-1, C-2, C-3
(b) Prestressed girder damage ..................................... C-6

II. Steel Trusses
(a) Replace damaged or deteriorated members ....................... S-1, S-2, S-3
(b) Addition of bridge rails ...................................... R-1
(c) Increase vertical clearance ................................... G-1

III. Steel Girders
(a) Corroded beam ends .............................................. S-4
(b) Replace steel girders .......................................... S-5
(c) Increase load capacity ......................................... R-2, R-5
(d) Provide improved distribution of live load to longitudinal girders .................................................. R-6
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IV. Timber Girders
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(b) Repair cracked girder .......................................... T-2
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V. Abutment Stability
   (a) Provide relief joint in approach pavement .......... R-3
   (b) Anchor abutment with attached concrete blocks ........ F-1

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   (a) Deck joints deteriorated .......................... C-4, C-5
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   (a) Deteriorated or damaged piling ....................... F-2, F-3, F-4, F-9
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   (a) Increase through truss vertical clearance ............... G-1
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   (c) Widening concrete deck bridges ....................... G-3
   (d) Widening a concrete slab bridge ..................... G-4

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3. Louisiana Dept. of Transp. & Development, Box 44245, Capitol Station, Baton Rouge, La. 70804.
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REPAIR PROCEDURES

Thirty-four procedures were found to correct a high percentage of the common bridge deficiencies. These repair, rehabilitation, and retrofitting procedures are provided in the following pages.
DESCRIPTION:
This procedure may be used to repair deteriorated ends of concrete beams. Such deterioration is usually caused by excessive shear forces from uneven settlement of the substructure. Similar distress may be caused by chlorides and/or freezing and thawing or from lack of provision for movement from temperature changes.

LIMITATIONS:
Concrete in piers or abutments adjacent to bearing areas should be sound and the distress limited to ends of concrete beams.

CONSTRUCTION PROCEDURE:
1. Direct traffic to the far side of the bridge until repairs on a beam end are complete.
2. Where required, construct temporary bent for supporting jacks and blocking. See Figures 1a and 1b.
3. Place jacks as shown in Figure 1a and raise entire end of bridge a fraction of an inch. The lift should be only that required to insert a piece of sheet metal (or other thin material) used as a bond breaker for the new concrete.
4. Place the sheet metal bond breaker referred to in step 3 on the beam seat at the pier or abutment.
5. Remove the deteriorated concrete, preferably in steps as shown in Figure 2 to provide horizontal bearing surfaces between the new and old concrete.
6. Place new reinforcing steel and secure to the old reinforcing steel by welding as shown in Figure 2. If weldability of the two steels is questionable, use low hydrogen electrodes and preheat the reinforcing bars. As an alternate to welding, the new reinforcement can be lapped with the old steel the amount of the development length.
7. Apply epoxy bonding compound to prepare the surfaces of sheared beam end.
8. After forming, place the new concrete. A non-shrink additive should be used in the new concrete.

CONSTRUCTION PROCEDURE (continued):
9. After the concrete has reached sufficient strength, jack all beams simultaneously to sufficient height to allow placement of elastomeric bearing pads.
10. Uniformly lower the entire end of the bridge. Check for possible distress in the repaired area.

NOTE: Where the distress in the ends of the concrete beams is not extensive and consists only of moderate cracking, an effective repair can be made by the injection of a solid epoxy adhesive.

RESOURCE REQUIREMENTS:
Shoring and heavy jacking equipment. Pneumatic chipping hammer. Qualified welder. Form carpenter(s).

REFERENCES:
Virginia Department of Highways and Transportation (Reference 1)
Weld Bars To End Of Main Reinforcing Steel [See Alternate In Step 6, Page 1]

Cut Offsets Across End Of Beam As Shown

Elastomeric Pad

Use Wedges To Hold Blocking Tight And Then Remove Jacks

Figure 1a. Partial Transverse Section

Figure 1b. Partial Side Elevation

Figure 2. Detail Of Repaired Area
TITLE: PIER SADDLES FOR DISTRESSED CONCRETE BEAM BEARING AREAS (TECHNIQUE A)

DESCRIPTION:
Relief of distressed beam ends by relocation of bearing areas using steel saddles.

LIMITATIONS:
This technique is appropriate where repair of concrete beam ends would be inadequate or inadvisable. While this procedure has been used primarily for concrete beams, it could be adapted to steel beam bridges. The dead load beam reactions from adjacent spans should be approximately equal and the live load shear should be small to prevent rocking of the saddle assembly.

CONSTRUCTION PROCEDURE:
1. Design the saddle components shown in Figures 3, 4a and 4b to support the maximum beam reactions. If the traffic volume is high, special attention should be given to weldment details to prevent fatigue cracks.
2. Apply red lead paint to the pier cap bearing area that will support the channel sections.
3. Place three layers of duck (12-14 oz. typical) over the bearing area. Each layer should be thoroughly swabbed with red lead paint.
4. Prefabricate the channel sections, box beams and other saddle components as shown in Figures 3 and 4a.
5. Place the channel sections over the pier cap and attach the supporting box beams with hanger straps and draw-up bolts.
6. Place elastomeric bearing pads on the box beams under the concrete girders and draw these beams up by using bolts passed through the lugs provided on the channels and saddle beam hanger straps.
7. After the beams are drawn up tight, weld the channels to the hanger straps and remove draw-up bolts. Bolts could be left in place and these welds eliminated.

RESOURCE REQUIREMENTS:
Qualified field welding crew. Rigging capability and availability of a crane or other lifting equipment.

REFERENCES:
Colorado State Department of Highways (Reference 2)
TITLE: PIER SADDLES FOR DISTRESSED CONCRETE BEAM BEARING AREAS (TECHNIQUE B)  

DESCRIPTION:  
Relief of distressed beam ends by extending the bearing areas using steel saddles.

LIMITATIONS:  
This technique is appropriate where repair of concrete beam ends would be inadequate or inadvisable. While this procedure has been used primarily for concrete beams, it could be adapted to steel beam bridges. The dead load beam reactions from adjacent spans should be approximately equal and the live load shear should be small to prevent rocking of the saddle assembly.

CONSTRUCTION PROCEDURE:  
1. Design the saddle components shown in Figures 5 and 6, Section AA.  
2. Apply red lead paint to the bearing area that will support the double angle sections.  
3. Place three layers of duck (12-14 oz. typical) over the bearing area. Each layer should be thoroughly swabbed with red lead paint.  
4. Place the angle assemblies over the pier cap and attach the supporting wide flange beams with the hanger straps.  
5. Place and weld the field shim plates to the hanger plates such that a snug fit with the pier cap is obtained as shown in Figure 5.  
6. Place formwork over the ends of the assembly to contain non-shrinking grout.  
7. Place the non-shrinking grout.  
8. After the grout has achieved final set, place the concrete between the angles and beams as shown in Figures 5 and 6.  
9. Remove the forms.  

NOTE: This is an alternate to the pier saddle installation described in Repair Number C-2. This procedure does not remove the existing dead load bearing forces from the pier cap.

RESOURCE REQUIREMENTS:  
Qualified field welding crew. Rigging capability and availability of a crane or other light lifting equipment.

REFERENCES:  
Louisiana Department of Highways (Reference 3)
Concrete Fill Between Angle and Beam

Non-Shrinking Grout Beneath Beam

Shim Size To Be Determined In The Field. Weld To Hanger Straps.

Existing Pier Cap

Figure 5. Side Elevation Of Pier Saddle [Technique B]

Figure 6. Pier Saddle, Section A A
DESCRIPTION:
Reconstruction and modification of existing expansion joints can be accomplished by using one of a number of proprietary joint systems that are available.

LIMITATIONS:
A bituminous concrete or other type of overlay system is required.

CONSTRUCTION PROCEDURE:
1. Determine the size and type of system that will be required to accommodate the existing joint.
2. Prepare the surface of the existing deck on each side of the joint by removing any uneven areas.
3. Drill the anchor bolt holes at the required intervals and to the required depth on each side of the joint (Fig. 7).
4. Apply sealant to the surface of the deck that will serve as bearing area for the joint.
5. Install the joint sections and drive the anchor bolts in place.
6. Tighten down the joint to the torque recommended by the joint specifications.
7. Apply the overlay system.

RESOURCE REQUIREMENTS:
Concrete drill and bits, wrenches, miscellaneous hand tools.

REFERENCES:
NCHRP Report 204 (Reference 4)
DESCRIPTION:
Method of sealing sliding plate expansion joints.

LIMITATIONS:
Limited to joints that have sufficient opening to accommodate the details shown in Figure 9. The existing concrete should provide a sound anchorage for the existing joint. This repair can only be used where the revised joint opening will be adequate for the anticipated expansion. Where this is not feasible, repair C-4 could be used.

CONSTRUCTION PROCEDURE:
1. Determine the size of the compression seal and dam plates to be used. See Figure 9.
2. Fabricate the dam plates and the supporting strut plates in appropriate lengths to allow for the repair to be completed under traffic if necessary. Note: The compression seal retaining bar should be shop welded.
3. Cut the existing sliding plate to clear the weld at the heel of the angle.
4. Install and weld the dam plate assembly across the full width of the roadway (or traffic lane if traffic is to be maintained).
5. Install the preformed compression seal.
6. Complete the repair with the addition of a bituminous concrete overlay.

RESOURCE REQUIREMENTS:
Torch or other steel cutting and field welding equipment; small hand tools.

REFERENCES:
Virginia Department of Highways and Transportation (Reference 1)
Figure 9. Typical Sliding Plate Joint Repair

Size Dam Plates To Achieve Proper Opening. Dam Plates May Be Of Different Thicknesses.
DESCRIPTION:
Prestressed beams with damaged tendons can be strengthened by adding new tendons along the lower flange. This repair recommendation is based on the State of Washington plan SR-5 overcrossing No. 12/221, Prestressed Beam Repair, Lewis County. September 16, 1977.

LIMITATIONS:
The added tendons are used to strengthen existing beams with severed or damaged tendons. The procedure is not normally used to strengthen undamaged beams. Existing diaphragms must be structurally adequate to support the end anchorages.

CONSTRUCTION PROCEDURE:
1. Remove all loose concrete from the damaged area (Figure 10a and 11, Section AA) and clean all areas where new concrete will be bonded. A high pressure water jet for thorough cleaning is recommended. All cracks should be chipped to a 1/2 in. deep V-shaped groove.
2. Restrict traffic to low speed and to one lane of the bridge.
3. Place an axle load over the damaged area of the beam. The amount and placement location of the load should be determined by an engineer.
4. Install any formwork necessary to replace the concrete. The beam is to be rebuilt to its original cross section.
5. Seal all cracks in the existing beam with epoxy. Coat the contact surfaces of the existing concrete with an epoxy resin of approximately a 10-15 mil thickness.
6. Place the new concrete while the epoxy resin is still tacky. The axle load should remain in place on the beam until the concrete has attained a strength of 3500 psi.
7. Remove the axle load from the damaged beam.
8. Remove the diaphragm concrete where shown in Figure 10b to allow for passage of the new posttensioning tendons. Chip shear keys (Section BB) in the existing beam at 18 in. on center along the length of the beam that will house the new tendons.
9. Drill 1-1/2 in. diameter holes through the web as shown in Figure 10b and Section BB to accommodate reinforcing steel to tie the new concrete together. These reinforcing bars are to be placed and grouted into the holes. Care must be exercised to avoid drilling through tendons or reinforcing bars.
10. Roughen and clean the surface of the concrete beams where the new concrete is to be bonded.
11. Install the posttensioning ducts, reinforcing steel and the forming for the new concrete.
12. Coat the contact surfaces with an epoxy resin and place the new concrete while the epoxy is still tacky.
13. After the concrete has attained design strength, tension the strands to the specified load. The strands should be tensioned in a sequence to balance the load on each side of the flange.
14. Fill the posttensioning ducts with grout.

NOTE: The added tendons could extend over greater length than that shown in Figure 10. It may be practical to posttension between the end diaphragms rather than the intermediate stiffeners as shown.

RESOURCE REQUIREMENTS:
Concrete breaking and drilling equipment, posttensioning jacks, loading equipment, epoxy and concreting materials.

REFERENCES:
Washington Department of Transportation (Reference 3)
FIGURE 10. (a) TYPICAL DAMAGED AREA OF A PRESTRESSED CONCRETE BRIDGE
(b) TYPICAL REPAIR BY ADDING POST-TENSIONED STRANDS

Existing Beam

FIGURE 11. SECTIONS SHOWING DAMAGED AREA (A A) AND ADDED TENDONS TO STRENGTHEN THE BEAM (B B).
DESCRIPTION:
Replacement of damaged or deteriorated diagonal tensile member on trusses having riveted or bolted connections. Replacement details for a pinned end diagonal are also suggested.

LIMITATIONS: The procedures described are limited to tensile members with riveted or bolted truss connections only. No more than one half of the member shall be removed and replaced at a time. The new diagonal must have a capacity equal to that of the member being replaced. Care must be taken to avoid damage to the members to be reused.

CONSTRUCTION PROCEDURE:
1. Design the new diagonal section and connections.
2. Restrict traffic to one lane on the opposite side of the bridge.
3. Cut and install the necessary wood blocking as shown in Figure 12.
4. Install a cable having the capacity to carry the full dead load in the diagonal plus the live load distributed from the restricted traffic.
5. Tighten the cable system.
6. If the member to be replaced is composed of angles, as shown in Section AA, Figure 13, it should be repaired by first removing and replacing two of the angles; then removing and replacing the last two angles. The two angles removed first should be the weaker ones or as otherwise determined by the existing condition of the diagonal member. If the member to be replaced is similar to that shown in Section BB, Figure 13, first one channel is removed and replaced, then the other. High strength bolts are used for connecting the new diagonal members. (See Figure 14 for suggested connection of pinned end diagonal.)
7. Install the batten plates or lacing bars at the required intervals along the diagonal. Tighten the high strength bolts at all connections.
8. Remove cable slings and other temporary components and restore the bridge to normal traffic conditions.

Note: A number of bridge design offices in the United States have developed satisfactory procedures for replacing damaged or deteriorated steel truss members. Substantial savings are
Existing member composed of four angles with batten plates can be replaced using angles or ST sections with batten plates.

SECTION BB
Existing member composed of two channels with batten plates or lace bars (usually found where diagonal may be required to sustain compressive and tensile forces) can sometimes be replaced with W or HP sections where conditions permit.
NOTE: Deteriorated diagonal tension members consisting of two eye bars can be replaced by using rods as shown with U-bolt end connections. With no traffic on the structure, one of the deteriorated eyebars at a time can usually be removed and replaced with the rod illustrated without the use of cables as shown on page 3 of 5.

New Diagonal Member

Figure 14. Truss Diagonal Replacement For Pinned End Connections
Replacement of damaged or deteriorated vertical tensile member on trusses having riveted or bolted connections.

LIMITATIONS:
Limited to tensile members on riveted or bolted truss connections. The new member is to have a capacity equal to that of the member being replaced. Traffic should be restricted to one lane during the repair.

CONSTRUCTION PROCEDURE:
1. Design the new vertical section and connections.
2. Restrict traffic to one lane on opposite side of the bridge.
3. Install the wood blocking and WF beam as shown in Figures 15 and 16, Section AA.
4. Install a cable having the capacity to carry the maximum load in the vertical member being repaired. See Figure 15.
5. Tighten the cable system to eliminate the dead load tensile force in the member being replaced.
6. If the member to be replaced is composed of angles, as shown in Section CC, Figure 16, it can be repaired by first removing and replacing two of the angles, then removing and replacing the last two angles. The two angles removed first should be the weaker one or as otherwise determined by the existing condition of the vertical member. If the member to be replaced is similar to that shown in Section BB, Figure 16, first one channel is removed and replaced, then the other. If the entire member can be safely removed, it can be replaced with other type sections of equal strength. High strength bolts are used for connecting the new vertical members.
7. Install the batten plates or lacing bars at the required intervals along the vertical. Tighten the high strength bolts at all connections.
8. Remove cable slings and other temporary components and restore the bridge to normal traffic conditions.
**Figure 15.** Existing members are frequently composed of angles or channels with batten plates or lace bars and may be replaced with the same section or ST sections with suitable batten plates or lace bars.

**Figure 16.** Typical Sections of a Vertical Tensile Truss Member
DESCRIPTION:
Splice plates are used to repair damage or deterioration in one channel of a two-channel bridge member. Procedure could be used for other built-up members as well.

LIMITATIONS:
The repair technique can be used only on built-up members which have only one of their components damaged.

CONSTRUCTION PROCEDURE:
1. Bolt a side splice plate to the damaged member as shown in Figure 17. Remove any rivet heads which would interfere with the splice plate if the repair is near a connection.
2. If necessary, remove old tie plates (or lacing bars) from the two channels in the area of the crack to allow placement of the bottom tie plate. Some temporary lateral bracing may be required prior to completing the repair.
3. Bolt the bottom tie plate to the member as indicated in Figure 17.

