T. J. Wipf, F. S. Fanous, F. W. Klaiber, A. S. Eapen

Evaluation of Appropriate Maintenance, Repair and Rehabilitation Methods for Iowa Bridges

April 2003

Sponsored by the
Iowa Department of Transportation
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Iowa DOT Project TR - 429

Iowa Department of Transportation

Final

REPORT

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Department of Civil and Construction Engineering

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ABSTRACT

Most states, including Iowa, have a significant number of substandard bridges. This number will increase significantly unless some type of preventative maintenance is employed. Both the Iowa Department of Transportation and Iowa counties in the state of Iowa have successfully employed numerous maintenance, repair and rehabilitation (MR&R) strategies for correcting various types of deficiencies. However, successfully employed MR&R procedures are often not systematically documented or defined for those involved in bridge maintenance. This study addressed the need for a standard bridge maintenance, repair and rehabilitation (MR&R) manual for Iowa with emphasis for secondary road applications. As part of the study, bridge MR&R activities that are relevant to the state of Iowa have been systematically categorized into a manual, in a standardized format. Where pertinent, design guidelines have been presented.

Material presented in this manual is divided into two major categories: 1) Repair and Rehabilitation of Bridge Superstructure Components, and 2) Repair and Rehabilitation of Bridge Substructure Components. There are multiple subcategories within both major categories that provide detailed information. Some of the detailed information includes step-by-step procedures for accomplishing MR&R activities, material specifications and detailed drawings where available. The source of information contained in the manual came from public domain technical literature and from information provided by Iowa County Engineers. A questionnaire was sent to all 99 counties in Iowa to solicit information and the research team personally solicited input from many Iowa counties as a follow up to the questionnaire.

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1. INTRODUCTION

1.1 Background

Bridges are one of the vital segments in a surface transportation system. According to the National Bridge Inventory, a large percentage of the nation's bridges are classified as functionally or structurally deficient.

Unfortunately, the state of Iowa has a disproportionate share of substandard bridges. The number of these deficient bridges will obviously increase unless some type of preventative maintenance is employed. These types of activities are referred to as maintenance, repair and rehabilitation (MR&R) activities. MR&R activities are used to keep bridge structures in their current condition and hence prolong their service lives.

The Departments of Transportation (DOTs) in numerous states and counties have successfully employed numerous MR&R procedures for correcting various types of deficiencies. However, for the same deficiency, the maintenance activities vary from county to county and from state to state. In other words, successfully employed MR&R procedures are not systematically defined for use by others involved in bridge maintenance.

In 1996, a research focus group created at the request of the Iowa DOT [8] to investigate bridge research needs concluded that there is a need for a standard bridge MR&R manual that could be used by the Iowa counties as well as the state. The group also recognized that unless current maintenance techniques and, in general, the significant experiences of those involved in bridge maintenance were documented, a sizeable investment of expertise would be lost due to retirements.

1.2 Research Objectives

The state of Iowa has 89,594 miles of county roads, most of which are unpaved, low traffic volume roads. Eighty two percent of the state's bridges are located on these county roads. This research study concentrated on the unique problems associated with these low volume road bridges.

The primary objective of the research project was to compile current information on MR&R techniques, implementation guidelines and design details that are relevant to the state of Iowa into a manual that would provide guidance for designers as well as field personnel involved in bridge MR&R at the secondary level.

1.3 Scope of Investigation

The research project consisted of two phases; 1) the compilation of MR&R procedures that were relevant to the secondary road system in the state of Iowa and, 2) development of design guidelines (where pertinent or relevant) for the compiled procedures.

To ensure that the research project would meet its ultimate objective, a project advisory committee that has representation from the Iowa DOT, county engineers and municipal engineers guided the research effort at every stage.

The MR&R procedures presented in the manual format provide information an engineer can use to resolve the majority of the problems on the local system. Because a wide variety of problems are reviewed in this study, the degree of complexity of the MR&R procedures vary from conceptual ideas to detailed design guidelines for some of the procedures.

1.4 Research Approach

1.4.1 Task 1

The purpose of Task 1 was to gather current information on MR&R practices. To this end a literature review was completed; sources of material included journal publications, conference proceedings, chapters of state bridge manuals and various technical reports.

1.4.2 Task 2

In this task, a questionnaire was developed and disseminated to all the 99 counties in the state of Iowa. The purpose of the questionnaire was to gather information on the MR&R issues that the county engineers face. Particular emphasis was paid to the problems faced and the solutions (if any) that were adopted. The questionnaires were followed up with visits to the several counties that had expressed an interest in discussing in greater detail their problems and the solutions employed.

1.4.3 Task 3

This task was devoted to compiling MR&R activities to be included in the manual. Essentially all areas of bridge maintenance, repair and rehabilitation were reviewed, and the gathered information was categorized on the basis of activities related to different bridge components.

1.4.4 Task 4

The compiled information was summarized and presented in a manual format; the manual includes details of the field implementation of the MR&R procedures and design guidelines where relevant. For each MR&R activity, a step-by-step procedure for accomplishing it, material specifications and detailed drawings are provided.

The input of the project advisory committee was sought and received on each of the above project tasks to ensure that all relevant MR&R activities were included.

2. BRIDGE MAINTENANCE REPAIR AND REHABILITATION (MR&R) MANUAL

Chapter 2 of this report is a maintenance repair and rehabilitation (MR&R) manual. The other chapters provide supplementary and background information. Sections 2.1 and 2.2 provide general information about the manual, while remaining sections (and subsections) present various MR&R techniques that have been compiled as part of the study.

2.1 Organization of the MR&R Manual

The material presented in the following sections is to be used primarily by bridge maintenance and rehabilitation personnel working at the secondary level. The material in the manual is classified according to the nature of the element (i.e. the element can be classified as a superstructure or as a substructure element).

Every effort has been made to present proven MR&R 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 details are provided to enable the engineer to evaluate the applicability of a procedure to his/her needs and to weigh its benefits against other alternatives.

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

1 foot (ft) = 0.3048 meter (m)

1 inch (in.) = 25.4 millimeters (mm)

1 ounce (oz) = 0.2780 Newtons (N)

1 pound (lb) = 4.448 Newtons (N)

1 pound per square inch (psi) = 6895 Pascals (Pa)

1 mil = 0.0254 millimeters (mm)

2.2 Commentary on Repair Procedures

The repair and rehabilitation procedures included in this chapter are applicable to common structural and functional deficiencies for bridges on secondary roads in the state of Iowa.

The plans and drawings presented in this manual were generalized to meet the needs of a broad group of bridges and are presented in a standardized format; however, the MR&R procedures presented in the manual do not encompass all of the deficiencies found in bridges on secondary highways and local roads.

Since all repair procedures would require the utilization of common hand tools such as wrenches, hammers, etc., their requirement is implied and is not explicitly stated in the list of materials.

2.3 Repair and Rehabilitation of Bridge Superstructure Components

2.3.1 Replacement of Steel Beams

2.3.1.1 General guidelines for the replacement of steel beams in bridges

Application

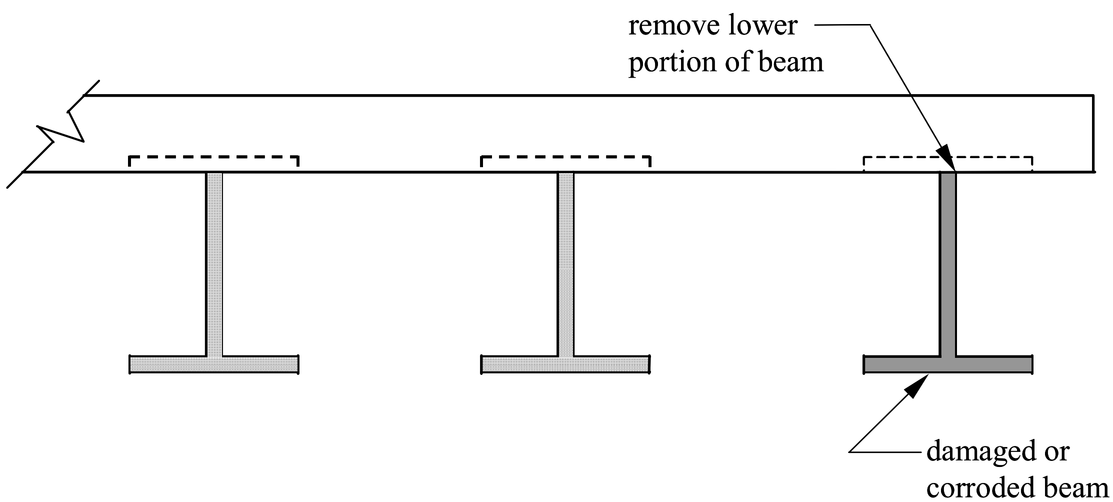
This method is used for either composite or non-composite construction where a beam has been damaged by collision or corrosion.

Repair Method

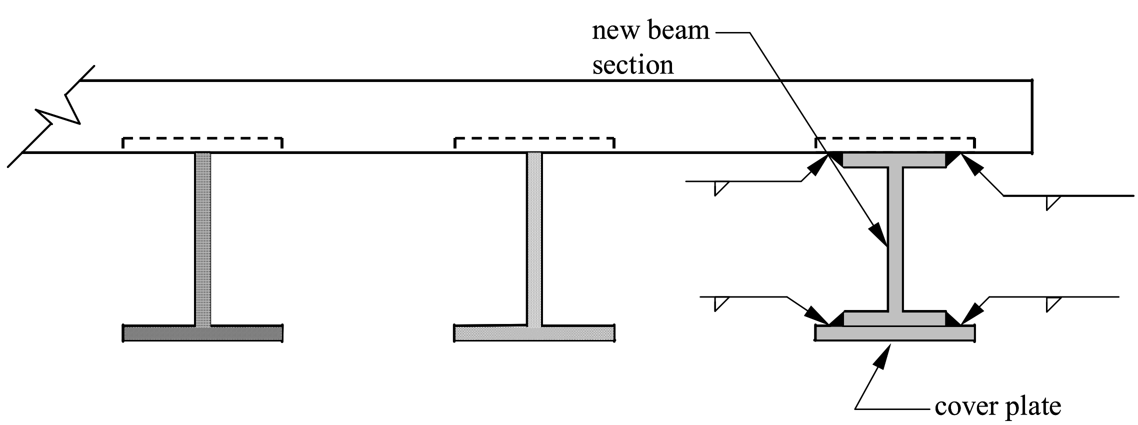
Lift the bridge so that the damaged beam is clear of the bearing surface. Remove the damaged portion of the beam by cutting through the web directly below the top flange. Weld the new steel beam in place by means of continuous fillet welds (see Fig. 2.3.1).

Materials

1. Hydraulic lifting equipment
2. Acetylene torch
3. New rolled steel sections
4. Steel cover plates



(a) Composite Slab with Damaged Beam



(b) New Beam Section Welded in Place

Figure 2.3.1 Replacement of Damaged or Corroded Steel Beams.

Construction Procedure

1. Limit traffic to light vehicles and direct traffic away from the damaged portion of the bridge roadway until the repair is completed.
2. Lift the bridge so that the damaged beam is clear of the bearing surface.
3. Provide temporary supports adjacent to the beam to be removed.
4. In the case of a composite deck, remove the damaged portion of the steel beam by cutting through the beam web directly below the top flange. The top flange must remain in the concrete slab.
5. Grind the bottom face of the top flange smooth.
6. Select or fabricate a replacement beam with a top flange width smaller than that of the original beam to allow for welding. A cover plate may be required on the new beam.
7. Weld the new steel beam in place with continuous fillet welds (see Fig. 2.3.1).
8. Remove temporary supports if they were originally provided.
9. Seat the new beam and remove the hydraulic lifting equipment.
10. If the construction was non-composite in nature, the damaged beams can be completely removed right after lifting the bridge. New beams should replace the damaged beam.

2.3.2 Installation of Intermediate Support for Steel Girder Bridges

2.3.2.1 General guidelines for the implementation of the retrofit

Application

This method is used to increase the load carrying capacity of a bridge by erecting an intermediate support to convert a simple span into two shorter continuous spans.

Repair Method

Piles are driven outside the existing bridge and pile caps are provided for the new piles. A new support beam is positioned snug against existing stringers and connected. Shim plates and non-shrink epoxy grout are used as needed.

Limitations

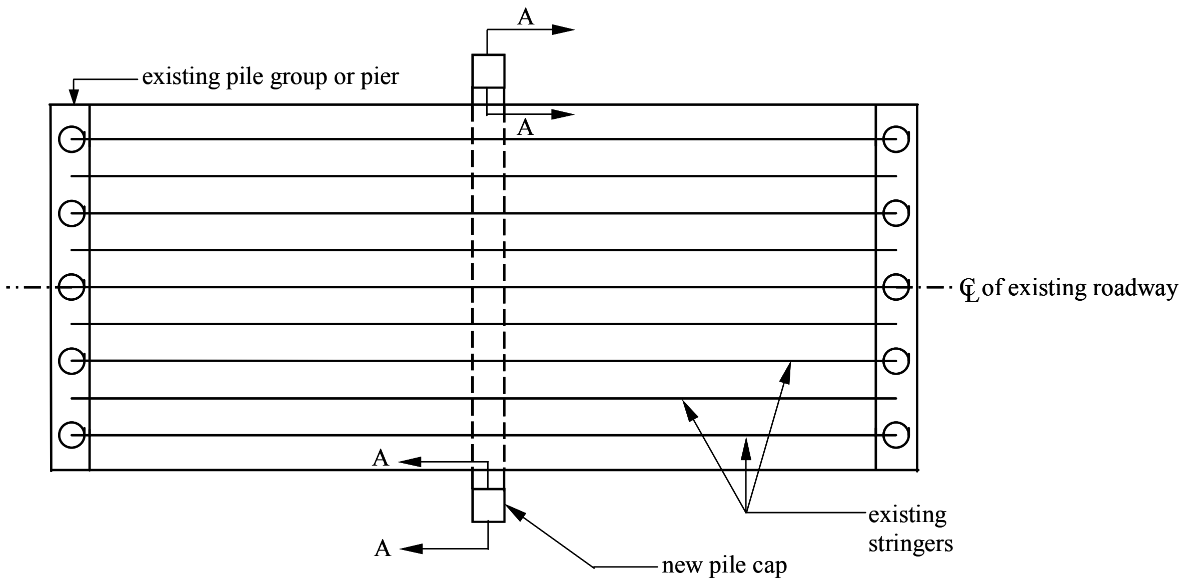
The main flexural members and the concrete deck of the existing bridge must be capable of resisting the negative moment over the new support.

Materials

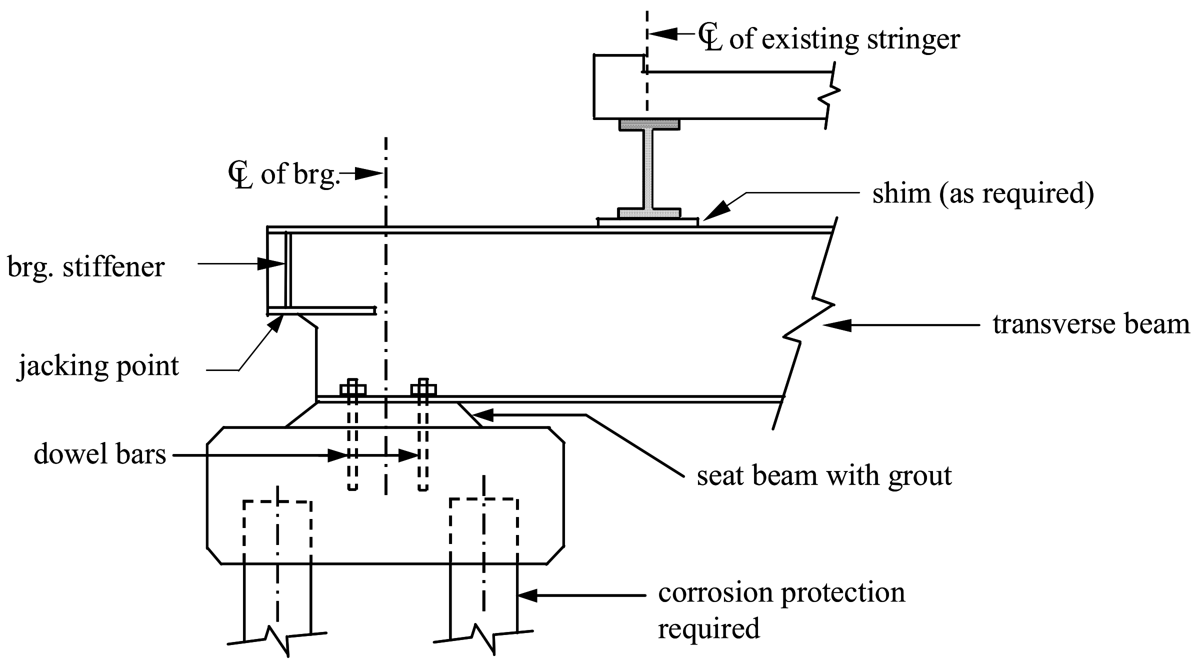
1. Steel H-pile sections
2. Hydraulic lifting equipment
3. Wide flanged steel beam sections
4. Dowel bars/bolts
5. Shim plates
6. Non-shrink epoxy grout
7. Suitable grade of concrete
8. Reinforcing steel

Construction Procedure

1. Close the bridge to all traffic before the initiation of the retrofit.
2. Design the new transverse beam and pile cap to support reactions due to the imposed live and dead loads.
3. Drive piles at the desired locations outside of the bridge rails (see Figs. 2.3.2 and 2.3.3).
4. Steel or concrete pile caps should be provided on top of the new piles.
5. Drill holes in the intermediate beam and the pile caps to accommodate dowel bars or bolts.



(a) Plan View



(b) Section A~A

Figure 2.3.2 Installation of Intermediate Support Beam.

Figure 2.3.3 Example of an Intermediate Support Installed to Strengthen a Simple Span Bridge.

6. Place the new support beam snug against existing stringers. Install shim plates as required; insert dowel bars or bolts between the beam and the pile cap. In case of concrete pile caps, place non-shrink grout between the beam and the pile cap.
7. Remove the jacking apparatus after the grout has set.

2.3.2.2 Design of the intermediate steel beam

Description

The procedure presented in this section outlines the design of the steel beam that would provide intermediate support for converting a simple span bridge into a two span continuous bridge.

Design Summary

1. Compute the magnitude and locations of critical stresses in the intermediate beam.
2. Design the W-shape (or the plate girder, as the case may be) to carry the maximum moment.
3. Check to make sure the shear capacity of the beam exceeds the maximum shear force.
4. Determine if the maximum deflection of the beam exceeds the permissible limits.
5. Design the end bearings.

Design Procedure

1. Using a suitable analysis procedure, determine the maximum moments and shears on the intermediate beam due to the imposed dead and live loads.
2. Choose trial size based on the value of the section modulus, S. For W-shapes the trial sizes can be picked from the relevant tables [3].

$$S \geq \frac{1.82 M_{max}}{F_y} \qquad (2.3.1)$$

where

M_{max} = maximum moment on the intermediate beam (lb-in)

S = section modulus (in^3)

F_y = yield stress of the material (psi)

3. Analyze the selected shape for the imposed live and dead loads; check if the maximum moment in the intermediate beam exceeds the moment capacity of the trial shape, M_{all}.

   M_{all} shall be taken as the lesser of:

$$f_{all,t} \times S_{xt}$$

$$f_{all,c} \times S_{xc} \tag{2.3.2}$$

where

S_{xc} = section modulus with respect to the compression flange (in^3)

S_{xt} = section modulus with respect to the tension flange (in^3)

$f_{all,t} = 0.55F_y$ (psi)

$f_{all,c} = 0.55F_y$ (psi) for compression flanges that are supported laterally along its full length

$$f_{all,c} = \frac{50 \times 10^6 C_b}{S_{xc}} \left(\frac{I_{yc}}{L}\right) \sqrt{0.772 \frac{J}{I_{yc}} + 9.87 \left(\frac{d}{L}\right)^2} \leq 0.55F_y$$

for unsupported/partially supported compression flanges

$$C_b = 1.75 + 1.05\left(\frac{M_1}{M_2}\right) + 0.3\left(\frac{M_1}{M_2}\right)^2 \leq 2.3$$

M_1 is the smaller and M_2 the larger end moment in the unbraced segment of the beam. $\left(\frac{M_1}{M_2}\right)$ is positive when moments cause reverse curvature and negative for single curvature.

C_b = 1.0 for unbraced cantilevers

L = unsupported length (in.)

I_{yc} = moment of inertia of the compression flange about the vertical axis (in^4)

d = depth of the girder (in.)

$$J = \frac{(bt^3)_c + (bt^3)_t + Dt_w^3}{3}$$

D = unsupported depth of web plate in inches between the flanges (in.)

t_w = thickness of the web plate (in.)

4. Check the minimum thickness of the flange and the web elements.

$$t_f \geq \frac{b\sqrt{f_b}}{3250} \qquad (2.3.3)$$

where

b = the width of the compression flange (in.)

t_f = thickness of the flange (in.)

f_b= calculated bending stress in compression flange

$$t_w \geq \frac{D\sqrt{f_b}}{23000} \quad \text{(and not less than D/170)} \qquad (2.3.4)$$

for girders without longitudinal stiffeners

$$t_w \geq \frac{D\sqrt{f_b}}{46000} \quad \text{(and not less than D/340)} \qquad (2.3.5)$$

for girders with longitudinal stiffeners

5. Determine if transverse intermediate stiffeners are required. Transverse stiffeners may be omitted if the average calculated unit shearing stress in the gross section of the web plate at the point considered, F_v, is less than the value given below:

$$F_v = \frac{7.33 \times 10^7}{\left(D/t_w\right)^2} \leq \frac{F_y}{3} \tag{2.3.6}$$

where

F_v = allowable shear stress (psi)

6. Where transverse intermediate stiffeners are required, their spacing should be such that the actual shearing stress will not exceed the value given below; the maximum spacing should be limited to 3D.

$$F_v = \frac{F_y}{3}\left[C + \frac{0.87(1-C)}{\sqrt{1+\left(d_0/D\right)^2}}\right] \tag{2.3.7}$$

where

d_0 = spacing of the intermediate stiffener (in.)

for $\dfrac{D}{t_w} < \dfrac{6000\sqrt{k}}{\sqrt{F_y}}$; C = 1.0

for $\dfrac{6000\sqrt{k}}{\sqrt{F_y}} \leq \dfrac{D}{t_w} \leq \dfrac{7500\sqrt{k}}{\sqrt{F_y}}$; $C = \dfrac{6000\sqrt{k}}{\left(\dfrac{D}{t_w}\right)\sqrt{F_y}}$

for $\dfrac{D}{t_w} \geq \dfrac{7500\sqrt{k}}{\sqrt{F_y}}$; $C = \dfrac{4.5 \times 10^7\, k}{\left(\dfrac{D}{t_w}\right)^2 F_y}$

where

$$k = 5 + \frac{5}{(d_0/D)^2}$$

k = 5 for unstiffened beams and girders.

