8-15-2003

# Bridge Design Guide, Chapter 10 : Rehabilitation, 2003

Maine Department of Transportation

# Chapter 10

# REHABILITATION

Pope Memorial Bridge, East Machias

Waldo-Hancock Bridge, Prospect-Verona

# 10 REHABILITATION

## 10.1 General

Bridge rehabilitation involves structural or functional upgrades to an existing bridge that leave part of that bridge remaining in place. The extent of the rehabilitation can range from relatively minor work such as replacement of curb and rail, to major work such as replacement of all deficient concrete in a multispan arch structure. Usually, a preliminary scope is defined that outlines the expected rehabilitation work. The Designer will review this scope, and through preliminary design analysis, determine whether the expected work is the optimal course for improvements to the bridge. It is very important that the contract clearly describe the expected repairs and the extent of work to avoid excessive and costly change orders in the field.

Rehabilitation work can be classified as minor or major rehabilitation. Minor rehabilitation addresses non-structural repair such as concrete surface repair, deck overlays, joint and bearing restoration, steel secondary member repair, and minor repair to primary steel members. Major rehabilitation involves structural repair or replacement of primary bridge elements, and includes such work as pier cap or pier replacement, deck replacement, superstructure replacement, bridge widening, and primary member replacement or strengthening.

Most rehabilitation projects should have a life cycle analysis done to confirm that rehabilitation is preferred over replacement. Refer to Section 2.2 Economic Comparisons for more information.

A scour evaluation should be completed for all structures for which the scope of rehabilitation exceeds deck, wearing surface, or rail rehabilitation/replacement. If the structure is scour critical, the appropriate counter measure should be investigated as part of the rehabilitation project.

## 10.2 Superstructure Rehabilitation

### *10.2.1 Evaluation*

The most common superstructure rehabilitation projects involve, in order of complexity, wearing surface replacement, deck replacement, or superstructure replacement. The degree of work is dependent upon the condition of the existing structure, which must be evaluated during preliminary design.

The Designer will compile the data needed for this evaluation. Activities include review of existing plans to determine rebar cover, slab thickness, type of original wearing surface, and presence or absence of membrane. Inspection and maintenance work reports are reviewed for the wearing surface, deck, and superstructure condition rating and description, and any maintenance work that has been required. The substructure condition rating should be noted, and an estimated remaining life of the substructure determined. Discussions with Bridge Maintenance will be useful to compare the predicted substructure service life to the expected life of the repair.

Field inspection should be done to document leakage and efflorescence, potholes, cracks, delamination, and spalling of the deck, as well as the condition of deck joints, curbs, and railing. Deck cores may be obtained at the discretion of the Designer to provide representative sampling for testing and to document the condition of the deck. Typical locations for deck cores are at the curb line and the center of wheel paths. Refer to Section 10.2.5 Evaluation of Deck Cores for a discussion of deck core interpretation. The need for concrete cores should be determined at the project kick off meeting and coordinated with the Project Manager. Refer to the Getting Started Chapter of the Project Management Guide for guidance.

Maintaining traffic during construction can cause issues in these projects. Refer to Section 2.4 Maintenance of Traffic During Construction.

### *10.2.2 Wearing Surface Replacement/Rehabilitation*

#### 10.2.2.1 General

This work involves replacing the existing wearing surface with a new partial or full-depth wearing surface. Material used can be either concrete or bituminous. A concrete wearing surface should be used only for those cases noted in Section 4.6 Wearing Surfaces. For all other wearing surface replacements, with or without rehabilitation of the existing deck, replace with 1/4” membrane, and 3 inches of hot bituminous pavement.

Selected areas of the deck may need to be repaired as discussed in Section 10.2.3 Deck Replacement/Rehabilitation. The removal is described as extending to rebar or extending below rebar, depending upon how extensive the deterioration. For minor deck rehabilitation, up to 5% of the existing deck area is removed below rebar, and up to 15% is removed to rebar. For most wearing surface projects, items for deck rehabilitation should be included in the contract, due to uncertainty of actual field conditions. Typical items for deck rehabilitation are described in Standard Specification Section 518 – Structural Concrete Repair and are as follows:

- Item 518.50 Repair of Upward Facing Surfaces to Reinforcing Steel, < 7.9 inches
- Item 518.51 Repair of Upward Facing Surfaces below Reinforcing Steel, < 7.9 inches

- Item 518.52 Repair of Upward Facing Surfaces, ≥ 7.9 inches

If the existing deck slab is expected to have a rough and irregular surface that could puncture the membrane waterproofing, the Designer should specify high performance membrane. A high performance membrane should also be considered if there are issues with vehicles breaking at the bridge, the performance of the previous membrane, or the design life of the rehabilitation project. Refer to Section 4.7 Membranes for further guidance. A rough surface may be expected on a deck that is to be scarified or where a well-bonded concrete wearing surface is to be removed.

> *Commentary: The Resident also has the option of modifying the specified membrane in the field, depending upon the roughness of the concrete surface. The Resident may choose to add a second layer of standard membrane when high performance membrane was not specified. In cases of extremely rough surfaces, the Resident also has the option of placing bituminous shim directly on the concrete prior to installing membrane, or substituting the bituminous and membrane with a concrete wearing surface. Both of these materials will be obtained through change order procedures and should not be estimated or shown on the plans.*

If the condition of the railing, curb, or joints is substandard, replace or modify to current standards. Refer to Sections 4.4 Bridge Rail and 10.5 Bridge Rail and Connections for further guidance.

#### 10.2.2.2 Bituminous Wearing Surfaces

Partial depth replacement of a bituminous wearing surface is known as a wearing surface rehabilitation, and is indicated if the deck condition is good, and there is an effective existing membrane. Rehabilitation may also be indicated as a low cost measure to prolong the life of a poor quality deck.

Full depth replacement of the wearing surface should be done when the deck is in good condition, but no membrane is present.

For bituminous wearing surface replacement of less than 3000 $ft^2$ of deck area, the surface should be prepared by sandblasting, or by using a scabbler. For deck areas greater than 3000 $ft^2$, the cost of scarifying equipment can be justified; specify scarifying the deck at least 1/2” when the chloride content is low, and 3/4” if the chloride content is high.

Certain situations may warrant a modification of the above or a different solution to provide an adequate wearing surface in order to meet depth, crown, or other existing conditions.