NOTE: Splice plates have been successfully attached using weldments but fatigue problems could result from welds where the structure experiences a high traffic volume. A bolted connection for the splice plate is preferable.

RESOURCE REQUIREMENTS:
Torch and/or other cutting tools. Power drills. Alternatively, welding equipment and a certified welder.

REFERENCES:
Texas State Department of Highways and Public Transportation (Reference 6)
DESCRIPTION:
The corroded ends of steel beams are replaced by cutting out the damaged portion and replacing it with a new WT section or built-up plate section.

LIMITATIONS:
Suitable only for simply supported spans. The top flange and a part of the web must be sound. The steel must be weldable. All stringers must be lifted simultaneously whether they are to be repaired or not.

CONSTRUCTION PROCEDURE:
1. Relieve the load at the bearing by jacking under the sound portion of the beams.
2. Cut out the corroded area as marked by the dashed lines in Figure 18. Bearing stiffeners, if present, must be removed.
3. Weld the new section into place using full penetration welds. The new section may be either a suitable WT or be shop fabricated from other suitable shapes. Replace the bearing stiffeners where required.
4. Lower the span to bear; check for distress.
5. Remove jacking equipment and other temporary supports.

RESOURCE REQUIREMENTS:
Qualified welding personnel, light lifting equipment, hydraulic jacks, clamps and hand tools.

REFERENCES:
Louisiana Highway Department (Reference 3).
DESCRIPTION:
For either composite or non-composite construction where a beam has been damaged by collision or corrosion.

LIMITATIONS:
The top flange must be in sound concrete and in good condition.

CONSTRUCTION PROCEDURE:
1. Limit traffic to light vehicles and direct to far side of bridge roadway until completion of repair.
2. Jack the bridge so that the damaged beam is clear of the bearing surface.
3. If necessary, provide temporary support adjacent to the beam to be removed.
4. Remove the damaged portion of the steel beam from the bridge slab by cutting through the web directly below the top flange. The top flange must remain in the concrete slab. See Figure 19a.
5. Grind bottom face of top flange smooth.
6. Select or fabricate a replacement beam having a top flange width smaller than that of the original beam to allow for welding. See Figure 19b.
7. Weld the new steel beam in place with continuous fillet welds. See Figure 19b.
8. Remove temporary supports if used.
9. Seat the new beam and remove the jacking equipment.

NOTE: A cover plate may be advisable on the new beam to lower the neutral axis and thereby reduce the lower flange flexural stress.

RESOURCE REQUIREMENTS:
Jacking equipment, steel cutting equipment such as an acetylene torch, qualified welding crew, a crane or other suitable lifting equipment.

REFERENCES:
Washington Department of Transportation (Reference 5)
Burn to Remove Lower Portion of Beam and Grind Smooth Damaged or Deteriorated Steel Beam Stringer

Figure 19(a)

Optional Cover Plate

Figure 19(b)

Replacement Of A Steel Beam
Title: timber stringer replacement

Description:
Replacement of cracked or deteriorated wooden stringer with new member.

Limitations:
For use where bridge deck and pier caps do not require replacement. Deteriorated stringer must be strong enough to serve as a nailing strip for new stringer.

Construction Procedure:
1. Cut the new stringer to the required length and taper the ends as shown in Figure 20(a).
2. Lift the new stringer into position as shown in Figure 20(b). Clip the ends of the beam as required to facilitate the placement operation.
3. Drive wedges under the new stringer until the deck bears against it.
4. Secure the wedges with nails as shown in Figure 20(c).
5. Secure the old stringer to new stringer at 2 ft. to 3 ft. intervals by using 3/4 in. bolts placed at mid-depth. See Figure 20(c)

Note: In some instances, it may be more convenient to install the replacement stringer in the flat position and then rotate 90° to the vertical position. This procedure could lessen trimming of the ends of the stringer but result in a more awkward wedging operation.

Resource Requirements:
Light lifting equipment and hand tools; power saw.

References:
Wyoming Highway Department (Reference 7)
DESCRIPTION:
Steel plates and bolts are used to prevent further deterioration of cracked timber stringers.

LIMITATIONS:
Repair is limited to situations where it is not desirable to remove the deck planks. Deck planks should be in good condition. Repair hardware will have to be removed if deck is replaced.

CONSTRUCTION PROCEDURE:
1. Close bridge to traffic during the repair period.
2. Calculate the load that would be necessary to jack at a location near the cracked position in the stringer to eliminate the dead load moment. Calculate the corresponding deflection this load would produce. The stringer to be repaired should be raised exactly that amount.
3. Remove the asphalt overlay in the area where the holes are to be drilled.
4. Drill holes for draw-up bolts. See Figure 21.
5. Place the retaining and support plates as shown in Section AA and tighten the draw-up bolts.
6. Replace the wearing surface.

RESOURCE REQUIREMENTS:
Hand tools and access to underside of structure.

REFERENCES:
Wyoming Highway Department (Reference 7)
**Title:** Addition of Bridge Rails to Through Truss  
**Repair Number:** R-1

## Description:
Bridge rails are added to existing through truss bridge in such a manner as to (1) prevent collision with truss members, (2) essentially maintain original roadway width, and (3) be independent of main structural elements of truss.

## Limitations:
Bridge and supporting frame are designed for through truss with a floor system composed of floor beams, stringers, and transverse timber floor planking. Could be adapted for a concrete roadway slab by placing the transverse channels on top of slab and adding an asphalt or concrete overlay equal to the vertical legs (about 2 in.) of the channels. The bridge rails do not meet AASHTO Specifications. On very light trusses the added dead weight of the rails and the supporting frames may be a limitation to its use.

## Construction Procedure:
1. Select the bridge rail post positions 6 to 12 ft. on center and between the floor beam locations. See Figure 22.
2. Remove the deck timbers at the locations of the bridge rail posts and replace them with steel channels (C6x8.2) 1 ft. longer than the existing deck width. See Figure 23.
3. If the stringers have wood nailing strips (as shown), attach the channels with lag bolts. If nailing strips are not used, tack weld the channels to the stringers, or use high strength bolts. See Figures 23 and 24.
4. Attach bridge rail posts to channels with HS bolts through 6 x 6 angle welded to post. See Figure 24.
5. Slide lower transverse member of frame (W6x15.5) into place and attach to posts. A suggested fabrication is indicated in Figure 24.
6. Fill the space over the channels in the timber deck with asphalt. See Figure 23.

## Resource Requirements:
Staging and rigging to suit the site. Light lifting equipment is required to lift transverse steel member under roadway.

**References:**
North Carolina Dept. of Transportation (Reference 8) "Upgrading Safety Performance in Retrofitting Traffic Railing Systems." FHWA Report, (Reference 9)
Existing Truss

Figure 22 Installation Of Truss Guardrail

Existing Deck Timbers

Existing Nailer

Existing Beams

C6 x 8.2, Attach to Existing Nailer (Top) or Steel Stringer (Bottom)

Figure 23.

Note: All holes in channels shall be drilled in the field

Figure 24.
INCREASE FLEXURE CAPACITY OF STEEL BEAM STRINGERS BY ADDITION OF COVER PLATES

DESCRIPTION:
Cover plates can be added to existing non-composite simple steel beam spans to increase the load carrying capacity.

LIMITATIONS:
The existing steel beam flanges must be weldable.

CONSTRUCTION PROCEDURE:
1. Design the cover plates to achieve the desired capacity. Check the stresses in the modified section to assure adequacy of the existing beam.
2. Close the bridge to traffic while it is being supported by jacks.
3. Prepare the surface of the existing beam flanges for welding of the flange plates.
4. Clamp the cover plates on the bottom flange of the stringers. Plates may also be added to the underside of the top flange.
5. Calculate the load that would be necessary to jack the center of the span to eliminate the dead load deflection. The beams should be raised by exactly that amount at midspan.
6. Place temporary supports similar to that shown in Figures 25 and 26 and jack all beams simultaneously.
7. Weld the cover plates to the beams. The welding of a cover plate should be completed within a period of a working day.
8. Remove jacking equipment and other temporary supports.

NOTE: Replacement System S-3 shows an alternate procedure for increasing the flexure capacity of steel beam stringer bridges by removing the existing concrete deck slab and adding shear connectors. Precast deck panels are then placed which have openings to accommodate the shear connectors.

RESOURCE REQUIREMENTS:
Excavating equipment, qualified welding personnel, light lifting equipment, hydraulic jacks, clamps and hand tools.

REFERENCES:
Virginia Highway and Transportation Department (Reference 1)
FIGURE 25. TRANSVERSE ELEVATION OF TEMPORARY SUPPORT
**DESCRIPTION:**

Joint to be installed in approach roadway to relieve expansion pressure on backwall of bridge abutment.

**LIMITATIONS:**

The design is for those situations where the expansion of the concrete approach pavement has been confirmed as the source of pressure on the abutment backwall.

**CONSTRUCTION PROCEDURE:**

1. Direct traffic to opposite side of roadway while pavement joint is being installed.
2. Position pressure relief joint beyond bridge as required by pavement conditions.
3. Remove existing concrete pavement as required.
4. Cast reinforced concrete slab as shown in Figure 27. Cast in sections as required using longitudinal joint key between pours.
5. Place two layers of building paper over entire top surface of concrete slab.
6. Place asphaltic concrete as shown in Figure 27.
7. Place bituminous top course.
8. Open to traffic only after concrete has cured. High early strength concrete can be used to minimize curing time.

**RESOURCE REQUIREMENTS:**

Pavement breaker, excavating equipment, concrete finishing tools, bituminous paving equipment.

**REFERENCES:**

Virginia Department of Highways and Transportation (Reference 1)
# Concrete Deck Strengthening Procedure

## Description:
A concrete deck supported on longitudinal stringers may be strengthened by adding new transverse floor beams and additional stringers.

## Limitations:
Concrete floor slab must be capable of resisting negative moments induced at the new support locations.

## Construction Procedure:
1. Weld the new connection plates to the web of the existing longitudinal beams. See Figure 28.
2. Tack weld shim plates to the top of the new transverse floor beams.
3. Place epoxy grout on top of the new transverse floor beams including the shim plates.
4. Install the jack support beam and the jacks (see transverse section).
5. Jack the beams against the slab and use clamps to secure the beam to the connection plates. (Jacks could remain in place until permanent welds are provided.)
6. After the new transverse floor beams are placed, install additional longitudinal stringers. Shim plates and epoxy grout are used on the top flange of the new stringer to provide contact with the deck slab. The longitudinal stringers are jacked into place by jacking at the center of the jack support beam.
7. Weld or bolt the new transverse floor beams to the connection plates on the existing stringers and the new longitudinal stringers to the connection angles on the new transverse floor beams.
8. Remove jacks, jack support beams, and excess grout.

## Resource Requirements:
Jacking equipment, blocking and support beams, welding equipment and/or wrenches and small hand tools.

## References:
Texas State Department of Highways and Transportation (Reference 6)
Floor Strengthening System

Jack
Jack Support Beam
Shim (Typ.)
Floor Beam - New
Longitudinal Stringer - New
Existing Beam
Connection Plate

Partial Transverse Section

Existing Beam
Shim Plate (Typ.)
Location of Jack
Floor Beam - New
Longitudinal Stringer - New

Partial Plan

REPAIR NUMBER R4
PAGE 3 OF 3

Figure 28.
DESCRIPTION: High strength steel rods may be used to increase the load carrying capacity of a steel beam (easily adaptable for wood beams also). Two techniques may be used, namely: (A) Providing vertical supports at one or two positions along the beam and (B) prestressing the lower flange with a small vertical force at the king-post.

LIMITATIONS: Attachments of the steel rod at the ends of the steel beam must be carefully designed to transfer the tensile forces in the rods to the steel beam. Clearance under structure is lessened by depth of king-post. Consideration must be given to induced local stresses in the beam by the intermediate support. Corrosion protection should be provided for the rods.

CONSTRUCTION PROCEDURE:
Technique A. The rods are placed with as much slope as feasible and attached to the ends of the beam at mid-height. The mid-span support should be as deep as practical for the site. See Figures 29 and 30.
1. Bolt end anchors to the beam web in the desired position. The end anchors must project far enough out from the web to provide clearance between the lower flange and rods. See Figures 29 and 31.
2. Attach the king-post support.
3. Place and tension the rods to the desired level of stress.

Technique B. The high strength rods are placed parallel (or nearly so) to the bottom flange (see Figure 29). These rods are then tensioned so as to place a compressive prestress in the lower flange of the beams.
1. Design the rods and attachments to carry the intended post-tensioning forces.
2. Bolt the end anchors for the high strength rods to the lower flange of the steel beam. A short center support may be used to provide a small vertical force at mid-span. See Figure 30.
3. Place the high strength rods through the anchors and tension to the desired stress level.

RESOURCE REQUIREMENTS:
Jacking equipment for post tensioning, lifting equipment; welding equipment.

REFERENCES:
"Extending the Service Life of Existing Bridges" FHWA Report (Reference 10)
Connecticut Department of Transportation (Reference 11)
Partial Elevation Showing Typical King-Post Design at Midspan

Figure 30.
Partial Plan

- ‘d’ should not exceed the minimum distance required for the tensioning rods to clear the flange.

Note: A built up section may sometimes be required.

Partial Elevation

Typical Rod Connection Detail at Ends of Beam
Provide Corrosion Protection To Rods

Figure 31.
DESCRIPTION:
For existing multi-stringer spans. By using an under-mounted transverse distribution beam, the normal live load stringer distribution requirements of the AASHTO Specifications can be liberalized, thereby equalizing the live load distribution to stringers and consequently allowing a higher live load rating.

LIMITATIONS:
1. Should be considered an expedient measure and not a permanent solution.
2. For use with steel beam spans with timber decks and closely spaced stringers.
3. The technique is best adapted to bridges having all I or WF beams of equal size with at least a 10 in depth.

CONSTRUCTION PROCEDURE:
1. Provide necessary underbridge scaffolding for workers.
2. Drill holes at mid-depth of the web of all existing stringers. The holes shall be of sufficient diameter to accommodate the hangers shown in Figures 32 and 33.
3. Weld the web shear reinforcement as shown in Figure 32.
4. Insert all hangers without yokes, saddles or nuts in the web holes. See Figure 32.
5. Position the distribution beam directly under the hanger rods; install the yoke plates on all rods and temporarily wire or wedge them in place. Lift the distribution beam up into the hangers far enough that the yoke plate wedges can be removed.
6. Raise both ends of the distribution beam to the final location; install saddles and tighten all nuts just enough to take up all slack.
7. As an alternate procedure, the upper flange of the distribution beam can be bolted to the lower flanges of the main stringers. See Figure 33. The flexural capacity of the stringer is, of course reduced when bolt holes are drilled through the lower flanges and the engineer is cautioned to check the resulting live load capacity when this type connection is used.
8. Remove scaffolding.

RESOURCE REQUIREMENTS:
"Come-alongs", chains, acetylene torch, electric welding machine, small tools, fabricated materials, scaffolding materials. Installation can be done by small bridge maintenance crew.

REFERENCES:
Virginia Department of Highways and Transportation (Reference 1)
Note: Hanger connection shown. Alternative bolted connection is shown in Figure 33.

FIGURE 32. DISTRIBUTION BEAM ATTACHMENT

FIGURE 33. ATTACHMENT DETAILS
DESCRIPTION:
A steel and concrete pier is erected at or near midspan to convert a single simply supported span into two shorter continuous spans. The supporting pile groups are driven to the sides of the existing bridge so interruption of traffic is kept to a minimum.

LIMITATIONS:
The main flexural members of the existing structure must be capable of resisting the negative moment over the new support. If used on a truss a detailed analysis should be carried out to ensure that the truss members are not subject to stress reversals or overstress.

CONSTRUCTION PROCEDURE:
1. Design the new transverse beam and pile cap to support the load to be imposed.
2. Drive piles at the desired locations outboard of the bridge rails. See Figure 34.
3. Cast the concrete pile caps on top of the pile groups. See Figure 35.
4. After the concrete has reached sufficient strength, place and jack the new support beam snug against existing stringers. See Figure 36. Shim plates are used as required.
5. Place a non-shrink epoxy grout between the beam and the concrete pile caps. See Figure 37.
6. After the grout has set, drill holes in the concrete pier cap and place the dowels as shown in Figure 37.
7. Remove the jacks.

RESOURCE REQUIREMENTS:
Jacking equipment, crane, pile driving equipment, concrete drilling equipment.

REFERENCES: Illinois Dept. of Trans. (Reference 12) Note: Illinois uses this procedure to replace deteriorated intermediate supports on continuous spans. The description here is for adding or replacing.
Shim Plate (Typ Each Beam).

New Transverse Support  Existing Stringers

Figure 36. New Transverse Beam
Provision Must Be Made For Temperature Expansion in End Span Bearings

Seat Beam With Grout Hold Jack Until Grout Is Set.