7. Determine the maximum deflections of the intermediate girder and check if they are within the permissible limits.

8. Design bearing stiffeners at the ends of the girder for the concentrated reactions from both the pile cap and the jacking system. The connection to the web should be designed to transmit the entire end reactions to the bearings. The minimum thickness of bearing stiffeners, t, is listed below.

$$t \geq \frac{b'}{12}\sqrt{\frac{F_y}{33{,}000}} \tag{2.3.8}$$

where

b' = width of stiffeners (in.)

2.3.2.3 Design of the concrete pier cap supporting the intermediate steel beam

Description

The design guideline listed below can be used in the design of a concrete pier cap that is to be placed over the new piles.

Design summary

1. Determine a trial size for the pile cap.
2. Check shear strength and provide sufficient shear reinforcement if required.
3. Determine amount of flexural reinforcement required.
4. Check bearing stresses.
5. Provide temperature reinforcement along the side faces of the cap.

Design procedure

1. Analyze the pier cap and the pile system, and determine the magnitude and location of the critical stresses.
2. The approximate depth of the member for the first trial is given by the expression,

$$d \geq \frac{V_u}{\Phi 2\sqrt{f_c'}b_w} \tag{2.3.9}$$

where

f_c' = allowable compressive stress in concrete (psi)

b_w = width of the pier cap (in.)

V_u = maximum factored shear force (lbs).

$\Phi = 0.85$

3. Usually, the minimum size of the cap that can be used is 3 ft deep by 2 ft - 6 in. wide. If a larger cap is needed, the size should be increased in 6 in. increments.
4. If the shear force, V_u, exceeds the shear strength of the concrete section, V_c, stirrups shall be provided to carry the force V_s given by:

$$V_s = \frac{V_u}{\Phi} - V_c \tag{2.3.10}$$

The size and spacing of stirrups my be determined from the equation, $\frac{A_v}{s} = \frac{V_s}{f_y d}$

where

V_s = additional shear strength provided by the stirrups (lbs)

A_v = area of shear reinforcement within a distance, s (in^2)

s = stirrup spacing (in.)

f_y = specified yield strength of shear reinforcement (psi)

5. When shear reinforcement is to be provided by 4., the following criteria have to be met:

i. $A_v \geq \frac{50 b_w s}{f_y}$

ii. Stirrups have to be provided when $V_u \geq \frac{\Phi V_c}{2}$.

iii. Spacing, s, of stirrups shall not exceed d/2 or 24 in.

iv. When $V_s \geq 4\sqrt{f_c'}b_w d$, the spacing, s, shall not exceed one half the limits prescribed in iii.

v. Shear strength V_s shall not exceed $8\sqrt{f_c'}b_w d$.

6. Use the selected cap cross section to determine the reinforcement required for positive and negative moments. Bars are placed straight in the cap. If the pier cap is cantilevered over exterior columns, the negative reinforcement may be bent down at the ends to develop end anchorage.

7. Check if the bearing stress on concrete is within allowable limits. Minimum dowel bars are required even if the bearing stresses are within allowable limits.

$$f_b \leq 0.85\Phi_b f_c' \qquad (2.3.11)$$

where

f_b = bearing stress on concrete

$\Phi_b = 0.70$

8. Determine the temperature steel required along the side faces of the cap. In addition, if the cap depth exceeds 3 ft, longitudinal 'skin' reinforcement needs to be distributed along the side faces of the member over one-half the depth nearest the main longitudinal reinforcement (Wisconsin Department of Transportation Bridge Manual [13]).

2.3.3 Repair of End Corrosion Damaged Steel Beams

2.3.3.1 General guidelines for implementation of the retrofit

Application

This method should be used to repair steel beams that have corrosion damage at one or both of their ends.

Repair Method

Cut out the corroded area and weld the new section into place.

Materials

1. Hydraulic lifting equipment
2. Rolled beam sections
3. Welding equipment

Construction Procedure

1. Close the bridge to traffic before initiating repairs.
2. Relieve the load at the bearing by jacking under the sound portion of the beams.
3. Cut out the corroded area, rounding the corners to a minimum radius of 3 in. to avoid abrupt changes (re-entrant corners that create stress concentrations). Also remove bearing stiffeners if they are present in the existing installation (See Fig. 2.3.4).
4. Weld the new section into place, using full penetration welds. The new section may be either a suitable rolled beam section or it may be shop fabricated from other suitable shapes. Replace bearing stiffeners where they are required.
5. Lower the span to bear and check for any immediate distress. Remove jacking equipment and other temporary supports.

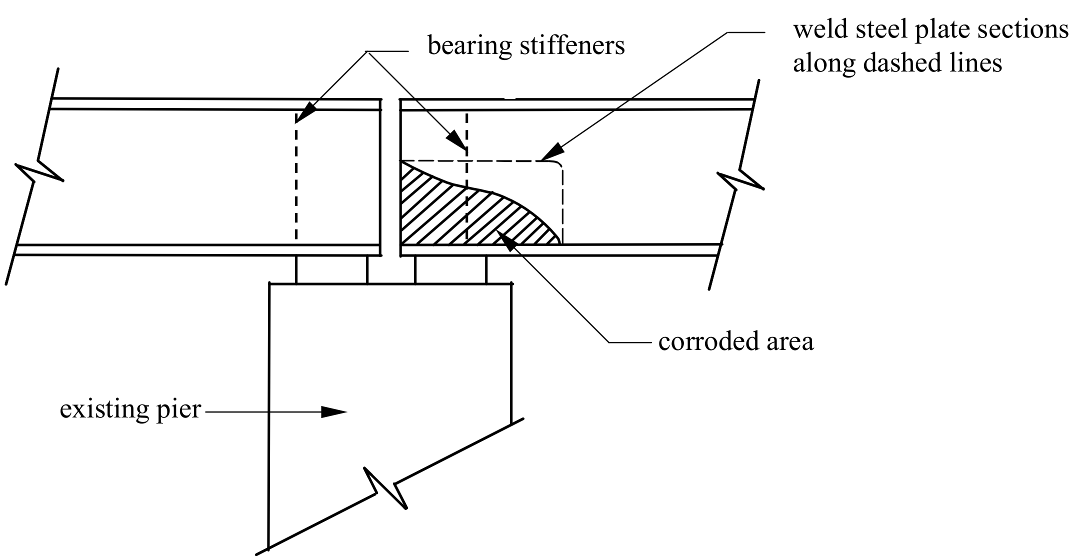


Figure 2.3.4 Repair of Corroded Steel Beam Ends.

2.3.4 Strengthening of Steel Beams With Insufficient Section

2.3.4.1 General guidelines for reinforcement of steel beams with angle stiffeners

Application

This method is used when a beam needs to be strengthened due to an increase in legal loads or when a section of the beam has deteriorated.

Repair Method

Bolt angles to both sides of the web near the top and bottom flanges to increase the moment capacity.

Material

1. High strength bolts
2. Angle sections
3. Hydraulic lifting equipment

Construction Procedure

1. Close the bridge to traffic before initiating the repairs.
2. Relieve the dead load stresses on the beams by uniformly jacking the beams up at midspan.
3. Position angles on both sides of the web near the top and/or bottom flanges (see Figs.2.3.5 and 2.3.6) and drill holes through the web and the angles for high strength bolts.
4. Bolt the angles to the beam web beginning at the center of the span and working toward the abutments.
5. Slowly release the jacking force to ensure equal distribution of dead load to the beams.

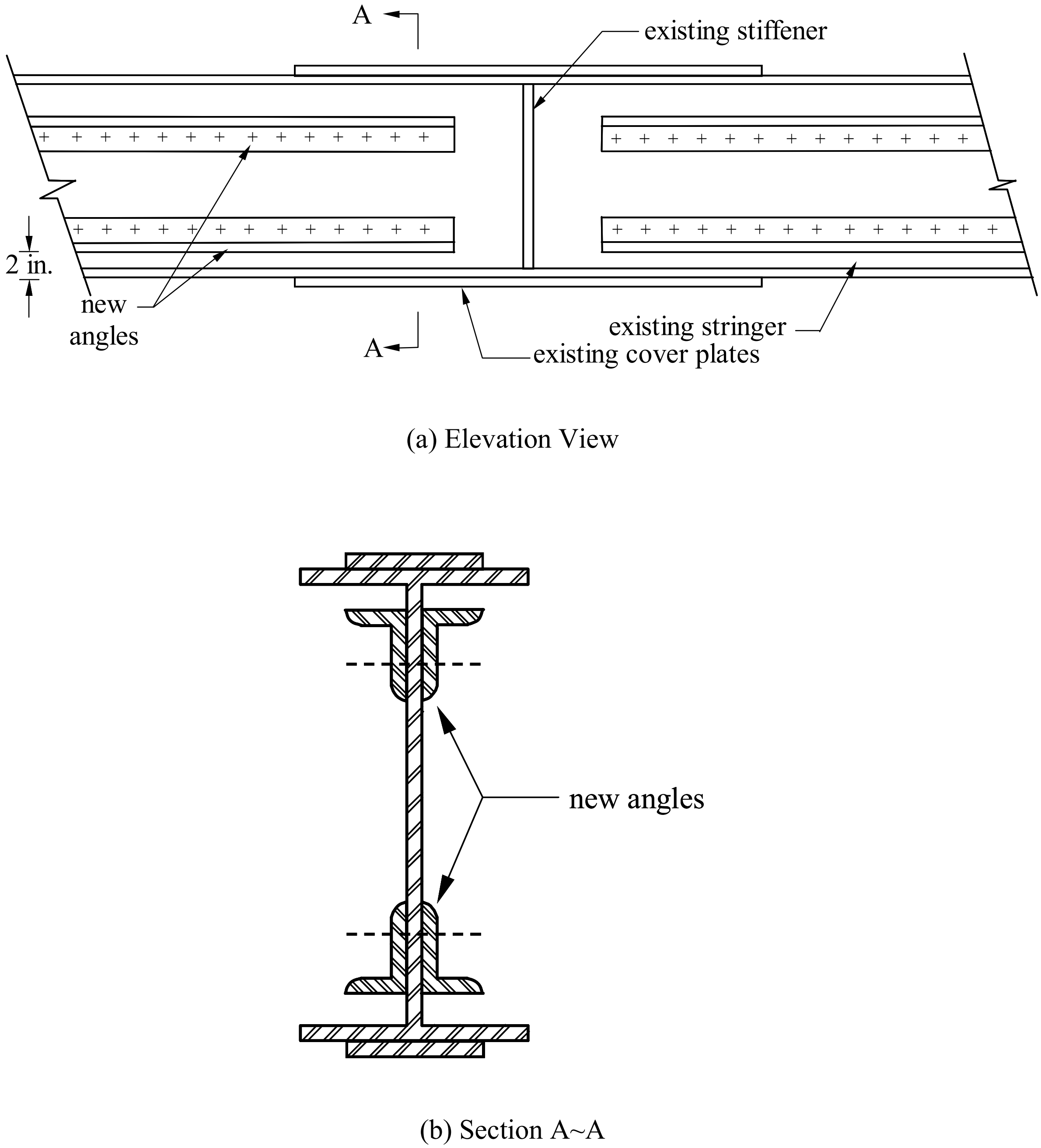


Figure 2.3.5 Reinforcement of Steel Beams by Addition of Angle Stiffeners.

(a) Exterior Girder Strengthened Using Angle Stiffeners

(b) Close up View of the Angle Stiffeners

Figure 2.3.6 Example of Angle Stiffeners Used to Strengthen Bridges.

2.3.4.2 Design of angle stiffeners

Description

Outlined below is a procedure for designing the angle stiffeners that are to be bolted to the web of existing beams.

Design Summary

1. Determine the required increase in moment capacity.
2. Choose a trial size of the angles and their location.
3. Determine the allowable flexural stresses in the new composite section.
4. Determine the moment capacity of the trial section, and compare with desired moment capacity.
5. Repeat Steps 2 to 4 until the desired moment capacity has been achieved.

Design Procedure

1. Determine the required additional moment capacity, ΔM, from the moment envelopes for the desired loading on the bridge.
2. After determining the location of the four the angle stiffeners, the area of each of the 4 angles can be determined using the following equation:

$$A_{angle} = \frac{\Delta M}{4a(0.55F_y)} = \frac{\Delta M}{2.2aF_y} \qquad (2.3.12)$$

where

A_{angle} = the area of each angle that has to be bolted to the steel beam section

ΔM = desired additional moment capacity

F_y = specified yield stress of steel

a = distance to the extreme fiber of the angle from the centroid of the composite section

3. The moment capacity M_{all} of the composite section shall be calculated to be the lesser of

   i. $f_{all,t} \times S_{xt}$ (2.3.13)

   ii. $f_{all,c} \times S_{xc}$

where

S_{xc} = section modulus with respect to the compression flange

S_{xt} = section modulus with respect to the tension flange

$f_{all,t} = 0.55F_y$

$f_{all,c} = 0.55F_y$ for compression flanges that are supported laterally along their full length

$$f_{all,c} = \frac{50 \times 10^6 C_b}{S_{xc}} \left(\frac{I_{yc}}{L} \right) \sqrt{0.772 \frac{J}{I_{yc}} + 9.87 \left(\frac{d}{L} \right)^2} \leq 0.55F_y$$

for unsupported/partially supported compression flanges

$$C_b = 1.75 + 1.05 \left(\frac{M_1}{M_2} \right) + 0.3 \left(\frac{M_1}{M_2} \right)^2 \leq 2.3$$

M_1 is the smaller and M_2 the larger end moment in the unbraced segment of the beam. $\left(\frac{M_1}{M_2} \right)$ is positive when moments cause reverse curvature and negative for single curvature.

C_b = 1.0 for unbraced cantilevers

L = unsupported length (in.)

I_{yc} = moment of inertia of the compression flange about the vertical axis (in^4)

d = depth of the girder (in.)

$$J = \frac{(bt^3)_c + (bt^3)_t + Dt_w^3}{3} \ (in^4)$$

D = unsupported depth of web plate in inches between the flanges (in.)

4. Check if the resulting moment capacity is equal to or greater than the desired moment capacity.
5. If the resulting moment capacity is lower than the desired value, select another angle and repeat Steps 2 to 4 until the required moment capacity has been achieved.

2.3.5 Installation of a Beam Saddle

2.3.5.1 General guidelines for installation of beam saddles

Application

Used to restore bearing for concrete beams where the beam or cap has deteriorated or been damaged in the bearing area.

Repair Method

Fabricate and install a structural steel saddle over the cap and under the beam to support beam.

Material

1. Structural steel sections
2. Bolts with nuts and washer
3. Neoprene bearing pads

Construction Procedure

1. Close the bridge to traffic before initiating repairs.
2. Check plans for width of beam and cap or obtain field measurements.
3. Design the saddle to resist appropriate loads.
4. Fabricate and paint saddle members.

5. Prepare top of cap and beam for good bearing contact between saddle and concrete.

6. Cut Neoprene bearing pads to cover areas of both the cap and the beam that is in contact with the saddle.

7. Set saddle members at right angles to the cap.

8. Install the saddle sections under the beam; place bearing pads before fastening the two sets of saddle members to each other (see Fig. 2.3.7).

2.3.5.2 Design of the beam saddle

Description

The following design procedure outlines the steps to design a steel saddle to relieve excessive bearing stresses.

Design Summary

1. Choose an initial trial size for the saddle.

2. Check if bearing stresses are within permissible limits.

3. Provide stiffeners in the webs if required.

4. Design bolts to carry tension.

Design Procedure

1. Calculate the net reaction, R (lbs), which has to be transferred from the beam to the pier cap.

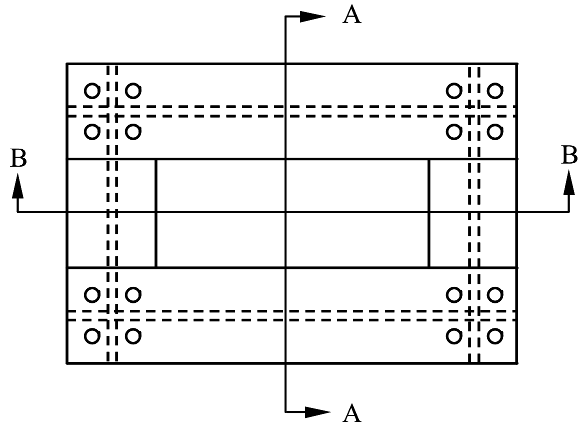
2. Select a trial shape for the rolled steel sections based on bearing stresses (such that the section need not be reinforced with bearing stiffeners).

$$A_w \geq \frac{2.3\,R}{F_{yw}} \qquad (2.3.14)$$

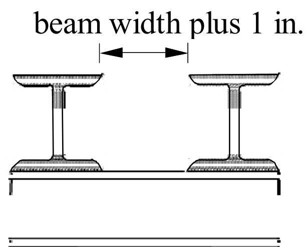
where

A_w = cross sectional area of the web (in^2)

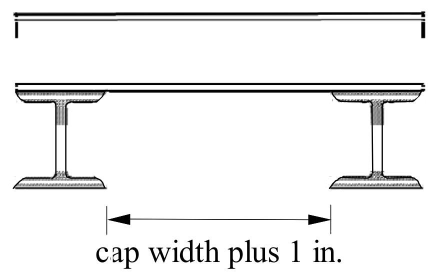
F_{yw} = yield stress of the web material (psi)



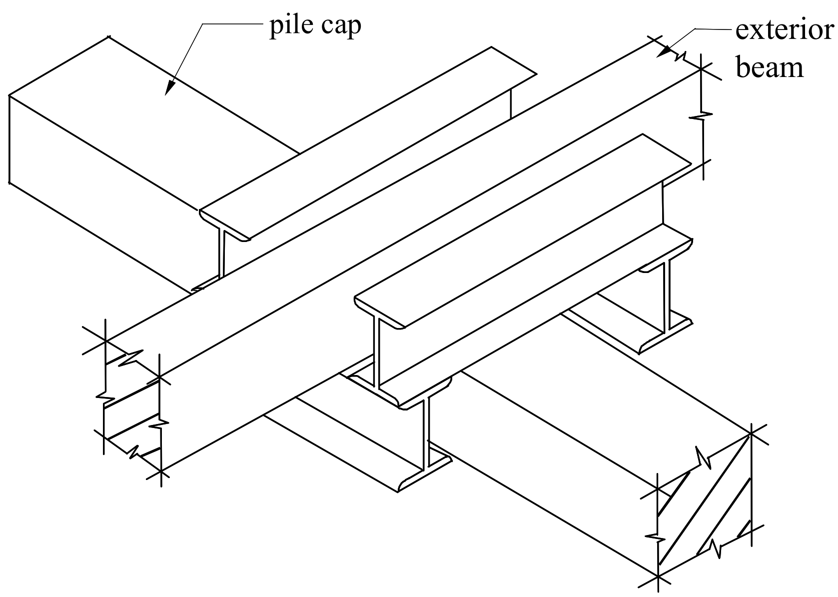
(a) Plan view



(b) Section A~A



(c) Section B~B



(d) Isometric view

Figure 2.3.7 Installation of a Beam Saddle.

3. If the web area determined from Equation 2.3.14 is not a practical value, bearing stiffeners are required in the regions where the beam bears on the saddle and in the region where the saddle bears on the pier cap. Bearing stiffeners should be checked for the following:

   i. Local buckling

$$t_p \geq \frac{b'}{12}\sqrt{\frac{F_y}{33{,}000}} \tag{2.3.15}$$

where

t_p = thickness of the bearing stiffeners (in.)

b' = width of the bearing stiffeners (in.)

F_y = yield stress of the bearing stiffeners (psi)

   ii. Bearing resistance

   iii. Axial resistance of the effective column section

4. Determine if the shear stresses induced are within allowable limits.

5. Check if the flexural stresses are within allowable limits.

6. Assuming a set of ‘N’ symmetrically arranged bolts (N=16 in Fig. 2.3.7), each bolt should be designed to carry an axial tension of R/N (lbs).

2.3.6 Repair of Damaged Bottom Chord Truss Members

2.3.6.1 General guidelines for the implementation of the retrofit

Application

This method is to be used when the damage to the truss member is localized, such as a transverse crack in one of the two channels in the bottom chord of a truss.

Repair Method

Bolt a splice plate to the damaged member. Remove the old tie plates or lacing bars and bolt the new bottom tie plate to the member.

Material

1. Bolts
2. Splice plate
3. New tie plate

Construction Procedure

1. Close the bridge to all traffic before initiating repairs.
2. Bolt a side splice plate to the damaged member. Remove any rivet heads or bolts that would interfere with the splice plate if the repair is near a connection. The plate should be centered over the damage.
3. Remove the old tie plates (or lacing bars) from the two channels in the area of the crack to facilitate the placement of the new bottom tie plate. Some temporary lateral bracing may be required before completing the repair.
4. Bolt the new tie plate to the bottom chord (see Fig. 2.3.8).