#### 10.2.2.3 Concrete Wearing Surfaces

If a concrete wearing surface is to be placed, a good bond with the deck is essential to prevent future maintenance problems. Scarify or scabble the deck, and then blast before applying the new wearing surface. Where non-integral concrete wearing surfaces are used, a 2 inch minimum unreinforced concrete wearing surface should be specified. Depths of unreinforced concrete should not exceed 4 inches.

### *10.2.3 Deck Replacement/Rehabilitation*

Rehabilitation of a deck involves removing selected areas of concrete down to sound concrete, and replacing with new concrete. Major deck rehabilitation is classified as removal of concrete below rebar for 5% to 40% of deck area and removal to rebar for greater than 15% of deck area. For deck areas greater than 3000 $ft^2$, scarify the existing deck. If the condition of the railing and curb is substandard, replace or modify to current standards.

In general, deck replacement should be performed if more than 40% of deck area is deficient below rebar. If more than 30% of deck area is deficient below rebar, a life cycle cost analysis should determine whether deck rehabilitation or replacement is warranted. Refer to Section 2.2 Economic Comparisons for more information.

### *10.2.4 Superstructure Replacement/Rehabilitation*

A life cycle analysis described in Section 2.2 Economic Comparisons may show that superstructure replacement is less costly than deck replacement, especially if the existing superstructure consists of painted steel girders. This is because the cost of painting steel often exceeds that of new steel due to paint containment costs.

Superstructure replacement may require substructure modifications, such as placement of a reinforced concrete cap to adequately distribute the loads.

### *10.2.5 Evaluation of Deck Cores*

The purpose of testing existing decks is to assist the Designer in judging the extent of deck rehabilitation or replacement that is warranted. The testing should include chloride content and compressive strength, and may also include rebar inspection and shear strength.

Chloride content is sampled in the top 1/2”, and then every inch thereafter. If the level is below 1.35 $lb/yd^3$, it is considered to be in a “non-corrosive atmosphere.” The depth of concrete that should be removed can be estimated based upon the depth where corrosivity diminishes below 1.35 $lbs/yd^3$ or solid concrete is found.

Compressive strength is sampled below the top 1/2" at the depth where the concrete can be cored intact. When a core cannot be taken effectively, the concrete should probably be removed. Core compressive strength should be compared to the expected design strength, and a judgment made by the Designer as to the extent of rehabilitation or the need for replacement.

If a core sample happens to go through rebar, the depth of steel is noted, and a visual inspection notes the degree of corrosion. Chloride content above and below the rebar may be taken.

Occasionally, a shear test between the existing asphalt and concrete will be done to determine the potential bond between the new surfaces. Values vary widely, from as low as 50 psi to as high as 1000 psi. These values may be used to determine the level of effort required to remove the existing wearing surface. Good engineering judgment should be used when interpreting the shear test results.

### *10.2.6 Bridge Widening*

Widening an existing structure to meet current standards may be cost effective if the condition of the existing substructure is good. Usually the structure should be widened to only one side, for ease of construction. The widened superstructure will be supported either on a widened substructure, or may be cantilevered from the existing substructure. An analysis of the capacity of the substructure by the Geotechnical Designer will determine whether a cantilever is feasible.

If a deck slab overhang is increased without adding girders, the existing exterior girder must be analyzed with the additional load, both during concrete placement and in final position. A torsional analysis will usually be required.

## 10.3 Bearings

When a bridge is to be rehabilitated, the bearings should be evaluated for the need to repair or replace them. Depending upon the expected life of the structure, repairing the existing bearings may be preferred over replacing with modern bearings. In some cases, no repair at all will be the most cost effective and practical solution.

Many existing steel bridges have rocker bearings that can be removed, refurbished, and then replaced. Contact Bridge Maintenance for further guidance on the rehabilitation of existing rocker bearings. If the bridge is in an SPC B seismic area, rocker bearings should be replaced with elastomeric or other bearing systems, as discussed in Section 10.9 Seismic Retrofit. A widened structure should be fitted with the same bearing type as that installed on the remaining structure for each substructure unit.

## 10.4 Expansion Devices

On a wearing surface replacement or deck rehabilitation project, the bridge expansion devices (joints) should be examined to determine their condition. The joint armor may be damaged, or the seal may be gone. The value of replacing the seal, repairing the joint armor, or replacing the entire joint should be assessed for each project. The Designer must consider the potential damage to the structure below if repairs or modifications are not made, as well as the expected life of the structure before full bridge replacement is warranted.

Often the joint must be modified or raised to accommodate the increase in grade created by additional pavement. If the joint armor is not damaged beyond repair, and a compression seal can be used, the joint should be modified by welding a round bar to the top of the joint armor. If the joint armor is damaged, the affected steel can be cut out and replaced with a new piece. Keeper bars should be added to the joint armor if not part of the existing joint configuration.

To select a new seal, field measurements must be taken to determine which manufacturer's seal will fit. The existing joint opening should be measured, along with the temperature and the location of the keeper bars if applicable. With this information, the maximum and minimum expected joint opening can be determined. The Designer should then use the manufacturer's literature from the two suppliers listed in Table 4-7 to determine the minimum installation opening and seal depth. A seal can be selected to fit within the given parameters (depth of seal, minimum installation opening, and movement rating) by using Table 4-7 Elastomeric Joint Seal Movement Ratings or the following link: http://www.state.me.us/mdot/planning/products/compressionseals.htm. The depth from top of new joint to top of seal should comply as closely as possible with the Standard Detail 520(10) minimum of 1/2".

For bridges with differential movement, excessive rotation at the joint, or if the joint space is measured and found to be uneven from one side of the bridge to the other, a gland seal may be selected instead of a compression seal.

In some cases, the existing seal type may be changed without modification of the existing joint armor. Prequalified seals listed in Section 4.8 Deck Joints and Expansion Devices should be evaluated for use inside existing joint armor.

If a prefabricated seal cannot be found to fit the existing joint armor, self-leveling joints can be considered. For the approved list of self-leveling joints refer to the following link to the MDOT product approval web page:

http://www.state.me.us/mdot/planning/products/jointsealant.htm. These seals are a temporary solution, with a service life of only six to seven years.

Modifications and replacement of existing joints should be specified in accordance with Table 10-1. The descriptions of these joint modifications are not meant to be all-inclusive but merely a broad description. The Designer should use good judgment in determining which type of modification to specify. These requirements are specified in Special Provision Section 520 Expansion Devices. The Designer must verify that the PS&E package contains this Special Provision.

