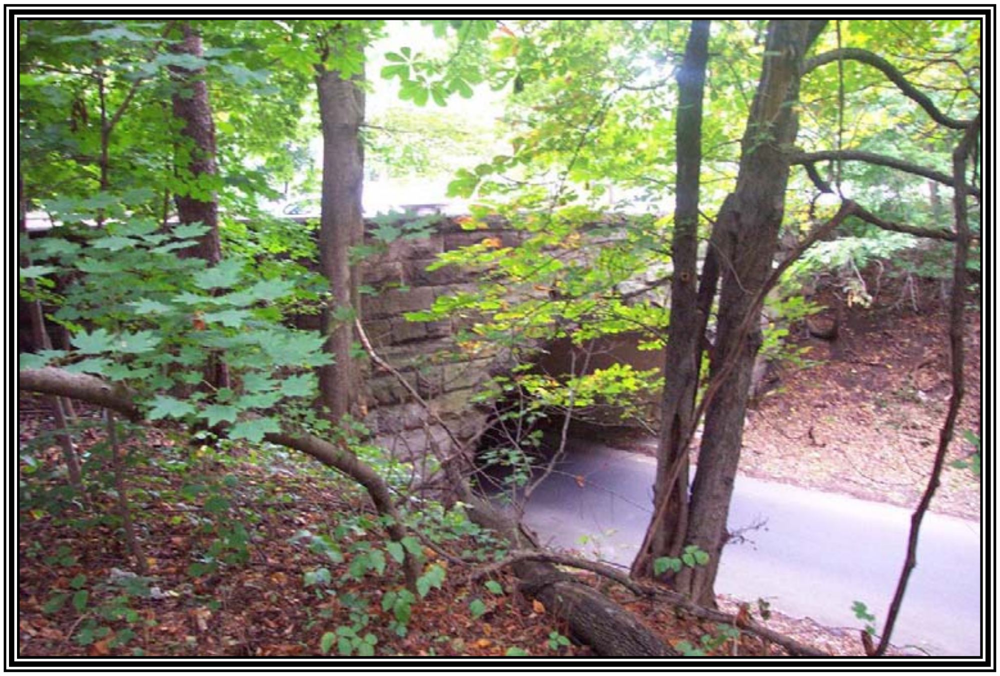
PENNDOT
STONE ARCH BRIDGE
MAINTENANCE MANUAL



OCTOBER 2007

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STONE ARCH BRIDGE
MAINTENANCE MANUAL

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Engineering District 6-0

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Cover: **The Belmont Avenue (S.R. 3005) Bridge, a single-span arch bridge in Fairmount Park, Philadelphia.**

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1.0 INTRODUCTION

This manual provides guidance to state and local bridge forces on maintaining, repairing, rehabilitating, and restoring stone arch bridges. The manual was developed as part of Project Keystone, a management plan designed to identify a portion of the stone arch bridges in the Greater Philadelphia region, which is Pennsylvania Department of Transportation (PennDOT) Engineering District 6-0, for long-term preservation. The guidelines, however, are broadly written and applicable to stone arch bridges throughout the Commonwealth.

Stone arch bridge technology represents the earliest extant bridge type in the Commonwealth. The time-tested technology was used in the state from the earliest days of settlement into the 1940s. Remaining examples in PennDOT Engineering District 6-0 date from 1697 through the mid-twentieth century, and represent the largest collection of stone arch bridges in the Commonwealth and one of the largest in the nation.

Stone arch bridges are often historically and culturally important to the local community. Consequently, there is value in preserving and sensitively treating stone arch bridges, within the limits of acceptable engineering and safety standards. Bridge owners must weigh a variety of factors in any decision to maintain, repair, rehabilitate, or replace a stone arch bridge. The physical condition of the bridge; the type and volume of traffic it must carry; its geometric features; its historic significance; the development pressures around it; the hydraulic capacity and clearance beneath it; the cost of maintenance, repair, or replacement; public safety; and public sentiment all must be taken into account.