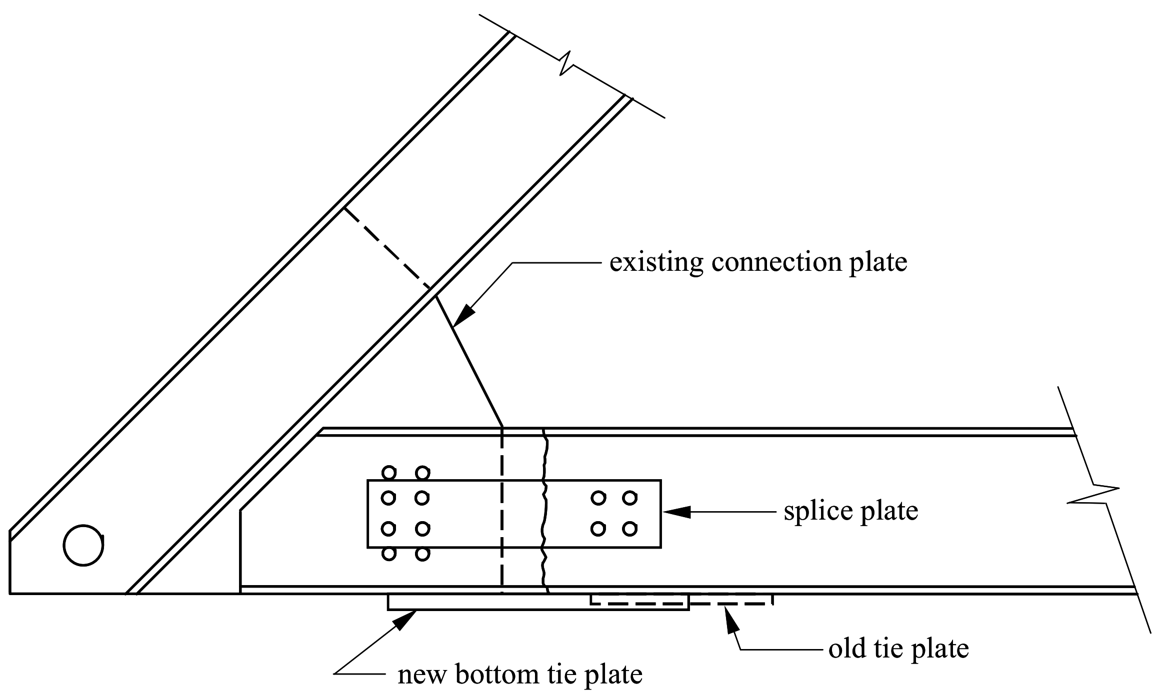


Figure 2.3.8 Repair of Damaged Bottom Chord Truss Members.

2.3.7 Replacement of Diagonal Tension Members

2.3.7.1 General guidelines for replacement of diagonal tension members

Application

This method is used to replace damaged or deteriorated diagonal tension members in trusses with riveted or bolted connections.

Repair Method

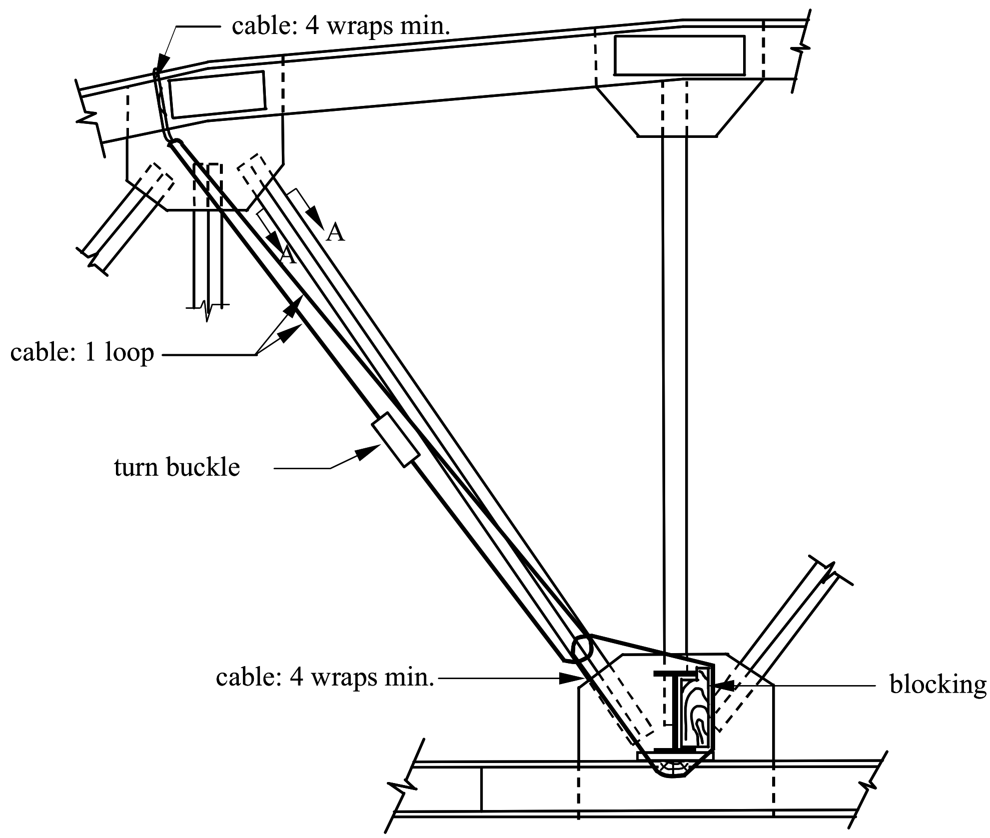
Design the new diagonal section and connections. Install wood blocking and cable having the capacity to carry the full dead load and the live load from restricted traffic. Replace the member providing batten plates and lacing bars where required.

Material

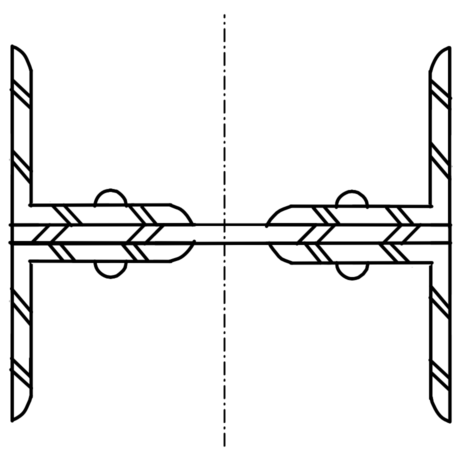
1. Cable sling with turnbuckles
2. Wood blocking
3. Prefabricated steel replacement components
4. Torch and/or other cutting tools

Construction Procedure

1. Restrict traffic on the bridge to the lane opposite of the side where the diagonal member is to be replaced.
2. Design the new diagonal section and its connections.
3. Cut and install the necessary wood blocking.
4. Install a cable with the capacity to carry the full dead load in the diagonal plus the live load distributed from the restricted traffic (see Fig. 2.3.9).
5. Tighten the cable system.
6. Install batten plates or lacing bars at required intervals along the diagonal.
7. Remove cable slings and other temporary components and restore the bridge to normal traffic conditions.



(a) Elevation



(b) Section A~A

Figure 2.3.9 Replacement of a Diagonal Tension Member.

2.3.8 Replacement of Vertical Tension Members

2.3.8.1 General guidelines for the replacement of vertical tension members

Application

The following method is used for replacement of damaged or deteriorated vertical tension member in trusses with riveted or bolted connections.

Repair Method

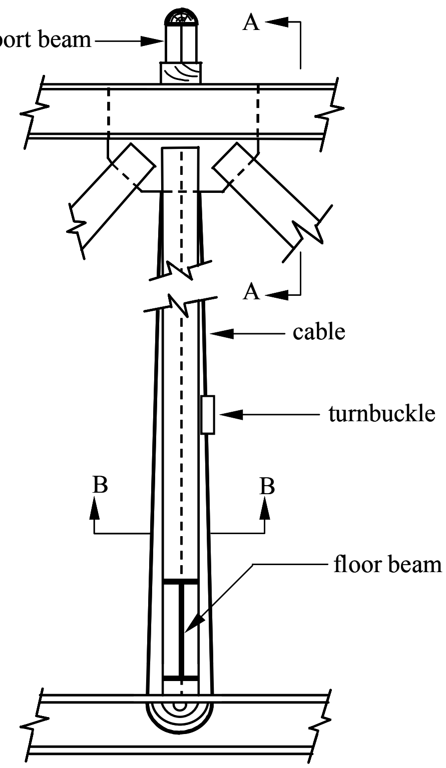
Design the new vertical member. Install wood blocking, support beam, and the cable. Tighten the cable system and replace the truss member, placing lacing bars and batten plates where required. Remove the cables and restore the bridge to normal traffic.

Material

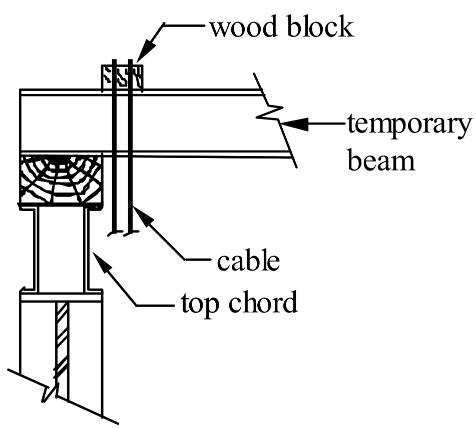
1. Cable sling with turnbuckles
2. Prefabricated steel replacement components
3. Wood blocking
4. Torch and/or other cutting tools

Construction Procedure

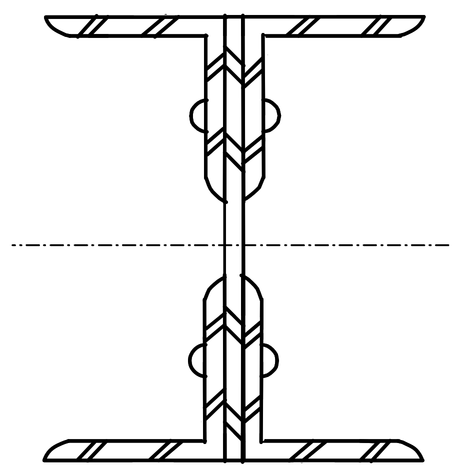
1. Restrict traffic to one lane on the opposite side of the bridge.
2. Design the new vertical section and its connections.
3. Install the wood blocking and the support beam as shown in Fig.2.3.10.
4. Install a cable having the capacity to carry the maximum load in the vertical member being repaired.
5. Tighten the cable system.
6. Install the batten plates or lacing bars at required intervals.
7. Remove cable slings and other temporary components and restore the bridge to normal traffic conditions.



(a) Elevation



(b) Section A~A



(c) Section B~B

Figure 2.3.10 Replacement of Vertical Tension Members.

2.3.9 Widening a Concrete Deck Bridge

2.3.9.1 General guidelines for widening concrete deck bridges

Application

This method is used for increasing the widths of concrete deck bridges.

Repair Method

I. Method A: Widen piers and abutments; erect new exterior girders for the widening. Place reinforcing steel and concrete for initial pour. Remove concrete from the old deck to expose reinforcing steel. Install lateral bracing between old and new girders. Install new reinforcing steel and place closure concrete.

II. Method B: Widen piers and abutments; erect new exterior girders for the widening. Remove concrete from the old deck to expose reinforcing steel. Install lateral bracing between old and new girders. Form a new deck and attach new reinforcing steel and place closure concrete.

Material

1. Shoring
2. Hydraulic lifting equipment
3. New girders
4. Reinforcing steel
5. Concrete

Construction Procedure

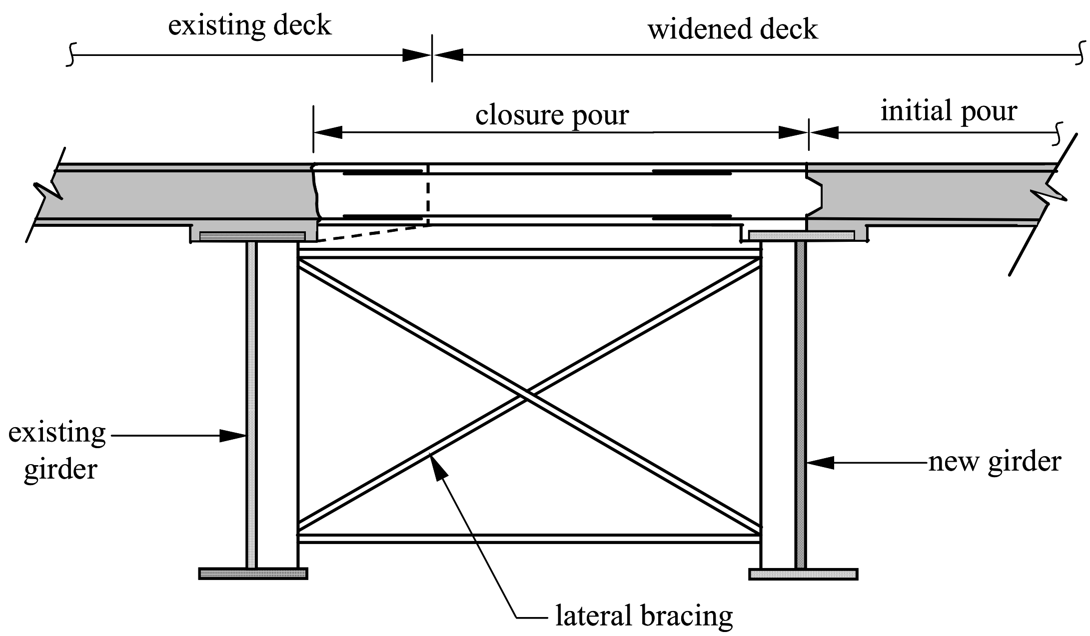
I. Method A

1. Eliminate traffic from at least the lane nearest the widening before the closure concrete is placed.
2. Widen the piers and abutments as necessary.
3. Design the new exterior beams. W-shaped beams or plate girders may be used.
4. Erect the new girders for the widening.

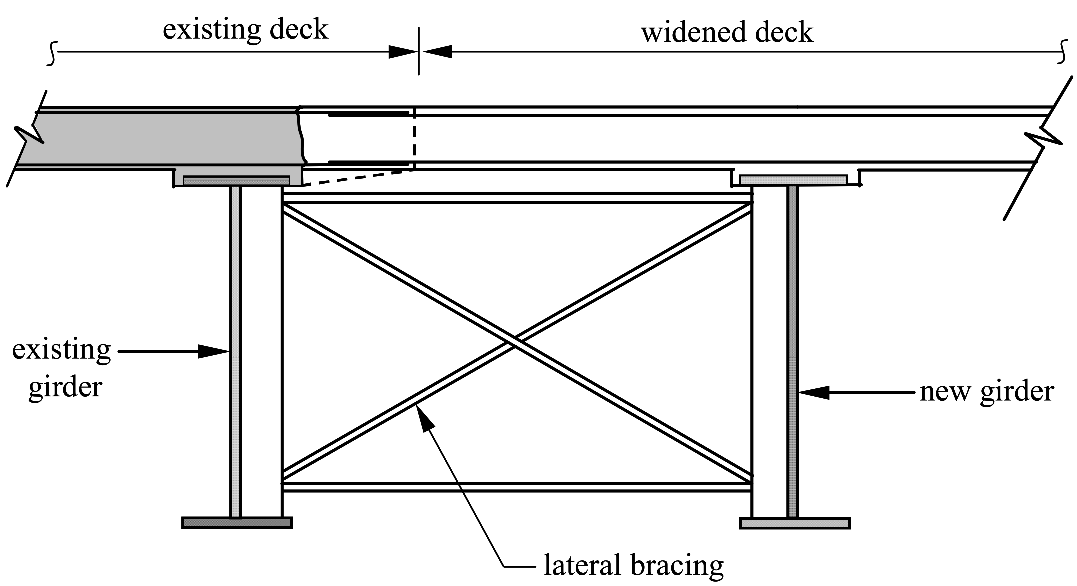
5. Form and place the reinforcing steel and concrete for the initial widening pour.
6. Remove the concrete from the old deck areas to expose the reinforcing steel to provide the length necessary to lap with the new steel.
7. Install adequate lateral bracing between the old exterior girder (i.e. now the interior girder) and the new adjacent girder (i.e. the new exterior girder)
8. Attach the new reinforcing steel to the original by lapping both the top and bottom transverse deck steel (see Fig. 2.3.11 a).
9. Remove falsework and restore the bridge to traffic after the last concrete pour has attained design strength.

II. Method B

1. Eliminate traffic from at least the lane nearest the widening before the closure concrete is placed.
2. Widen the piers and abutments as necessary.
3. Design, fabricate, and erect the new girders for the widening.
4. Remove the concrete from the old deck area to expose the reinforcing steel to the length required to provide necessary development length.
5. Place adequate lateral bracing between the old exterior girder and the new adjacent girder.
6. Form the new deck area and attach the new reinforcing steel to the original by lapping both the top and bottom transverse deck steel (see Fig. 2.3.11 b).
7. Place the concrete for the widening.



(a) Method A



(b) Method B

Figure 2.3.11 Widening Concrete Deck Bridges.

2.3.10 Widening a Concrete Slab Bridge

2.3.10.1 General guidelines for widening concrete slab bridges

Application

This method is used for increasing the width of concrete slab bridges.

Repair Method

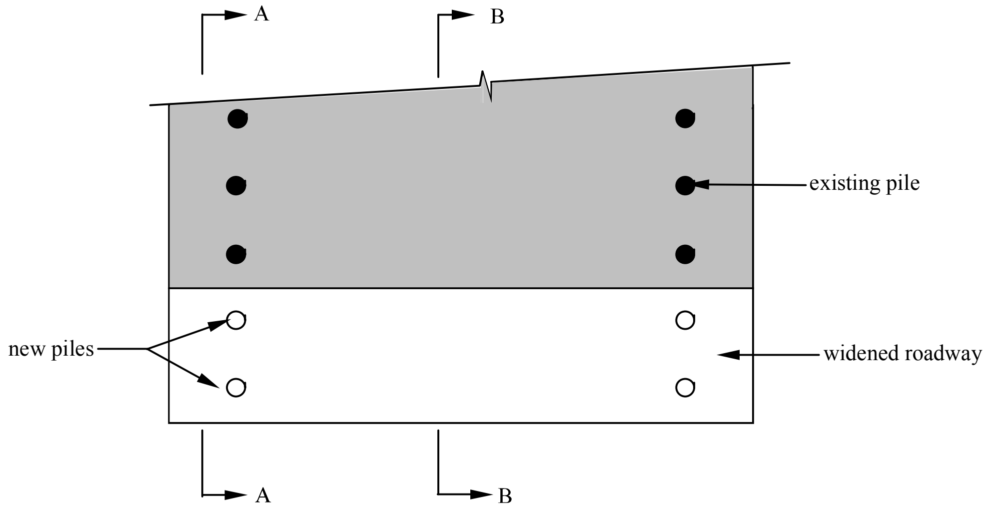
Widen piers and abutments to the new width (refer to Section 2.4.7 for information on widening piers). Support existing slab with shoring. Remove existing parapet and remove adequate concrete from the existing slab to expose the transverse steel. Provide an edge beam for the widened slab. Remove shoring and place bituminous overlay.

Material

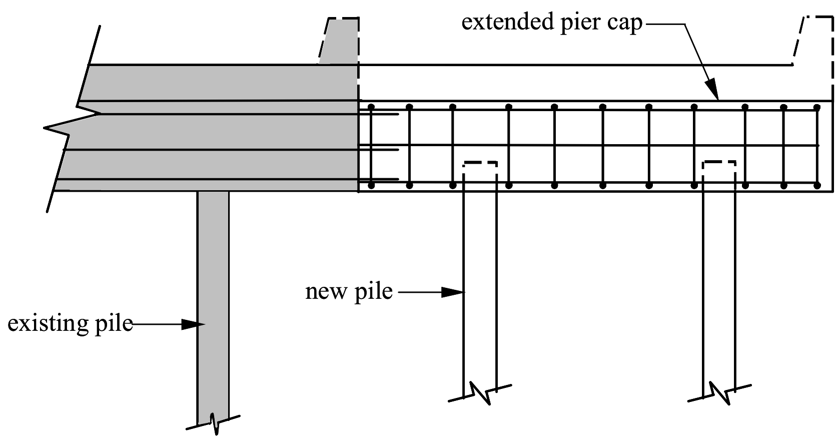
1. Shoring
2. Light lifting equipment
3. Concrete
4. Reinforcing steel
5. Formwork for concrete

Construction Procedure

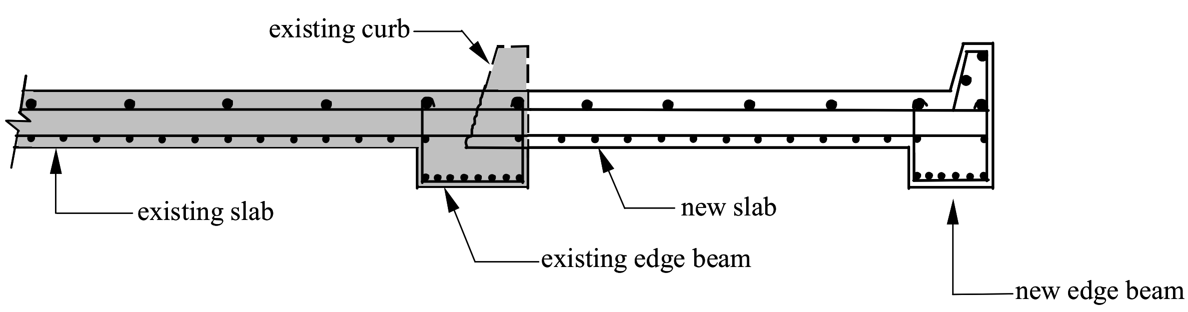
1. Direct traffic to the opposite side of the bridge roadway during slab widening.
2. Widen the piers and abutments to the new width (refer to Section 2.4.7 for information on widening piers). Support the existing slab with shoring before removing the edge parapet curb.
3. Remove the existing parapet concrete and approximately 12 in. of the existing concrete slab to expose the old transverse reinforcing steel.
4. The reinforcing steel in the new section of roadway slab is lapped with the transverse steel in the existing roadway slab.
5. Provide an edge beam for the widened slab by placing extra reinforcement and a new parapet integral with the slab similar to that removed (see Fig. 2.3.12).



(a) Plan View



(b) Section A~A



(c) Section B~B

Figure 2.3.12 Widening of Concrete Slab Bridges.

6. Remove the shoring and falsework after the concrete has attained the desired strength.

7. Place a suitable bituminous overlay across the entire new deck surface to provide a crown to the roadway and a smoother riding surface.

2.3.11 Repair of Cracked or Split Timber Stringers

2.3.11.1 General guidelines for repair of cracked or split timber stringers

Application

This procedure is to be used to repair damaged stringers, which have longitudinal cracks when it is not desirable to remove the deck planks and replace the stringer.

Repair Method

Steel plates and bolts are used to carry out the retrofit.