**Table 10-1 Bridge Joint Modification Types**

| Item Number | Modification | Seal Type | Scope of Work | Examples of Work Scope |
|---|---|---|---|---|
| 520.241 | Type I | Compression or Gland | Minor | • Raising profile grade by adding bar or plate<br>• Adding retention bars to existing joint armor |
| 520.242 | Type II | Compression | Minor | • Cutting/modifying existing steel plate<br>• Welding retention bars to existing steel plates |
| 520.243 | Type III | Compression | Major | Concrete removal on one or both sides of the joint. |
| 520.244 | Type IV | Gland | Minor | • Cutting/modifying existing steel plate<br>• Welding extrusions to existing steel plates |
| 520.245 | Type V | Gland | Major | Concrete removal on one or both sides of the joint. |

## 10.5 Bridge Rail and Connections

### *10.5.1 General*

Bridge rehabilitation projects and resurfacing projects should consider the need for the replacement, retrofitting, or retention of existing bridge rails. In general, bridge rails should be replaced or retrofitted to meet AASHTO LRFD standards. Refer to Section 4.4 Bridge Rail for further guidance.

For rehabilitations where it is desirable to leave the existing end posts in place and the bridge transition is in question, it is acceptable to use Bridge Transition Type 2 as shown in Standard Detail 606(26).

## *10.5.2 Retrofit Policy*

### 10.5.2.1 Interstate System

Bridge rails on the interstate system have been identified as shown in Figure 10-1, Figure 10-2, and Figure 10-3. The policy for retention, replacement, or retrofit for these existing bridge railings on the interstate system is as follows:

- Type B, C, E, H, & K: Either replace the existing rail and curb system with F-shaped barrier or retrofit existing rail and curb system with a crash-tested retrofit system.
- Type F, G, J, & L: Retain existing rail and curb system. Consider replacing rusted toggle bolts on Type J.
- Type M & Z: Retain existing rail and curb system. Retrofit splice detail.

Bridge rails similar to the above interstate bridge rails on non-interstate systems should be treated similarly as prescribed for the interstate system except as otherwise discussed here.

### 10.5.2.2 Non-Interstate System

Retention of existing sound substandard bridge railings is acceptable on non-interstate systems for economic reasons when the bridge has a low accident history (CRF < 1.0), and has either a low posted speed limit (mph < 45), or a low traffic volume (AADT < 400).

Retrofitting of existing substandard bridge railings on non-interstate systems having sound concrete posts should be considered utilizing 10 gauge thrie beam with block-outs on posts not exceeding a spacing of 10'-6" (refer to Figure 10-4). The thrie beam must be specified as 10 gauge on the plans since the Standard Specifications call for the thinner 12 gauge. Top of thrie beam should be 2'-10" above traveled way and curb offset should not exceed 3-1/2". Existing substandard railings behind the thrie beam should remain in place. This retrofit is based on a Michigan crash tested retrofit.

### 10.5.2.3 Existing Bridges on Highway Projects

For a bridge within the limits of an NHS Arterial Program project, the existing bridge rail should be considered for replacement, retrofitting, or retention as part of the highway project. The only exception to this is when the bridge has been scheduled for additional work as a separate Bridge Program project.

For a bridge within the limits of a non-NHS highway project that is not otherwise programmed for work, the existing bridge rail does not require consideration for improvements as part of the highway project. However, a rigid guardrail to bridge connection and additional stiffening posts in the approach rail should be provided.

For a bridge just outside the project limits of a highway project, the existing bridge rail need not be considered for improvements. However, if the approach guardrail is within NHS highway project limits, then the bridge connection should be upgraded to current standards. Non-NHS projects should have a rigid guardrail to bridge connection and additional stiffening posts in the approach rail provided within the highway project limits.