Corrosion Protection Required

3/8" Dowel Bars (4 ea. beam)
Drill 7/8" Holes In Beam And Drill 2" Hole In Cap Grout After Beam Is In Place.

Figure 37. Detail Of New Beam Support
DESCRIPTION:
Clearance on through truss bridges can be increased by rearranging the portal bracing.

LIMITATIONS:
Stresses in all members of the portal bracing should be checked for the new configuration. If existing connections are riveted, bolting is recommended for the new connections, since weldability is uncertain on many old trusses. Traffic should be limited to light loads at low speeds while the portal bracing is being modified.

CONSTRUCTION PROCEDURE:
Technique A. See Figure 38.
1) Remove all portal bracing and install replacement members, which must be fabricated to fit between end posts.

Technique B. See Figure 39.
1) Remove lower horizontal member and cut diagonals to new length.
2) Replace horizontal member in new position and add new diagonals.

Technique C. See Figure 40.
1) Remove knee braces.

Note: The three procedures briefly described above present portal bracing modifications that have been successfully used. The new arrangements of the structural members will result in different loads in the members from the external lateral forces. The altered designs must be checked by a qualified structural engineer in each case.

RESOURCE REQUIREMENTS:
Metal cutting equipment, light lifting equipment, torque wrenches and small hand tools.

REFERENCES:
Virginia Highway and Transportation Department (Reference 1)
Louisiana Department of Highways (Reference 3)
Missouri State Highway Department (Reference 13.)
DESCRIPTION:
Typical details of technique that can be used to increase the vertical clearance under steel or prestressed concrete girder bridges.

LIMITATIONS:
This technique has been used to increase the vertical clearance under bridges by approximately 3 ft. Structural members that are jacked against to raise the structure must be checked to ensure that they can resist stresses induced by the jacking operation. Traffic must be detoured during the repair. Vertical alignment of approach roads leading to raised structure must be adjusted. Stability of abutments and wing walls must be checked for the additional horizontal force resulting from the revised design of the substructure.

CONSTRUCTION PROCEDURE:
1. Design the steel pedestals to support the given beam loading. Some typical details that can be used are shown in Figures 41 and 42 for steel girder bridges and Figures 43 and 44 for prestressed concrete girder bridges.
2. Prefabricate the pedestals.
3. Calculate the total reaction due to the dead load of the span to be elevated by the jacking operation.
4. Estimate the number of jacks required to support the load in a uniform fashion across the width of the bridge.
5. Select the bridge members to be jacked against.
6. Check the loading on the selected members to determine if modifications are required to resist the jacking forces. (When jacking against diaphragms, for example, stiffeners, additional welding at the connections, or other similar procedures may be required to ensure that the member can resist the load to be imposed.)
7. If it is necessary to jack against a footing or other substructure member, excavate and install cribbing and blocking to support the jacks.
8. Raise the span by jacking. Pressure gages should be used to keep all jacks lifting the span as evenly as possible.
9. Jack, block, and rejack until sufficient clearance is obtained to install the prefabricated pedestal.

CONSTRUCTION PROCEDURE (continued):
10. Remove any temporary blocking, install 1/4 in. preformed fabric pad on the bearing surface, and place the permanent pedestals in position. (The fabric pad and bearing surface should be swabbed with red lead paint.)
11. Install cross bracing or other type bracing; field weld or bolt as required and make any necessary adjustments; anchor the pedestal to the pier or abutment.
12. Reposition the beam bearing assemblies on top of the pedestals.
13. Lower the span to bear evenly on the pedestal bearings.
14. Complete all field welding and/or make other final adjustments; tighten all anchor bolts.
15. Remove jacking equipment, cribbing, etc.
16. Excavate behind the abutment backwalls and wingwalls to a depth sufficient to facilitate the removal of concrete as required to ensure bond to the existing reinforcing steel.
17. Construct back and wingwalls to the new elevation as required.
18. Backfill abutment and wingwalls; reconstruct bridge approaches as required.

NOTES:
1. A similar procedure is available for prestressed concrete spans. See Figures 43 and 44.
2. The description given herewith is for raising a single simple span. However, the Texas Highway Department has used a similar procedure to raise by 2.75 ft. a 4-span continuous bridge (60 ft.-75 ft.-75 ft.-60 ft.) on a 30° skew.

RESOURCE REQUIREMENTS:
Excavating equipment, hydraulic jacking system, welding equipment, small crane or other suitable lifting equipment, and miscellaneous hand tools.

REFERENCES:
Texas Department of Highways and Public Transportation (Reference 6)
Figure 43. Transverse Elevation of Pier Cap Showing Raised Prestressed Concrete Beam Span.

Figure 44. Details of Exterior and Interior Beam Pedestals (see Figure 43)
DESCRIPTION:
This procedure describes a method for increasing the width of the roadway on concrete deck bridges. Suggestions for widening another type of concrete slab bridge are given in Repair G-4.

LIMITATIONS:
The substructure must be widened to accommodate the widened superstructure. The order of ranking of the structure types that present the fewest widening problems are: steel, prestressed concrete, concrete "T" girders, and conventionally reinforced and cast-in-place prestressed concrete box girders. Method "A" requires a time delay between the widening concrete placement and the closure pour as described below. It is preferable to use steel or precast prestressed concrete girders for the widened portion of the structure.

CONSTRUCTION PROCEDURE:
Method "A" (Preferred Procedure)
1. Widen the piers and abutments as necessary.
2. Design, fabricate and erect the new girders for the widening.
3. Form and place the reinforcing steel and concrete for the initial widening pour as shown in Figure 45, Method "A".
4. Remove the concrete from the old deck areas as indicated in Figure 45, Method "A" to expose the reinforcing steel to provide the length necessary to lap with the new steel.
5. Install adequate lateral bracing between the old exterior girder and the new adjacent girder.
6. Attach the new reinforcing steel to the original by lapping both the top and bottom transverse deck steel.
7. If the bridge is widened using steel or precast, prestressed concrete girders, a period of 3 to 15 days should be allowed before the closure concrete shown in Figure 45 "A" is placed. If the bridge is widened with cast-in-place girders, considerable plastic deformation may occur after removal of the falsework, and waiting periods on the order of 60 days may be advisable.
8. Eliminate traffic from at least the lane nearest the widening before the closure concrete is placed.
9. Place the closure concrete.
10. Remove falsework and restore the bridge to traffic after the last concrete pour has attained design strength.

Method "B"
1. Widen the piers and abutments as necessary.
2. Design, fabricate and erect the new girders for the widening.
3. Remove the concrete from the old deck area as indicated in Figure 45 "B" to expose the reinforcing steel to the length required to provide necessary development length.
4. Place adequate lateral bracing between the old exterior girder and the new adjacent girder.
5. Form the new deck area and attach the new reinforcing steel to the original by lapping both the top and bottom transverse deck steel.
6. Place the concrete for the widening.

RESOURCE REQUIREMENTS:
Form carpenters, qualified welding personnel, shoring, crane and/or other lifting equipment.

REFERENCES:
Figure 45. Two Methods for Widening an Existing Concrete Bridge Deck. A Steel Girder Section is Shown; Other Types Can Be Widened Using Either Method.
DESCRIPTION:
This procedure provides a method for increasing the width of the roadway of a concrete slab bridge. The example illustrated has a concrete parapet placed integrally with the concrete deck slab.

LIMITATIONS:
The substructure must be widened to accommodate the widened slab. Shoring must be provided for the formwork for the widened slab.

CONSTRUCTION PROCEDURE:
1. Additional piling may be necessary. Drilling into the ends of existing pier caps and abutments and grouting the new reinforcing steel are recommended. This procedure can provide adequate connection ties with the existing pier cap and abutments. Widen the piers and abutments to the new width. See Figure 46.
2. Direct traffic to the opposite side of the bridge roadway during the slab widening construction.
3. Support the existing slab with shoring prior to removing the edge parapet or curb. See Figure 47.
4. Remove the existing parapet concrete and approximately 12 in. of the existing concrete slab to expose the old transverse reinforcing steel.
5. The reinforcing steel in the new section of roadway slab is lapped with the bent down steel from the removed parapet and with the straight transverse steel in the existing roadway slab.
6. Provide an edge beam for the widened slab by (1) placing extra reinforcement and a new parapet integral with the slab similar to that removed; or by (2) strengthening the edge with an increased depth of slab (as shown in Figure 47). Place the concrete for the new slab.
7. Remove the shoring and falsework after the concrete has attained the desired strength.
8. Place a suitable bituminous overlay across the entire new deck surface to provide a crown to the roadway and a smoother riding surface.

REFERENCE REQUIREMENTS:
Form carpenters, shoring, light lifting equipment.
Dowels; Drill and Grout
New Pier Cap Extension
Pile

Figure 46.

Existing Slab
Existing Curb
Roughened Face
New Slab

Provide Temporary Support
If Necessary

Slab Extension
Figure 47.

REPAIR NUMBER G4
PAGE 3 OF 3
DESCRIPTION:
Placement of a heavy mass attached to a bridge abutment to anchor the abutment and resist overturning. Bridge abutments are anchored via steel rods to large concrete blocks to prevent overturning. The concrete blocks are referred to as deadmen.

LIMITATIONS:
The concrete deadmen should be placed in undisturbed earth or cast around the exposed tops of piling to provide lateral resistance to movement.

CONSTRUCTION PROCEDURE:
1. Excavate the area where the deadmen are to be placed and provide a trench for the restraining rods. See Figures 48 and 49.
2. Drive piles for the deadmen. If soil is sufficiently firm, the piles may be eliminated.
3. Place formwork and concrete for the deadmen. Note that the side of the deadmen facing the abutment should be cast without forms. See Figure 50.
4. Drill through the wing walls and place the restraining rods. Wrap and cast with tar or provide other means to protect rods from corrosion.
5. Bolt the restraining rods at the deadmen. See Figures 49 and 50.
6. Place the waler beams and tighten the rods. See Figures 49 and 50.

RESOURCE REQUIREMENTS:
Excavation equipment, light lifting equipment for waler beams, and concrete, drills, miscellaneous hand tools.

REFERENCES:
North Carolina Department of Transportation (Reference 8)
Existing Abutments

Provide Hole In Wingwall And Grout After Rods Are Placed

Restraining Rod Provide Corrosion Protection

Face Of Wingwall

Fill Side

60-100' Typical

Deadman

This Face to be Poured Against Firm Soil Without Forms. The Size Of Area Of Face is Important To The Restraint Provided By The Deadman.

Longitudinal Section
DESCRIPTION:
Repair of deteriorated timber or concrete piles and pier columns by encasement in concrete using a permanent fiberglass form. This procedure may be used for piling immersed or out of water.

LIMITATIONS:
Can be used where much of pile cross section has been lost. Qualified divers may be required. Some of the repair systems are proprietary.

CONSTRUCTION PROCEDURE:
1. Scrape surface of the pile clean, removing deteriorated concrete or wood.
2. Sandblasting may be used to clean the exposed reinforcement in concrete piles (above water line). Splice with new reinforcement if required. Install steel mesh reinforcing cage around timber pile (Figure 51a) or concrete pile (Figure 51b). Use spacers to keep the forming in proper position.
3. Place the forming jacket around pile and seal the bottom of form against pile surface. (Figure 52)
4. Pump suitable concrete into form through opening at the top. Sulfate resistant concrete should be used in salt water locations.
5. Finish top portion of repaired area.

NOTES:
A. Form should reach from above the splash zone down to sound wood or concrete.
B. Steel piles can be protected by coatings that prevent the dissolved oxygen in the water from contacting the steel. Epoxy coating systems and polyvinyl chloride barriers have been used.

RESOURCE REQUIREMENTS:
Underwater survey and repairs will require qualified divers. Form jackets must be purchased or fabricated. Concrete pump required.
Existing Timber Pile

Existing Concrete Pile With Deteriorated Concrete Removed

Permanent Form

Spacers

Steel Reinforcement

Form Extends Below Grnd Line

(a)

(b)

Figure 51. Typical Technique For Repairing
(a) A Timber Pile
(b) A Concrete Pile

Note That Either Type Can Be Repaired Above Ground Or Below The Waterline.

Figure 52. Completed Repair Using Permanent Forming Jacket With Bottom Seal
DESCRIPTION:
Helper bents are installed under sound pier caps to provide support after existing piles have deteriorated or settled out of position. See Figure 53. Repair R-7 describes a procedure for adding a new pier if an existing pier has deteriorated beyond feasible repair.

LIMITATIONS:
Existing pier cap must be in sound structural condition. Requires piles to be driven through deck slab. Bridge must be able to support the weight of pile driving equipment. Dry land or floating pile driving rig could be used.

CONSTRUCTION PROCEDURE:
1. Restrict traffic to one lane of the bridge or close bridge if necessary.
2. Cut openings in existing bridge deck of sufficient size to allow driving of the new piles. Use temporary deck hole covers to maintain traffic during the repair.
3. Drive the new piles. Do not cut off the piles.
4. Place cap support snug against pier cap and mark piles for cut off.
5. Cut off new piles.
6. Wedge cap support into position atop the new piles and fix by any suitable method.
7. Remove the temporary deck hole covers and close.

RESOURCE REQUIREMENTS: Pile driving, jacking and lifting equipment. Scaffolding may be required to gain access to underside of bridge deck. Pavement breaking and concrete sawing equipment may be required for use on concrete decks.

REFERENCES: Wyoming (Reference 7), North Carolina (Reference 8), and Florida (Reference 15) all use systems similar to the one described but varying in details and complexity.

Figure 53. Installation of Crutch Bent
TITLE: ADDITION OF SUPPLEMENTAL PILES

REPAIR NUMBER: F-4

PAGE 1 OF 2

DESCRIPTION:

Strengthening of weak or settled pile bent through use of supplementary steel H piles and steel beam subcaps. See Figure 54.

LIMITATIONS:

Traffic must be restricted to one lane or bridge closed to traffic as necessary. Piles are driven through holes in the deck. The bridge must be able to support the weight of pile driving equipment. Dry land or floating pile driving rig could be used.

CONSTRUCTION PROCEDURE:

1. Restrict traffic flow as required to facilitate the repair.
2. Cut holes in the deck large enough to accommodate piles battered as necessary. The holes in the deck should be as close to the end diaphragm as possible to minimize length of the subcap.
3. Drive piles and cut off at level sufficiently below pier cap to accommodate the subcap support beams.
4. Weld subcap support beams to the piles. Piles may be bent to a slight degree to match the subcap.
5. Shim cap for fit to the existing pier cap.
6. Close deck holes; restore traffic.

RESOURCE REQUIREMENTS: Pile driver and cutting equipment required. Steel members should be designed, detailed and shop fabricated. Pavement breaking and concrete sawing equipment may be required for use on concrete decks.

REFERENCES:

North Carolina Department of Transportation, (Reference 8) Louisiana, (Reference 3) and others.
TITLE: REPAIR NUMBER
REPAIR OF ERODED AREAS AT PIER FOUNDATIONS  F-5

DESCRIPTION:
Prevent further erosion and deterioration by encasing existing footings and piling in tremie concrete. See Figures 55(a) and 55(b).

LIMITATIONS:
Pier or abutment must not have shifted position and must have adequate anchorage support on firm material or on piling. Additional loading on the piling and underlying soil from the added concrete must be considered.

CONSTRUCTION PROCEDURE:
1. Clean all exposed concrete surfaces of marine growth and of loose or deteriorated concrete.
2. Place welded wire mesh around footing as shown in Figure 55(c).
3. Set forms and pour tremie concrete to height shown in Figure 55(c).
4. Metal forms to remain in place.

RESOURCE REQUIREMENTS:
Pile driving equipment for cofferdams, if required; pumping and tremie concreting equipment; crane or other lifting equipment.

REFERENCES:
Virginia Highway and Transportation Department (Reference 1)
REPAIR OF SHEARED CONCRETE BEAM SEATS

DESCRIPTION:
Repair deteriorated concrete beam seats by removing spalled concrete and replacing with new concrete using an epoxy bonding compound.

LIMITATIONS:
Area of deteriorated concrete should not be extensive. The cause of the deterioration should be determined and corrected. For example, deteriorated bearings should be corrected or replaced and high edge loads on beam seats relieved by properly designed bearings.

CONSTRUCTION PROCEDURE:
1. Restrict traffic to the lane furthest from the repair area until repairs are complete.
2. Construct temporary bent for supporting jacks and blocking if jacking from abutment or pier elements cannot be accomplished.
3. Place jacks and lift beam until bearing pressure is completely relieved.
4. Remove deteriorated concrete to horizontal and vertical planes as shown in Figure 56 and Section AA.
5. Add new reinforcing steel where required as shown in Figure 56.
6. Apply epoxy bonding compound to prepared surface of sheared beam seats.
7. Form as required and cast new concrete.
8. After concrete has reached required strength, remove forming, blocking, jacks and temporary supports.