Material

1. Draw up bolts

2. Steel straps

3. Retaining plates

4. Jacking equipment

Construction Procedure

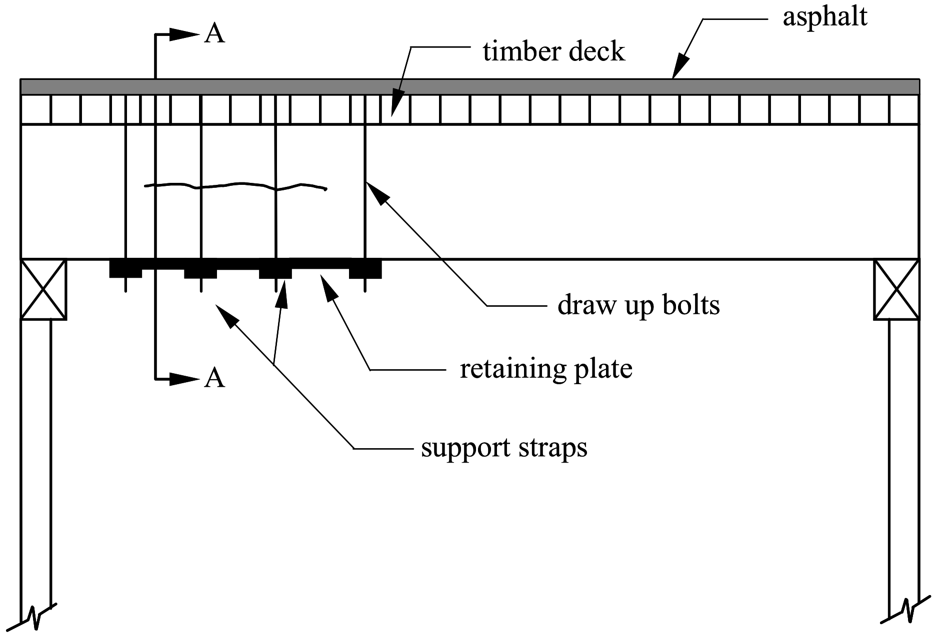
1. Close bridge to traffic during the repair period.

2. Determine the force that would be necessary at a location near the cracked portion of the stringer to eliminate the dead load moment. Calculate the corresponding deflection this force would produce at the point where the beam is to be lifted up. The stringer to be repaired should be raised exactly this amount.

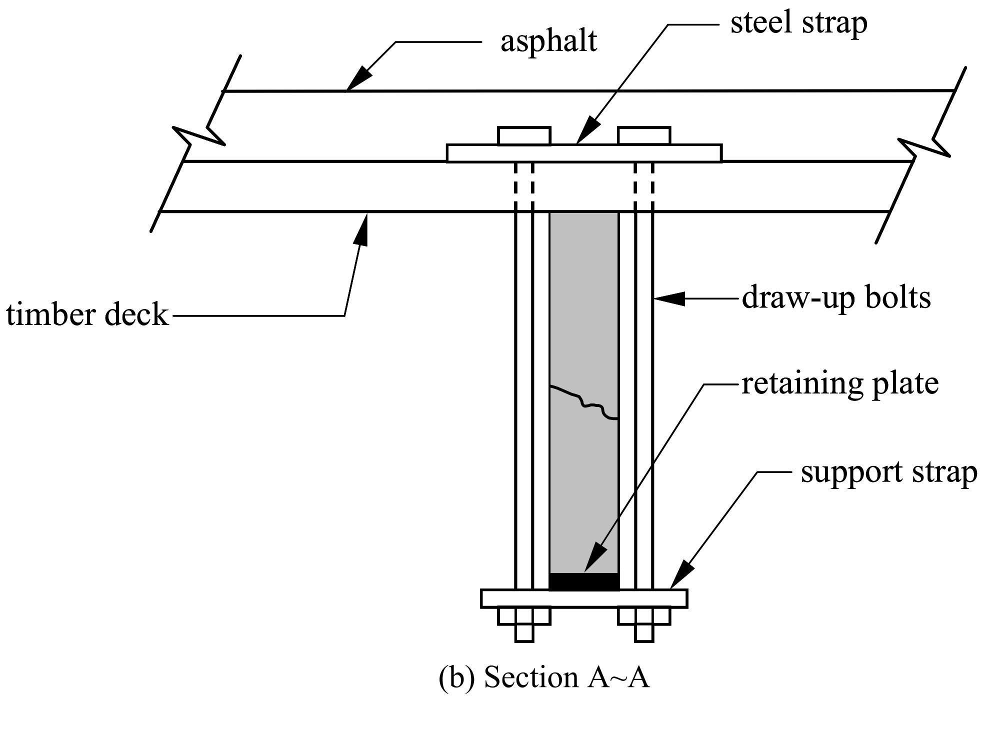
3. Remove the asphalt overlay in the area where the holes are to be drilled.

4. Drill holes for ‘draw up’ bolts through the bridge deck.

5. Place the retaining and support plates (see Fig.2.3.13) and tighten the draw up bolts.



(a) Elevation



(b) Section A~A

Figure 2.3.13 Repair of Cracked or Damaged Timber Stringers.

6. Replace the wearing surface.

2.3.11.2 Design guidelines for the repair of cracked or split timber stringers

Description

The procedure presented below outlines the method for calculating the distance the cracked stringer has to be jacked up prior to repairing the cracked or split timber stringer. The procedure presented is specific to simply supported stringers.

Design Summary

1. Compute the dead load moment at the section of interest.
2. Compute the jacking force that is required to counter the dead load moment.
3. Calculate the deflection that is produced by the load from the jack.

Design Procedure

1. Compute the dead load that is carried by each stringer, W_d (lbs/in.).
2. Assuming the stringer to be simply supported, the dead load moment at the section a distance x from the end of the beam is given by:

$$M_x = W_d \frac{x}{2}(L - x) \tag{2.3.16}$$

where

M_x = dead load moment (in.-lbs) at a distance x (in.) from one end of the beam

L = span of the stringer (in.)

3. The load P from the jack that should be applied at the section x from the end of the beam is given by:

$$P = \frac{W_d L}{2} \text{ (lbs)} \tag{2.3.17}$$

4. The deflection Δ_x that the load P would induce is given by

$$\Delta_x = \frac{M_x x(L - x)}{3EI} \text{ (in.)} \tag{2.3.18}$$

where

E = elastic modulus of the timber stringer (psi)

Δ_x = deflection at section x from the end of the beam

I = moment of inertia of the cracked stringer (in^4)

2.3.12 Replacement of Timber Stringers

2.3.12.1 General guidelines for replacement of timber stringers

Application

This method is used for the replacement of cracked or deteriorated wooden stringers supported on pier caps. The deteriorated stringer is used as a nailing strip for the new stringer.

Repair Method

Cut to length and taper new stringer ends. "Clip" ends of the stringer to facilitate the placement operation, and drive wedges under the new stringer and secure with spikes. Secure the old and new stringer at intervals with bolts.

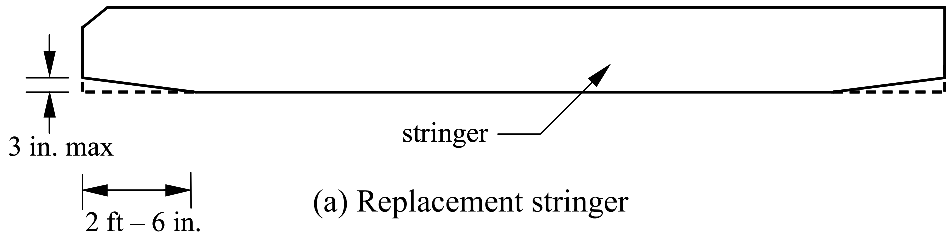
Material

1. Timber stringers
2. Light lifting equipment
3. Hand tools
4. Power saw

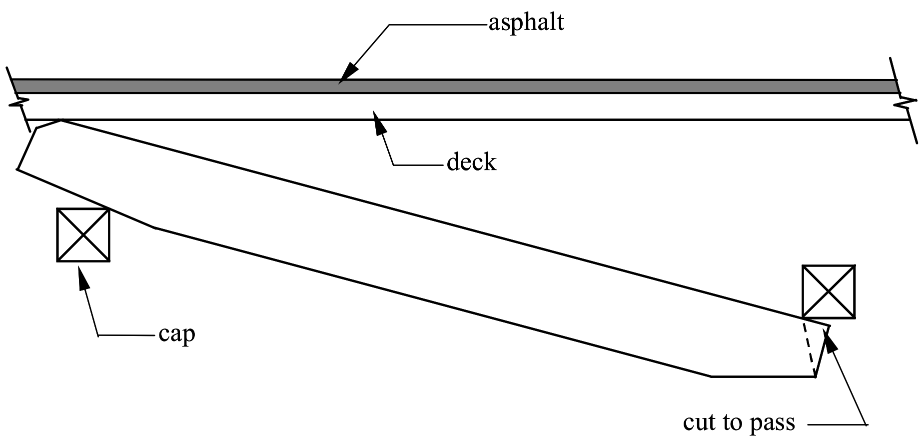
Construction Procedure

1. Close bridge to traffic before initiating repairs.
2. Cut the new stringer to the required length and taper the ends (see Fig 2.3.14 a).
3. Lift the new stringer into position (see Fig 2.3.14 b). Clip the ends of the beam as required, to facilitate the placement operation.
4. Drive wedges under the new stringer until it bears against the deck.
5. Secure the wedges with spikes (see Fig 2.3.14 c).

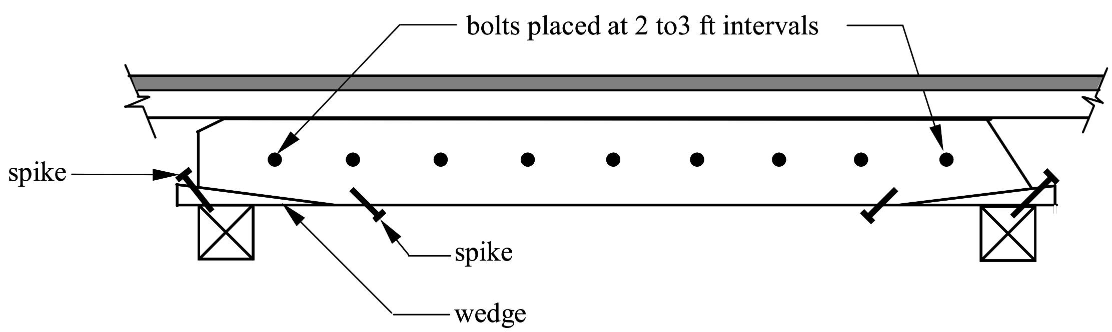
6. Secure the old stringer to new stringer at 2 ft to 3 ft intervals by using 3/4 in.ϕ bolts placed at mid-depth.



(a) Replacement stringer



(b) New stringer lifted into position



(c) New stringer secured in place using spikes and bolts

Figure 2.3.14 Replacement of Timber Stringers.

2.3.13 Repair of Decaying Timber Bridge Deck Members

2.3.13.1 General guidelines for the replacement of timber deck planks.

Application

This method is used when only a few of the timber planks in a bridge are decayed.

Repair Method

Remove and replace the deteriorated decking; spike the new deck planks into place.

Materials

1. Timber planks
2. Spikes
3. Anchor plates

Construction Procedure

1. Close the bridge to all traffic before initiating repairs.
2. Remove and store deck-mounted curbs, parapets, wheel guards and railings.
3. Remove existing deteriorated decking that can be repaired or replaced in the same workday.
4. Clean and paint top flanges of stringers.
5. Place deck planks on the stringers parallel to the abutments. Make certain that each plank rests on at least three stringers and that all end joints of planks are staggered across the deck.
6. Spike each plank in place with spikes spaced 12 in. apart and alternate adjacent spikes (one being about 2 in. from the top of the plank and the next about 2 inches from the bottom of the plank).
7. Place anchor clips and space them at approximately 12 in. centers (see Fig. 2.3.15)
8. Apply wood preservative to the ends of any plank that is field cut (treated lumber should always be used for timber deck maintenance and replacement). Replace

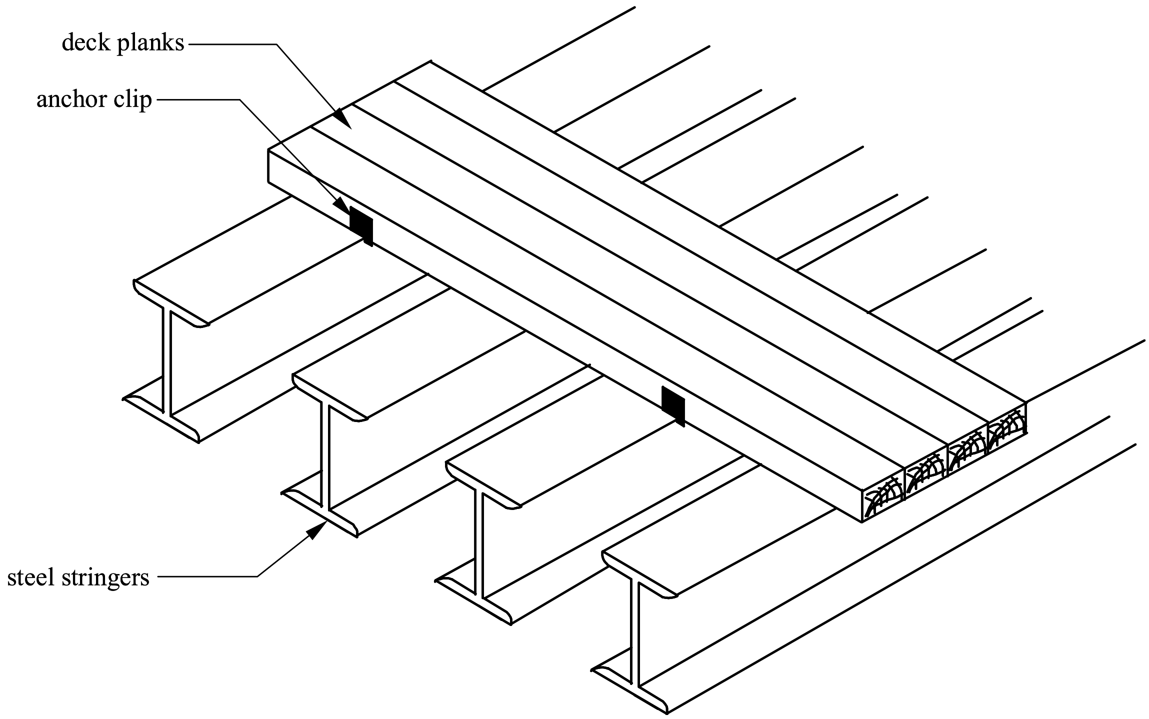


Figure 2.3.15 Replacement of Timber Deck Planks.

all deck-mounted appurtenances (curbs, wheel guards, railings etc.) after any wearing surface has been applied.

2.3.14 Concrete Deck Patching

2.3.14.1 General guidelines for concrete deck patching

Application

This method is to be used when the area of delamination is limited.

Repair Method

Determine the areas of the bridge deck with mild to severe deterioration of concrete. Mark the deteriorated areas for rehabilitation, and determine the size of the area and the depth of patching. Replace the deteriorated reinforcement and place the concrete patch.

Material

1. Concrete patching mixture
2. Epoxy coated reinforcing steel bars
3. Epoxy bonding compound or mortar cement.

Construction Procedure

1. Close bridge to all traffic before initiating repairs.
2. Evaluate the surface areas to be patched, using hammers or a drag chain for hollow sounding.
3. Outline the area to be patched with spray paint (or lumber crayon). A rectangular area with square corners best facilitates using the concrete saw. Mark the area about 6 in. beyond the detected delamination to ensure removal of all damaged concrete.
4. The saw cut should be about 0.6 in. deep around the edge of the patch to provide a good vertical edge face. Monitor sawing to ensure that no reinforcing steel is cut. Patch areas that are within 2 ft of each other should be combined into a single larger patch.
5. Workers should use hand tools or pneumatic hammers weighing 30 lbs or less, at an angle of 45° or 60° to the deck, to remove the concrete within the patch area. The patch area should be periodically sounded to ensure that the area and depth are correct and that all deteriorated concrete has been removed. Fracture lines over a reinforcing steel bar indicate a potential spall and should be removed.
6. The patch area should be thoroughly cleaned by sandblasting or water blasting to remove loose concrete, rust, oil, or other material that would prevent good concrete bond.
7. Reinforcing steel will deteriorate from any form of corrosion. As a general rule, if the reinforcing bars have lost more than 20% of their original cross section, new reinforcement should be added by lapping, welding, or mechanically connecting

them to the deteriorated bars. Reinforcing steel not being replaced can be coated with epoxy.

8. A full depth removal of concrete is recommended if less than 50% of the original sound concrete remains. Patching is often classified according to the depth of the patch required to make the necessary repairs.

    i **Type A:** Patch only above the top layer of the reinforcing steel. This type of patching may require special aggregate since the largest diameter of aggregate particles cannot exceed the depth of patch. If the depth is too thin for effective concrete patching and simultaneously too thick for epoxy mortar patching, then the patch depth may need to be increased to create an effective concrete patch.

    ii **Type B:** Patch from the deck surface to at least 1 in. below the top mat of the reinforcing steel. Type B patching will require removing enough concrete from under the reinforcing steel bars to permit fresh concrete to flow under the bars and to ensure that no voids form.

    iii **Type C (Full Depth Patch):** If Type C patching is required, ensure that preparation includes gaining access to the deck's underside. Type C patching will require formwork to support the patch. When any Type C patch exceeds a 4 ft x 4 ft area, an engineer qualified to assess the structural implications should be consulted (see Fig 2.3.16).

9. Before placing the patch concrete, an epoxy bonding compound or mortar cement should be placed on the old concrete surface to ensure the two surfaces adhere to one another.

10. When the fresh concrete is placed in the patch hole, the surface of the concrete to be patched should be free of standing water. The patch concrete should be finished with a straight edge or float to produce a patch surface that is no more than 1/8 in. above or below the surrounding concrete surface.

11. If the patched area must be opened to vehicular traffic quickly, rapid setting patch materials can be used. However, maintenance personnel must follow the

Figure 2.3.16 Full Depth Deck Patching.

manufacturers or agency's specification exactly while applying these materials.

12. Any patching concrete mixed at the job site should be mixed in accordance with a design developed by a qualified materials engineer using agency specifications. If large areas of a deck are being patched, a qualified bridge engineer should be consulted to determine if the patching process would adversely affect the bridge's structural capacity.
13. Proper curing of the patch is important. If the concrete being used is supposed to have a wet cure, ensure that the surface remains wet until it is opened to traffic. Membrane sealing cures may be appropriate to avoid problems with moisture.

2.3.15 Installation of Expansion Joint Seals

2.3.15.1 General guidelines for installation of expansion joint seals.

Application

This method is used to seal open joints or reseal joints where preformed joint material has failed.

Repair Method

Clean the joint and install seal after applying an appropriate lubricant. Recess the seal from the deck surface.

Materials

1. Elastomeric compression seal
2. Lubricant

Construction Method

1. Close the bridge to traffic before initiating the repairs.
2. Determine the size of the joint material required.
3. Clean joint as necessary. If joint contains compressed debris or preformed joint material, a high-pressure water jet may be required to clean the joint.
4. Apply adhesive/lubricant by brush to each inner joint face.
5. Position seal over joint as shown Fig. 2.3.17.
6. Install compression seal as per manufacturer's recommendation.
7. Recess the seal 1/4 in. below deck surface.

2.3.16 Maintenance of Bridge Bearings

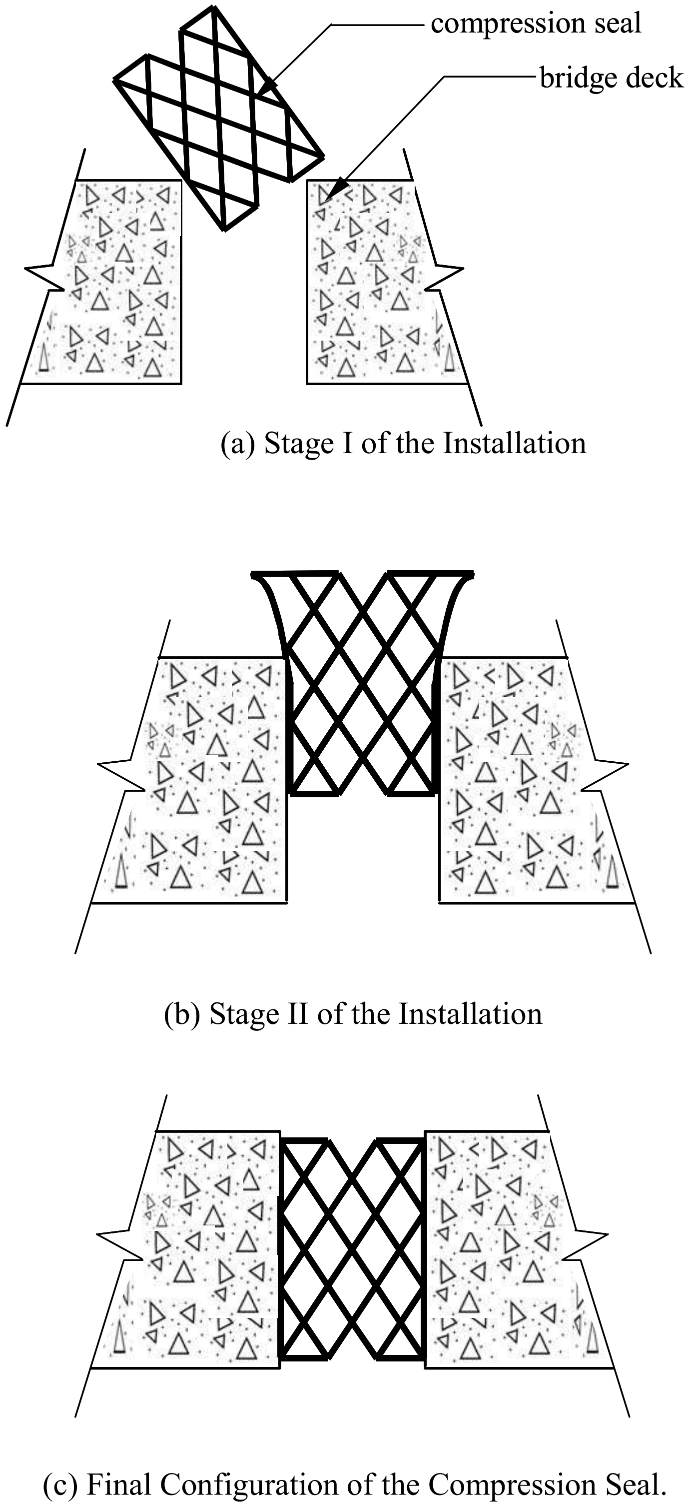
2.3.16.1 General guidelines for the maintenance of bridge bearings

Application

This operation is performed to prevent seizing or freezing of bearing components usually caused by corrosion between moving and non-moving components.

Repair Method

Lift up the beam, clean and then lubricate individual components. Reinstall the components.



(a) Stage I of the Installation

(b) Stage II of the Installation

(c) Final Configuration of the Compression Seal.