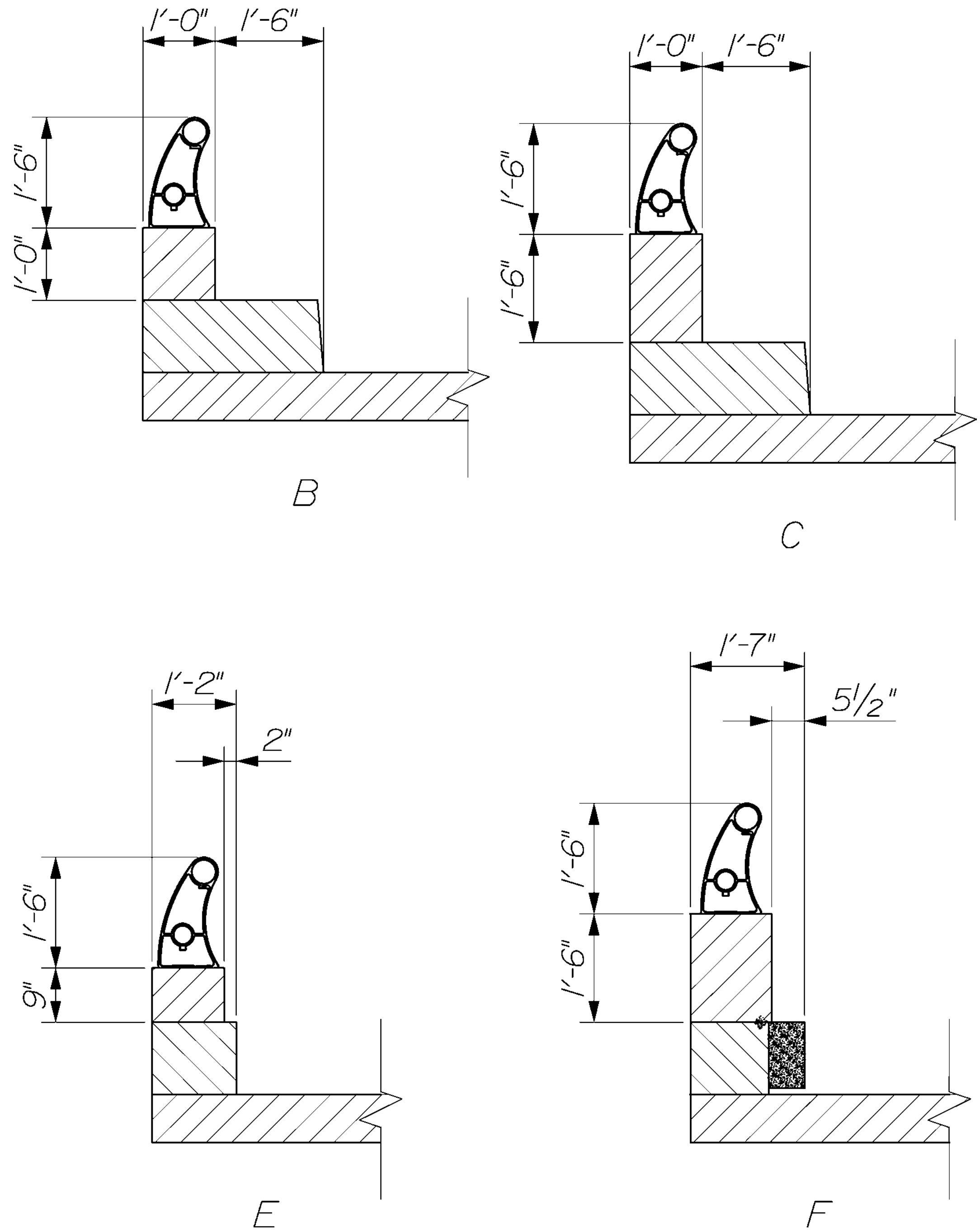


**Figure 10-1 Interstate Rails Attachment Type "A" – Rail Types B, C, E, & F**

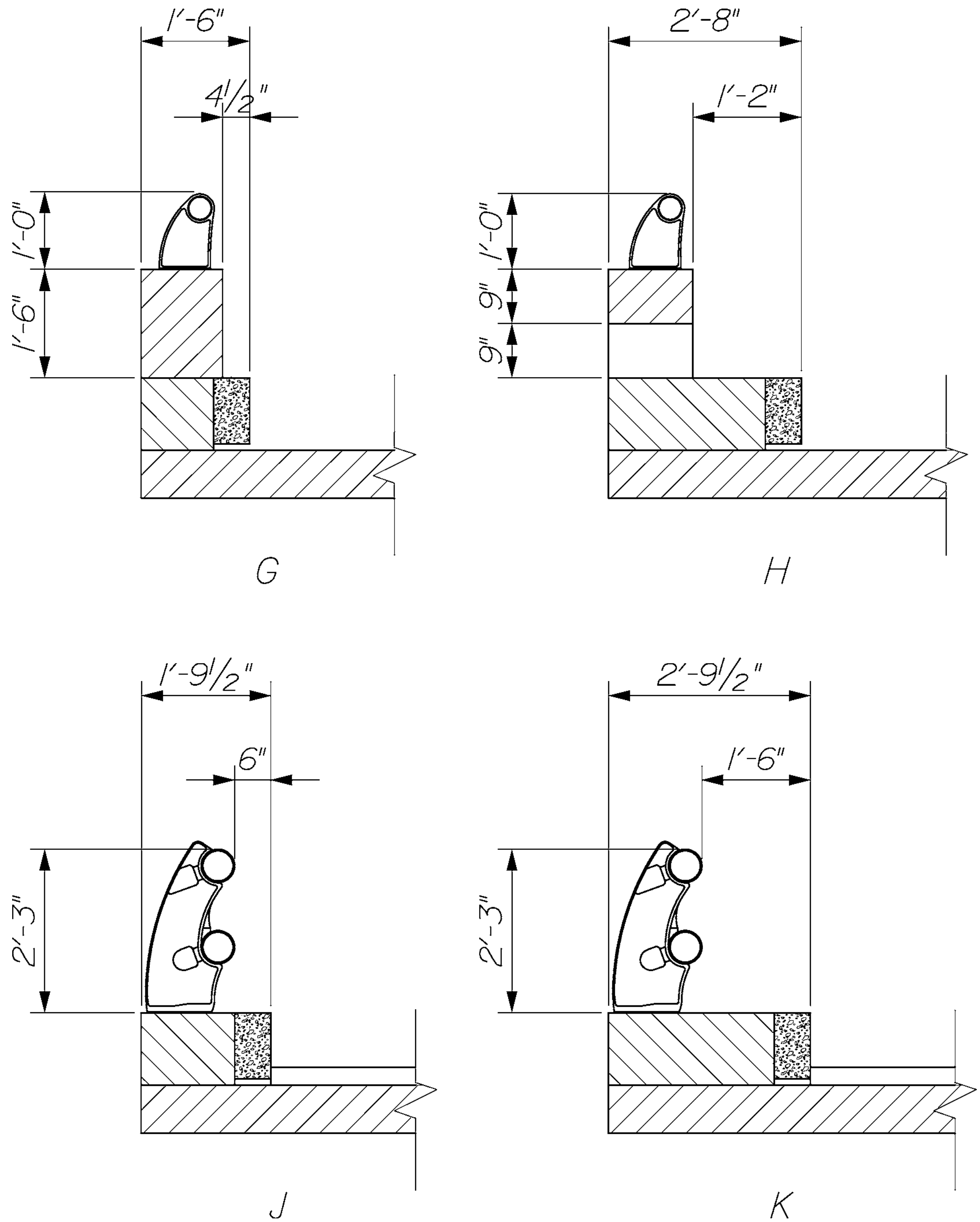


**Figure 10-2 Interstate Rails Attachment Type “A” – Rail Types G, H, J, & K**

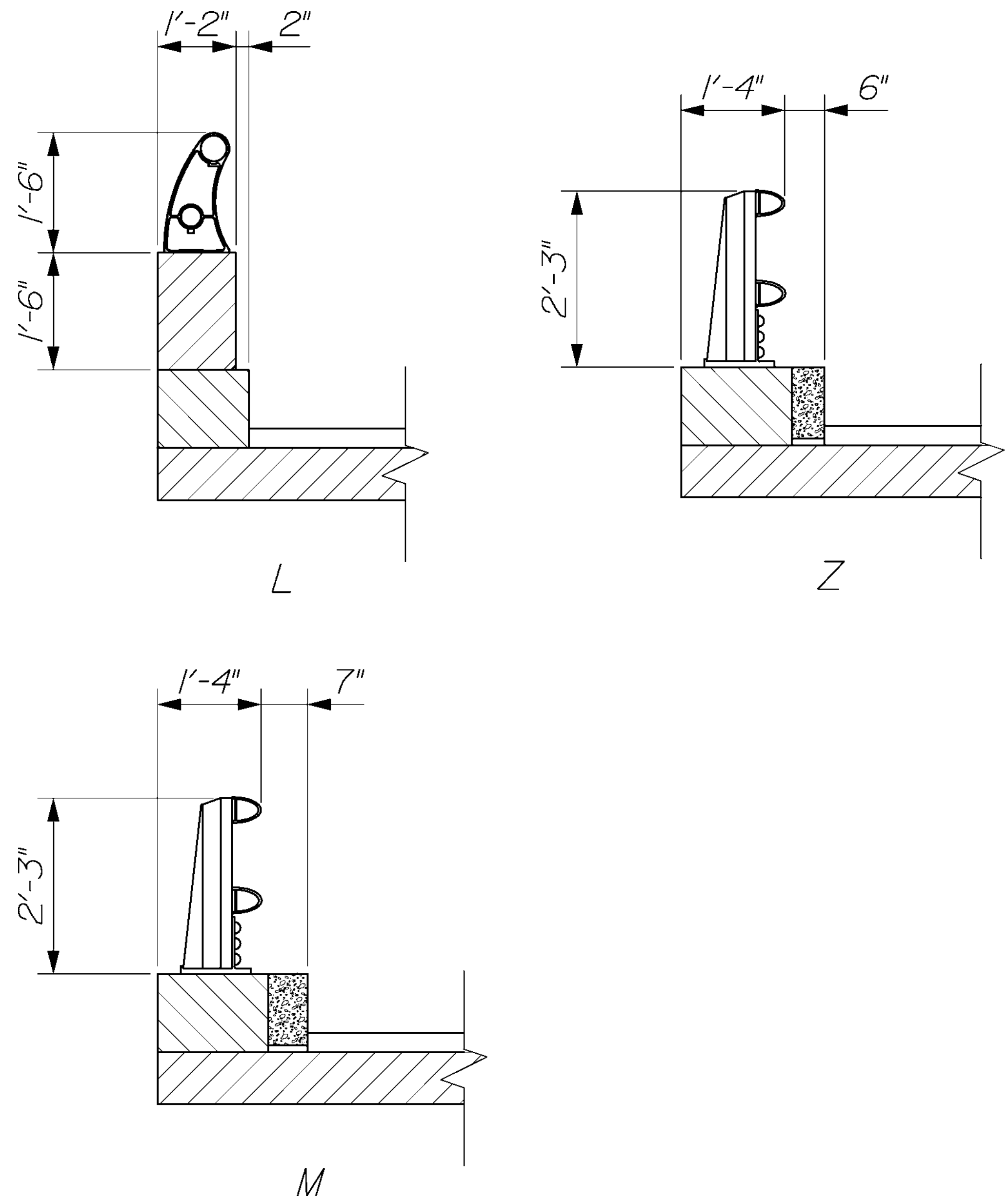


**Figure 10-3 Interstate Rails Attachment Type "A" - Rail Types L, M, & Z**

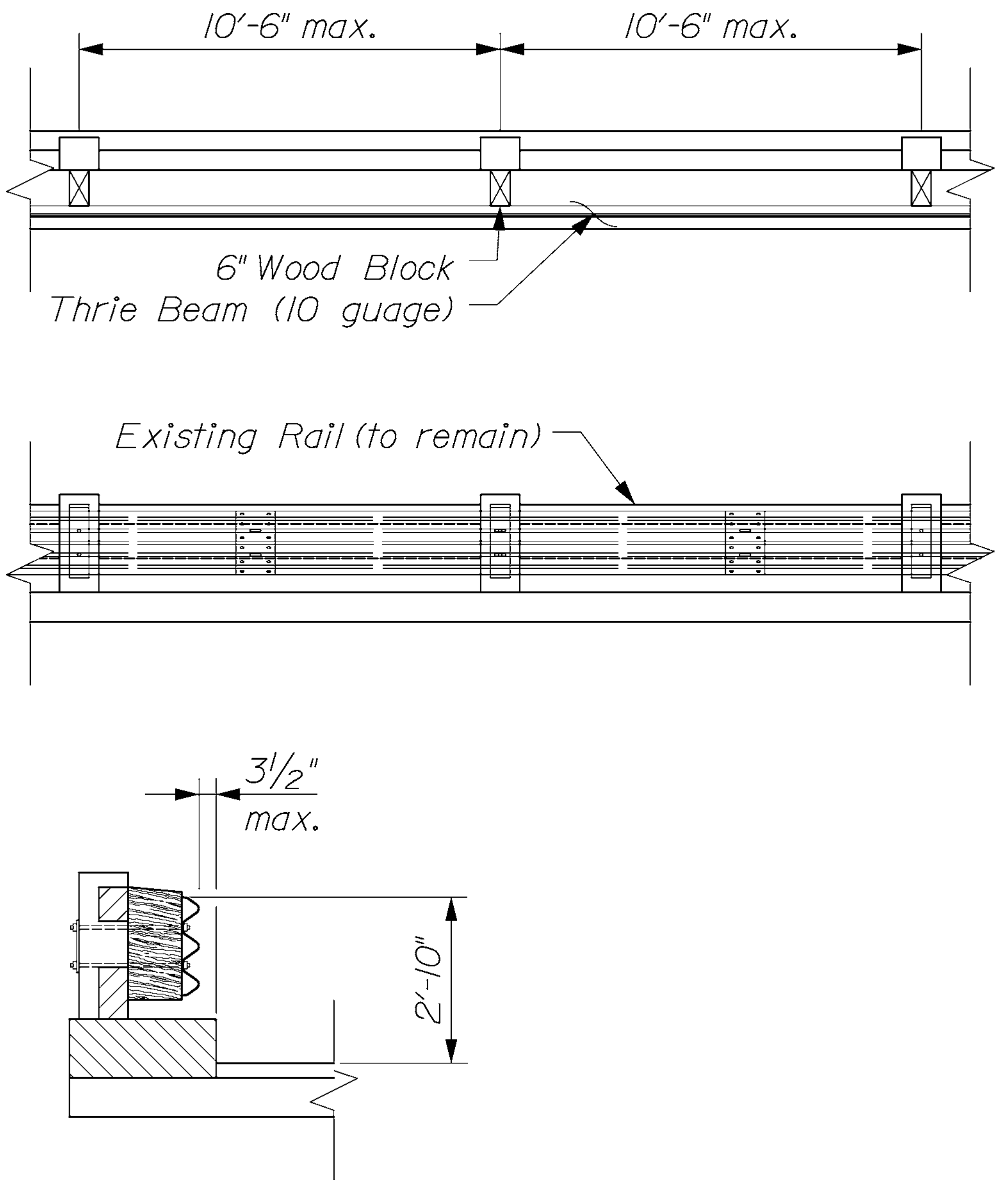


**Figure 10-4 Non-NHS System Rail - Attachment Type "B" - Rail Retrofit**

## 10.6 Substructure Rehabilitation

Substructure rehabilitation work may involve such activities as scour repair, jacketing an abutment or pier, grouting of a granite block abutment or pier, or post-tensioning an unreinforced pier cap.