The framework for this manual is the *Secretary of the Interior's Standards for Rehabilitation* (National Park Service 2001). These standards provide guidance on maintaining and repairing historic resources. Ten basic principles have been created to help preserve the distinctive character of a historic resource, while allowing for reasonable change to meet new needs. As originally construed, the Secretary's Standards were most applicable to historic buildings. The Virginia Transportation Research Council, in its *Management Plan for Historic Bridges in Virginia* (Miller *et al.* 2001), adapted the standards to address the special requirements of historic bridges. The adapted standards are presented on the following page. This manual uses these guidelines, plus information from a variety of other publications (see References) to develop techniques to maintain, repair/rehabilitate, and reconstruct stone arch bridges.

Guidelines for Historic Bridge Maintenance and Rehabilitation Based on the Secretary of the Interior's Standards[1]

1. Every reasonable effort shall be made to continue an historic bridge in useful transportation service. Primary consideration shall be given to rehabilitation of the bridge on site. Only when this option has been fully exhausted shall other alternatives be explored.

2. The original character-defining qualities or elements of a bridge, its site, and its environment should be respected. The removal, concealment, or alteration of any historic material or distinctive engineering or architectural features should be avoided.

3. All bridges shall be recognized as products of their own time. Alterations that have no historical basis and that seek to create a false historical appearance shall not be undertaken.

4. Most properties change over time; those changes that have acquired historic significance in their own right shall be retained and preserved.

5. Distinctive engineering and stylistic features, finishes, and construction techniques or examples of craftsmanship that characterize an historic property shall be preserved.

6. Deteriorated structural members and architectural features shall be retained and repaired, rather than replaced. Where the severity of deterioration requires replacement of a distinctive element, the new element should match the old in design, texture, and other visual qualities and where possible, materials. Replacement of missing features shall be substantiated by documentary, physical, or photographic evidence.

7. Chemical and physical treatments that cause damage to historic materials shall not be used. The surface cleaning of structures, if appropriate, shall be undertaken using the most environmentally sensitive means possible.

8. Significant archeological and cultural resources affected by a project shall be protected and preserved. If such resources must be disturbed, mitigation measures shall be undertaken.

9. New additions, exterior alterations, structural reinforcements, or related new construction shall not destroy historic materials that characterize the property. The new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.

10. New additions and adjacent or related new construction shall be undertaken in such a manner that if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired.

[1] A.B. Miller, K.M. Clark, and M.C. Gaines, *Final Report for Historic Bridges in Virginia* (Virginia Transportation Research Council, Charlottesville, Virginia, 2001).

2.0 COMPONENTS OF A STONE ARCH BRIDGE

2.1 Stone Arch Bridge Components

Stone arch bridges are built in *courses* of stone. Figure 1 illustrates the component parts of a stone arch bridge. The load is carried by the *arch barrel*. The outer rings of the barrel are generally composed of cut-and-matched, wedge-shaped stones called *voussoirs*. The voussoirs are held in place by the *keystone*. *Abutments and piers*, substructure elements, absorb the thrust placed on the arch and transfer it to the ground. *Wing walls* are extensions of the abutments designed to retain side slope material from the approaches. The *spandrels* are exterior walls that surround the arch barrel and act as retaining walls for fill material, which carries the roadway. The portions of the spandrel walls above the roadway are called the *parapets*. In most cases, flat stones known as *coping* top the parapets. On some bridges, a decorative band of stone work called the *belt course* or *stringcourse* differentiates between the spandrels and the parapets. The bridge's stones are bonded together by a cementitious mixture called *mortar*. Early mortars consisted of sand, lime, and water. Other mortar mixtures include slag cement and Portland cement. The outer mortar material is called *pointing*. The horizontal mortar layers between stones are referred to as *beds*; the vertical layers are called *joints*. Replacing deteriorated exterior mortar is known as *repointing*.

Stone arch bridges can feature a variety of decorative treatments. These include recessed spandrel walls, recessed voussoirs, curved wing walls, *pilasters*, *buttresses*, *towers*, and *look-outs*.

Three broad categories can be used to describe the methods of finishing the stone surfaces of the bridge. *Rubble stone* bridges consist of rough, unsquared stone. The stone is leveled off at specific heights to an approximately horizontal surface. *Squared stone masonry* consists of stones roughly squared and dressed. *Ashlar* is precisely squared and finely dressed stone. Ashlar can be worked to produce a variety of finishes.