Figure 2.3.17 Installation of Elastomeric Compression Seals.

Material

1. Hydraulic lifting equipment
2. Waterproof grease

Construction Procedure

I. Maintenance of sliding bearings

1. Close bridge to traffic before initiating the repair.
2. Lift the bridge deck up; remove both components of the sliding bearing.
3. Clean the bearing sliding surface and the bearing plate surface.
4. Apply a liberal coating of waterproof grease on both surfaces.
5. Reinstall the bearing components to their original configuration (see Fig 2.3.18.a).

II. Maintenance of rocker bearings

1. Close bridge to traffic before initiating the repair.
2. Lift up the bridge deck; remove the pins and rockers.
3. Clean the surfaces in contact and remove any foreign material.
4. Apply coating of waterproof grease on the rocker pin.
5. Reinstall the bearing components to their original configuration (see Fig 2.3.18.b).

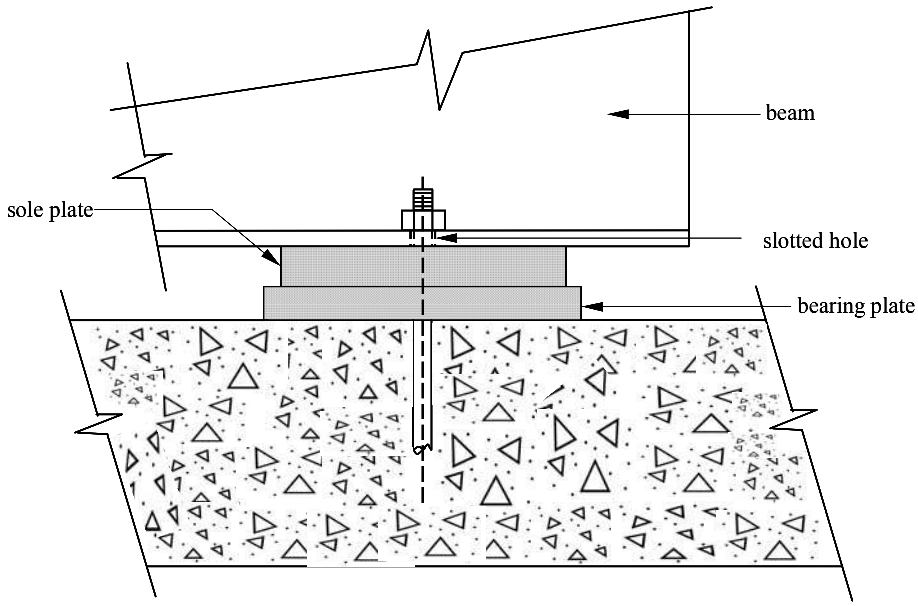
2.4 Repair and Rehabilitation of Bridge Substructure Components

2.4.1 Installation and Repair of Timber Pile Sway Bracing

2.4.1.1 General guidelines for installation and repair of sway bracing

Application

This repair procedure outlines the installation of new sway bracing for timber bents that have been determined to be unstable. The repair procedures for replacing existing sway bracing has also been outlined.



(a) Sliding Bearings

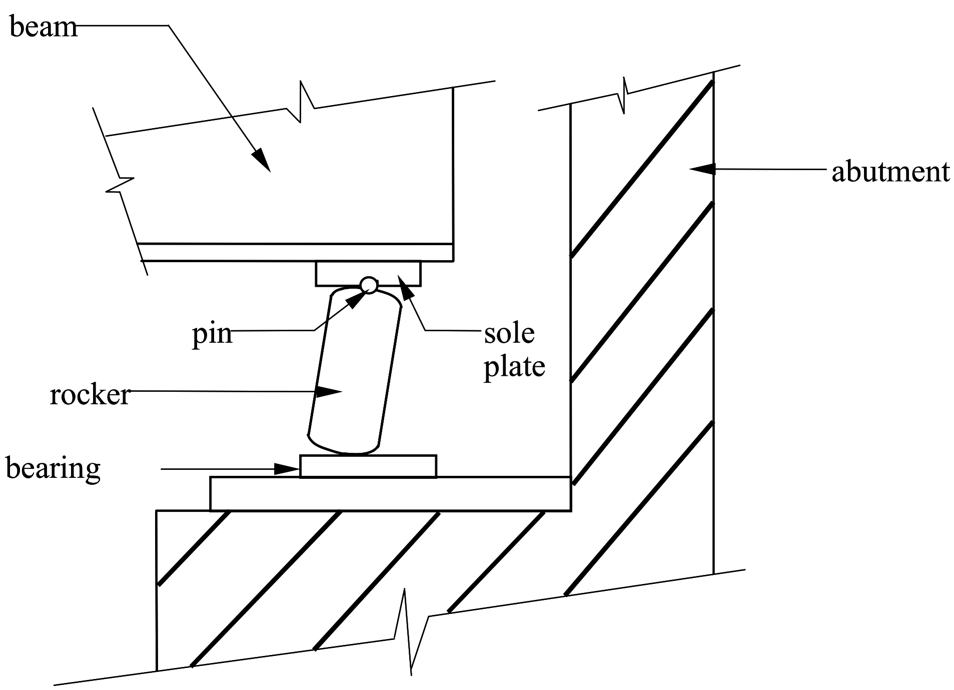


Figure 2.3.18 Maintenance of Common Bridge Bearings.

Repair Method

I. Installation of new sway bracing: Use nails to temporarily fasten the sway bracing to the timber piles; drill holes through both the bracing and the piling to permanently fasten the bracing to the piles with bolts.

II. Repair of deteriorated sway bracing: Cut the bracing at the pile nearest to the the deterioration so that the deteriorated material is removed. Provide new bracing sections.

Material

1. Treated timber sections
2. Galvanized bolts
3. Cast Iron washers

Construction Procedure

I. Installation of sway bracing in pile bents without sway bracing

1. Temporarily attach the sway bracing to piling with galvanized nails.
2. Determine the position of bolt holes and drill through both the bracing and the pile.
3. Treat all holes with hot oil preservative before installing the bolts.
4. Place and tighten the bolts and washers.

II. Repair of existing sway bracing

1. Locate the terminus of deterioration or damage of the sway bracing. Cut off the bracing at the pile nearest to the terminus.
2. Measure length of new bracing required for reconnecting the piles. Cut new sections based on this length.
3. Use existing bolt holes in piles, where possible. Drill new holes in piles when sway bracing must be realigned. Treat both new bolt holes and old ones to be reused with hot oil preservative (see Fig. 2.4.1).

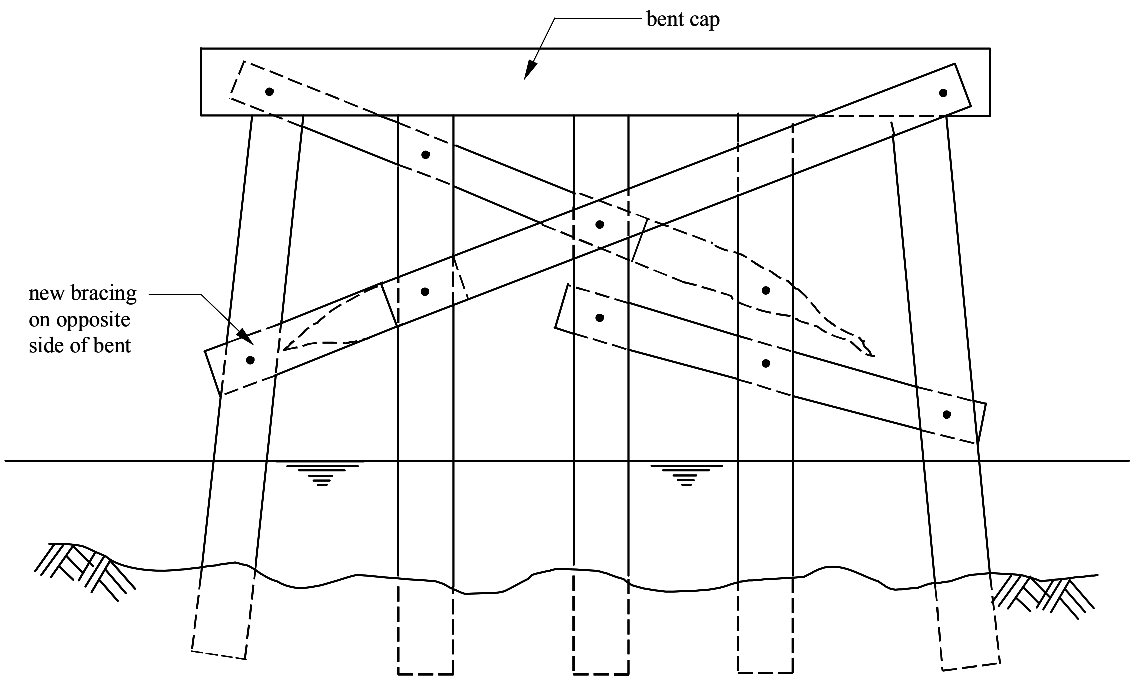


Figure 2.4.1 Installation and Repair of Timber Pile Sway Bracing.

4. Treat all timber cuts; both old and new sway bracing, with a hot oil preservative followed by a coating of hot tar.

2.4.2 Shimming Timber Piles

2.4.2.1 General guidelines for shimming timber piles

Application

This method may be used to restore bearing that has been lost between the pile cap and the pile due to settlement or decay.

Repair Method

The cap is lifted up and a wedge is inserted between the cap and the pile head.

Materials

1. Treated timber for shim pieces

2. Nails

3. Hydraulic lifting equipment

Construction Procedure

1. Close bridge to traffic before initiating repairs.
2. Place cribbing (strut) adjacent to pile to be shimmed. If several piles in one bent need to be shimmed, cribbing should be placed to allow shimming of all piles at one time.
3. Set the hydraulic lifts on the cribbing (strut) and raise the pile cap approximately 1/2 in. higher than the desired elevation.
4. Cut the shim pieces 1/4 in. less than the opening between the cap and the pile head and then place them into position.
5. Lower the pile cap and fasten the shim pieces to the pile using nails (see Fig. 2.4.2).
6. Remove the cribbing.

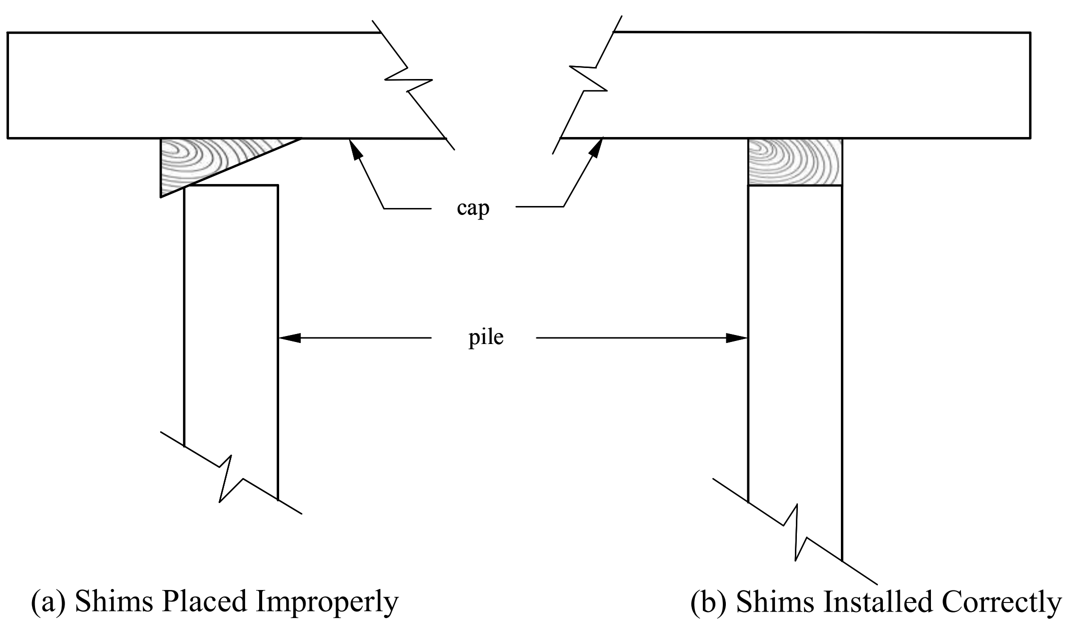


Figure 2.4.2 Shimming Timber Piles.

2.4.3 Pile Splice

2.4.3.1 General guidelines for implementation of the retrofit

Application

This method may be used for repairing timber piles that are deteriorated at or above the ground level. No more than half of all the piles in a bent should be repaired using this method.

Repair Method

Excavate soil around the pile. Install a timber strut to support the hydraulic lifting equipment and lift up the cap. Cut the existing pile below the permanent moisture line. Position the new pile section under the pile cap at the same location as the original pile. Place and form reinforcing steel for concrete jackets, and cast the concrete. There should be a minimum cover of 6 in. around the pile.

Materials

1. Treated timber pile
2. Reinforcing steel
3. Jacket formwork.
4. Bolts and nails

Construction Procedure

1. Close bridge to traffic before initiating repairs.
2. Excavate around the pile to depth well below the permanent moisture line.
3. Construct cribbing or place struts for supporting the jacking equipment.
4. Lift the cap by 1/2 in. to 1 in.
5. Remove the dowel connecting the pile cap and the pile.
6. Cut deteriorated pile below the permanent moisture line.
7. Cut a new pile section 1/ 4 in. longer than the removed section.

8. Place the new pile section on top of the stump of the older pile. Make sure there is even bearing. Lower the existing pile.
9. Place the formwork and the reinforcing steel for the pile jacket.
10. A minimum of 6 in. cover should be provided around the pile (the top of jacket should be sloped slightly to allow for run off.).
11. Fasten the top of the pile to the pile cap using metal fasteners (see Fig 2.4.3).

2.4.4 Addition of Supplemental Piles for Strengthening Pile Bents.

2.4.4.1 General guidelines for the addition of supplemental steel piles

Application

In this method, supplemental steel H-piles are added to strengthen a timber pile bent that has been weakened due to pile deterioration or settlement.

Repair Method

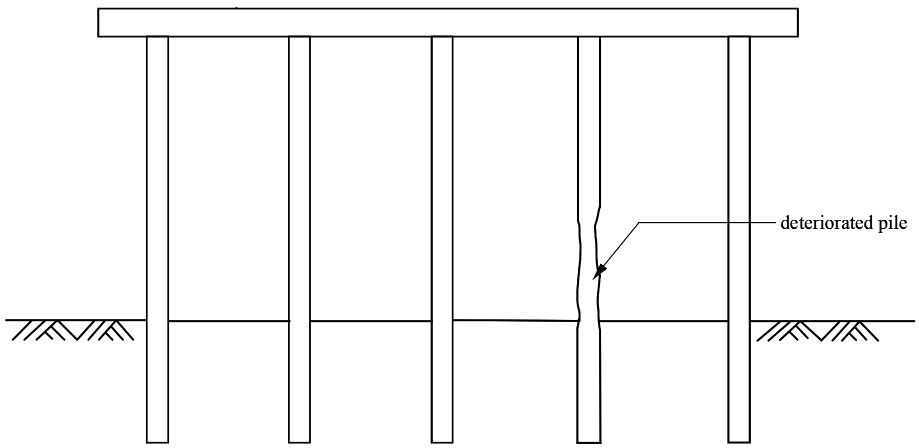
Cut holes in the bridge deck and drive new piles as needed. Weld or bolt support beams to the new piles. Provide shim plates as needed to provide uniform bearing between the support beams and the timber pile cap.

Material

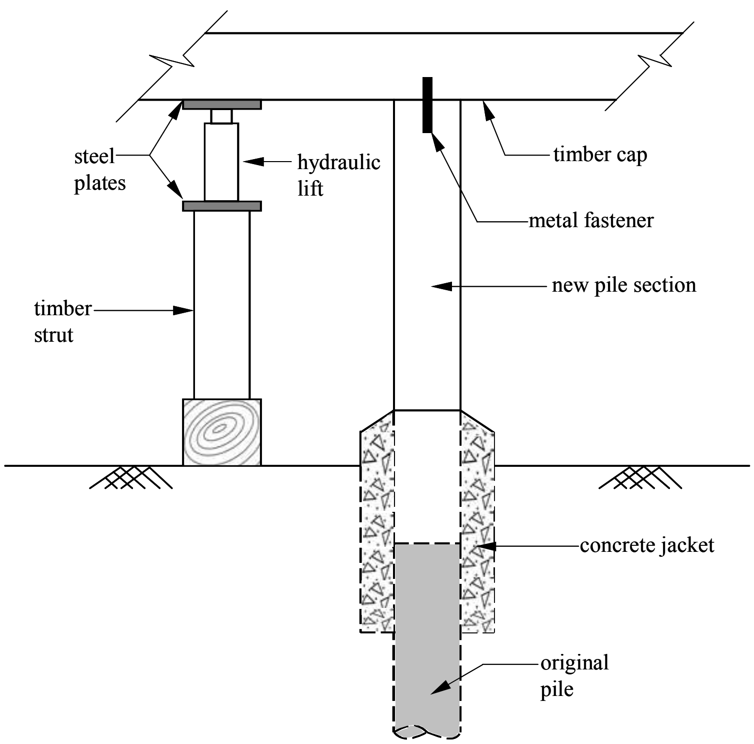
1. Steel H piles
2. Steel cap beams
3. Cross bracing as needed
4. Welding equipment
5. Patching material

Construction Procedure

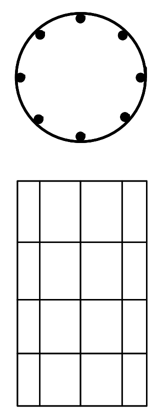
1. Close bridge to traffic before initiating repairs.
2. Cut holes in the deck large enough to accommodate the supplemental piles, which may be battered as necessary.



(a) Damaged Pile to be Retrofitted by Splicing



(b) New Pile Section Spliced to the Stub of the Original Pile



(c) Reinforcement Details

Figure 2.4.3 Timber Pile Splice.

3. Cut any deck reinforcement that may obstruct the driving of piles; adequate splice length should be provided.
4. Drive piles and cut off at a level sufficiently below the pier cap to accommodate the support beam.
5. Weld or bolt the piles to the support beam.
6. The support beam must be fit snug against the pier cap; shim plates may be used to provide uniform bearing between the top flange of the support beam and the bottom of the pier cap (see Figs. 2.4.4. and 2.4.5).
7. Splice new reinforcing bars to both the top and bottom reinforcement that were cut to drive the piles.
8. Repair the deck holes with a suitable patching material.

2.4.4.2 General guidelines for the addition of supplemental timber piles

Application

In this method, supplemental timber piles are installed for strengthening a weakened bridge substructure.

Repair Method

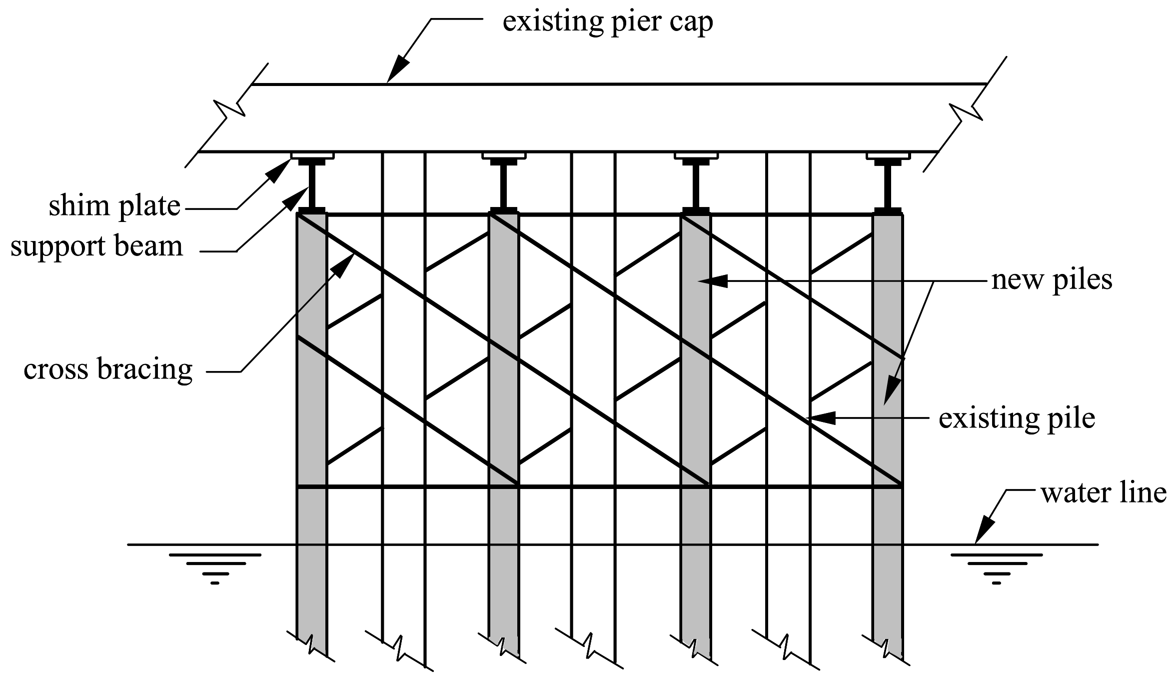
Supplemental timber piles are installed under a sound pier cap to provide support after existing piles have deteriorated or settled out of position.