RESOURCE REQUIREMENTS:
Jacking equipment, tools to remove deteriorated concrete as necessary. Form carpenter and necessary staging.

REFERENCES:
Virginia Department of Highways and Transportation (Reference 1)
TITLE: STRENGTHENING EXISTING TIMBER PIER CAP

DESCRIPTION:
Additional timbers are bolted to an existing bent or pier to provide required capacity.

LIMITATIONS:
Original timber cap should be in good structural condition and not susceptible to abnormal deterioration.

CONSTRUCTION PROCEDURE:
1. Construct scaffolding as required around existing bent.
2. Notch existing piles or columns in order to accommodate new timber cap members.
3. Place new members snug against existing cap and stringers; temporarily clamp in place. See Figure 57 and Section AA.
4. Drill 13/16" φ holes for 3/4" φ bolts.
5. Place bolts, tighten, and remove clamps.
6. Remove scaffolding, if used.

RESOURCE REQUIREMENTS:
Access to pile cap; heavy duty drilling and light lifting equipment. Small hand tools; wrenches.

REFERENCES:
Louisiana Department of Transportation (Reference 3)
**TITLE:**
**INCREASING LIVE LOAD CAPACITY OF EXISTING FOOTING**

**DESCRIPTION:**
Incorporation of additional piles into a concrete footing and increasing the thickness (height) of the footing to provide greater capacity for carrying live load.

**LIMITATIONS:**
Footing must be fully excavated and there must be sufficient headroom under the bridge for pile driving equipment.

**CONSTRUCTION PROCEDURE:**
1. Excavate around the footing.
2. Chip concrete to expose edges of lower mat of reinforcing steel as shown in Figure 58. Generally the footing depth must be increased to adequately support the increased live load. Additional reinforcing steel would generally be required in the added top concrete as well as lapped with the reinforcement in the existing bottom mat. Clean the old concrete that will be in contact with the new concrete.
3. Drive all additional new piles.
4. Form the new extended footing.
5. Lap the new reinforcement to old bars and construct reinforcement cage. If lapping is not feasible, new reinforcement would have to be connected to existing footing by drilling and grouting.
6. Place and cure the concrete in the extended footing.
7. Backfill over the footing.

**RESOURCE REQUIREMENTS:** Excavation and pile driving equipment is required. Material requirements include concrete, reinforcing steel, splice sleeves, formwork, and bearing or displacement piles.

DESCRIPTION:
Defective portion of existing piles are removed and replaced with steel piles. See Figure 59. The bases of the old piles are left in place and used to support concrete footings to which the new columns are bolted.

LIMITATIONS:
Piling below the surface must be in good condition and have sufficient capacity to support the new concrete footing. Further, the existing cap must be in good condition. If abutment piling is repaired by this method, it would be necessary to limit the fill height behind the abutment and give special consideration to the resistance of the lateral earth pressure.

CONSTRUCTION PROCEDURE:
1. Determine all cutoff points on the existing piles and the column length needed for the repair.
2. Construct temporary support for the superstructure before beginning the repair.
3. Construct cofferdam, if necessary, and dewater.
4. Excavate if required and cut existing piles off below the ground line such that the top of the footing will be approximately 9 in. below this level. See Figure 59.
5. Separate the old sections of piling from the pier cap.
6. Form and pour concrete footings over the existing pile stubs. The pile stubs should project at least 12 in. into the new footing.
7. Place the anchor bolts in the footing concrete prior to initial set.
8. Cut the steel columns to the proper length and weld on the base plates shown in Section AA.
9. After concrete has reached required strength, attach new steel columns to footings with nuts and washers.
10. Attach the top of the new columns to the existing pier caps with lag screws.
11. Remove all temporary supports, backfill where necessary, and remove the cofferdam if one was used.
Sizes of footing and reinforcing steel should be designed to accommodate the particular structure being repaired.

Use Shim Plates to Provide Fit

Grout Pad

Ground Elevation

Steel Plate

Anchor Bolts Cast In Footing

3 Bars At Each End Existing Piles

Field Weld Top and Bottom Plates

Section A-A

Replacement of Defective Portion of Existing Timber Piling Under a Timber Bent

REPAIR NUMBER F9

Figure 59.
DESCRIPTION:
This method may be used for existing spans where it has been determined that the present pier columns and/or pier caps are no longer structurally adequate due to distress or upgraded bridge loadings. This procedure provides a convenient method for widening the existing roadway as well as strengthening the existing pier cap.

LIMITATIONS:
The beam seats on the existing pier cap must be in good condition or be repairable when the new pier cap is used only to supplement the capacity of the existing pier cap which remains in place. The replacement of the bearing assemblies could also be a part of this rehabilitation procedure.

CONSTRUCTION PROCEDURE:
1. Locate the new pier columns in line with the existing pier cap.
2. Erect scaffolding around old columns.
3. If the existing columns are piles having concrete encased H piles, remove the encasement from the piling in the area where it will be embedded in the new pier cap. See Figure 60. If the existing columns are reinforced concrete, prepare the surface of the column which will be embedded in such a manner as to ensure adequate bond to the new pier cap. (Chip the concrete to expose the reinforcing steel such that the new concrete can bond to total surface area of the steel.)
4. Excavate for footings for new columns.
5. Form and place concrete for new footings.
6. Drill through the existing columns or piles to provide holes for the new cap’s reinforcing bars. The main horizontal reinforcing steel in the new pier cap should be uninterrupted. This requires that holes be drilled through the existing pier columns.
7. Place the formwork and the required reinforcing steel and cast the new pier columns.
8. Remove the column forming; form and place the concrete for the new pier cap.
9. When concrete has achieved the required strength, remove the cap formwork and remove the existing columns in the region extending from the new cap to below the original ground line if necessary. In many cases the old columns can remain in place to provide additional capacity.
10. Complete removal of all scaffolding; backfill where required.

RESOURCE REQUIREMENTS:
Concrete breaking and drilling equipment, light lifting equipment.

REFERENCES:
Texas Department of Highways and Transportation (Reference 6)
Old Pier Cap

New Pier Cap

New Pier Column

Old Pier Cap

Old Pier Column

Plan

New Stringer And Pedestal For Widening Roadway

New Pier Cap

Old Pier Column

Elevation

Note: If the new pier cap is to accommodate a widened roadway as well as strengthen the existing pier cap, pedestals can be provided for new bearings and stringers.

FIGURE 60. TECHNIQUE FOR STRENGTHENING A DETERIORATED PIER CAP
CHAPTER THREE

RECOMMENDED REPLACEMENT SYSTEMS

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REFERENCES

1. Prestressed Concrete Institute, "Short Span Bridges." Chicago, Ill. (1975).
24. MUCHMORE, F. W., "Portable Bridges for Use in Logging Roads."
38. Colorado Department of Highways, "Plans for Michigan Creek Bridge, Jackson County Road #12." Colorado Springs, Colo.
42. U.S. Steel Corporation, "Bridge Structural Report—Holbrook Bridge Furnas County, Nebraska" (Sept. 1973).
Transportation Research Board Circular 181 (Sept. 1976).


SELECTED BIBLIOGRAPHY


REPLACEMENT SYSTEMS

Twenty-seven bridge replacement systems were identified. With the exception of two of the four prefabricated steel bridges in System Number S-1, all have been used successfully in the United States. The two exceptions noted have been used in Western Europe and are available in the United States.

Each system meets one or more of the criteria of ease of construction, inexpensive construction, relatively short construction time, or long, useful life expectancy. These replacement systems are provided in the following pages.
Precast and/or prestressed slabs. Solid or with voids.

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

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

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

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

REFERENCES:
Pre-stressed Concrete Institute (Reference 1)
Louisiana Department of Highways (Reference 2)
Federal Highway Administration (Reference 3)
NAME OF SYSTEM:

PRECAST BOX BEAM.

SYSTEM NUMBER

C-2

PAGE 1 OF 2

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

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

CASE EXAMPLES:
Widely used.

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

REFERENCES:
Prestressed Concrete Institute (Reference 1)
Federal Highway Administration (Reference 3)
Virginia Prestressed Concrete Association (Reference 4)
Public Works (Reference 5)
NAME OF SYSTEM: DOUBLE-TEE AND CHANNEL BEAM

SYSTEM NUMBER: C-3

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

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

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

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

REFERENCES:
Virginia Prestressed Concrete Association (Reference 4)
Prestressed Concrete of Colorado (Reference 6)
Choctaw, Inc. (Reference 7)
Central Premix (Reference 8)
Mississippi Highway Department (Reference 9)
Kentucky Department of Transportation (Reference 10)
DESCRIPTION:
Prestressed, inverted channel beams with cast-in-place concrete deck.

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

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

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

MANUFACTURERS:
Ontario Precast Concrete Manufacturers Association
Local precast, prestressed concrete producers

REFERENCES:
Salmons, John R. (Reference 11)
Salmons, John R. (Reference 12)
Nairn, R. D. (Reference 13)
NAME OF SYSTEM: 
MULTISTEMMED BEAM

SYSTEM NUMBER
C-5

PAGE 1 OF 2

DESCRIPTION:
Precast, prestressed multistemmed beams.

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

CASE EXAMPLES:
Several bridges have been constructed in the northwestern states.

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

REFERENCES:
Prestressed Concrete Institute (Reference 1)
"Instant Bridges" (Reference 8)
NAME OF SYSTEM: PRESTRESSED SINGLE-TEE

SYSTEM NUMBER: C-6

PAGE 1 OF 2

DESCRIPTION:
Precast, prestressed single-tee beam.

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

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

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

REFERENCES:
Prestressed Concrete Institute (Reference 1)
Prestressed Concrete of Colorado (Reference 6)
"Instant Bridges" (Reference 8)
Virginia Department of Highways & Transportation (Reference 14)
Curtis, Robert B. (Reference 15)
Sprinkel, Michael M. (Reference 16)
NAME OF SYSTEM: PRESTRESSED BULB-TEE

DESCRIPTION:
Precast, prestressed bulb-tee beams.

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

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

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

REFERENCES:
Prestressed Concrete Institute (Reference 1)
"Instant Bridges" (Reference 8)
Anderson, Arthur R. (Reference 17)
"RTP Markets Instant Bridges" (Reference 18)
Prestressed Concrete Institute (Reference 19)
**NAME OF SYSTEM:** Prestressed I-Beam

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

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

**CASE EXAMPLES:**
Numerous examples can be found throughout the United States.

**MANUFACTURERS:**
Most producers of prestressed concrete.

**REFERENCES:**
Federal Highway Administration (Reference 3)
Virginia Prestressed Concrete Association (Reference 4)
Anderson, Arthur R. (Reference 17)
Engineering News-Record (Reference 20)
DESCRIPTION:
Standard prefabricated steel superstructure components are connected and topped with a wearing surface to provide a fast-assembly bridge.

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

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

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

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

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

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

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

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

REFERENCES:
"Nobels-Kline, Ltd." (Reference 21)
Kroger, E. (Reference 22)
Godfrey, K. A., Jr. (Reference 23)
Muchmore, F. W. (Reference 24)
One Web/Add-On Unit

Structural Tee

Transverse Roadway Rib

Steel Plate (Covered with 1\(\frac{3}{4}\)" thick modified asphalt wearing surface)

Wearing Surface (8mm thick shop applied epoxy or 50-75mm thick field applied modified asphalt)

Longitudinal Rib

Transverse Beam

Web Plate

Stiffener

Main Flange Plate

Rubber Joint

FIGURE 9. PREFABRICATED STEEL TEE-SHAPED UNITS

FIGURE 10. PREFABRICATED STEEL RECTANGULAR UNITS
System Number S1

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Bituminous Wearing Surface (3" min. thickness)
Steel Bridge Plank
Diaphragms in Accordance with
AASHTO Specs
Plate Girder (Spokane) or
Rolled Beam (Armco)
For Shorter Spans Depth is Constant

Figure 11. Steel Bridge Plank on Plate Girders

System Number S1

Page 6 of 6

1' x 2' Rail
4' x 12' Timber Plank
8' x 10' Treated Timber
Standard Wide Flange Structural Shape

Figure 12. Treated Timber Deck on Steel Stringers
**NAME OF SYSTEM:** Temporary Bridges  
**SYSTEM NUMBER:** S-2  
**PAGE 1 OF 2**

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

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

**CASE EXAMPLES:**
Bridges can be found all over the United States and other parts of the world.

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

**REFERENCES:**
- Acrow Panel Bridge, (Reference 25)  
- "Acrow Panel Bridge Replaces Two Spans Destroyed by Flood", ENR (Reference 26)
**DESCRIPTION:**

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

**PROMINENT FEATURES:**

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

**CASE EXAMPLES:**

New York, Alabama, Indiana, Pennsylvania

**MANUFACTURERS:**

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

**REFERENCES:**

"Short-Span Steel Bridges, U. S. Steel Corp. (Reference 27) Biswas, Mrinmay and others (Reference 28) "Low-Cost, No-Care Bridge", Better Roads, (Reference 29) NCHRP (Reference 30)
Transverse Reinforcing Steel as Required
Reinforced Concrete Panel
Non-corn etite Site-Cast Concrete Joint to
ConnectPon DetaII &
Steel Beam
Bolt Pre •
½" Plate
Epoxy Mortar Required for
Uniform Bearing

"Minimum W controlled by
development length for
slab reinforcement

**SYSTEM NUMBER S 3
PAGE 3 OF 4

FIGURE 15. PRECAST PANELS PLACED TRANSVERSELY (NON-COMPOSITE CONNECTION)**
DESCRIPTION:
Laminated timber deck is placed on steel stringers.

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

CASE EXAMPLES:
Virginia, Alaska and a number of other states.

MANUFACTURERS:
Supplies can be obtained from distributors located throughout the country.

REFERENCES:
U. S. Steel Corporation (Reference 31)
"Steel Beams with Glulam Flooring", VDHT (Reference 32)
Sprinkel, M. M. (Reference 33)
DESCRIPTION:
Solid sawn timber planks are placed on steel stringers.

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

CASE EXAMPLES:
Numerous examples in Virginia and elsewhere.

MANUFACTURERS:
Materials are obtainable from local suppliers.

REFERENCES:
"Standard Steel Beam Bridges", VDHT (Reference 34)
DESCRIPTION:
Modular steel grid units are placed on steel stringers.

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

CASE EXAMPLES:
Kansas, Pennsylvania and Virginia

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

REFERENCES:
Greulich, Inc. (Reference 35)
"Pittsburgh's Troubled Bridges: What To Do About Them?" (Ref. 36)
NAME OF SYSTEM: BITUMINOUS CONCRETE DECK ON STEEL PLANKS

SYSTEM NUMBER
S-7

PAGE 1 OF 2

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

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

CASE EXAMPLES:
Used in Ohio, Colorado and Virginia.

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

REFERENCES:
Schukraft, Bernard (Reference 37)
Colorado Department of Highways (Reference 38)
**NAME OF SYSTEM:** ORTHOTROPIC STEEL PLATE DECK  
**SYSTEM NUMBER:** S-8  
**PAGE 1 OF 2**

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

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

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

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

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

**REFERENCES:**
Orthotropic Plate Design for Steel Bridges (Reference 39)  
Design Aid for Orthotropic Bridge Decks (Reference 40)
**NAME OF SYSTEM:** SITE-CAST DECK ON STEEL BEAMS  
**SYSTEM NUMBER:** S-9  
**PAGE 1 OF 2**

### DESCRIPTION:

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

### PROMINENT FEATURES:

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

### CASE EXAMPLES:

This bridge system is widely used all over the world.

### MANUFACTURERS:

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

### REFERENCES:

- Engineering News Record (Reference 20)
- U. S. Department of Transportation (Reference 41)
- U. S. Steel Corporation (Reference 42)
NAME OF SYSTEM: GLUED LAMINATED TIMBER

SYSTEM NUMBER: T-1

DESCRIPTION:
Glued laminated timber "Glulam" beams and deck panels.

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

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

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

REFERENCES: Bruesch, L. D. (Reference 43)
Virginia Department of Highways & Transportation (Reference 44)
Weyerhauser (Reference 45 and 46)
AITC (Reference 47), VDOT (Reference 48)
Steel Dowel 1\(\frac{1}{2}\) Diameter x 1'-7\(\frac{1}{2}\) (Purchased Hole for Tight Fit)

Figure 25. Dowel Connection Detail

Figure 26. Bracket Connection Detail
NAME OF SYSTEM: NAIL LAMINATED TIMBER
SYSTEM NUMBER T-2

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

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

CASE EXAMPLES:
One example in Virginia.

MANUFACTURERS:
May be constructed with locally available materials.

REFERENCES:
Federal Highway Administration (Reference 49)

Figure 27. Nail Laminated Timber Superstructure
NAME OF SYSTEM: SOLID SAWN TIMBER BEAMS

DESCRIPTION:
Solid sawn timber beams support various types of decking material.