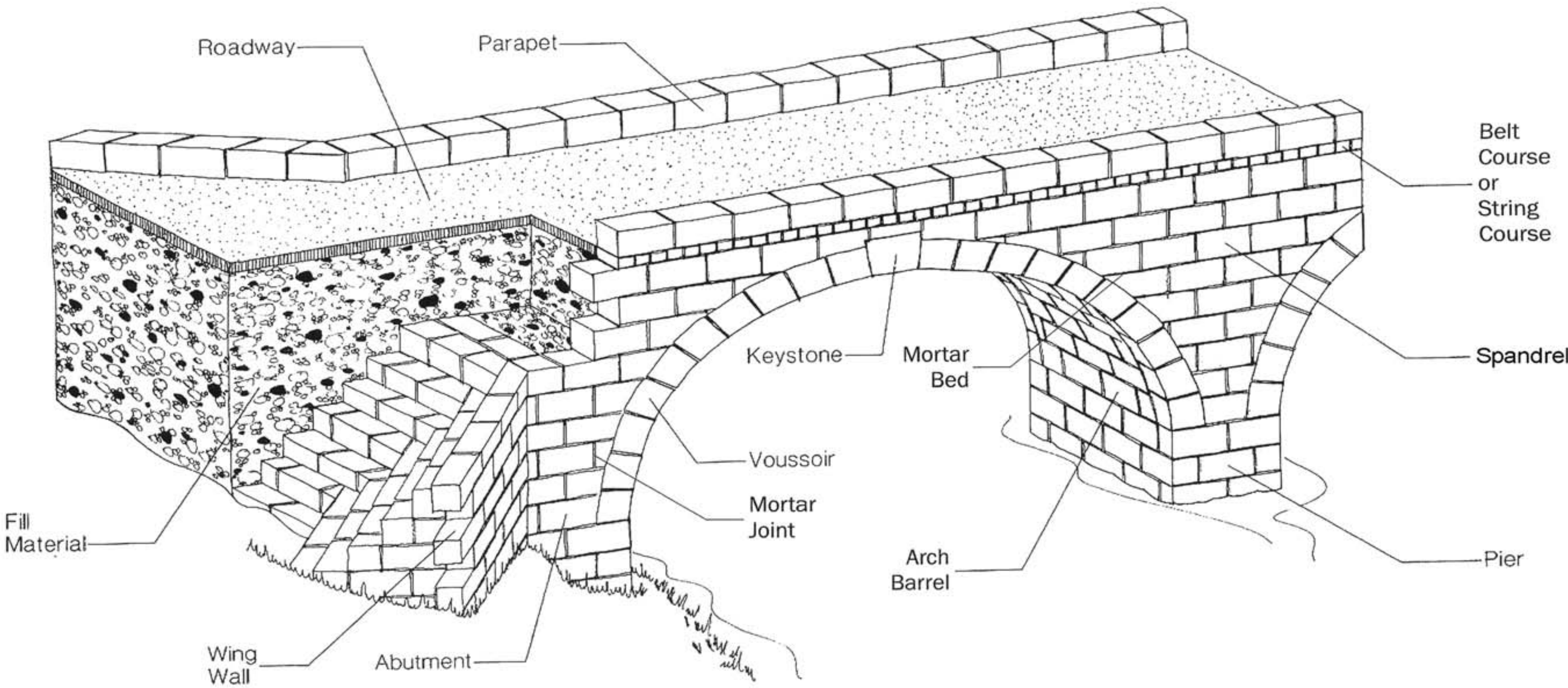
Definitions for italicized words are provided in the Glossary of Terms, located in Appendix A.

2.2 Stone Arch Bridge Character-Defining Elements

All historic resources have character-defining elements, those essential physical features that are important in conveying their historical, cultural, or architectural values. Identifying, retaining, and preserving the character-defining elements of a resource type are important first steps in maintaining and preserving the historic character. The character-defining features of a stone arch bridge are these:

- Voussoir Arch
- Stone material, its cut and coursing
- Stone abutments and wing walls
- Arch Barrel
- Parapet height and shape

It is essential that repairs or rehabilitation do not damage or destroy the materials, features, and finishes that are important in defining the character of the stone arch bridge. Original decorative elements or non-original elements that have obtained a historical significance over time, like those enumerated in the preceding section, add an aesthetic component to the bridge and



Typical Stone Arch Bridge

Source: Commonwealth of Pennsylvania 1986 become character-defining elements in their own rights. Decorative treatments should be respected in the course of completing repairs, rehabilitations, or restorations.