Material

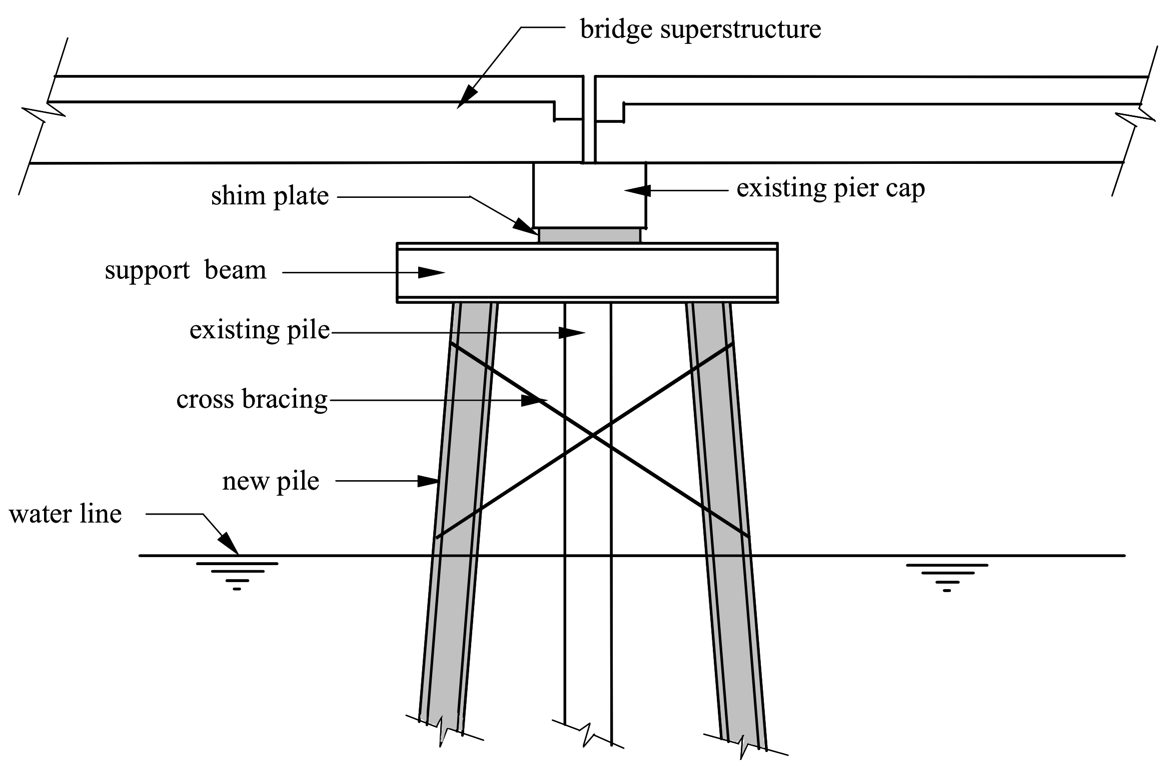
1. Timber piling
2. Patching material

Construction Procedure

1. Close bridge to traffic before initiating repairs.
2. Cut any deck reinforcement that may obstruct the installation of the new piles; adequate splice length should be provided.
3. Cut openings in the bridge deck to allow the new piles to be driven.



(a) Front Elevation



(b) Side Elevation

Figure 2.4.4 Addition of Supplemental Steel Piles.

(a) Deteriorated Pile

(b) Strengthening by Addition of Supplementary Steel Piles

Figure 2.4.5 Example of Addition of Supplementary Steel Piles.

4. Drive the new piles into position. Cut the piles off so that there would be even bearing between the pile cap and the new support beams.

5. Wedge the support beam into position on top of the new piles (see Fig. 2.4.6).

6. Splice new bars that were cut to drive the piles to both the top and bottom reinforcement.

7. Repair the opening in the bridge deck with a suitable patching material.

2.4.5 Repair of Steel H-Piles

2.4.5.1 General guidelines for the implementation of the retrofit

Application

When pile replacement is not practical, this method can be used to repair deteriorated or damaged steel H-piles.

Repair Method

Temporarily clamp the channel sections to the steel pile. Fasten the channels permanently to the pile using high strength bolts.

Material

1. Drilling equipment

2. High strength bolts, nuts and washers

3. Steel channel sections

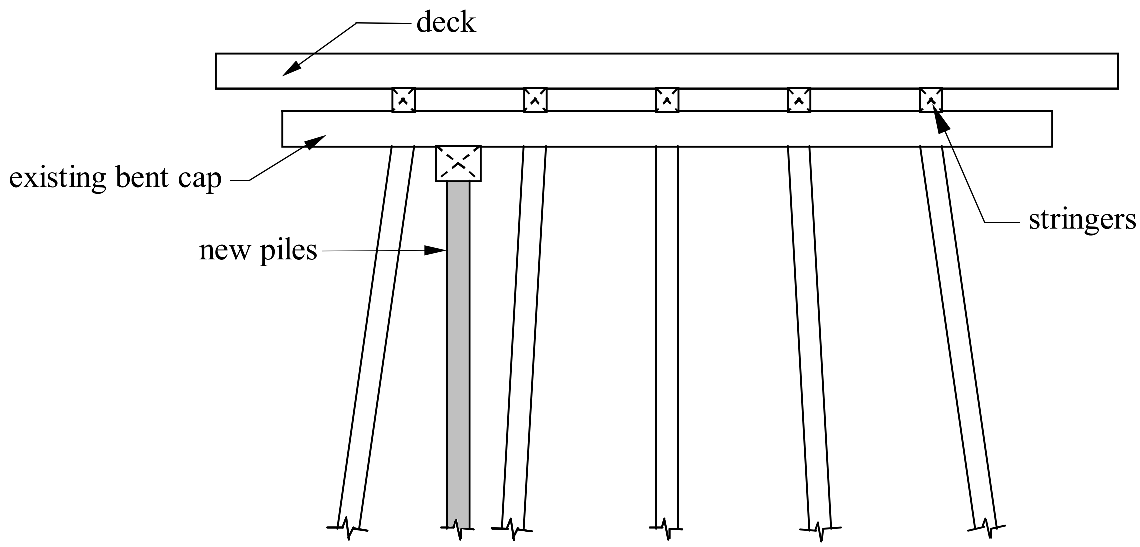
Construction Procedure

1. Locate the extremes of the region(s) of deterioration and/or damage. The channel sections to be spliced to the pile in these regions shall extend 9 in. past the deteriorated region.

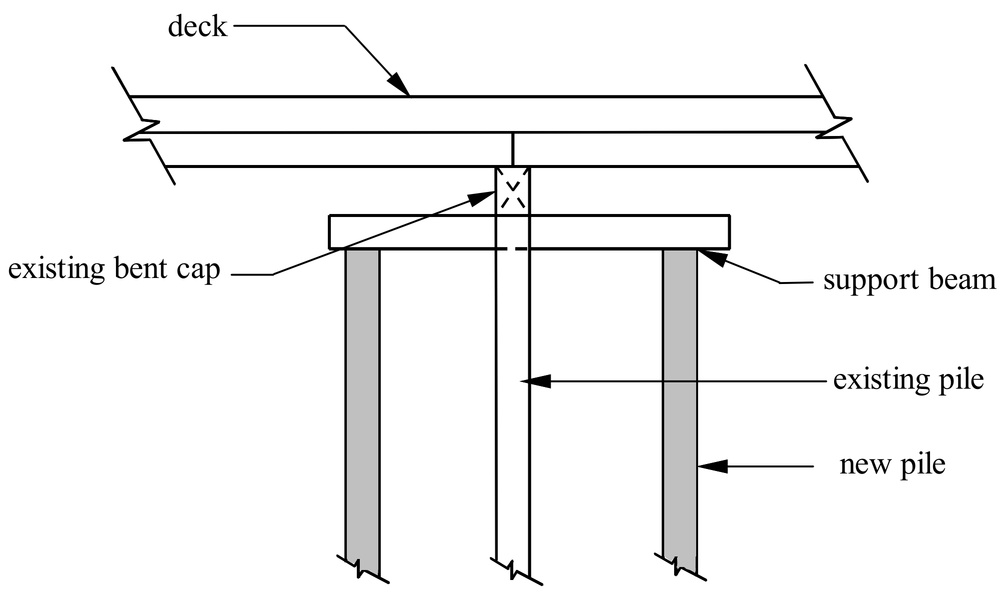
2. Design the channel section based upon required axial capacity and stability criterion.

3. Thoroughly clean the area to which the channel is to be bolted.

4. Clamp channel section in place against the pile.



(a) Front Elevation



(b) Side Elevation

Figure 2.4.6 Pile Bent Strengthening with Supplemental Timber Piles.

5. Locate and drill holes through the channels and the pile for the high strength bolts.

6. Place and secure the bolts.

7. Remove the temporary clamps (see Fig. 2.4.7).

8. Corrosion protection may be required if part of the pile is submerged.

2.4.6 Repair of Deteriorated Timber or Concrete Piles

2.4.6.1 General guidelines for pile repair by jacketing

Application

This method can be used when a timber or concrete pile is severely deteriorated and pile replacement is not viable.

Repair Method

The deteriorated portion of the pile is encased in concrete using a fiberglass or steel form jacket.

Material

1. Form jacket

2. Concrete

3. Reinforcing steel

Construction Procedure

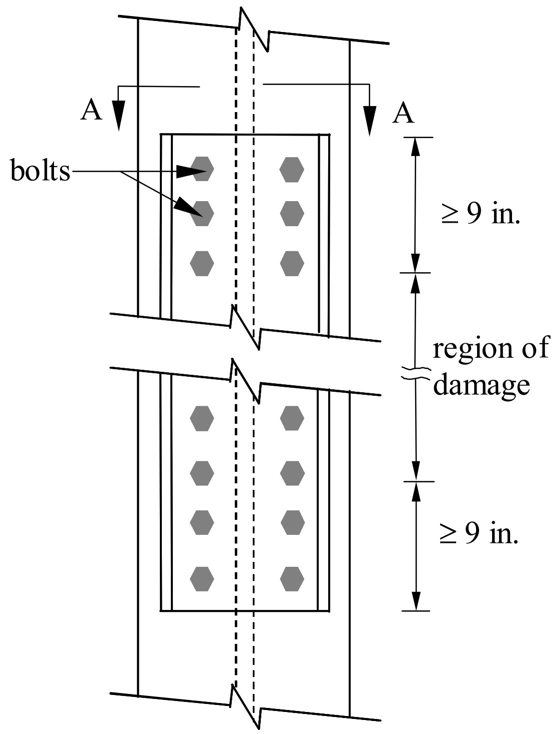
1. Clean the surface of the pile where the jacket is to be installed.

2. Install a reinforcing cage around the pile; use spacers to keep the reinforcement in place.

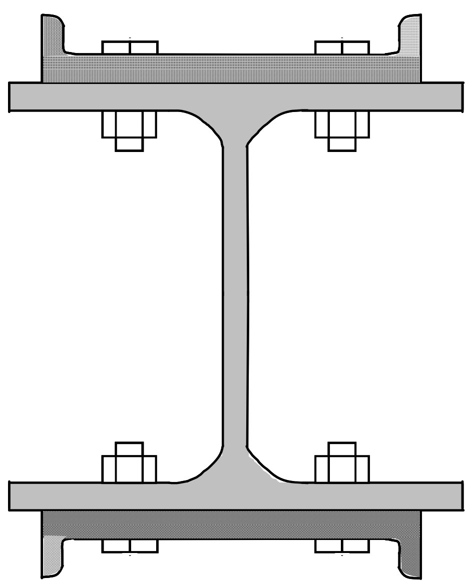
3. Place the forming jacket around the pile and seal the bottom of the form.

4. Pump the concrete into the form through the opening at the top.

5. Finish top portion of the repaired area, the top surface of the pile jacket should be sloped to allow runoff (see Fig. 2.4.8).

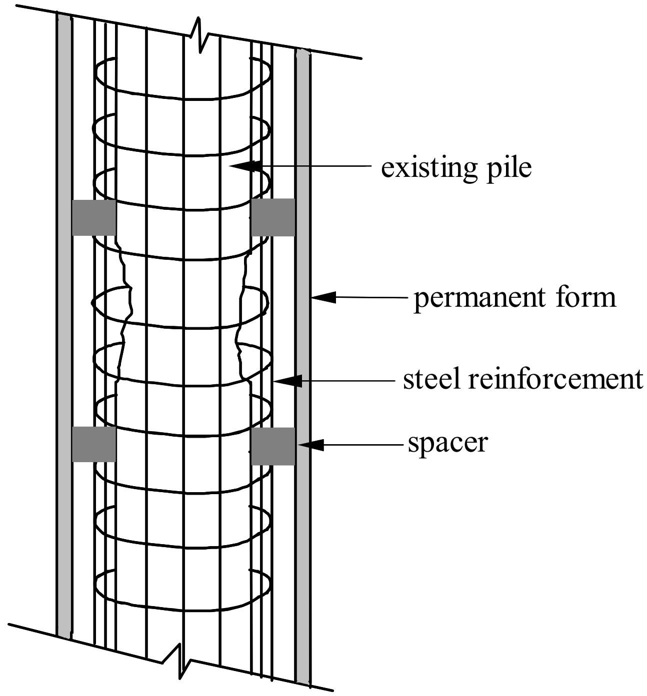


(a) Elevation View of H-pile

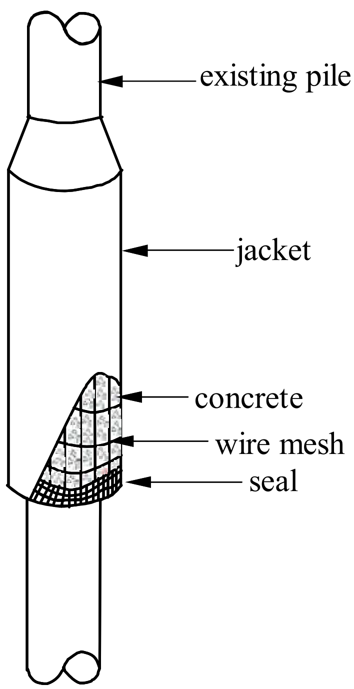


(b) Section A~A

Figure 2.4.7 Repair of Steel H-Piles.



(a) Construction of the Pile Jacket



(b) Completed Repair

Figure 2.4.8 Repair of Deteriorated Timber or Concrete Piles.

(a) Jacketing of Concrete Piles

(b) Jacketing of Timber Piles

Figure 2.4.9 Examples of Pile Jacketing in Iowa.

2.4.7 Pier Strengthening or Widening

2.4.7.1 General guidelines for strengthening or widening concrete piers

Application

This method may be used when it has been determined that the existing pier columns or pier caps are no longer structurally adequate. This procedure may also be used to widen an existing pier for a wider bridge.

Repair Method

Form and place concrete for the new footing. Prepare the surface of the existing columns for the new pier cap. Place formwork for the new pier columns, drill holes through existing pier columns to provide reinforcement for the new pier cap, and cast the new pier columns. Remove the column forming and place concrete for the new pier cap. Remove the cap formwork after the concrete has achieved the required strength.

Material

1. Drilling equipment
2. Formwork
3. Reinforcing steel
4. Concrete

Construction Procedure

1. Close bridge to traffic before initiating repairs.
2. Align the new columns to existing pier cap.
3. Erect scaffolding around the old columns.
4. Prepare the surface of the existing pier columns to ensure adequate bond to the new pier cap.
5. Excavate for footings of the new columns.
6. Form and place concrete for the new footings.

7. Drill through the existing columns or piles to provide holes for the new pier cap's reinforcement. The main horizontal reinforcing steel in the new pier cap should run uninterrupted.
8. Place the formwork and the required reinforcing steel and cast the new pier columns.
9. Remove the column forming; form and place the concrete for the new pier cap.
10. When concrete has achieved the required strength, remove the cap formwork.
11. Complete removal of all scaffolding; backfill where required (See Fig. 2.4.10).

2.4.7.2 Design of the pier cap

Description

The design guidelines that follow can be used to design the new pier cap for a given configuration of piles.

Design summary

1. Choose an initial trial size and analyze the structural system.
2. Check shear strength and provide sufficient shear reinforcement.
3. Determine amount of flexural reinforcement required.
4. Check bearing stresses.
5. Provide temperature reinforcement.

Design procedure:

1. Analyze the pier cap and the pile system and determine the magnitude and location of the critical stresses.
2. The approximate depth of the member for the first trial is given by the expression:

$$d \geq \frac{V_u}{\Phi 2\sqrt{f_c'}\, b_w} \tag{2.4.1}$$

where

f_c' = compressive stress of concrete (psi)

b_w =width of the pier cap (in.)

V_u = maximum factored shear force (lbs).

$\Phi = 0.85$

3. The minimum size of the cap that can be used is 3 ft deep by 2 ft - 6 in. wide. If a larger cap is needed, the size should be increased in 6 in. increments.

4. If the shear force, V_u, exceeds the shear strength of the concrete section, V_c, stirrups shall be provided to carry the force V_s given by:

$$V_s = \frac{V_u}{\Phi} - V_c \qquad (2.4.2)$$

The size and spacing of stirrups my be determined from the equation, $\frac{A_v}{s} = \frac{V_s}{f_y d}$

where

V_s = additional shear strength provided by the stirrups (lbs)

A_v = area of shear reinforcement within a distance, s (in^2)

s = stirrup spacing (in.)

f_y = specified yield strength of shear reinforcement (psi)

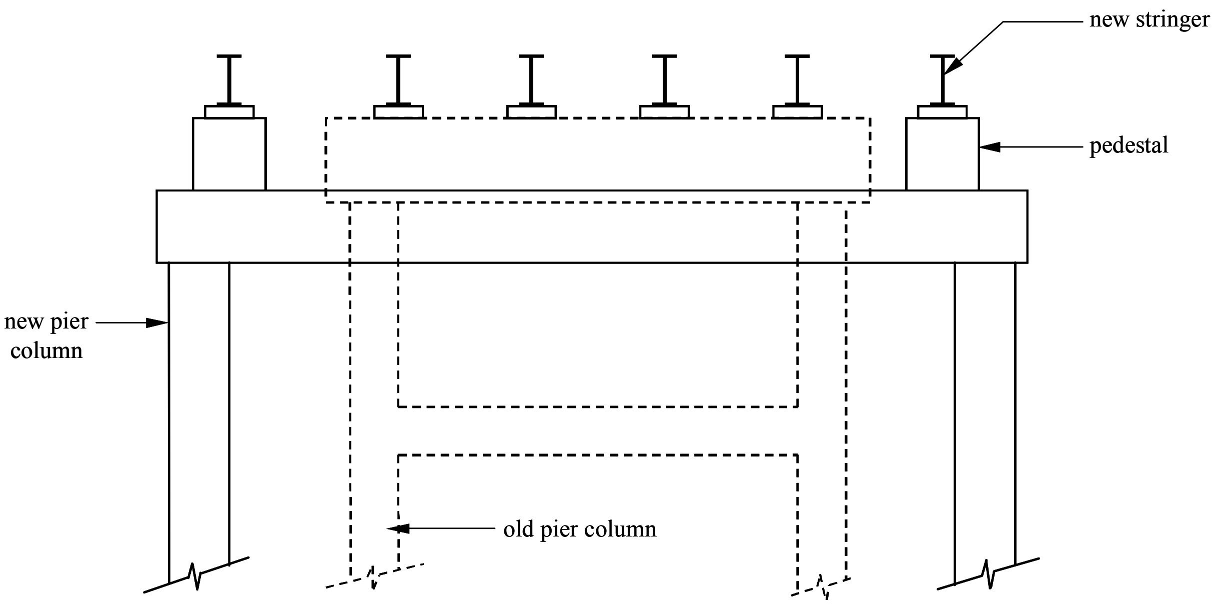
5. When shear reinforcement is to be provided by 4., the following criteria have to be met:

i. $A_v \geq \frac{50 b_w s}{f_y}$

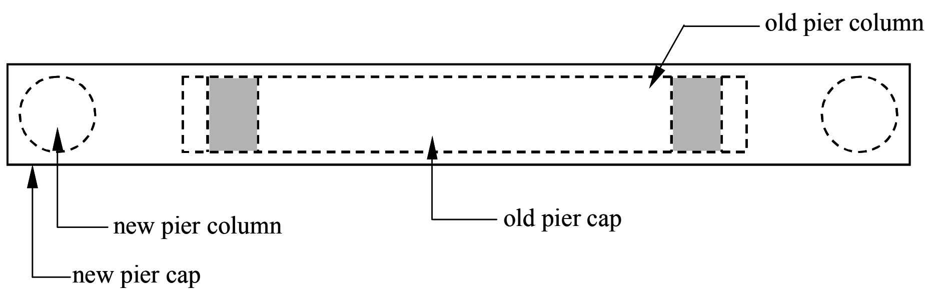
ii. Stirrups have to be provided when $V_u \geq \frac{\Phi V_c}{2}$.

iii. Spacing, s, of stirrups shall not exceed d/2 or 24 in.

iv. When $V_s \geq 4\sqrt{f_c'} b_w d$, then the spacing, s, shall not exceed one half the limits prescribed in iii.



(a) Elevation



(b) Plan View

Figure 2.4.10 Widening Concrete Piers.

v. Shear strength V_s shall not exceed $8\sqrt{f_c^{'}}b_w d$.

6. Use the cap cross section dimensions previously determined in the calculations for determining the positive and negative flexural reinforcement.

7. Check if the concrete bearing stress on concrete is within allowable limits; minimum dowel bars have to be provided even if the bearing stresses are within allowable limits.

$$f_b \leq 0.85\Phi_b f_c^{'} \tag{2.4.3}$$

where

f_b =bearing stress on concrete

Φ_b =0.70

8. Determine the temperature reinforcement required along the side faces of the cap. In addition, if the cap depth exceeds 3 ft, longitudinal skin reinforcement needs to be distributed along the side faces of the member over one-half the depth nearest the main reinforcement. (Wisconsin Bridge Manual [13])

2.4.8 Strengthening Existing Timber Pier Cap

2.4.8.1 General guidelines for the implementation of the retrofit

Application

This procedure is used to strengthen pier caps by bolting additional timber members to the cap.

Repair Method

Erect scaffolding; notch existing piles to accommodate new timber members. Place the new members against existing cap. Drill holes for required bolts; place bolts and then tighten them.

Material

1. Timber pieces
2. Equipment for drilling required holes
3. Light lifting equipment
4. Scaffolding

Construction Procedure

1. Close bridge to traffic before initiating repairs.
2. Construct scaffolding as required around the existing bent.
3. Notch the existing pile to accommodate new timber members.
4. Place new members snug against the cap; temporarily clamp the members in place.
5. Drill holes for bolts.
6. Place and tighten the bolts.
7. Remove clamps and the scaffolding (see Fig. 2.4.11).

2.4.9 Repair Procedures for Minor Deteriorated Concrete Abutment and Footings

2.4.9.1 General guidelines for implementation of the retrofit

Application

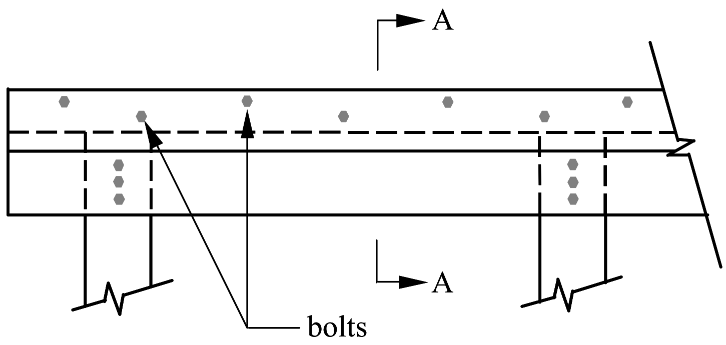
This procedure is used to offset the damage caused by badly spalled and cracked concrete abutments.