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

CASE EXAMPLES:
Several examples in rural Virginia

MANUFACTURERS:
Locally available materials and labor.

REFERENCES:
Federal Highway Administration (Reference 49)
DESCRIPTION:
Polyurethane-resin-coated plywood serves as deck surface.

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

CASE EXAMPLES:
New Hampshire

MANUFACTURERS:
Contact American Plywood Association

REFERENCES:
American Plywood Association (Reference 50)
**NAME OF SYSTEM:** Precast Abutment and Wingwall  
**SYSTEM NUMBER:** M-1  
**PAGE 1 OF 2**

**DESCRIPTION:**
Precast concrete abutment and wingwall panels.

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

**CASE EXAMPLES:**
A prototype structure has been constructed in Garfield County, Washington, and proposed in Oklahoma.

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

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

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**Figure 30. Precast Abutment and Wingwall**
**NAME OF SYSTEM:** SYSTEM NUMBER

**PILE SUBSTRUCTURES**

**SYSTEM NUMBER**

**DESCRIPTION:**
Prestressed concrete or steel H-piling with concrete or steel cap.

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

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

**MANUFACTURERS:**
Materials should be readily available.

**REFERENCES:**
U. S. Steel Corporation (Reference 27)
Imel, K. Dean (Reference 52)
Engineering News-Record (Reference 53)
<table>
<thead>
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<th>SYSTEM NUMBER</th>
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<td>Field Weld</td>
<td>Weld Plate</td>
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<td>Site Cast Concrete Reinforcing Bar</td>
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1 Steel Cap on Steel Pile  
2 Precast Concrete Cap on Steel Pile  
3 Site-cast Concrete Cap on Steel Pile  
4 Site-cast Concrete Cap on Prestressed Concrete Pile  
5 Precast Concrete Cap on Prestressed Concrete Pile

Figure 33.  
Connection Details for Pile Substructures
NAME OF SYSTEM: SPAN SHORTENING SUBSTRUCTURES

DESCRIPTION:
Slanted leg piers serve as supporting members.

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

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

MANUFACTURERS:
Local precast concrete producers or steel fabricators.

REFERENCES:
"Ardrossan Bridge Employs Precast, Prestressed Components" (Ref. 54)
Jacques, F. J. (Reference 55)
Casad, D. D. and H. W. Birkeland (Reference 56)
NAME OF SYSTEM: PERMANENT BRIDGE DECK FORMS

SYSTEM NUMBER M-4

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

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

CASE EXAMPLES:
Case examples can be found throughout the United States.

MANUFACTURERS:
Local steel fabricators and prestress concrete producers.

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

NOTE: Vertical leg downward allows for higher form support elevations. Vertical leg upward allows for lower form support elevations.
Prestressed Concrete Subdeck Panels.

Figure 37:
NAME OF SYSTEM: PARAPET AND RAIL SYSTEMS

SYSTEM NUMBER: M-5

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

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

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

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

CASE EXAMPLES:
Examples can be found throughout the United States.

MANUFACTURERS:
Materials are usually available locally.

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

Figure 38. Precast Concrete Parapet
Figure 39. Site Cast Concrete Parapet
Figure 40. Steel Rail and Post Connected to Deck and Exterior Beam
Figure 41. Steel Rail and Post Connected to Exterior Beam

Figure 42. Timber Rail and Post Connected to Deck
### Description:
Structures are made of corrugated-metal structural plate sections, field assembled in various closed or arch configurations to serve as large culverts or grade separation structures.

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

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

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

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

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

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

### References:
APPENDIX

DESCRIPTION OF RESEARCH EFFORT

CHAPTER ONE

INTRODUCTION

PROBLEM STATEMENT

Since the collapse of the Silver Bridge at Point Pleasant, West Virginia, in 1967, considerable attention has been given to bridges on the federal-aid system. Current federal regulations require periodic inspections and ratings of each bridge, and federal and state funding is available for rehabilitation and replacement. Although much work remains to be done and many problems remain, the bridges on the federal-aid system are receiving the attention necessary for maintaining safety and serviceability.

With major emphasis being placed on bridges on the major highways, especially those on the interstate system, and new construction in recent years, bridges on secondary highways and local roads have frequently been neglected; they have been given irregular inspections, inadequate maintenance, and infrequent load capacity ratings. A large number of these bridges are in serious need of structural repair, or, as is the case in many instances, their load carrying capacity is so impaired that total replacement is necessary. In addition to the number of bridges that have structural deficiencies, there are many other structures classified as functionally obsolete. A structurally deficient bridge in defined as one that, because of damage or deterioration, has been restricted to carrying light traffic only or has been closed. A functionally obsolete bridge is one whose deck geometry, load carrying capacity, clearance, or approach roadway alignment can no longer safely service the system of which it is a part.

It has been estimated that more than 100,000 bridges in this country are inadequate for heavy loads or in need of major repairs. Further, it has been estimated that over 50,000 bridges are functionally obsolete because of such geometric constraints as narrow width, poor clearances, and dangerous approaches. Thousands of additional bridges fall into one of these categories each year.

Major structural failures of rural bridges with resulting loss of life and significant requirements for structural replacement in terms of cost are not infrequent occurrences. It has been reported that approximately 150 bridge failures occur in the United States each year. This unsatisfactory condition of thousands of rural bridges, accompanied by periodic failures and potential disasters in terms of loss of life and damage, simply cannot be tolerated much longer.

Under the severe fiscal constraints that exist at the local, state and federal levels, however, most of these bridges cannot be totally replaced in the foreseeable future. In fact, the cost of replacement, estimated to be in excess of $23 billion, is so excessive as to preclude any serious consideration. Nevertheless, these bridges must remain in service to prevent disruption of a major United States transportation system.

Until recently, little attention had been given to the problems associated with the maintenance and rehabilitation of older structures on the secondary highways and local road systems. However, the rehabilitation of bridges which are deficient from either a structural or a functional point of view is an essential alternative to total replacement. Also, because of the lack of attention previously given to rehabilitation and repairs, local agencies responsible for inspection, maintenance, and repair are currently required to make decisions without benefit of very much supporting information. If judgments are to be made, and it is likely that this is the path that will be followed, it is essential that guidelines be provided for specific rehabilitation procedures for certain types of deficiencies.

Thus, under the conditions described above, there is a clear and immediate need for research that will identify the needs of bridge rehabilitation and replacement on rural and secondary roads and that will provide guidelines and methodologies to enable local engineers to reach rational, cost-effective decisions regarding rehabilitation and replacement. Such research should address the need for economical and feasible rehabilitation and replacement procedures so that inadequate bridge structures can be rendered fully serviceable and safe.

RESEARCH OBJECTIVES

The overall goal of this research investigation was to identify and develop procedures for the repair or replacement of bridges on secondary highways and local roads.

To attain such a broad objective, it was necessary to address a number of more specific goals. For example, it was necessary to identify the types of deficiencies experienced by rural bridges, and to identify corresponding repair procedures and evaluate their cost and effectiveness. In many instances, the deterioration of a bridge is so severe as to preclude any rehabilitative approach other than replacement. In this event, the replacement operation can be made efficient and economical if proper consideration is given to standard types of construction techniques and modular elements for the bridge.

It is desirable that the repair and replacement procedures developed be both cost-effective and feasible, and that some type of simple selection process be devised to enable engineers to select, from several alternatives including replacement, the best procedure for a specific job.

In summary, the overall objective of this program was achieved by a plan of attack that addressed the following specific objectives:

- Identify common structural and functional bridge deficiencies.
- Categorize these deficiencies with regard to their seriousness and frequency of occurrence.
- Identify existing repair and replacement procedures.
- Evaluate these procedures with regard to their effectiveness and cost.
- Relate the deficiencies and remedies to specific bridge types.
- Synthesize state-of-the-art technology in the use of standardized modular components and construction concepts.
- Develop a simple procedure for the cost-effective selection between alternative strategies for repair.
- Document the significant results of this study in a Manual of Recommended Practice.

The end product is directed toward the primary user; namely, the engineer directly concerned with the repair or replacement of older bridges on local
roads. The results of this project should become of considerably greater value to engineers responsible for secondary highway bridges because of passage of the 1978 Surface Transportation Act, which provides federal funds for repair and replacement of off-system bridges.

SCOPE

The problem of repairing various components of highway bridges and of constructing new bridges as replacements for those deteriorated beyond repair is not a new one. Studies relating to this problem have been under way for a number of years. Thus, in undertaking the study of procedures for the rehabilitation and replacement of bridges on secondary highways and local roads, it was particularly desirable that the study be structured to make maximum use of previous related work and to avoid unnecessary and costly duplication. Accordingly, the investigation carried out under this project was subject to certain specific limitations and a very well-defined focus.

The study was directed exclusively at bridges on secondary highways and local roads. Thus, in identifying deficiencies, developing repair procedures, and developing replacement concepts, such techniques and procedures were restricted to those that could be realistically applied by local agencies to those types of bridges occurring on highways under their cognizance. For example, no effort was directed toward identifying and correcting deficiencies that occur on long span bridges carrying large volumes of traffic. Further, in developing procedures for choosing between various alternatives in a cost-effective manner, it was kept in mind that these procedures would be utilized by local engineers who generally would not have access to sophisticated computers and software that might otherwise be utilized in such a selection process.

Initial efforts in this investigation were concerned with a review of previous work related to bridge repair, rehabilitation, and replacement. Of particular interest was a recent study sponsored by the FHWA and entitled "Extending the Service Life of Existing Bridges by Increasing Their Load Carrying Capacity". Although both studies had basically the same overall objective, the FHWA study was directed toward bridges on primary highways (and thus newer bridges), whereas the current investigation was directed toward bridges on secondary and rural roads, primarily off-system bridges that were likely older and in worse condition. A major effort in the FHWA study was visiting various states, inspecting a large number of bridges, and cataloging and identifying deficiencies. Accordingly, emphasis in this investigation was modified to reflect the results of the FHWA work.

The FHWA study was primarily concerned with increasing the load carrying capacity of bridges whose capacity was not adequate for current service loads. Accordingly, this project was largely limited to repair and rehabilitation procedures directed specifically toward returning the deteriorated bridge to its original state, wherever the capacity might have been. This limitation was not a real restriction because conversations with local bridge engineers indicated that their bridge repair efforts rarely involved increasing the load carrying capacity. A few retrofitting procedures are included which can be used for upgrading underdesigned structures as well as for increasing the capacity of a deteriorated structure. Examples are procedures R1, R2, R4, and R5.

A number of other studies sponsored by the FHWA or NCHRP have been concerned with bridge repairs. Recent projects have been concerned with repair techniques for accidentally damaged steel bridge members (3), or the repair of fatigue damage in steel bridge members (4-5), bridge railings (6), and deficiencies and repairs associated with bridge decks (7,8,9). Accordingly, these areas were largely omitted from consideration. Exceptions are repair procedures R1 and R4. The principal areas excluded from this study are discussed in Chapter Three where related work is described.

A number of findings were a direct result of a questionnaire distributed to the 50 state highway departments and of site visits to state and local officials in 10 states. Certain limitations are inherent in these survey procedures; the questionnaire necessarily could not include all information that would be desired or useful, and time and funding restricted the visits to only 10 states. During the visits, a major portion of the time was spent talking to bridge engineers in the state highway departments and only limited discussions were held with county engineers. Accordingly, a number of the results of this study, including deficiencies identified and repair procedures selected, were to a large extent the result of information gained from states rather than local jurisdictions.

As a final part of this section, it is desirable to establish some basic definitions of terms related to the repair of bridges which will be adhered to throughout. These definitions are not suggested as the best or only meanings for the terms listed, but rather represent the opinions of the investigators, and they provide the meanings of the terms as they are used in this report.

The definitions are as follows:
1. Maintenance — The work required to continue a bridge in its present condition and to control future deterioration.
2. Repair — Action taken to correct damage or deterioration on a structure or element to return the structure to its original capacity.
3. Upgrade — To raise a structure's capacity to a level above that of the original design.
4. Retrofit — To add a new element to an existing structure to correct or prevent distress or to upgrade.
5. Rehabilitation — To carry out an extensive repair procedure.
6. Restore — To return a structure or element to its original condition (often used in connection with historical structures).
7. Replacement — To install a new structure at the site of a previously existing structure.

BACKGROUND

On December 15, 1967, the Silver Bridge over the Ohio River at Point Pleasant, West Virginia, collapsed, plunging 24 cars into the Ohio River and 7 on the Ohio shore, causing the death of 46 people. This catastrophe precipitated a sudden awareness in both the public and the Congress of the potential danger of unsafe bridges on the nation's highways and the seriousness of the deficiencies in these bridges. This tragedy proved to be the catalyst that produced a concerted effort by federal and state agencies to identify and repair highway bridges with serious deficiencies.

The initial program arising from these efforts began when Congress
added a section to the Federal-Aid Highway Act of 1968 that required the Secretary of Transportation to establish national bridge inspection standards and to develop a program to train inspectors. This addendum to the 1968 Highway Act was naturally directed only to bridges on the federal-aid system of highways. The reasons for this restriction were reasonable and obvious at the time. Federal-aid system highways, particularly the Interstate roads, were the most heavily travelled and the most visible, and deficient bridges on this system naturally were assigned first priority for repair and replacement. Further, data regarding these bridges, such as number and condition, could be easily obtained from state highway departments.

The PHWA's "Sixth Annual Report to Congress on the Special Bridge Replacement Program" showed a total of 262,000 bridges on the federal-aid system. Of these, a total of 40,700 were classified as deficient, i.e., either structurally deficient or functionally obsolete. The data provided by the FHWA are developed from the inventory of bridges on the federal-aid system tabulated by each state as required by the 1978 Highway Act. The serious condition of the highway bridges in the United States may be attributed to a number of very valid reasons. These include the following:

1. Over 75% of the bridges were designed and built prior to 1935.
2. Present allowable vehicle loads are far in excess of those considered in the design of these early bridges.
3. There has been a natural deterioration from weather and old age.
4. There have been insufficient funds for proper maintenance and, with available funds, maintenance is frequently given low priority.
5. There has been no regular inspection and rating program.

Although the addendum to the Highway Act of 1968 did such to focus attention on bridges on the federal-aid system and resulted in a detailed inspection system and an awareness of the needs for repair and replacement, those bridges not on the federal-aid system (or off-system bridges) continued to be ignored, at least at a national level. Again, the reasons for this neglect seemed logical. The majority of off-system bridges were typically on secondary and rural roads and thus had lower traffic volume and lower visibility than did the on-system bridges. In addition, most of these off-system rural and secondary bridges were the responsibility of a variety of local agencies and obtaining information on these bridges was difficult at best.

Because off-system bridges were not covered by the Highway Act of 1968, there were few available data concerning the number and condition of these bridges until very recently. However, in 1978 the National Association of Counties (NACo) conducted a survey of all counties in 38 states in which counties have primary responsibility for local highways and bridges. This survey requested data on off-system bridges 20 ft (6.1 m) or longer that were under direct county supervision. Although the number of responses from the counties was modest, several statistical approaches to the data indicated a total of 233,800 off-system bridges under county jurisdiction, of which 71,900 are structurally deficient and 89,900 are functionally obsolete.

The impressive statistics briefly cited in the foregoing were brought to the attention of the 95th Congress by the FHWA, the NACo, and many concerned local governments. This Congress was influenced to hold its own investigation and extensive hearings on this serious nationwide situation. The result was new legislation that included the Highway Bridge Replacement and Rehabilitation Program of the Surface Transportation Assistance Act of 1978, signed into law by the President on November 6, 1978. This legislation has been hailed as introducing a new era in surface transportation.

The Highway Replacement and Rehabilitation Program includes the following features:

1. A total of $6.2 billion are to be spent in the next four fiscal years: $0.9 billion for FY 1979, $1.1 billion for FY 1980, $1.3 billion for FY 1981, and $0.9 billion for FY 1982.
2. The federal-state matching ratio for bridge funding has been increased from 75/25 to 80/20.
3. No state can receive more than 80% of the total and no state can receive less than 0.75% of the total.
4. Each state is required to use not less than 5% and not more than 15% for off-system bridges.
5. To expedite the availability of the bridge funds, the FY 1979 bridge money comes out of the Highway Trust Fund and is available for obligation immediately.
6. Allowance for funds for rehabilitation of highway bridges as well as bridge replacement.