By contrast, the roadway surface and the fill material employed to support it are not character-defining elements of a stone arch bridge. Replacing these components to strengthen a bridge or improve its drainage will not adversely affect its historical or architectural character.

3.0 BUILDING WITH STONE AND MORTAR

3.1 Reference Works

Stone and mortar are building materials that require special preparation and treatment in order to ensure the best possible bond between the elements, and thus provide the bridge with the necessary strength and durability. A number of reference books are available that provide detailed information on building and repairing in stone. Two of the most useful are:

Cramb, Ian
1992 *The Art of the Stonemason*. Betterway Books, Cincinnati.

McRaven, Charles, and Chandis Ingenthron
1989 *Building with Stone*. Storey Books, North Adams, Massachusetts.

3.2 Needed Skills

In general, the maintenance functions described in Section 4.2 can be undertaken by laborers working under the supervision of a maintenance foreman. Repairs and rehabilitations of stone arch bridges should be completed under the direction of a professional engineer. Repair and rehabilitation work should be supervised by a mason experienced in the stone work, in shaping and coursing stones, and in the use and mixture of mortar. Generally, the mason will need one or more laborers to assist with tasks such as transporting stones, mixing mortar, and laying the stones.

3.3 General Guidelines on the Use of Building Stone on Stone Arch Bridges

There is great variety in building stone. Structural stone varies in content, color, structure, workability, strength, and durability. When treating historic stone arch bridges, the following general guidelines apply to building stones:

- Ideally, bridges should be repaired using the original stones, if possible.

- If it is not possible to use the original stones, the replacement stones should match the existing stones in type, size, texture/finish, and color.

3.4 General Guidelines for Repairs on Stone Arch Bridges

When repairing or rehabilitating stone arch bridges, all work should be performed in accordance with Publication 55 (PennDOT 2002), Publication 408 (PennDOT 2003), and Chapter 14 of Bulletin 15 (PennDOT 2006), and the following general guidelines:

- All repair, rehabilitation, and restoration projects should be undertaken cautiously and only when necessary and specified in the biennial bridge safety inspection report.

- In general, all repairs should be undertaken using the least obtrusive means possible, with a plan to disturb the least amount of original material; unnecessary repairs and replacements should be avoided.

- All stone work, even random rubble, is built in courses, with the lift or height of each level typically being approximately 18 to 24 inches. To break the monotony of straight, long lines (known as *levels)*, *risers* (stones that rise above or through the line) were often placed at fairly regular intervals. A bridge should be studied and documented through photographs and (if necessary) engineering drawings prior to beginning treatment to discern and create a visual record of workmanship and the conditions to be addressed. The original pattern should be replicated as much as possible in the course of the repairs.

- Where repair or rehabilitation is necessary, the work should use original material wherever possible. If it is not possible to use original material, in-kind material should be used; if replacement of a missing element is required, the replacement should also be in-kind. Stones used should match existing stones in type, size, texture/finish, and color.

- All stones should be clean, durable, properly quarried, and free from structural defects.

- Stones should be thoroughly saturated with clean water prior to beginning work, but no standing water should be present. Dry stones draw moisture from the mortar, causing it to dry out and crack.

- When undertaking large repairs and reconstruction, build up at 18 to 24 inch increments; do not *finish point* until all construction is complete. The process is build up, point, and clean down upon completion.

- When laying stones, place each so that it would stay in place even without mortar; mortar is a binding, not a glue. Stones should be well-bedded in the mortar, and placed without hammering or jarring any stone already in place.

- Document all repair/rehabilitation work, including date, limits of work, and a description of the work undertaken.