Repair Method

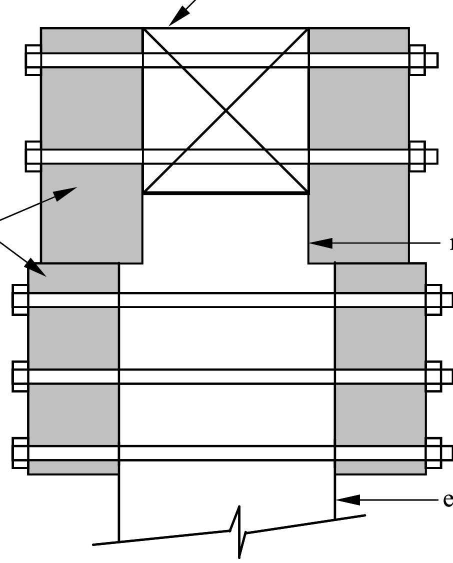
Construct a cofferdam and pump out water. The deteriorated concrete is cut out and a new reinforcement mat is placed.

Material

1. Water pump
2. Sand bags



(a) Elevation



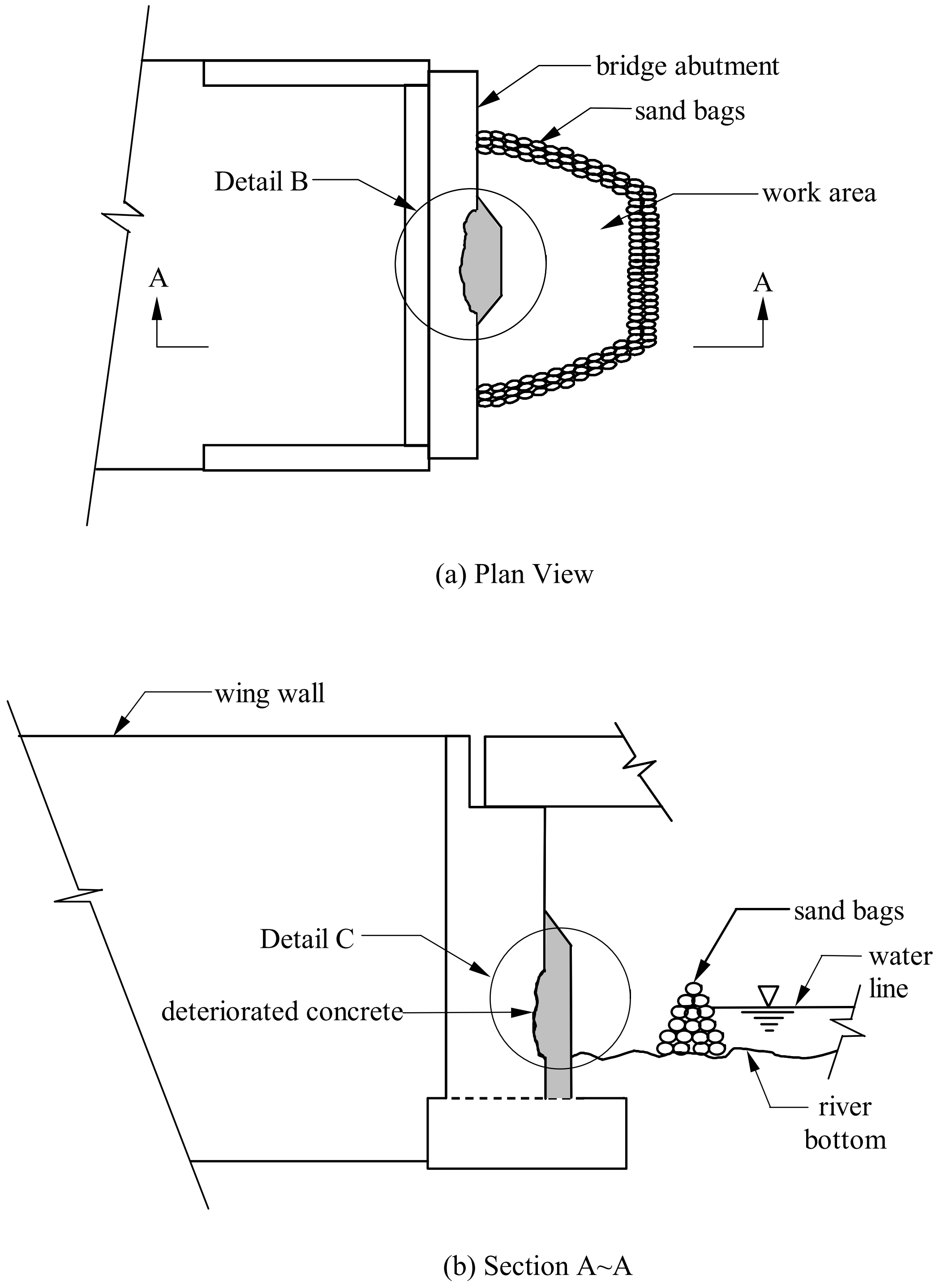
(b) Section A~A

Figure 2.4.11 Strengthening Timber Pile Caps.

3. Steel reinforcement
4. Concrete

Construction Procedure

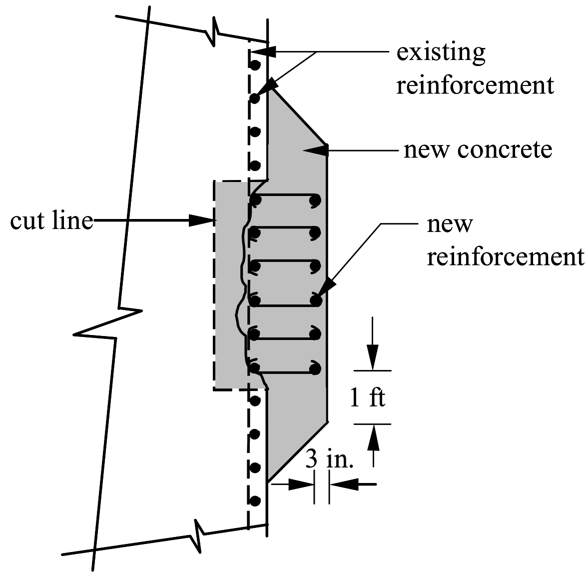
1. Construct a cofferdam and pump out water as necessary.
2. Remove the deteriorated and expose steel reinforcement.
3. Form and add a new reinforcement mat and concrete to make the abutment 4 to 6 in. thicker. The newly placed concrete will be at least 1 ft wider than the region of damage, in all directions (see Fig. 2.4.12).
4. Remove the sandbags after concrete has gained sufficient strength.



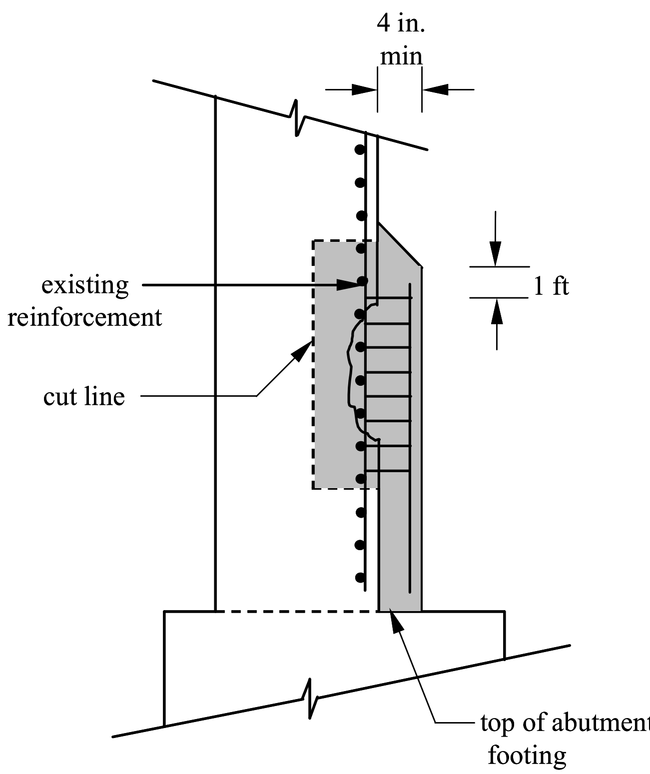
(a) Plan View

(b) Section A~A

Figure 2.4.12 Repair of Concrete Abutments.



(c) Detail B – Top View



(d) Detail C – Side View

Figure 2.4.12 Continued.

3. RESULTS AND SUMMARY

During the initial phase of the study, literature pertaining to bridge maintenance, repair and rehabilitation (MR&R) at the secondary level was compiled; the primary sources for most MR&R items were National Cooperative Highway Research Program (NCHRP) Reports 222 and 293. In addition to these reports, state bridge maintenance manuals and responses to a standardized questionnaire (see Appendices B and C) sent to all 99 counties in the state of Iowa were also useful. Only 18 counties responded to the questionnaire (a response rate of 18.2%). Because of a low rate of response, the information gathered from the questionnaires may not truly represent the magnitude of the problems faced by the counties. Seventy two percent of the respondents indicated that they had faced or were faced with problems that arise from damaged or deteriorated bridge substructure components. Issues related to maintenance and rehabilitation of bridge superstructure components were cited by 50% of the respondents.

Among the respondents who cited issues related to bridge substructure MR&R, the primary problem cited was timber piling damage (66%); the two commonly adopted solutions to this problem were the addition of supplemental piles or concrete encasement. Forty-six percent of the above mentioned respondents indicated problems associated with deterioration or damage of bridge abutments.

Sixty-six percent of the respondents, who indicated that maintenance of bridge superstructures was an issue, indicated that they were faced with problems arising from damaged or deteriorated beams. The same percentage of the above respondents indicated that they faced problems that arise from deterioration of decking components. Thirty-three percent of the respondents cited problems related to damage and deterioration of truss members. Eleven percent of the respondents indicated that MR&R issues of slab bridges were pertinent to them.

The questionnaires were followed up by personal visits by the research team to Buchanan, Butler, Cerro Gordo, Dickinson, Monona, and Taylor counties, as these counties had expressed an interest in discussing in greater detail the problems they face and the solutions adopted for these problems. These visits proved to be invaluable in gathering visual information on the MR&R procedures that were implemented. Some counties had photographs of bridges before and after the implementation of the retrofit.

Different techniques for the repair and rehabilitation of both superstructure and substructure elements in varying degrees of detail were compiled. MR&R procedures for 16 different superstructure related problems and 9 different substructure problems are included. Details of these strategies were obtained from published literature or from the results of the questionnaires disseminated to the counties. This information was presented in a manual format that is intended to aid personnel at the secondary level who are involved in bridge MR&R activities.

In addition to general field implementation guidelines, the following items include design guidelines based on AASHTO standard specifications [2]:

Installation of Intermediate Support for Steel Girder Bridges (2.3.2)
Strengthening of Steel Beams with Insufficient Section (2.3.4)
Installation of a Beam Saddle (2.3.5)
Repair of Cracked or Split Timber Stringers (2.3.11)
Pier Strengthening or Widening (2.4.7)

Finite element analysis of individual retrofitted and deteriorated piles were completed to investigate their stability; based on the results of the analysis, non-dimensional design plots were developed (see Appendix D). These plots are intended to aid the designer in making a decision as to whether pile buckling or axial stresses would be the governing mode of failure.

At all stages of the study, a project advisory committee with representatives from the Iowa DOT, county engineers and municipal engineers guided the research effort to ensure that the project would meet the intended objectives.

4. ACKNOWLEDGEMENTS

The study presented in this report was sponsored by the Iowa Department of Transportation, Highway Division, and the Iowa Highway Research Board under Research Project TR-429. The research was conducted by the Bridge Engineering Center.

The authors wish to thank Don Beck, Norm McDonald, Dennis Edgar and Tom Rohe for serving on the project advisory committee and for guiding the project from its infancy to its completion. Thanks are accorded to all of the Iowa counties for their time and for contributing technical information and materials that were used in the development of the manual. The authors also wish to thank Justin Doornink, Dimitri Mitchell and David Evans for helping with the research effort at various stages and in various capacities.

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APPENDIX A. CROSS REFERENCE BETWEEN MR&R ITEMS AND REFERENCE SOURCES

Replacement of Steel Beams (2.3.1)	NCHRP 222 [14]
Installation of Intermediate Supports (2.3.2)	NCHRP 222[14], WI DOT Manual [13]
Repair of End Corrosion Damaged Steel Beams (2.3.3)	AASHTO Manual [1]
Strengthening of Steel Beams With Insufficient Strength (2.3.4)	NCHRP 293 [10]
Installation of Beam Saddles (2.3.5)	FL DOT Manual [7]
Repair of Damaged Bottom Chord Members (2.3.6)	AASHTO Manual [1]
Replacement of Diagonal Tension Members (2.3.7)	AASHTO Manual [1], MN DOT Manual [12], NCHRP 222 [14]
Replacement of Vertical Tension Members (2.3.8)	AASHTO Manual [1], MN DOT Manual [12], NCHRP 222 [14]
Widening Concrete Deck Bridges (2.3.9)	NCHRP 222 [14]
Widening Concrete Slab Bridges (2.3.10)	NCHRP 222 [14]
Repair of Cracked or Split Timber Stringers (2.3.11)	NCHRP 222 [14]
Replacement of Timber Stringers (2.3.12)	NCHRP 293 [10], NCHRP 222 [14], FL DOT Manual [7]
Repair of Decaying Timber Bridge Deck Members (2.3.13)	AASHTO Manual [1]

Concrete Deck Patching (2.3.14)	AASHTO Manual [1]
Installation of Expansion Joint Seals (2.3.15)	AASHTO Manual [1], KS DOT Manual [9], FL DOT Manual [7]
Maintenance of Bridge Bearings (2.3.16)	AASHTO Manual [1], KS DOT Manual [9], FL DOT Manual [7]
Installation and Repair of Timber Pile Sway Bracing (2.4.1)	FL DOT Manual [7]
Shimming Timber Piles (2.4.2)	FL DOT Manual [7]
Pile Splice (2.4.3)	FL DOT Manual [7]
Addition of Supplemental Piles (2.4.4)	NCHRP 222 [14]
Repair of Steel H-piles (2.4.5)	FL DOT Manual [7]
Repair of Deteriorated Timber or Concrete Piles (2.4.6)	NCHRP 222 [14], FL DOT Manual [7], MN DOT Manual [12]
Pier Strengthening or Widening (2.4.7)	NCHRP 222 [14], WS DOT Manual [13]
Strengthening Existing Timber Pier Cap (2.4.8)	NCHRP 222 [14]
Repair Procedures for Concrete Abutments (2.4.9)	MN DOT Manual [12]

APPENDIX B. MR&R QUESTIONNIARE

Iowa Department of Transportation Research Board

Research Project TR-429

"Evaluation of Appropriate Maintenance, Repair and Rehabilitation Methods for Iowa Bridges"

Questionnaire completed by ______________________________

Title ______________________________

Address ______________________________

City ______________ State ______________ Zip __________

Phone ______________ Fax ______________

E-mail ______________________________

Please return the completed questionnaire using the enclosed envelope (or fax your response) to:

Prof. T. J Wipf
Dept. of Civil and Construction Engineering
Iowa State University
Ames, IA 50011
Phone: (515) 294-6979
Fax: (515) 294-8216

Note: If your answers to questions 1 and/or 2 are so complex that they cant easily be described on this questionnaire would you be willing to share these repair techniques or problems with us if we visited your office.

☐ I have expressed my answers to Q-1 and Q-2 on this questionnaire

☐ Please stop by my office (at an arranged time) to discuss my response to this questionnaire.

Q-1

Please describe (include drawings, pictures, etc) any repair/strengthening/rehabilitation procedure (RSRP) you have had success with when employed on superstructure or substructure elements.

RSRP # 1

RSRP # 2

RSRP # 3

Q-2

Please describe specific existing superstructure and/or substructure problem(s) you would like to see addressed in the manuals being developed.

Problem # 1

Problem # 2

Problem # 3

APPENDIX C. SUMMARY OF QUESTIONNAIRE RESPONSES

Table C.1 Summary of Questionnaire Responses

COUNTY	RSRP#1	RSRP#2	RSRP#3	PROBLEM #1	PROBLEM#2	PROBLEM#3	FIELD VISIT?
Carrol	Driving sheeting along abutments to prevent undermining of back planks.			Deterioration of timber piling.			N
Kossuth	Concrete deck overlay.	Replacement of deteriorated timber deck planking.					N
Buchanan	Splicing steel H-piles to strengthen deteriorated timber piles.	Concrete encasement of deteriorated timber piles.	Addition of supplemental timber piles.				Y
Monona	Driving supplemental piles to replace deteriorated piling.	Replacing deteriorated timber pile caps.					Y
Henry	Replacement of floor beam seats.	Strengthening bridge bearings.		Replacement of trestle piles.			N
Marshall	Driving supplemental steel H-piles piles to replace deteriorated timber piling.			Replacement of timber piles in abutment and piers.	Retrofitting deadmen to back walls of abutments.		N

Table C.1 (Contd.)

COUNTY	RSRP#1	RSRP#2	RSRP#3	PROBLEM#1	PROBLEM#2	PROBLEM#3	FIELD VISIT?
Dickinson	Increasing flexural strength of steel beams by welding cover plates.	Driving supplemental steel H-piles to strengthen timber pile bents.	Replacing deteriorated concrete on bridge decks with timber planking.				Y
Poweshiek				Widening existing roadways.	Increasing the weight limits of existing structures.		N
Allamakee	Driving supplemental steel H-piles to strengthen timber pile bents.	Driving sheet piles to replace failed abutment back walls and to reduce scour.		Damaged concrete on pier walls.	Insufficient number of beams.		N
Des Moines				Deteriorating timber substructure.			N
Winneshiek	Strengthening tension members using wire rope.						N
Cerro Gordo	Jacketing timber piles.			Deteriorated timber piling in piers and abutments.	Widening 16' to 18' pony truss bridges.		Y

Table C.1 (Contd.)

COUNTY	RSRP#1	RSRP#2	RSRP#3	PROBLEM#1	PROBLEM.#2	PROBLEM#3	FIELD VISIT?
Linn	Repair of deteriorated timber piling.	Repair of deteriorated trestle piles.	Repair of deteriorated timber pile caps.	Repair of damaged truss members.	Floor beam replacement.	Deteriorated bridge bearings.	N
Butler	Concrete encasement of timber piles.						Y
Delaware	Concrete deck overlay.				Deteriorated timber piling.	Deteriorated timber abutments.	N
Hamilton				Increasing the strength of a three span continuous slab bridge.			N
Adams	Bridge deck patching	Addition of steel channel diaphragms to exiting steel stringer bridges.					N
Taylor	Driving supplemental piles to replace deteriorated piling.	Rotating timber pile caps back into position.	Replacement of deteriorated timber stringers.	Deteriorated timber piles.			Y

APPENDIX D. NON DIMENSIONAL BUCKLING CURVES FOR PILES WITH DETERIORATED AND RETROFITTED SECTIONS

Figure D.1 illustrates typical timber pile exterior deterioration. Damage and deterioration to timber piles in bridges may occur because of termite attack or due to fungal decay. Piles may also deteriorate due to abrasive action of suspended particulate matter, damage from floating craft, drifting objects and ice. Pile deterioration may occur anywhere along the length of the pile or may also be in the interior of the pile.

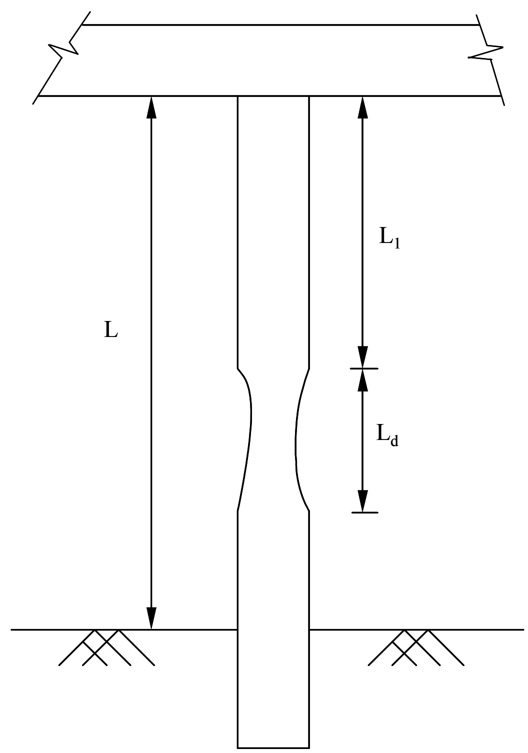

Figure D.1 Deteriorated Timber Pile

The results presented in this Appendix can be used to calculate the buckling capacity of piles similar to the one shown in Fig. D.1. Curves are presented that can be used to estimate the critical load for piles that have been retrofitted (i.e. piles that have an increased cross-sectional moment of inertia for the length of the retrofit). These results were obtained from elastic buckling analyses of timber piles with various boundary conditions.

The finite element method in conjunction with the ANSYS (14) multipurpose finite element program was used to carry out the analyses. Input data files were created using the ANSYS Parametric Design Language (APDL). The output from each the analysis was then imported into Excel spreadsheets and normalized to generate the non-dimensional curves.

Definition of Terms Used

L = Unsupported length of the pile

L_d = Length of the region of deterioration (or retrofit)

L_1 = Depth from the top of the pile to the point of initial of deterioration (or retrofit)

I_1 = Moment of inertia of the undeteriorated section of the pile

I_2 = Moment of inertia of the deteriorated (or retrofitted) section of the pile

Pcr = Buckling load of deteriorated (or retrofitted) pile

Pcr,o = Buckling load of undeteriorated pile

$$R = \left(\frac{I_2}{I_1}\right)^{1/4}$$

R < 1.0 for piles with a deteriorated section

R > 1.0 for retrofitted piles

Figures D.2 to D.5 present the buckling capacities for the pinned-pinned end conditions, while Figs. D.6 to D.9 presents the buckling capacities for the fixed-fixed support condition. The results for the pinned-fixed support conditions are presented in Figs. D.10 to D.13.

The support conditions that apply to a particular pile have to be judged by an engineer based on parameters that include depth of embedment of the pile into soil, relative stiffness of the pile and the pile cap and soil characteristics. An example illustrating how to utilize the developed graphs to calculate the capacity of a deteriorated pile is provided at the end of this Appendix.