There are several requirements that local governments must meet in order to qualify for these funds. The principal requirements include (a) an inventory and classification of all off-system bridges on the basis of serviceability, safety, and essentiality for public use prior to December 31, 1980, and (b) a priority ranking system to determine which bridges should be repaired or replaced first. However, the FHWA recognizes the intent of Congress that the off-system program should get moving quickly and has developed an arrangement by which federal funding can be provided immediately for a bridge that is plainly unsafe without waiting for the complete inventory.
limited results and little effort beyond the questionnaire was devoted to
this phase of Task 1. The limited amount of information obtained on
pursued at the beginning of this investigation, was found to produce only
and/or in terms of their relative frequency of occurrence.
An initial list of deficiencies was established based on
to effectively accomplish this task, the following steps were under-
taken.
1. An initial list of deficiencies was established based on
experience and knowledge within the research team and through
conversations with bridge engineers in the Virginia Depart-
ment of Highways and Transportation.
2. An initial ranking of these deficiencies was established in
terms of a subjective decision on their relative importance.
3. A questionnaire was prepared and distributed to all state
highway departments and to certain local agencies requesting
additional information on bridge deficiencies and their
relative degrees of importance.
4. Based on the initial tabulation, results of the questionnaire,
and information obtained through subsequent visits to selected
highway departments and county agencies, the final tabulation
of common bridge deficiencies by categories was established.
The identification and categorization of bridge failures, although
pursued at the beginning of this investigation, was found to produce only
limited results and little effort beyond the questionnaire was devoted to
this phase of Task 1. The limited amount of information obtained on
bridge failures is presented in Chapter Four.
Task 2: Identification and Evaluation of Concepts for Economical Re-
placement Systems
The primary components of this task were to identify and cate-
corresponding repair and rehabilitation techniques. Efforts included the identification of one or
more feasible repair procedures appropriate for application to each cate-
gory of deficiency.
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Task 3: The Development of a Methodology for Selecting Among Alternative
Strategies
The goal of this task was to develop a simplified but rational pro-
cure to assist local engineers in making cost-effective selections be-
tween alternative repair and replacement procedures and between the basic
alternative of repair or replace.
A list of factors to be used in evaluating various alternatives was
complied and a procedure for weighting these factors as a means of ranking
alternatives is described in Chapter Five of this report.
Task 4: Preparation of Final Report and a Manual of Recommended Practice
The final task was the preparation of this Manual of Recommended
Practice including this Appendix describing the research performed.
The Manual is organized in a format for use by local engineers. This
user oriented Manual provides a practical guide for engineers facing
the responsibility of rehabilitating or replacing bridges on secondary
highways.
highways and local roads. It emphasizes the most practical repair techniques and replacement systems, which are briefly described, with drawings as required.

**Questionnaire Development and Utilization**

A major portion of the efforts of Tasks 1, 2, and 3 was expended in the collection and synthesis of information relating to deficiencies, repair procedures, and replacement systems. To ensure that representative information was obtained, it was decided to develop and distribute a questionnaire to all states and selected local jurisdictions to solicit information relating to bridge deficiencies and repairs.

The initial draft of the questionnaire was prepared by the research team and submitted to the Virginia Department of Highways and Transportation and the NCHRP Project Panel C12-20 for comment. As a result of suggestions and recommendations made during this review process, a final questionnaire was developed which specifically requested information regarding record keeping related to bridges, bridge inventories, bridge repairs, and the quantity and frequency for particular types of deficiencies. Formal replies to the questionnaire were received from all 50 states, and a summary of the results of the questionnaire is provided in Chapter Four of this report. A copy of the final questionnaire as distributed is attached. (See pages A-81 through A-88.)

**Site Visits**

Although the returns from the questionnaire provided a considerable amount of information, it was felt essential to make visits to representative states to talk directly with state and county bridge engineers and to conduct on-site inspections of bridge deficiencies, bridge repairs, and recently constructed replacements.

Based on the experience of the research team, as well as that of bridge engineers within the Virginia Department of Highways and Transportation and the FHWA, a preliminary list of states having a reputation for innovative repair work was prepared. This list of states was refined to ensure that a reasonable geographical distribution would be obtained. It was also desired to visit some states who have responsibility for all rural bridges as well as those on primary highways and some states that have well-organized county bridge departments. Further refinement of the list of states to be visited was sought from the advisory panel, and the final list consisted of 10 states, including Virginia. Table 1 presents a summary of the organizations and personnel visited, other than the Virginia Department of Highways and Transportation and FHWA offices in Washington, D.C. and Langley, Virginia.

Three county engineers contacted during the visit to Washington are also included in Table 1. Visits to various sites within the state of Virginia and discussions with bridge engineers in Virginia were also made periodically throughout the study. Discussions with bridge department personnel from the state of Missouri were conducted at the TRB Bridge Engineering Conference held in St. Louis in September 1978. Specific visits were made to the bridge departments of the other states.

It was found that the most effective and efficient use of time during the visits was to meet briefly with various bridge engineers in their offices to discuss the organization of bridge maintenance and repair within the state and county jurisdictions and to review specific plans and procedures. The remaining time was spent on brief site visits to bridges to obtain firsthand knowledge of the repair and replacement techniques used.

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td><strong>Visits to State and Local Transportation Officials</strong></td>
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<tr>
<td><strong>Organization Visited</strong></td>
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<tr>
<td>1. Colorado Department of Highways</td>
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<td>2. Florida Department of Transportation</td>
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<td>4. Illinois Department of Transportation</td>
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<tr>
<td>5. Massachusetts Department of Public Works</td>
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<tr>
<td>10. Washington County Road Administration Board</td>
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</table>

During the visits it became apparent that most of the problems and deficiencies that had been identified were common to a majority of the states and that the repair procedures were generally similar. In addition, it became clear that few states have any kind of standard model for deciding between alternate repairs or between repair and replacement in a given situation. It is doubtful that visits to states beyond the ten initially chosen would have yielded much new information.

Nevertheless, the visits and site inspections by the research team were a significant ingredient in the research program. These personal contacts provided detailed information on bridge repair procedures across the country and, in the case of the visit to the Washington County Road Administration Board, an insight into the problems and needs of county engineers.
CHAPTER THREE

RELATED WORK

As was noted in Chapter One, extensive research relating to the repair and rehabilitation of highway bridges has been conducted by other investigators. Much of this work accomplished to date has been sponsored either by the FHA or by AASHTO through the NCHRP. The purpose of this chapter is to briefly review some of these major national studies to the extent necessary to give completeness to this report.

REPAIR OF FATIGUE DAMAGE

The major effort in the study of fatigue damage in highway bridges, which was carried out at Lehigh University under the direction of Dr. John W. Fisher, was directed toward designing against fatigue damage, limiting damage once fatigue cracks develop, and repairing extensive fatigue damage. The most recent portions of this work were sponsored under NCHRP Project 13-15. Under Phase 1, the principal objectives were to review existing methods of nondestructive inspection for fatigue, to review and evaluate existing welded bridge details with regard to their susceptibility to fatigue, and to review and evaluate methods for improving fatigue life and arresting the progress of fatigue damage in welded highway bridges.

Phase 2 of the project included three tasks. Task 1 consisted of inspecting and retrofitting a highway bridge which had sustained fatigue damage. In Task 2, 15 full-scale cover-plated bridge beams were tested to determine their fatigue strength and to assess the merits of retrofitting fatigue-damaged details by various techniques. Task 3 was to define the behavior of web gaps at the end of transverse stiffeners when subjected to out-of-plane displacements.

In Phase 1, the evaluation of methods for improving fatigue life and arresting the progress of fatigue damage was conducted using three procedures that appeared, based on experience, to be the most likely to be successful. These included (1) grinding the weld toe to reduce the stress concentration, (2) air hammer peening the weld toe to introduce compressive residual stresses, and (3) remelting the weld toe using the gas tungsten arc process.

The three repair improvement procedures were found to be effective to varying degrees in extending the fatigue life of cover-plated beams. In general, grinding was not very effective since it resulted in the removal of only those discontinuities near the surface. Peening was more effective than grinding and can be applied with good results to both uncracked welded details and details with surface cracks having depths up to about 1/8 in. (3 mm). The remelt method was the most effective of the three and showed the least amount of minimum-stress-dependency.

Crack initiation in repaired beams generally resulted from defects introduced by the repair method itself. Some increase in fatigue life was usually experienced, and additional increases in fatigue life could be obtained when the repairs were made with great care.

Weld details subject to cyclic loads can be repaired or improved providing the cracks have not penetrated more than about 1/8 in. (3 mm) into the flange. Retrofitting such details by either peening or the remelt procedure will provide a detail that equals or exceeds the original condition. For deeper fatigue cracks, repair can be accomplished most effectively by the application of bolted splice plates which transfer the stress around the crack.

The results from Phase 2 of this same study may be summarized as follows. The two repair or retrofitting methods (peening and the remelt process) were again found to be effective in extending the fatigue life of cover-plated beams. Fatigue-damaged bridge details which have cracks at the end of the stiffener or along the web-flange fillet weld resulting from out-of-plane displacements can be satisfactorily retrofitted by drilling holes at the ends of the fatigue cracks. It was also found that in those cases where structural members intersect such that the flange of one pierces the web of the other the fatigue resistance was so low that the bridge structures with this detail eventually experienced fatigue cracks.

It was recommended that consideration be given to retrofitting these and any similar details as soon as possible.

REPAIR TECHNIQUES FOR DAMAGED BRIDGE MEMBERS

A major thrust of this effort was performed under NCHRP project 12-17 by the Columbus Laboratories of the Battelle Memorial Institute. The objective was to provide guidance for the assessment of accidental damage to steel bridge members and to identify and develop a variety of repair techniques and evaluate their effectiveness. Information relating to specific types of collision damage and the remedies employed by various states was obtained from questionnaires distributed and through visits to representative state highway departments.

Also, according to the responses, no state has written procedures or specifications that relate to decisions regarding the method of repair or whether the damaged member should be repaired, replaced or left as is. This is consistent with the findings regarding the decision-making processes for general repair and rehabilitation procedures. There are, in some cases, procedures designated by the state for the repair of the specific damaged bridge. In all the states, the decisions regarding repair are made by people in the office of the bridge engineer. The decisions are based on various combinations of (1) experience, (2) technical or analytical analyses, (3) the cost-effectiveness of repair vs. replacement (a subjective determination), (4) the lengths of time required for the procedures being considered, and (5) the degree to which traffic must be interrupted.

With regard to flame straightening as a procedure for repairing collision damaged members, four states were found to have conducted some type of analytical or experimental studies that could support decision making. However, none of the states had results that were available for the survey conducted under the project.

Four processes were found to be most commonly used for repairing collision damage. These were welding, cold mechanical straightening, hot mechanical straightening, and flame straightening. It was also found that decisions on the need for repair, the selection of a particular process to be used, and the details of the process used were based almost entirely on the experience of the people responsible for repairing the damage. There were no guidelines or specifications for these decisions in any of the states surveyed.

Based on the data collected through these surveys and visits, it was determined, during the past 5 years, that the total number of bridges damaged was 815 and that 767 of these were repaired. Those damaged and not repaired were either replaced or left in service in their damaged state.

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states. Damage had been inflicted primarily by vehicles carrying loads in excess of the bridge clearance heights. Some damage also had been inflicted by vehicles that were overweight, overwidth, or out of control, but the incidence of damage by these vehicles was relatively small. In all of the state responses, almost 70% of the instances of collision damage were reported to have involved vehicles that exceeded the height clearance. The instances were almost evenly divided between girder and truss bridges.

Welding repair was used by nearly all of the states responding. There were two categories of welding repair: (1) welding discrete defects such as cracks and (2) cutting out and replacing portions of damaged bridge members. In replacing members, flame cutting was the conventional method for preparing the weld joint.

Two-thirds of the states surveyed used mechanical straightening for repairs. Several states have certain limitations on the use of this procedure such as restricting its use to members with only gradual bends. Mechanical straightening was reported to be done either cold or hot, although most of the respondents indicated that the former was preferred.

The use of flame straightening was widespread throughout the country. This process was used to some degree by the majority of states and by most contractors retained by the states to conduct repairs. The heating is always done with gas torches. Very little information was available on specifications or procedures for flame straightening, although most states indicated that they had some general procedure applicable to a certain repair concept. Over half of the states that used flame straightening had established maximum limits on the temperature to which the steel could be heated.

Additional details concerning the repair of damaged members may be found in the bibliography on repair procedures in the Manual.

**INCREASING THE LOAD CARRYING CAPACITY OF EXISTING BRIDGES**

A recent study supported by the FHWA and titled "Extending the Service Life of Existing Bridges by Increasing Their Load-Carrying Capacity" was conducted by Byrd, Tallamy, McDonald, and Lewis under contract No. DOT-FH-11-9214. The study was initiated in 1977 and the final report was issued in June 1978. Among the objectives of the study, which very closely paralleled those of the present investigation, were to identify and evaluate the effectiveness of existing rehabilitation techniques and to develop new techniques for making bridge repairs, improving geometrics, increasing load carrying capacity, and correcting mechanical and other minor deficiencies. Additional objectives included defining and cataloging common bridge deficiencies and types of structures.

The objectives were accomplished using a three-phase plan. Phase 1 included a field inspection of representative deficient bridges to develop the catalog of bridge types and bridge deficiencies. Phase 2 consisted of a review of selected rehabilitative procedures in use by state bridge departments and a literature search to assemble a comprehensive data file on bridge rehabilitation techniques. Finally, Phase 3 consisted of a demonstration of the techniques judged to be most effective by developing specific plans for rehabilitating five selected structures.

In considering bridge deficiencies, it was concluded that the most important contributor was the level of maintenance employed. Based on the data collected from the states, the causes of deficiencies were categorized into two broad areas; namely, those which result from the design of the facility — i.e., inherent deficiencies — and those which result from the use of the facility — i.e., the result of wear or age. A catalog of bridge deficiencies was developed which included the delineation of specific deficiencies categorized under the major headings of superstructure and substructure and further subdivided under each of these as primary support system or deck system, and, finally, subdivided as to type of material, i.e., steel, concrete, or timber. Typical deficiencies listed included such items as paint deterioration, inoperable bearings, corrosion, collision damage, spalling, and delamination.

With regard to rehabilitation techniques, the study utilized data from a literature search and from manufacturers, trade associations, and transportation agencies. A listing of the rehabilitation techniques submitted by the states is provided in the appendix to the report. A review of the rehabilitation procedures indicated that the major concepts intended to extend the service life of defective bridges could be classified according to the following: (1) to increase the live load capacity to a level greater than the original design level, (2) to improve geometrics, and (3) to correct mechanical deficiencies.

The study identified and developed two concepts to be used in arriving at decisions as to how a bridge should be rehabilitated. These concepts were the "improvement factor" and "cost-effectiveness factor". The improvement factor is defined as the percentage of improvement in live load capacity to a level greater than the original design level. The cost-effectiveness factor was determined by dividing the improvement factor by the estimated unit cost. Thus, the higher the value of this factor, the greater the cost-effectiveness for a given technique.

Major contributions from the study were details, plans and specifications to demonstrate rehabilitation techniques on a concrete T-beam simple span, two steel multiple-beam simple spans, a timber multiple-beam simple span, and a steel through-truss simple span.

The recommendations for additional research included the following, which have some bearing on the current investigation: (1) develop new techniques for strengthening deficient bridges, (2) develop parameters for prioritizing bridge repairs, and (3) establish guidelines and procedures for deciding between rehabilitation and replacement. These particular areas were directly addressed in the present investigation.

**BRIDGE DECK REPAIRS**

The spalling of concrete bridge decks, caused primarily by corrosion of the top mat of reinforcing steel, has emerged as a major problem over much of the United States in recent years. Accordingly, various state agencies, the FHWA, and the NCHRP have focused on factors affecting the incidence of spalling, the proper repair of the distress, and preventative measures. This intensive research effort has produced a relatively sophisticated series of procedures encompassing the determination of the extent of necessary repair, selection of the proper repair methods and materials, and the elimination of further corrosion and resultant spalling. While there is some variation in the procedures used, there is a general consensus that has resulted in a reasonably consistent set
of guidelines.

Most experienced field engineers can recall having seen spalling adjacent to earlier patches, and it is generally agreed that the situation results from a failure to remove enough chloride contaminated concrete during the original repairs. Replacement of only the loosened concrete is seldom sufficient, and guidelines for determining the extent of repairs have been published by the FHWA. Generally, three factors, discussed below, are evaluated.

1. The extent of the delaminated, or loosened, deck surface is determined by sounding the deck with a hammer or chain drag. These areas would, of course, be replaced.

2. The extent of active corrosion of the reinforcing steel is determined by measuring the half-cell potentials relative to a copper-copper sulfate-reference electrode, a measure of galvanic corrosion, as points on the bridge deck. The equipment required to perform this test is available at a reasonable price. Since the areas of active corrosion and the delaminated areas located in item 1 above are not necessarily coincident, both surveys are required.

3. The final factor is the determination of the chloride content of the delaminated concrete around the spalled areas. If chloride contaminated concrete remains after repairs, corrosion of the reinforcing mat with subsequent spalling can continue. A laboratory procedure for the determination of the chloride content of powdered concrete samples obtained by drilling the deck to the level of the steel has been established.