3.5 Mortar

Mortar consists of binders (such as cement and lime), aggregates, and water. It is a sacrificial material that is expected to be replaced through repointing over time. It is preferred that mortar deteriorates rather than the adjacent stones. Mortar acts as a bonding and filling agent that binds the stones together in one mass, strengthening the structure. A stiff, semi-liquid form when applied, mortar can conform to all irregular spaces between stones, distributing weight and stress evenly. When cured, it acts in concert with the stones. Mortar keeps moisture from penetrating between stones and draw moisture that has penetrated back out. It also keeps seedlings and roots, which will crack a wall as they grow, from infiltrating the bridge. Keeping mortar in good repair is an essential part of extending the life of a bridge.

3.5.1 Mortar Mixes for Stone Arch Bridges

Depending on the date of construction, a variety of binders may be present in the mortar of stone arch bridges, including earth and clays; lime; natural cements; hydraulic cements; other manufactured cements; Portland cement; and masonry cements. The type of binder used significantly affects the characteristics and performance attributes of the mortar. For example, mortars made with lime binders generally have lower compressive strength, lower bond strength, and greater permeability than mortars containing Portland cement binders. Mortars with high lime content also have the ability to re-seal small hairline cracks, provide greater prevention against rain penetration, and allow moisture that has penetrated the masonry to escape. However, they take longer to cure and reach full compressive strength. By contrast, mortar mixes containing high Portland cement ratios cure and reach full compressive strength quickly, but they lack the flexibility of lime-based mortars and tend toward hairline cracks as the mixture dries, which allows moisture to penetrate the structure. As the moisture freezes and thaws, stones can be pushed apart and out of place. Mortars with high Portland cement ratios can also cause sandstones, granites, and limestones to decay. For these reasons, mortars with high Portland cement ratios are generally not recommended for repairing historic stone arch bridges.

Mortar characteristics, such as compressive strength, permeability, and durability are related to its component elements and their proportions. When creating a repair mortar, the exact physical and chemical properties of the historic mortar are not of major significance as long as the repair mortar can coexist with the historic mortar in a sympathetic and supportive capacity and it is compatible with the type of stone used to construct the bridge. It must have a lower compressive strength and a greater *vapor permeability* the masonry units of the bridges. Vapor permeability is defined as the ability to move moisture from the interior of the structure back out into the atmosphere.

For these reasons, this manual recommends mortar mixtures that may vary from the mortar recommended in Publication 408, Section 705.7. The design and selection of a repair mortar for use on historic stone arch bridges should be based on the type of stone present, the current site conditions, the intended use or use of the mortar (bedding, pointing, etc.), and the characteristics of the historic mortar. To determine the proper mortar mix, it may be necessary to analyze the composition of the historic mortar. Petrographic examination of samples of the historic pointing mortar can be used to help determine the composition of the original mortar for use in developing a repointing mix. In some special case, detailed compositional analysis of a historic mortar may be required. This type of analysis can be performed following methods of ASTM C1324, *Standard Test Method for Examination and Analysis of Hardened Masonry Mortar*.

3.5.2 General Guidelines for Using Mortar

When treating historic stone arch bridges, the following general guidelines apply to mortar:

- Repair mortar (repoint) only when there is evidence of deterioration. Evidence includes disintegrating mortar, cracks in the mortar joints, gaps at the mortar/stone interface, loose stones, or damp walls.

- The repair should address only those areas of the bridge where deterioration is present; sound mortar that is well-bonded to the adjacent masonry should not be removed.

- Repoint using a mortar that is compatible with the historic mortar and which matches it in color, texture, and finish.

- Mortar should be stiff. Stiff mortar shrinks less and allows the stone to set up without squeezing the mortar out. Mortar is a good consistency when, if the mixture is squeezed by hand, it does not run out.

- Mortar should not be allowed to dry out during use and should be reworked at intervals before being placed in joints. *Retempering*, or adding more water, should not be permitted.

3.6 General Treatments Not Recommended for Stone Arch Bridges

- Using replacement stones that do not match the existing stones in type, size, texture/finish, and color.

- Using repair mortars that are incompatible with the type of stone or the historic mortar.

- Using repair mortars with a greater compressive strength and a lesser vapor permeability the masonry units of the bridges

- Using mortar for repointing that does not match the historic mortar in color, texture, and finish.

- Using mortars with high Portland cement ratios.

- Repairing bridge components with concrete, gunite/shotcrete, or other historically inappropriate material.