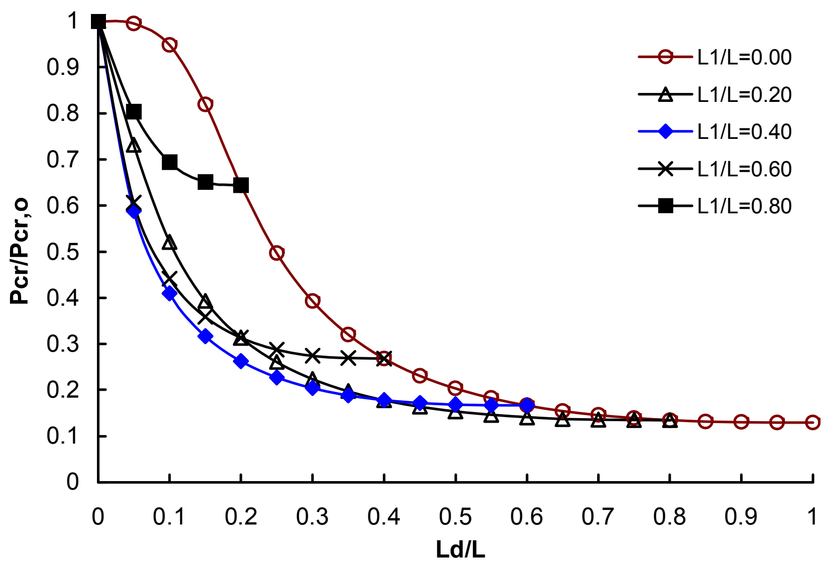

Figure D.2 Buckling Load for Deteriorated Piles with Pinned - Pinned Support Conditions: R = 0.6

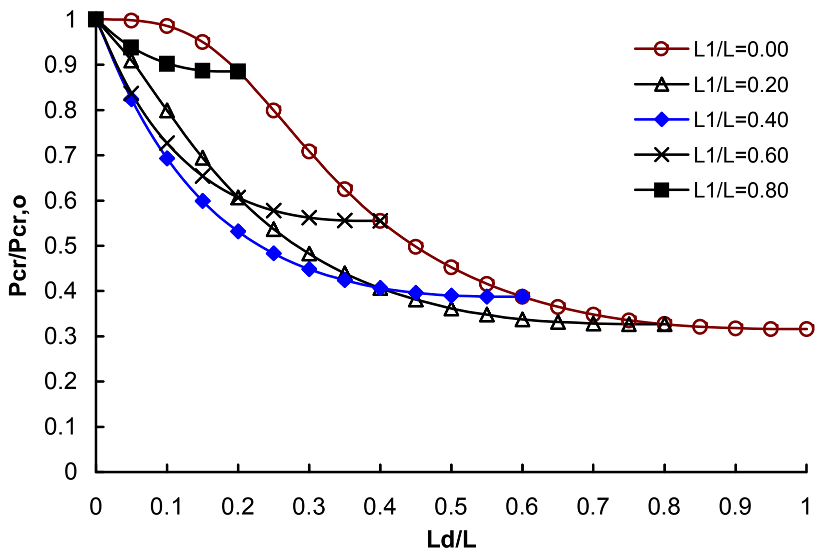

Figure D.3 Buckling Load for Deteriorated Piles with Pinned - Pinned Support Conditions: R = 0.75

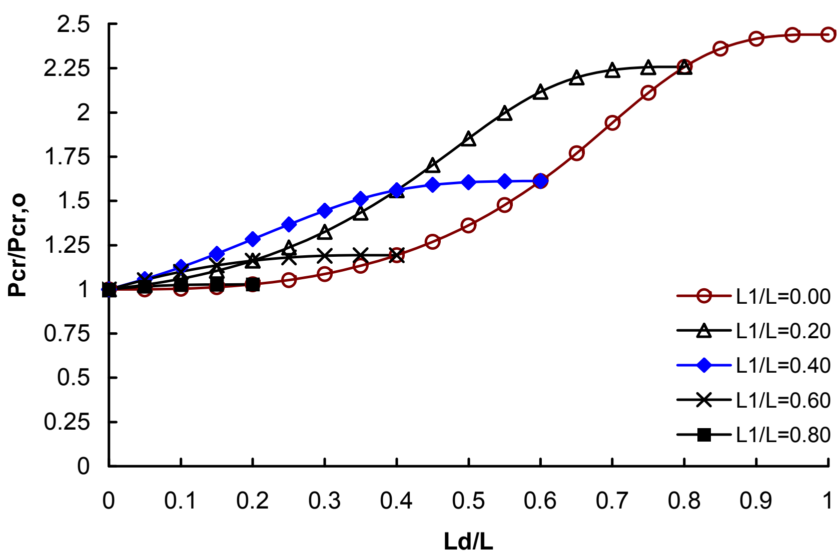

Figure D.4 Buckling Load for Retrofitted Piles with Pinned - Pinned Support Conditions: R = 1.25

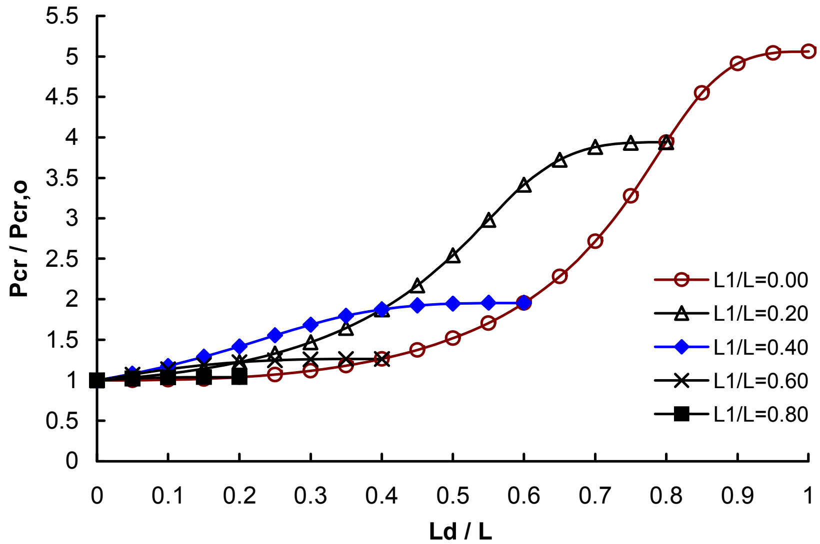

Figure D.5 Buckling Load for Retrofitted Piles with Pinned - Pinned Support Conditions: R = 1.5

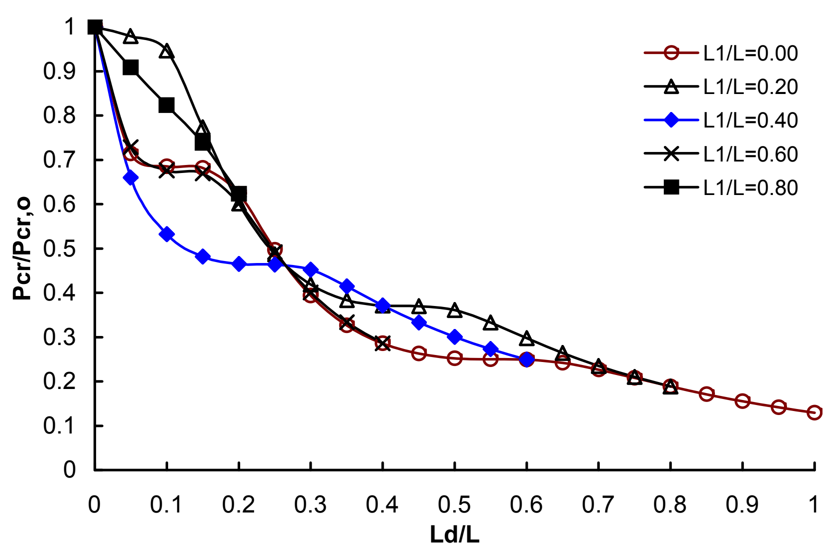

Figure D.6 Buckling Load for Deteriorated Piles with Fixed - Fixed Support Conditions: R = 0.6

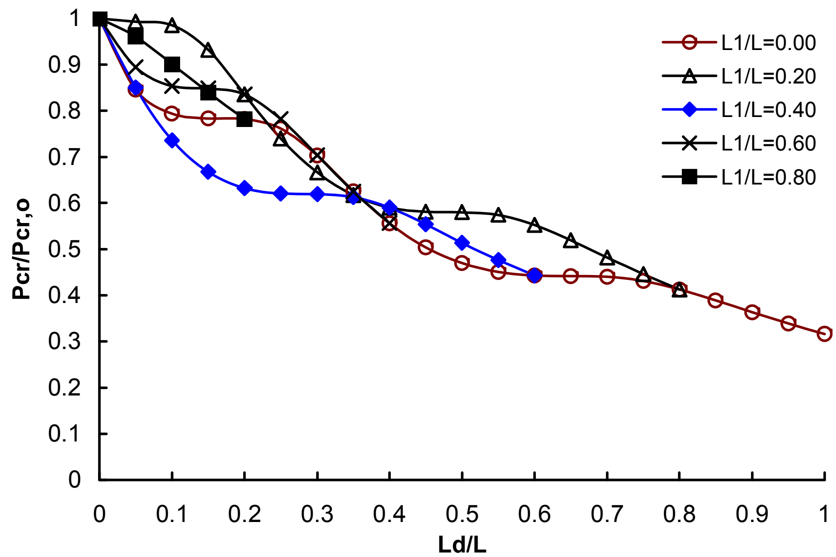

Figure D.7 Buckling Load for Deteriorated Piles with Fixed - Fixed Support Conditions: R = 0.75

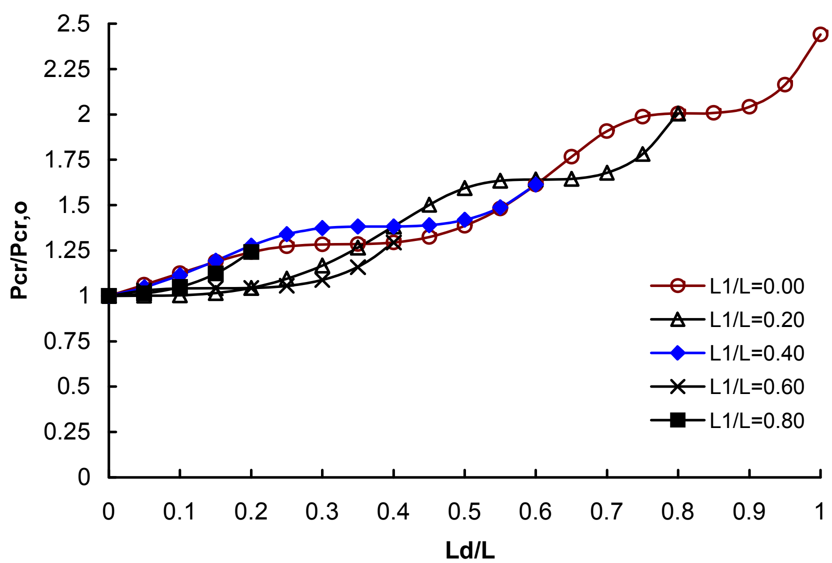

Figure D.8 Buckling Load for Retrofitted Piles with Fixed - Fixed Support Conditions: R = 1.25

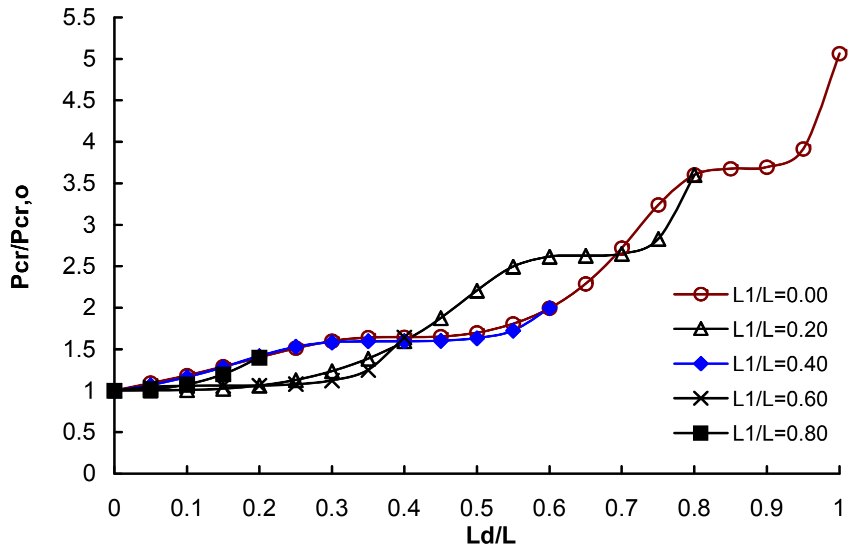

Figure D.9 Buckling Load for Retrofitted Piles with Fixed - Fixed Support Conditions: R = 1.5

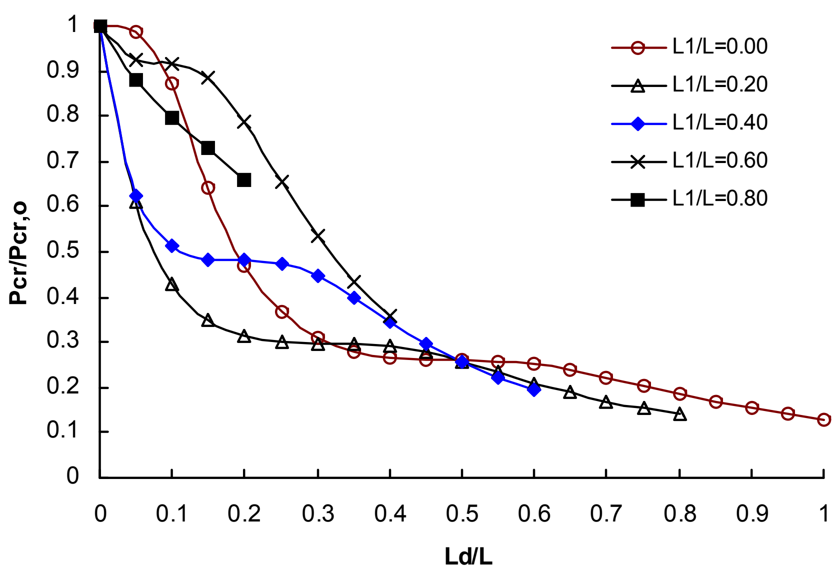

Figure D.10 Buckling Load for Deteriorated Piles with Pinned - Fixed Support Conditions: R = 0.6

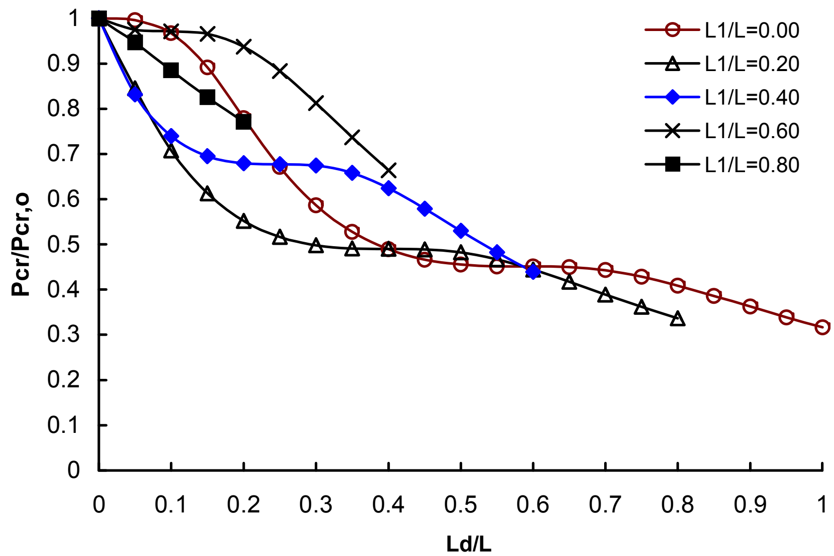

Figure D.11 Buckling Load for Deteriorated Piles with Pinned - Fixed Support Conditions: R = 0.75

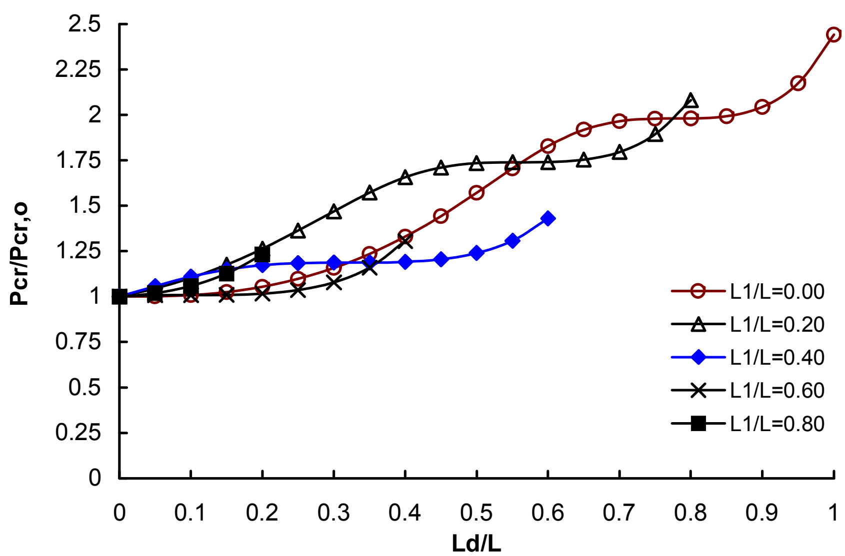

Figure D.12 Buckling Load for Retrofitted Piles with Pinned - Fixed Support Conditions: R = 1.25

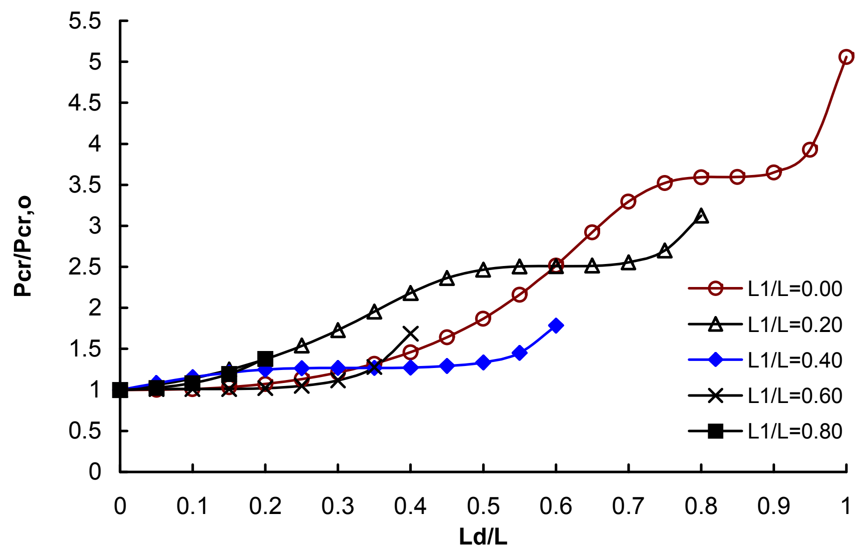

Figure D.13 Buckling Load for Retrofitted Piles with Pinned - Fixed Support Conditions: R = 1.5

Illustrative Example for the Use of Non-Dimensional Curves

The example below illustrates a 15 ft long timber pile in a bridge structure. In the example, it was assumed that deterioration took place over a length, L_d, of 2.5 feet as shown in the figure. The original diameter, D_1, of the pile was assumed to be 2.5 ft. and the diameter, D_2, of the deteriorated section was assumed to be 1.5 ft. Other information required to calculate the pile capacity is listed in Fig. D.14.

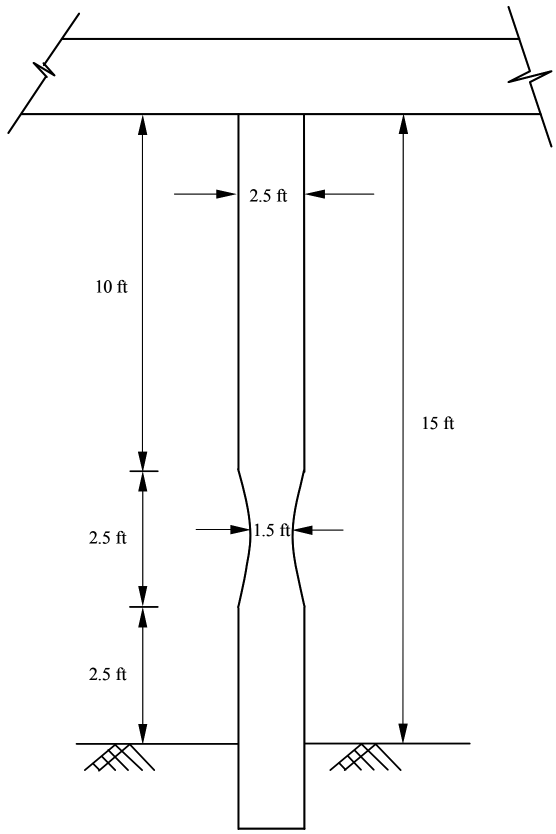

Figure D.14 Example of a Deteriorated Pile

Given Data

E = 1900 ksi (modulus of elasticity)

F_a = 2 ksi (compressive strength)

Assume that the pile is pinned at the top and fixed at the base

The following ratios are needed to utilize the graph pertaining to this specific case:

$$\frac{L_1}{L} = 0.667$$

$$\frac{L_d}{L} = 0.167$$

$$I_1 = \frac{\pi D_1^4}{64}$$

$I_1 = 39760 \text{ in}^4$

$$I_2 = \frac{\pi D_2^4}{64}$$

$I_2 = 5153 \text{ in}^4$

$$R = \left(\frac{I_2}{I_1}\right)^{\frac{1}{4}}$$

R = 0.6

$$Pcr,o = \frac{\pi^2 EI_1}{L^2} \text{ (Buckling capacity of the undeteriorated pile)}$$

$Pcr,o = 2.301x10^4$ kip

From Fig. D.10 and the non-dimensional parameters computed above, one estimates the critical load for the pile considered here in as:

Pcr = 0.9x Pcr,o

$Pcr = 2.071x10^4$ kip

However, the maximum allowable axial load based on an allowable compression stress of 2 ksi is:

$$Pa = F_a \times \frac{\pi D_2^2}{4}$$

Pa = 508.94 kip

The axial strength of the pile is the least value of either Pcr or Pa. Thus, the capacity of the pile is 509 kips based on the allowable compressive stress.