A general overview of the bridge deck problem and its solutions is also provided by NCHRP Synthesis of Highway Practice 57. Included are an assessment of the extent of the problem, and descriptions of techniques for evaluating the condition of decks and repair and construction techniques and materials. While reference to source reports will be required to apply the procedures, the comprehensive scope of the synthesis and its complete list of references make it a useful document for the bridge engineer.

The effects of available techniques and materials used in deck repairs were studied in NCHRP Project 12-16 "Influence of Bridge Deck Repairs on the Corrosion of Reinforcing Steel" by the Battelle-Columbus Laboratories. Only a brief acquaintance with secondary highway and local road bridges is required to demonstrate the ineffectiveness of the barrier railings on many of these structures. With few exceptions, rail designs were not considered in the current study because several significant efforts had been funded by the FHWA and NCHRP. It was also recognized that these efforts were not directed to the means of obtaining data, such as information on the properties of materials and members required for analysis, and description of analytical procedures, including available computer programs. While the application of the broadly described methods to any of the wide variety of individual trusses will require additional engineering, experienced engineers on the task committee have stressed a practical and workable approach in their report.
CHAPTER FOUR
FINDINGS — STATUS OF BRIDGES

The development of the Manual of Recommended Practice for this project required the documentation of information on the types and condition of bridges on secondary highways and local roads, and the way in which they were being affected. This was accomplished through the use of the questionnaire on pages A-81 through A-88, and by personal contacts with selected engineers in state and local governments as described in the earlier chapter.

The questionnaire responses received from the 50 state transportation agencies are discussed in this chapter. While some of the responses were incomplete, the data are believed to represent the status of secondary road bridges. Establishing contact with county engineers is difficult and the number of local agencies overwhelming. Thus, most of the information obtained from the county and local engineers was through personal contact. Some of the county engineers interviewed felt that the questionnaire reflected the situation of state rather than local agencies because of the advanced degree of deterioration of local road bridges. While there is definitely a greater need for the rehabilitation of local bridges, the problems faced by the state and local agencies differ primarily in degree rather than in nature. It is believed that the Manual of Recommended Practice will be useful in varying degrees to agencies throughout the transportation field.

TYPES AND CLASSIFICATION OF BRIDGES

Question 8 of the questionnaire requested a list of the type of structures on secondary road systems in order of frequency of occurrence and the number of bridges of each type, if that figure was available. Although very few states provided numerical data, the estimates of frequency of occurrence by 47 states are summarized in Table 2.

The high number of citations among the first four superstructure categories probably reflects the large number of short span structures, although the steel beam category can include a large range of span lengths. There are still a significant number of steel trusses in the secondary highway systems in spite of the fact that these bridges are often programmed for replacement as rapidly as funding permits because of their limited horizontal and vertical clearances. Replacement of steel trusses assumes a greater importance when the incidence of failure, discussed later, is considered.

As would be expected, recently developed components such as prestressed concrete beams and box beams are relatively rare on low class highway systems. Other portions of the questionnaire indicated few problems with designs utilizing these components.

Table 2 does not include all of the bridge types mentioned in the survey, but only those most frequently noted. The other types mentioned included stone, brick and masonry arches; timber, iron and concrete trusses; steel arch, frame, suspension and movable bridges; and concrete rigid frames. Some of the prized wooden covered bridges were mentioned, while others were probably omitted as atypical structures or included in the general timber category.

<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>Number of Times Ranked</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Steel Beam</td>
<td>18</td>
<td>46</td>
</tr>
<tr>
<td>2. Timber Beam</td>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td>3. Concrete Beam</td>
<td>5</td>
<td>34</td>
</tr>
<tr>
<td>4. Concrete Slab</td>
<td>7</td>
<td>33</td>
</tr>
<tr>
<td>5. Steel Truss</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>6. Prestressed Concrete</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>7. Concrete Arch</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>8. Box Beam</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>47</strong></td>
<td><strong>187</strong></td>
</tr>
</tbody>
</table>

NOTE: The above rankings do not reflect the total number of bridges of each type throughout the country, but are the rankings of the most common types of bridges by the responding states, regardless of the number of bridges under their purview.

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NATURE AND FREQUENCY OF DEFICIENCIES EXPERIENCED

Table 2 presents structural deficiencies of bridge superstructures. Table 4 contains ratings of functional deficiencies, and Table 5 concerns deficiencies of substructure elements regardless of the type of superstructure. The right-hand column indicates the number of states that had developed a repair procedure for the listed deficiency. On the normalized scale, a rating of 6.7 indicates a "moderately severe" condition, or one that is, at least, "occasionally observed". Since the ratings represent the average of values given by
Table 3
Severity and Frequency of Occurrence of Structural Deficiencies

<table>
<thead>
<tr>
<th>NATURE OF DEFICIENCY</th>
<th>SUPERSTRUCTURE ELEMENTS</th>
<th>TYPE OF SPAN</th>
<th>No. Repair Procedures Offered by States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural</td>
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<td></td>
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</tr>
<tr>
<td>1) Original Design Inadequate for Present Loads</td>
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<td></td>
</tr>
<tr>
<td>a) Main Members or Truss</td>
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<tr>
<td>b) Deck</td>
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<td></td>
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<tr>
<td>c) Joints or Other Details</td>
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<tr>
<td>2) Fatigue Cracking</td>
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<tr>
<td>3) Deck Spalling (Corrosion Induced)</td>
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<tr>
<td>4) Spalling of Deck at Joints (Stress Induced)</td>
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<tr>
<td>5) Structural Cracking of Deck</td>
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<tr>
<td>6) Cracking in Concrete Beams</td>
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<tr>
<td>7) Spalling of Concrete Beams</td>
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<tr>
<td>8) Loss of section Due to Corrosion</td>
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<td></td>
<td></td>
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<tr>
<td>9) Deterioration of Timber Deck or Beams</td>
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<td></td>
<td></td>
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<tr>
<td>10) Inoperative Bearings</td>
<td></td>
<td></td>
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<tr>
<td>11) Inoperative Expansion Joints, Include Leaking</td>
<td></td>
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<tr>
<td>12) Deteriorated Rails or Barriers</td>
<td></td>
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<tr>
<td>13) Dislocation or &quot;Creep&quot;, of Spans Under Traffic</td>
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<tr>
<td>14) Inadequate Deck Drainage</td>
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<tr>
<td>15) Collision Damage</td>
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</tbody>
</table>

*According to FHWA terminology, a structure whose load carrying capacity can no longer safely service the system of which it is a part is classified as functionally obsolescent. For purposes of this study, structural deficiencies are separated from geometric type deficiencies.
### Table 4
Severity and Frequency of Occurrence of Functional Deficiencies

<table>
<thead>
<tr>
<th>Nature of Deficiency</th>
<th>Type of Bridge</th>
<th>No. Repair Procedures Offered By States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel Beam</td>
<td>Steel Truss</td>
</tr>
<tr>
<td>17) Narrow Highway</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>18) Undue Ball Configurati on or Weak Design</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>19) Undue Approach Alignment</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>20) Exposed Rail Terminals</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>21) Trape Zebra Crossing to Impact</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>22) Slippery Deck Substructure</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>23) Inadequate Vertical Clearance (on Bridge)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24) Inadequate Underclearances</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 5
Severity and Frequency of Occurrence of Deficiencies of Substructure Elements

<table>
<thead>
<tr>
<th>Nature of Deficiency</th>
<th>Severity</th>
<th>Frequency</th>
<th>No. Repair Procedures Offered</th>
</tr>
</thead>
<tbody>
<tr>
<td>28) Original design of piers and other elements presently inadequate.</td>
<td>5</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>29) Deterioration, due to salt exposure, of piers, bents, or piles.</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>30) Spalling of beam seats.</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>31) Shoving of abutments or cracking of backwalls.</td>
<td>6</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>32) Settlement of substructure elements.</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>33) Lateral Movement of Substructure Elements.</td>
<td>5</td>
<td>9</td>
<td>-</td>
</tr>
</tbody>
</table>
those states that responded to Part II of the questionnaire, values of 6 and above may be regarded as significant in either severity or frequency.

**Structural Deficiencies**

Inadequate strength of the main structural members due to a light original design was identified as a frequent and severe problem. Structural deficiency was only an occasional problem in the case of cast-in-place concrete superstructures, which usually exhibit significant reserves of strength, and there were no problems indicated with the newer prestressed concrete superstructures.

Limitations in carrying capacity due to the strength of the deck, item 11(b), was a more severe problem in the timber and steel truss categories than for the other types, due in large measure to deterioration. The responses to item 9 would seem to confirm that deterioration may be more of a problem than inadequate strength.

Structural cracking and spalling of superstructures were cited as only minor to moderate problems in the overall survey. Fatigue cracking, while a subject of national concern in major highway bridges, does not appear to be a serious problem in secondary road structures. Corrosion-induced bridge deck distress, which was not covered in the study, is more severe and a more frequent problem.

Corrosion of superstructure elements, reflected in the related items 8, 10 and 11, constitutes a significant problem on steel beam and steel truss bridges. Corrosion of beams and bearings is usually a result of poor handling of the deck drainage and of leaking expansion joints. The latter factor is generally rated highly regardless of the type of superstructure.

Deterioration of guardrails was rated a significant problem on perhaps all but the newer bridges, and, under functional deficiencies, unsafe rail configurations were rated similarly. As discussed in Chapter Three, attention has been directed toward this hazardous situation through other, ongoing studies.

Collision damage to steel beam and concrete T-beam bridges emerges as a frequent problem, as indicated by both the ratings and the number of repair procedures available. This problem has also received extensive attention elsewhere, as noted in Chapter Three. The remaining items shown under structural deficiencies are relatively minor problems, nationally.

**Functional Deficiencies**

Functional deficiencies related to the geometrics of the structures, reflected in responses to items 17-11, are seen as the greatest challenges facing engineers involved with secondary road bridges. The difficulties associated with steel truss bridges are particularly significant, especially in terms of limitations on roadway clearances posed by the structures themselves. The problems of narrow roadway and exposure of the truss members to impact are rated the most serious of any on the questionnaire, while inadequate vertical clearance is a significant though less severe deficiency.

Unsafe alignment of the approach roadway was considered a significant problem but, with a scope that extends beyond the repair of the bridge itself, it is one that is difficult to handle. Right-of-way acquisition and changes in road geometrics away from the structure can present extraordinary problems.

Functional obsolescence appears to be much less of a problem in the case of prestressed concrete superstructures because these are among the newest bridges on secondary highways. The most serious problems lie in areas such as deck spalling, poor performance of the expansion joints, and unsafe rail terminals, none of which are directly related to the type of structural member.

**Deficiencies of Superstructure Elements**

The distress of superstructure elements is not related to the type of superstructure in most instances, nor is it unique to bridges on the low class highways. The most common reported deficiency associated with substructure elements was chipping of the abutments or cracking of the backwall. Distress of this sort has been noted for years on all classes of highways.

The strength of piers and other substructure elements appears to be generally adequate. However, the deterioration of these structures is a common problem. Spalling of the upper concrete surfaces due to exposure to deck drainage and of piles and columns near the waterlines is widespread. Settlement of the substructure elements, while less common, is also a problem.

**Frequency and Causes of Failures**

Question 13 was an attempt to obtain data on the number of bridge failures experienced on secondary roads including information on the type of structures involved and the causes. It was recognized from the outset that only a rough estimate could be provided, but it was felt that the information would be useful to bridge engineers.

The estimates of the number of failures varied widely between states, as shown in Table 6. Including those structures damaged to such an extent as to be unusable, the number of failures was estimated to be 588 over the last 5 years by the respondents to the questionnaire. It is likely that this number is low as it does not include data from many local agencies that keep their own records or from 9 states that did not have the information available.

Table 7 shows the number of times that responding agencies ranked each type of structure either first, second, or third in terms of frequency of failure. The steel truss was considered by the responding agencies to be the structure most prone to failure, followed by the timber bridge. These two types of structures were judged to be the most critical in terms of the adequacy of the original design to carry present loads (see Table 3). In addition, the truss is particularly prone to failure under impact. Field visits showed these two types of structures generally to be in poor condition.

Only the most general information was provided on the causes of failures. One state estimated that 80% of approximately 200 failures were caused by collision. Other states considered overloading to be a greater problem. However, both overloading and collision were considered more critical than deterioration. It is possible, however, that failure of a bridge that had a low posted capacity due to deterioration would be described as being caused by overloading. The seriousness of deterioration, and the importance of timely maintenance on potential failures, should not be underestimated.
The state of the art in the repair of bridges varies between agencies at any level of government and, often to a great degree, between levels of government. All of the 50 state highway departments have bridge offices adequately staffed with competent engineers, while the qualifications and size of county engineering staffs differ from place to place. Some local governments require trained engineers, who are often registered; others do not. Because of these factors the degree of attention devoted to the maintenance and repair of bridges varies widely.

It is generally agreed that both the federal-aid secondaries and the roads not included in the system encompass the same types of bridges with similar deficiencies, although the off-system group may include more timber bridges and old trusses. It also seems, however, that inspection and maintenance of the off-system bridges have been more sporadic. Many of the repairs seem in the field were admittedly of a stop-gap nature, so-called "band-aid" repairs that slow the worsening of the distress without addressing the cause of the problem. From the county perspective, the high cost of repairs, coupled with major structural and geometric inadequacies, makes replacement rather than rehabilitation the primary concern.

Considerable repair work is being undertaken by the state agencies. As indicated earlier in Tables 3 through 5, repair schemes were available from at least one state for most of the deficiencies listed in the questionnaire. Generally, the corrective procedures attempt to restore the strength of the bridge and to eliminate the cause of the distress.
Certain deficiencies, as discussed in Chapter Three, were not addressed because they were the subjects of other major research efforts. Other deficiencies were omitted when they proved to be either relatively unimportant or were judged to be beyond the scope of the study. Among these were the differential, or creep, of spans under traffic (a minor problem, often ignored); slippery deck surface (primarily seen as a problem on timber bridges); lateral movement of substructure elements and inadequate waterway opening causing scour (both difficult problems with no simple solution); and unsafe approach alignment (considered beyond the scope of bridge repair).

After final deliberations, significant deficiencies were addressed in the Manual of Recommended Practice and correlated with the appropriate repair procedures. (See pages 35 and 36 of this Report.)

DEVELOPMENT OF REPAIR TECHNIQUES

Fortunately, a review of the questionnaire responses indicated that plans covering virtually all of the listed deficiencies were available from numerous agencies. Other procedures were obtained during visits by the research team and from a review of the literature. The plans were requested and reviewed and, where beneficial, the best features of two or more similar procedures were combined.

Every effort was made to obtain rehabilitation procedures that had been successfully applied in the field. Included in the supporting data provided in the Manual are limitations to the use of the procedures, an assessment of the equipment or other resources required, and the names of using agencies. To ensure the practicality of the schemes, each was reviewed in detail by the bridge engineers on the research team after preliminary review by the other members.

Most of the repair procedures in the Manual were adapted from plans developed by state highway organizations to meet the needs of specific structures. After review, the individual plans were generalized to meet the needs of a broad group of bridges. The standard repairs presented in the Manual are essentially step-by-step procedural guidelines applicable to commonly encountered deficiencies. Sufficient dimensions are provided to enable the engineer to evaluate the applicability of a procedure to his needs and to weigh its benefits against those of alternate schemes or complete replacement of the structure. In the generalized standard procedures presented in the Manual, it was impossible to completely detail the connections and member sizes to meet the wide variety of span lengths and loadings encountered in the field. In the preparation of final plans for a particular bridge after the appropriate procedure has been selected, the services of a competent engineer will be required to establish the design.

Some of the repair techniques are applicable to more than one deficiency. For example, the strengthening of a column pier or pile bent through the addition of a supplemental transverse “pony” bent is useful when the original plies have deteriorated, when settlement has occurred, or when upgrading of the superstructure has increased the load on the pier beyond its capacity. In contrast, more than one procedure may be applicable to a single deficiency, the degree of repair being left to the judgement of the engineer. While the Manual documents successful procedures, it is also hoped that it may lead the engineer to devise his own creative solution to his problem.

After intensive selection and review, a total of 34 repair procedures were finally chosen for inclusion in the Manual.

SELECTED REPLACEMENT SYSTEMS

A second major part of the Manual was a survey of state-of-the-art technology in the use of standardized construction and modular components to meet the need for economical and serviceable replacement structures. For many bridge structures, replacement is the most attractive and, often, the only cost-effective alternative. This is particularly true for old bridges that were designed to carry light loads on narrow roadways and have often been improperly maintained.

Information on replacement systems was gathered from several sources. These included recognized authorities in the field, the FHWA and state agencies, technical associations, and fabricators. Systems from throughout the United States and Europe were included in the survey. Eventually, 37 systems were selected for inclusion in the Manual.