The application of exterior coatings, such as granite/shotcrete, can trap moisture, making the mortar susceptible to frost damage. Frost damage can cause cracks in the gunite/shotcrete and in the bridge mortar, leading to further water penetration and freeze/thaw damage. Also, exterior coatings may not allow the stones to dry out, which can lead to *spalling* and *delamination*, and obscure or conceal problems that can be addressed only if discovered during bridge inspections.

4.0 TREATMENT OF STONE ARCH BRIDGES

The following sections provide guidelines for preserving/maintaining, repairing, rehabilitating, and restoring stone arch bridges.

The first source of information available to the bridge owner is the bridge safety inspection report, which lists both short-range actions (maintenance, preservation, or repair) and long range actions (rehabilitation or complete reconstruction) needed by the bridge. Repairs should be noted on Screen AH of Publication 100A (PennDOT 1995). Procedures and standards for bridge repair are described in Publication 55 (PennDOT 2002). However, inspection reports need to be carefully reviewed, as several maintenance items related to stone masonry structures are not well defined by Publication 55 BMS Activity Numbers.

For bridges recommended as strong-candidates for long-term preservation, the owner should consider the maintenance needs and more serious structural needs and develop a long-range plan to maintain the arch. Failure to develop and implement a preservation plan will generally relegate the bridge to eventual replacement. The decision to preserve or replace a stone arch bridge must be made carefully using “context-sensitive” engineering techniques.

Once a decision to preserve or restore a stone arch bridge has been made, the preservation of the character-defining elements of the bridge -- the voussoir arch, the arch barrel, the coursing and cut of the stone material, the parapet height and shape, the stone abutments and wing walls, and any decorative elements -- should be a priority, in order to protect the bridge’s historical and architectural character. Wherever possible, structural and safety considerations made to meet current engineering standards should be done in concert with historic preservation concerns.

4.1 Recommended Maintenance Program for Stone Arch Bridges

The most cost-effective method of preserving stone arch bridges is to develop a program of routine maintenance. A routine maintenance program arrests problems before they develop or threaten the continued viability of the bridge, reducing the need for and frequency of major repairs and the costs associated with the bridge. Routine maintenance can ultimately extend the life of a stone arch bridge for a relatively small amount of money when compared to the cost of repair and rehabilitation.

Perhaps the most important maintenance measures involve arresting water infiltration. Many structural problems associated with stone arch bridges can be traced to an influx of water. It is critically important, therefore, that existing drainage systems be kept open, pointing be maintained in good repair, and holes in the roadways and other places on the bridge be repaired quickly in order to limit water infiltration.

A suggested program of routine maintenance is provided below. Some measures, such as removing vegetation, cleaning joints, clearing drainage openings, and removing debris from arch openings should be done a minimum of once a year, and more frequently if noted on the biennial inspection report. Other measures, such as repointing, should be noted on the biennial inspection report and Screen AH of Publication 100A (PennDOT 1995) and done on an as-needed basis.

4.1.1 Clearing Vegetation

Vegetation touching bridge surfaces, such as bushes or tree branches, can trap moisture and not allow the bridge to dry out, potentially leading to mortar deterioration, cracks in mortar joints, and spalling and delamination. Vegetation that has infiltrated the bridge structure, such as vines or roots, can cause a host of problems, including deteriorated mortar, cracks in mortar joints, loose stones, bulging walls, and greater water infiltration. Unchecked, vegetation infiltration can result in structural damage.

The removal of vegetation penetrating masonry does not have an associated activity code in Publication 55. The following treatments are recommended.

4.1.1.1 Clearing Vegetation - Treatment Recommended

Vegetation should be cleared from the bridge annually.

- Clear all vegetation touching the bridge (leaves, brush, branches); clear the width of the right-of-way or a distance of 5 feet away from the structure, whichever is greater.

- Remove any vegetation or roots that have infiltrated the bridge:

  Removal should be done carefully; pulling vines or roots from the structure without care can damage the mortar, mortar joints and/or the structure and potentially lead to structural failure.

  If possible, remove growth on a section-by-section basis (each section approximately 10 square feet), rather than all at once, to decrease the danger of structural failure or damage.