Where substructures have rotated due to inadequate bearing capacity, the angular distortion due to rotation can be restored in some cases with the use of underpinning. Where substructures are actively rotating, underpinning can be used to stop or decrease the magnitude of the movement. Underpinning consists of increasing the foundation soil bearing capacity by either driving structural elements (piles) or constructing cast-in-place elements (micropiles) adjacent to or under the existing foundation. In some cases, the footing dimensions need to be extended to incorporate the underpinning elements. Underpinning can also be used to increase foundation capacity for substructures that are to remain in place when the superstructure dead and live loads are increased, as with a superstructure widening. The feasibility of the use of underpinning for substructure rehabilitation should be evaluated by the Geotechnical Designer.

## 10.7 Substructure Reuse

### *10.7.1 General*

When an existing substructure is to be reused with new loads applied, the existing foundation should be evaluated to assure adequate capacity. When not known, determination of the existing foundation geometry and condition should be made through exploration and testing. Where foundation deterioration is suspected or indicated, such as pile section loss or weakening due to corrosion or decay, a structural analysis should be conducted to evaluate the effects of the deterioration.

### *10.7.2 Timber Pile Foundations*

Where an existing timber foundation is being considered for reuse, the condition of the existing timber piles should be assessed and the capacity of the piles evaluated. The evaluation for reuse needs to be appropriate to the particular site. FHWA estimates a 50-year life span for timber piles in a marine environment. A typical procedure for timber pile investigation and evaluation should include any appropriate combination of the following:

- Obtain cores of at least one pile from each foundation to evaluate soundness of the pile and the presence of marine borers if applicable.
- Conduct at least one static pile load test to 2.5 times the proposed pile design load.
- Conduct at least one pile integrity test (impact echo test) to evaluate the structural integrity of piles and estimate the length of the piles.
- Evaluate groundwater conditions and subsurface conditions with borings.
- Assess the theoretical capacity of the piles using confirmed soil statigraphy.

### *10.7.3 Granite or Stone Substructure*

If "as-built" plans cannot be found, an investigation to determine the granite or stone abutment configuration should be performed. If "as-built" plans are available, efforts should be directed toward verifying their correctness. The abutment investigation strategy chosen by the Geotechnical Designer needs to be appropriate to the particular site.

A typical procedure for preliminary abutment investigation includes the following:

- Obtain existing records such as "as-built" plans, etc.

- Assess the condition of the existing substructures. Document:

    1. indications of foundation instability (settlement, sliding, or overturning), deterioration of materials (pointing mortar, stones)

    2. localized bulging, rotation of stones

    3. location of cracks, modifications such as concrete caps or facing, and the condition of the modified portions

    4. drainage issues

- Conduct a subsurface investigation to verify abutment geometry and integrity as outlined below.

- Evaluate the reuse potential of the substructure relative to the proposed alignment, width, grade, and loads.

- Perform a cost analysis to determine whether the reuse or reuse with retrofitting alternative is a cost savings compared to new construction.

In order to verify abutment geometry and integrity, the Geotechnical Designer should conduct the subsurface investigation that is appropriate to the particular site. This investigation may include the following:

- *Ground Penetrating Radar (GPR) Survey*: A GPR survey is a useful and economical tool that can be used to determine abutment geometry. A geophysicist's report with an interpretative picture of the geometry of the wall is to be submitted to the Geotechnical Designer.

- *Borings:* Standard wash borings and augers are taken behind each abutment to verify the geometry of the abutment back and footing, and to acquire data on the backfill and foundation material.

- *Test pits:* Test pits are dug to confirm footing dimensions, foundation material, and depth.

- *Seismic techniques*: Various seismic methods, such as crosshole seismic refraction, can be used to define the abutment geometry.

Where reuse of a substructure is selected for final design, stability analyses should be performed as described in Chapter 5, Substructures. The analysis needs to demonstrate that the reused or retrofitted substructure achieves or exceeds the minimum factors of safety for overturning, sliding, and bearing capacity under the proposed grades, widths, and superstructure loads.

## 10.8 Major Rehabilitation Strategy

Large rehabilitation projects occur on long bridges where replacement costs are high, and a life cycle analysis shows that keeping the existing structure in service is more cost effective than replacement. Another project may involve a historic bridge that is rehabilitated rather than being replaced in an effort to salvage it. Work often consists of repairing parts of the bridge that may be difficult to assess, such as vast areas of concrete or wrapped cables. The work may involve both the superstructure and substructure.

A thorough investigation of the extent of work required is important prior to advertising the project. The investigation should include concrete core samples taken at strategic locations and exposing any hidden components that may be in disrepair. During the final design phase, experienced design, construction, and maintenance team members should spend time in the field physically identifying and marking those areas or members that should be rehabilitated. This information must be transferred to the contract drawings and documents.

Historically, these projects tend to overrun the budgeted cost due to unforeseen conditions. Cost estimates should include adequate contingencies to cover any unexpected findings. Concrete rehabilitation or replacement items that are dissimilar in nature should be paid for under separate pay items.

A mandatory pre-bid meeting should be conducted on site to explain how the proposed repair areas were delineated. At this meeting, one of the proposed repair areas may be removed by a maintenance crew for demonstration purposes. All available test reports, documents, and other data relating to the condition of the bridge should be made available to the bidders. Such information may influence or provide information that may affect the bid process or the construction work effort.

## 10.9 Seismic Retrofit

### *10.9.1 General*

The Structural Designer should evaluate the seismic failure vulnerability of bridges programmed for rehabilitation. The Structural Designer should then assess options for seismic retrofit measures that will mitigate or eliminate failure vulnerability.