The systems presented cover a wide spectrum of bridges, although not all of them are suitable or attractive for use on every site. They range from log bridges that might offer an economical solution on extremely low volume roads to extremely sophisticated European systems suitable for use as movable bridges in urban settings. Regardless of the level of sophistication, every effort was made to present proven systems rather than unproved concepts. Each description includes a source of information on the system, if available, and a list of the agencies using the system.

As in the case of repair procedures, sufficient dimensions and details are presented to allow an evaluation of the utility of the system against possible alternatives. Additional engineering design will be required in the preparation of final plans for any system chosen for use in the field.

An often economical alternative to conventional bridge construction is the use of long span structural plate culverts of either steel or aluminum. Bridge construction can also be facilitated and savings realized through the use of portions of the systems presented.

DEVELOPMENT OF A SELECTION PROCESS

A large number of repair procedures are presented in the Manual. These should provide local bridge engineers with the concepts necessary to remedy the large majority of common deficiencies in bridges on secondary roads. For those cases in which total replacement is necessary, a number of replacement systems have also been presented from which the local engineer can select the one most appropriate for the particular demands of the situation.

In certain cases, only one repair procedure may be available for a given deficiency. In other cases, however, more than one procedure may be available and it becomes necessary for the local engineer to select, from among two or more, the most appropriate one for a particular bridge. When a bridge is to be replaced, a similar selection must be made from among the feasible replacement systems. And, at some point, one responsible individual must decide whether a bridge should be repaired at all, or whether total replacement is the more cost-effective alternative.

It would be desirable, therefore, for local bridge engineers to have available a simple and feasible procedure which would assist them in
their selection tasks. One task of this project was to develop such a procedure and the philosophy and results of this task are described in this section.

The state bridge officials responding to the questionnaire indicated that a number of factors were taken into consideration in deciding between repair or replace alternatives, but only one state had formalized the process in any way. Further, there was no evidence of any standard procedure for decision making being used by county or local agencies. A selection process developed by Kepner and Tregoe and adopted by Maryland is a rational one in which the alternatives are judged by their abilities to fulfill desirable objectives. In simple terms, the decision maker first compiles a list of “must” objectives, those that must be met, and “want” objectives, those for which fulfillment is desirable but not essential. Weighting factors are then assigned to the “want” objectives in the order of their importance. The various alternatives are then compared by their ability to meet the “must” objectives and those failing are eliminated from consideration. The remaining alternatives are then rated with regard to meeting the “want” objectives using a yes/no or percentage fulfillment criterion. Finally, the weighting factors for the “yes” (net) objectives are totalled. The alternative having the highest score is tentatively selected.

In spite of the progress made in the development of decision models applied to various aspects of bridge repair and replacement, few of these procedures have been used in field situations and most require data that would be difficult to accurately prescribe at the county level. Accordingly, in an effort to develop a selection procedure that would be both reasonable and easy to use, it was decided to structure a methodology similar in concept to the rational, common sense, subjective approach currently used by essentially all state and local bridge engineers in making selections.

The selection processes proposed in this Manual are simple in application and involve no complex formulas or sophisticated computer algorithms. It is felt, however, that the information these procedures can provide to the engineer will significantly facilitate the decisions that must be made when a bridge is to be repaired or replaced.

The decision-making processes most frequently encountered by local bridge engineers are divided into four major phases and were briefly discussed in the introduction of this Manual. Recommendations for implementation are offered in each of the four categories. In summary, these are:

1. the FHWA sufficiency rating procedure is recommended for prioritizing bridges for attention within a class of structures.

2. the decision between repair or replace is generally based on the relative costs and the final decision is always a subjective one. However, in addition to cost, other significant factors are suggested for consideration in a step-by-step procedure.

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(1) the choice between repair procedures to correct a particular deficiency is frequently a simple commonsense decision. However, an approach to this selection process utilizing a matrix formulation for comparison of a number of factors is explained and illustrated.

(4) The same matrix formulation is illustrated as an aid in selecting between replacement structures when there is no clear choice.

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CHAPTER VI
RECOMMENDATIONS FOR RESEARCH

This investigation relating to the repair, rehabilitation and replacement of bridges on rural and secondary roads achieved several distinct objectives. These included a survey of state bridge departments and personal contacts with state and local engineers; the identification of the more common bridge deficiencies and corresponding repair procedures; the identification and evaluation of feasible replacement systems; the suggestion of a procedure to assist in the selection between repair and replace alternatives on the basis of cost-effectiveness; and, finally, the development and preparation of a Manual of Recommended Practice. Although much of the information obtained in this study is extremely useful, the primary product of the research is the Manual.

The Manual contains descriptions of repair procedures and replacement systems that will be of direct and immediate use to those local bridge engineers responsible for the maintenance of bridges on secondary roads.

Consistent with this philosophy, any research undertaken as a second phase of the current study should be concerned almost exclusively with improving and updating the Manual and generally making it more useful. There are a number of additional tasks that would significantly contribute to the total package of repair procedure and replacement systems, and, based on the experience of the current research team, the following additional areas of research are suggested.

REVIEW OF MANUAL OF RECOMMENDED PRACTICE

The initial efforts in any continuation of the current research should be concerned with an evaluation of the Manual of Recommended Practice by engineers in the field. This task would comprise a critique of each of the repair procedures and replacement systems listed, with specific criticisms and identification of modifications, omissions, and possible errors in each. While the repair procedures and replacement systems described are based to a large extent on information obtained from state and local engineers, the sample from which this information was drawn was necessarily small. There is a need to involve a larger group in any evaluation of the Manual and, in particular, to include more county engineers to assess its usefulness in local situations.

During the present study efforts were made to establish contacts with county and local engineers having experience in bridge design and repair. Visits were made to the headquarters of the National Association of Counties (NACo) in Washington, D.C. and from discussions there contacts were made with a number of county engineers and other local officials throughout the United States. A large number of these were contacted by letter and telephone to inform them of the research study and request their assistance. However, the project schedule provided insufficient time for adequate follow-up and full involvement of the county engineers in the development of the Manual. Nevertheless, at the present time an excellent cadre of local engineers has been compiled which could serve as the basis for an expanded list needed for completion of a second phase of this project.

CONTINUING EVALUATION OF EXISTING REPAIR PROCEDURES AND REPLACEMENT SYSTEMS

Since essentially all of the repair procedures presented in the Manual have been tried in one form or another by some state or local agency, it seems worthwhile to obtain a status report or state-of-the-repair evaluation concerning repairs that have been in place for some time. Specifically, it would be extremely useful to provide, in an updated Manual, a complete evaluation of the procedures including answers to such questions as, How are they holding up? Were they implemented without difficulty? Did they remedy the problems as intended? Would they be used again? If not, what procedures would be used? And, if so, how would they be modified to make them more effective? Such information would enhance the practicality and value of the evaluation of the repair procedures and replacement systems and would improve the quality and utility of a modified and updated Manual.

IDENTIFICATION OF NEW DEFICIENCIES AND REPAIR AND REPLACEMENT TECHNIQUES

Although every effort was made during this investigation to identify the common bridge deficiencies and their corresponding remedies, it is inevitable that some common problems have been overlooked and their solutions not included in the present Manual. While obtaining evaluations of the current Manual, particular attention should be given to identifying those deficiencies which are of particular interest to county engineers and which were not included in the Manual. Similarly, input from county engineers should be sought to obtain new and innovative repair procedures which have been tried successfully on a local level but which were not uncovered in the survey employed in the present investigation. A similar effort should be made with regard to replacement systems.

PUBLISH MODIFIED AND EXPANDED VERSION OF MANUAL OF RECOMMENDED PRACTICE

The results from the previously described tasks should produce new repair procedures and replacement systems not covered by the first edition of the Manual. In addition, expanded contact with county engineers and other local officials will permit improvements to the repair procedures and replacement systems that are included. Thus, the primary product of Phase II of this project should be an updated and significantly improved Manual of Recommended Practice that should enjoy wide usage by county engineers throughout the country.

The additional areas of suggested research identified and described in this section have been deliberately defined to be realistically accomplishable within the funding and time constraints of the proposed second phase of this project. It is recognized that there are a number of other important tasks that would materially contribute to the repair and replacement of bridges on secondary roads. For example, it would be worthwhile to attempt to develop standard plans for specific repairs and standard modular elements for replacement systems. Tasks of this nature, however, would require considerably more effort than currently budgeted for the second phase of this project and, accordingly, have not been included in these recommendations for research.
REFERENCES


12. NCHRP Research Results Digest No. 84, 1976.


16. NCHRP Research Results Digest No. 98, 1977.


3. Do the records include secondary highway bridges not in the Federal-Aid System (FAS)?

Yes  No

4. Do you regularly inspect bridges on secondary roads and not in the FAS for deterioration and damage?

Yes  No

5. Do you regularly inspect secondaries in the FAS for live load carrying capacity?

Yes  No

6. For steel bridges, at what % yield stress are the ratings made? ___% for inventory, ___% for operating rating.

7. Are the bridges on secondary roads not in the FAS posted as a result of the ratings?

Yes  No

8. Please list bridge types on secondary roads currently in place in order of frequency of occurrence, i.e., steel beam, concrete beam, timber beam, slab span, steel truss, "other." If the numbers of these types of bridges are available, please list. If numbers of the structures are not available, simply list in order using your best judgment.

1. 
2. 
3. 
4. 

9. Has your office developed standard repairs or procedures to correct the more common forms of deterioration or deficiency? Please describe with sketches or furnish plans for typical repairs.

Yes  No

10. What is the basis for making the decision whether to repair (or renovate) or replace a damaged or deteriorated bridge structure?

Yes  No

11. Who makes the decision to repair or replace?

Yes  No

12. Who conducts repair and replacement operations?

Yes  No

13. How many bridge failures (including those structures damaged to such an extent that they are unusable) have been experienced in your state in the last five years? Exclude those that failed as a result of natural disaster. If number is not available, please estimate. 

14. Does your state have any standard replacement bridge systems for structures that have suffered complete structural failure, or have deteriorated beyond feasible repair or are functionally obsolete?

Yes  No

Please attach a brief narrative description.

15. Person completing this questionnaire:

Name:

Title:

Address:

Telephone No.:

16. Person to be contacted for additional information if different from above:

Name:

Title:

Address:

Telephone No.:

If you desire that the information you provide be held in confidence, please check .

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The table attached is intended to provide information relating to specific deficiencies and repair procedures. In completing this table, please indicate your judgment of the severity of each deficiency listed and an estimate of its frequency of occurrence for each superstructure type and for substructure elements. Indicate the severity and frequency using a scale of 0 to 3, where these numbers are assigned the following interpretation.

**Severity**

0  not severe (of no concern)

1  minor importance

2  moderately severe

3  very severe

**Frequency**

0  never observed

1  seldom observed

2  occasionally observed

3  frequently observed

Please indicate in the right column if your organization has developed repair procedures that might be useful to others.

Please return at your earliest convenience, but no later than June 15, to:

Mr. H. L. Kastner, P. E. (804) 977-0290

Faculty Research Engineer

Virginia Highway & Transportation Research Council

Box 3817 University Station

Charlottesville, Va. 22903

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<table>
<thead>
<tr>
<th>NATURE OF DEFICIENCY</th>
<th>SUPERSTRUCTURE ELEMENTS</th>
<th>TYPE OF SPAN</th>
<th>Repair Procedure Available? (Check □)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Original Design</td>
<td>Beam</td>
<td>Truss</td>
<td>Concrete T-Beam</td>
</tr>
<tr>
<td>Inadequate for</td>
<td>Sev</td>
<td>Freq</td>
<td>Sev</td>
</tr>
<tr>
<td>Present Loads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Main Members or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truss</td>
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<td></td>
<td></td>
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<tr>
<td>b) Deck</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>c) Joints or Other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Details</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2) Fatigue</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cracking</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3) Deck Spalling</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(Corrosion Induced)</td>
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<td></td>
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<tr>
<td>4) Spalling of Deck</td>
<td></td>
<td></td>
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<tr>
<td>at Joints (Stress</td>
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<tr>
<td>Induced)</td>
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<tr>
<td>5) Structural</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cracking of Deck</td>
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<td></td>
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<tr>
<td>6) Cracking in</td>
<td></td>
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<tr>
<td>Concrete Beams</td>
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<td></td>
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<tr>
<td>7) Spalling of</td>
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<tr>
<td>Concrete Beams</td>
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<tr>
<td>8) Loss of section</td>
<td></td>
<td></td>
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<tr>
<td>Due to Corrosion</td>
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<td>9) Deterioration of</td>
<td></td>
<td></td>
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<tr>
<td>Timber Deck or</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Beams</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10) Inoperative</td>
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<td></td>
<td></td>
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<tr>
<td>Bearings</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>11) Inoperative</td>
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<td></td>
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<tr>
<td>Expansion joints,</td>
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<td></td>
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<tr>
<td>include leaking</td>
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<tr>
<td>12) Deteriorated</td>
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<td></td>
<td></td>
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<tr>
<td>Rails or Barriers</td>
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<td></td>
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<tr>
<td>13) Dislocation or</td>
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<td></td>
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</tr>
<tr>
<td>'Creep', of Spans</td>
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<td></td>
<td></td>
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<tr>
<td>Under Traffic</td>
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<tr>
<td>14) Inadequate Deck</td>
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<tr>
<td>Drainage</td>
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<tr>
<td>15) Collision Damage</td>
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<td></td>
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<td></td>
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<tr>
<td>16) Other (List)</td>
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<thead>
<tr>
<th>NATURE OF DEFICIENCY</th>
<th>SUPERSTRUCTURE ELEMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE OF SPAN</td>
</tr>
<tr>
<td></td>
<td>Steel Beam</td>
</tr>
<tr>
<td></td>
<td>Steel Truss</td>
</tr>
<tr>
<td></td>
<td>Concrete T-Beam</td>
</tr>
<tr>
<td></td>
<td>Concrete Slab</td>
</tr>
<tr>
<td></td>
<td>Timber Deck or Beam</td>
</tr>
<tr>
<td></td>
<td>Prestress Concrete</td>
</tr>
<tr>
<td></td>
<td>Other (List)</td>
</tr>
<tr>
<td></td>
<td>Repair Procedure</td>
</tr>
<tr>
<td></td>
<td>Available?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FUNCTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>17) Narrow Roadway</td>
</tr>
<tr>
<td>18) Unsafe Rail Configuration or Weak Design</td>
</tr>
<tr>
<td>19) Unsafe Approach Alignment</td>
</tr>
<tr>
<td>20) Exposed Rail Terminals</td>
</tr>
<tr>
<td>21) Truss Members Exposed to Impact</td>
</tr>
<tr>
<td>22) Slippery Deck Surface</td>
</tr>
<tr>
<td>23) Inadequate Vertical Clearance (on Bridge)</td>
</tr>
<tr>
<td>24) Inadequate Under clearances</td>
</tr>
<tr>
<td>25) Inadequate Waterway (Scour &amp; Erosion of Slopes)</td>
</tr>
<tr>
<td>26) Other (List)</td>
</tr>
</tbody>
</table>

27) If readily available, please provide information on the total number of each type of span in your system.
<table>
<thead>
<tr>
<th>NATURE OF DEFICIENCY</th>
<th>SEVERITY</th>
<th>FREQUENCY</th>
<th>Repair Procedure Available? (check ✓)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28) Original design of piers and other elements presently inadequate.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29) Deterioration due to salt exposure of piers, bents, or piles.</td>
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<tr>
<td>30) Spalling of beam seats.</td>
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<tr>
<td>31) Shoving of abutments or cracking of backwalls.</td>
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<tr>
<td>32) Settlement of substructure elements.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33) Lateral Movement of Substructure Elements.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 150 committees and task forces composed of more than 1,800 administrators, engineers, social scientists, and educators who serve without compensation. The program is supported by state transportation and highway departments, the U.S. Department of Transportation, and other organizations interested in the development of transportation.

The Transportation Research Board operates within the Commission on Sociotechnical Systems of the National Research Council. The Council was organized in 1916 at the request of President Woodrow Wilson as an agency of the National Academy of Sciences to enable the broad community of scientists and engineers to associate their efforts with those of the Academy membership. Members of the Council are appointed by the president of the Academy and are drawn from academic, industrial, and governmental organizations throughout the United States.

The National Academy of Sciences was established by a congressional act of incorporation signed by President Abraham Lincoln on March 3, 1863, to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance. It is a private, honorary organization of more than 1,000 scientists elected on the basis of outstanding contributions to knowledge and is supported by private and public funds. Under the terms of its congressional charter, the Academy is called upon to act as an official—yet independent—advisor to the federal government in any matter of science and technology, although it is not a government agency and its activities are not limited to those on behalf of the government.

To share in the tasks of furthering science and engineering and of advising the federal government, the National Academy of Engineering was established on December 5, 1964, under the authority of the act of incorporation of the National Academy of Sciences. Its advisory activities are closely coordinated with those of the National Academy of Sciences, but it is independent and autonomous in its organization and election of members.