  Herbicides can be a non-invasive treatment to kill growth or prevent new growth. Department staff should consult their roadside manager for acceptable treatments.

4.1.2 Improving Drainage and Reducing Water Infiltration

4.1.2.1 Improving Drainage - Treatment Recommended

<u>Cleaning Drainage Openings</u>

Clean and flush drainage openings to remove any accumulated debris. The continuity of the existing drainage system should be first checked to ensure that leakage to the arch fill will not occur. Cleaning should follow the procedures outlined in Publication 55, Chapter 2 (BMS Activity Numbers A743101 and B743101), as supplemented by the guidelines below:

- The cleaning method should not damage the bridge or drainage system; cleaning can be done by hand, or by using compressed air or pressurized water (maximum 1,500 psi). The results should be monitored and pressure reduced if any damage occurs.

- If necessary, install screening material over surface drain openings to reduce debris penetration; screens should be checked and cleaned at least annually, and more often if possible.

- If drains have been overlaid with bituminous, the bituminous material should be cleared.

Adding Drainage Openings/Weep Holes

Add weep holes or other forms of drainage as described in Publication 55, Chapter 9 (BMS Activity Number 744401), or based on the guidelines provided below:

- Core through the arch or spandrel wall and into fill using a bit with a diameter as required to install a PVC pipe without interference, cut no larger than 3 inches wide. Insert a 2 inch PVC pipe and seal around with mortar.

- The pipe should be cut flush with the spandrel or arch barrel to make it as inconspicuous as possible.

4.1.2.2 Reducing Water Infiltration - Treatment Recommended

- Clean and seal cracks in the roadway pavement and at the joints where the parapet meets the roadway. Follow the procedures of Publication 55, Chapter 8 (BMS Activity Number BITWRGS), as supplemented by the guidelines below:

  Cleaning should be done by hand or by using compressed air. For this treatment, pressure washing is not recommended due to the possibility of causing damage and increasing the level of water infiltration into the fill.

- Surface grade to reduce the amount of water reaching the arch embankment:

  For bridges with sloped grades through the arch, roadway inlets, placed near the corners of the bridge can, with proper grading, capture roadway drainage and reduce the volume of water passing along the roadway/parapet joint, thus reducing infiltration to the fill.

  Creating a chamfer in the wearing surface along the parapets so that water flows away from the joints will also prevent infiltration.

- Repair cracks in the mortar joints when bridge inspections reveal problems with the pointing, such as disintegrating mortar, cracks in the mortar joints, loose stones, and damp spandrels/arch barrel.

  Follow the repointing procedures provided in Section 4.3.1.1.

4.1.3 Removing Debris from Substructure Elements and the Arch Opening

Debris and vegetative matter around the substructure elements in the arch opening restricts the free flow of water. This impediment can result in the undermining of the bridge and/or cause *scour* problems.

4.1.3.1 Removing Debris – Treatment Recommended

Remove and dispose of debris as outlined in Publication 55, Chapter 16 (BMS Activity Numbers ECREMVG and ECREMDP).

4.2 Repairing, Rehabilitating, and Restoring Stone Arch Bridges

4.2.1 Repairing and Rehabilitating Stone Arch Bridges

When working on historic resources, such as the bridges recommended for historic preservation, the terms “repair” and “rehabilitation” have specific meanings. *Repair* refers to a corrective measure or corrective measures or task(s) intended to return a specific defect or deterioration to a functional or near original condition or state. *Rehabilitation* is defined as “the process of returning a property to a state of utility, through repair or alteration, which makes possible an efficient contemporary use while preserving those portions and features of the property that are significant to its historic, architectural, and cultural values.” Common repairs to stone arch bridges include rebuilding parapets and wing walls damaged due to traffic impacts. More substantial rehabilitation involves rebuilding bulging spandrel walls and rebuilding arch rings and arch barrels.

Repair and rehabilitation can be cost-effective treatments. The continued utilization of a bridge saves on demolition costs, the need to excavate for new substructure elements and/or cofferdams, and the cost of a new substructure and superstructure.