> *Commentary: Included here are guidelines for determining when seismic retrofit is warranted and what measures should be considered. The retrofit guidelines present concepts in seismic retrofitting, but should not be considered as restricting innovative designs which are consistent with good engineering practice. Much of the guidelines presented are taken directly from the New York Department of Transportation's Interim Seismic Policy.*

The primary goal of seismic retrofitting is to minimize the risk of the collapse of all or part of a bridge, and the loss of the use of a vital transportation route, which may pass over or under a bridge. Because of the difficulty and cost associated with strengthening a bridge to current seismic standards, it is not usually economically feasible to do so. For this reason, the goal of seismic retrofitting is limited to preventing unacceptable collapse modes while permitting a considerable amount of structural damage during an earthquake. The unacceptable modes of failure are:

- Loss of support at the bearings that will result in a partial or total collapse of the bridge
- Excessive strength degradation of the supporting components
- Abutment and foundation failures resulting in a loss of accessibility of the bridge

### *10.9.2 Criteria for Evaluation*

Refer to Section 3.7 Seismic for seismic loading criteria. In addition, the following criteria should be considered:

- *Age and condition of the bridge:* An unusually high seismic vulnerability may justify seismic retrofit or replacement of a bridge with little service life remaining.
- *Rehabilitation project scope:* The nature and extent of scheduled rehabilitation work can influence the decision to include or defer the recommended seismic retrofit activities.

### *10.9.3 Analysis*

Refer to Section 3.7.2 Seismic Analysis for a discussion of seismic categories listed here.

- *SPC A bridges:* These bridges in general, will not require seismic retrofit. However, “essential” bridges programmed for major rehabilitation should be considered for seismic retrofit measures described below.

  For example, consider replacing tall steel rocker bearings with a more flexible bearing such as an elastomeric bearing if extensive bearing restoration work is already required. Tall rocker bearings may fail in shear and topple. Elastomeric bearings can be used to achieve a more uniform load distribution or direct load to the desired substructure. Merely by adjusting the height and shear stiffness of the elastomeric bearing, the distribution of seismic forces can be controlled.

  Another retrofit measure is to replace the existing bearings with more sophisticated energy dissipating devices. These dissipaters limit the seismic force to the superstructure, thereby limiting the damage to the substructure.

  Continuity is also a concern. A multi-simple span bridge does not have the same degree of redundancy as a continuous bridge. Consider providing a continuity retrofit at piers supporting simple spans if bearing or deck replacement work is contemplated. Cable restraints should be considered at piers where the available support length is inadequate and a continuity retrofit is not being considered.

- *SPC B bridges:* The recommended retrofit actions are as follows:

  Replace tall rocker bearings with a more flexible bearing type or an energy dissipating device, and replace or retrofit companion fixed bearings.

  Replace short steel sliding bearings (6 inches deep or less) on “essential” structures and on structures requiring bearing restoration work. Short steel fixed bearings that are in good condition may be kept or replaced as conditions warrant.

  Exceptions may be made to this general guideline when bridges are extremely wide with many stringers in cross section, or when continuous over several supports and bearings are functioning properly and in good condition. Fixed or tall steel expansion bearings supporting non-redundant elements should always be replaced.

Provide continuity at piers for multiple simple span bridges. When conditions permit, the preferred method is to retrofit beams at piers by splicing for continuity. Where this is not feasible, cable restrainers or other connecting devices should be added.

Widen bridge seats where appropriate.

Add lateral restraint systems at substructures.

Concrete columns should be evaluated for reinforcement details. In general, it is preferable to use the principles of seismic isolation by upgrading the bearings rather than retrofitting substructure components. Certain types of bearings can alter the dynamic response of a bridge and as a consequence, can reduce superstructure forces by a factor of 5 to 10.

- *Bridges with special conditions:* Consider additional retrofit measures or structure replacement for bridges with vulnerable components discussed in Section 3.7.1.5 Structure Type and Detail, especially if functionally important, and especially if located in an SPC B area.

### *10.9.4 Scheduling of Seismic Retrofit Work*

For "essential" bridges and bridges with special conditions, seismic retrofit work should be included in the first scheduled general rehabilitation activity for the structure.

For other SPC B bridges, the seismic retrofit work should be included in the next scheduled major rehabilitation work. Minor rehabilitation contracts should include as much of the seismic retrofit work as can be accommodated by the project cost and compatibility of activities. At a minimum, cable restraints or continuity at piers should be included where necessary, and lateral restraint systems should also be included. Bridges with tall steel rocker bearings should be scheduled for follow-up retrofit activity, if necessary.

### *10.9.5 Retrofit Costs*

The cost of retrofitting structures will vary significantly based on the type and extent of needed work, as well as site conditions. It may be appropriate in some cases to limit immediate retrofit action to a predetermined cost ceiling, while deferring remaining less critical actions to a future project. As a guideline, a cost increase in the range of 10% -15% is considered appropriate, with 15% being typical when project cost is less than $2 million. When a bridge is considered to be highly vulnerable, a cost increase in excess of 15% may be warranted to guarantee the structural integrity of the bridge.

In general, a Structural Designer's decision to defer seismic retrofit work for SPC B bridges should be made in concurrence with the Engineer of Design, with appropriate documentation made.

*10.9.6 Procedure*

According to the map in Figure 3-4, only bridges in the extreme northwest of the state are classified as SPC B, with the remaining bridges classified as SPC A. According to the AASHTO Standard Specifications, no detailed seismic analysis is required for any bridge in SPC A or for any single span bridge. However, the connections must be analyzed for specified static forces, and the supports must meet the given minimum support lengths. In addition to these requirements, "essential" bridges in SPC A should be evaluated based on the procedures outlined for SPC B.

The detailed seismic evaluation of a bridge in SPC B should be performed in two phases. The first phase is a qualitative analysis of individual bridge components using one of the methods described in Section 3.7.2 Seismic Analysis. Once the analysis is performed, and the resulting forces and displacements (referred to as demands) are determined, they are compared with the ultimate force and displacement capacities of each of the components. A capacity/demand (C/D) ratio is then calculated for each potential mode of failure in each component. The ratio denotes the portion of the design earthquake that each of the components is capable of resisting.

The second phase of evaluation is an assessment of the consequences of failure in each of the components. Consideration should be given to retrofitting substandard components if their failure results in bridge collapse or, in some cases such as "essential" bridges, the loss of function. A flow chart detailing this procedure is shown and discussed in FHWA, May 1995.

*10.9.7 Seismic Retrofit Systems*

Seismic retrofit systems are designed to prevent collapse and/or severe structural damage of the bridge due to the following modes of failure:

- Bearing failure
- Loss of support due to insufficient seat width
- Pier column failures

Each retrofit system selected must be evaluated to ensure that it does not transfer excessive force to other less-easily inspected and repaired components. All retrofit components should be designed to the standards listed here but, whenever possible, not less than the standards for the design of new structures. Reduced standards may be used when the use of full design standards is not practical or economically feasible, and partial strengthening significantly reduces the risk of unacceptable damage. Further guidance and illustrations of the retrofit systems are found in FHWA, May 1995. The following are examples of systems that can be used:

- *Replacement of bearings:* Certain types of bearings, such as tall steel rocker bearings, have performed poorly during past earthquakes because of their low resistance to horizontal loads. Replace these bearings with modern bearing types such as steel laminated elastomeric bearings or multi-rotational bearings such as pot or disc bearings.

- *Bearing restrainers:* Transverse and longitudinal restrainers will keep the superstructure from sliding off the bearings. Conditions that are particularly vulnerable include tall concrete pedestals that serve as bearing seats for individual girders, and bearing seats where the transverse distance between the bearing and the edge of the seat is small.

- *Bearing seat extension:* Extension of bearing seats may be a feasible retrofit measure in certain situations. Since high forces may be imposed on these extensions, it is recommended that they be supported directly on a foundation structure when possible. All bearing seat extensions should provide a final minimum seat width equal to or greater than the specified value given in Section 3.7.2 Seismic Analysis.

- *Pier column retrofitting:* Under seismic loads, high shear stresses develop between column and cap beam or between column and footing. Therefore, increased transverse confinement should be located within the column end regions. Refer to AASHTO Standard Specification Section 6.

  Be aware that retrofit schemes for increasing confinement may redistribute moments and shears resulting in overstress in other members of the pier, i.e., footing and bent caps.

  Five retrofitting systems are commonly used to retrofit concrete columns. The following systems laterally confine the concrete and increase the member's strength and ductility.

  1. Preformed jacketing: This technique uses steel or FRP plates or shells to passively confine the column.

  2. Prestressed wire wrapping: This technique uses wire wrapped around the column under tension to actively confine the column.

3. Composite fiberglass/epoxy wrapping: This technique involves an FRP fabricated on-site and wrapped around the column. When the FRP cures, the system confines the column.

4. Concrete jacketing: This involves the addition of a thick layer of reinforced concrete.

5. External hoops*:* This technique uses external hoops that are tensioned around columns using turnbuckles.

## 10.10 Buried Structures

MDOT has hundreds of steel culverts that are considered minor spans or bridges. Many of these steel culverts are reaching the end of their design life of 45 to 55 years. Instead of culvert replacement, another option to consider is culvert rehabilitation. MDOT began rehabilitating culverts in the early 1990s.

If culvert rehabilitation is a feasible option, the final decision to rehabilitate or replace usually depends upon one of the following issues:

- Maintenance of traffic
- Right-of-Way impacts
- Utility impacts
- Environmental impacts, including fish passage (short & long term)
- Constructability
- Maintenance
- Cost (first cost and life cycle)

### *10.10.1 Invert Lining*

Culvert invert lining consists of placing a minimum of 5 inches of reinforced concrete in the bottom and sides of a pipe or pipe arch that has a rusted or missing bottom. The Contractor has the option of using shotcrete or cast in place concrete. The top of the concrete invert lining should extend a minimum of 6 inches above the limit of the rust line or the proposed location of shear studs, whichever is higher. The estimated life for a concrete invert lining is about 25 years.

Culvert invert lining is a feasible alternative if all of the following statements are true:

- The culvert has not distorted significantly.

- The top plates and side plates for the culvert are in good condition. Some very minor rusting in spots is acceptable as long as the areas are painted with zinc-rich paint.

- The alignment and/or road width will not change in the next 20 years +/-.

- The hydraulic capacity is adequate even with the reduction in opening area. The Designer should check the reduced opening for its flowing full capacity and its ability to handle Q50. A reduced design flow may be acceptable depending on the individual project, and good engineering judgment is required to evaluate the adequacy of the reduced opening.

- Fish passage can be maintained when necessary. This may involve the use of grade control structures, weirs, baffles, or other methods. Refer to Section 2.3.8.6 Fish Passage.

- The culvert has adequate cover.

- The rust line does not extend more than half way up the side of a pipe or much above the corner plates for a pipe arch.

A site visit for a possible culvert rehabilitation project should include measurements of the rust line height and the lowest elevation at which shear studs can be welded.

### *10.10.2 Sliplining*

Sliplining consists of installing a slightly smaller diameter pipe or pipe arch inside an existing culvert. The gap (i.e. annular space) between the new and existing culvert is filled with grout or flowable fill. Typically an aluminum pipe or pipe arch will be used inside an existing rusted steel culvert. The estimated life for a sliplining is about 75 years. As a general rule, sliplining is a feasible alternative if the all of the following statements are true:

- The culvert has not distorted significantly.

- The alignment and/or road width will not change in the next 20 years +/-.

- The hydraulic capacity is adequate even with the reduction in opening area. The Designer should check the reduced opening for its flowing full capacity and its ability to handle Q50. A reduced design flow may be acceptable depending on the individual project, and good engineering judgment is required to evaluate the adequacy of the reduced opening.

- o Fish passage can be maintained when necessary. This may involve the use of grade control structures, weirs, baffles, or other methods. Refer to Section 2.3.8.6 Fish Passage.
- o The culvert has adequate cover.

Sliplining should be given serious consideration in the following situations:

- o High traffic volumes
- o Lack of a detour route or a reasonably short detour
- o Deep fills (8 feet or more over the culvert)

If there is any doubt that distortion of the culvert may preclude the use of sliplining, the interior of the culvert should be surveyed as discussed in Section 2.5.2 Field Survey.

## References

AASHTO, 1998 and Interims, *Load and Resistance Factor Design (LRFD) Bridge Design Specifications*, Washington, DC

AASHTO, 1996 and Interims, *Standard Specifications for Highway Bridges*, Sixteenth Edition, Washington, DC

Federal Highway Administration, 1996, Seismic Design of Bridges, *FHWA Publication No. FHWA-SA-97-006*, October

Federal Highway Administration, 1987, Seismic Design and Retrofit Manual for Highway Bridges, *FHWA Report No. FHWA/IP-87-6*, May

Federal Highway Administration, 1995, Seismic Retrofitting Manual for Highway Bridges, *FHWA Publication No. FHWA-RD-94-052*, May

National Highway Institute, 1993, Seismic Design of Highway Bridges*, NHI Course No. 13048*, Participant Workbook, prepared by Imbsen Associates, June