4.2.2 Restoring Missing Elements to a Stone Arch Bridge

Restoration is defined as the act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by removing features from other periods in its history and reconstructing missing features from the restoration period. Restoration describes, for example, reconstructing parapets that were removed and replaced at some past time by W-beam or reinforced concrete safety shaped barriers. Restorations should be historically accurate, based on historic photographs, historic plans and drawings, or other research that shows the bridge during the restoration period. Conversely, historically inaccurate restorations based on speculation should not be undertaken. Conjectural features create a false sense of historical development.

4.3 Repair, Rehabilitation, and Restoration Treatments

Repair, rehabilitation, and restoration treatments are provided below. The first four treatments -- repointing, repairing spalling and delaminated stones, replacing missing stones, and removing gunite -- apply to all bridge components. The remaining treatments are organized by bridge component, with repair and rehabilitation treatments given first, followed by restoration treatment. Actual costs associated with stone arch bridge repair and rehabilitation are provided in Appendix B.

4.3.1 Repointing

Repointing is the process of replacing deteriorated exterior mortar with new. Keeping mortar in good repair is an essential part of extending the life of a stone arch bridge. Mortar keeps moisture from penetrating between stones, allows moisture entering the masonry to escape, and stops seedlings and roots, which can crack a wall as they grow, from infiltrating the structure. Repointing should be undertaken only when there is evidence of deterioration, such as disintegrating mortar, cracks in the mortar joints, gaps between the mortar joints and stone, loose stones, or damp surfaces. Repointing should be performed in accordance with Publication 55, Chapter 14 (BMS Activity Code 744804) and the guidelines outlined below.

4.3.1.1 Repointing - Treatment Recommended

- Remove all deteriorated and loose mortar to a minimum depth of 2 to 2½ times the width of the joint to ensure an adequate bond. Removal to a greater depth may be required to reach sound mortar.

- Clean mortar joints using hand tools such as a trowel, hand chisel, and hammer or a small pneumatic chisel; the use of power saws and grinders is not recommended because of the potential to damage the surrounding stone. Remove mortar cleanly, leaving square cuts at the rear of the joint, if possible.

- Rake out loose material using a natural bristle or nylon brush or low-pressure compressed air (40-60 psi). Low pressure water (maximum pressure 400 psi) may also be used, although care should be taken not to scour additional bedding mortar out of the joints.

- Any loose stones encountered should be carefully removed, cleaned, and reset in their original positions (see Section 4.3.3).

- Repoint only when the ambient temperature is between 41 and 86 degrees F, and is expected to remain above 41 degrees for several days following repointing; the stone should be free of frost.

- Repoint using a mortar that is compatible with the historic mortar and which matches the historic mortar in color, texture, and, finish.

- Measure and mix mortar components carefully to assure uniformity of visual and physical characteristics. Measure dry ingredients by volume and thoroughly mix them before adding water.

  After dry mixing, add half the needed water and mix for approximately five minutes. Then add the remaining water in small portions until the desired consistency is reached.

- Before placing the repointing mortar, dampen masonry surfaces and joints with a spray bottle to control suction and evaporation. Joints should be damp, but with no standing water present.

- Place new mortar to within 1½ inches of the face of the stone. Mortar should be compacted in successive layers, with each layer permitted to reach thumb-print hardness before the next layer is applied.

  Hand pointing is the preferred method; a pressure gun may be used by experienced operators.

- Finish point the remaining 1½ inches:

  Finish pointing should be done by hand, using a pointing tool. For the outer ¾ inches, install mortar in ¼ in lifts, compacting each layer. Permit each layer to reach thumbprint hardness before the next layer is applied.

  Upon completion, the new pointing should match the historic finish and tooling; the finish should match the stone face or be slightly concave, to channel water out of the wall and to avoid water pooling.

- The repointed mortar joints should match the width of the historic mortar joints.

- Immediately after repointing, clean excess mortar from adjacent masonry, taking care not to damage newly pointed joints. Use only natural bristle or nylon brushes and wood or plastic tools to remove excess mortar.

- After mortar has begun hardening (about 12 hours), tamp back with a stiff brush to further compact the material.

- Protect the finished work from direct sun and rain until the face has cured and hardened, approximately 48 hours.

- After mortar has been allowed to cure for 7 to 14 days, clean exposed masonry surfaces using stiff nylon or natural bristle brushes and clean water sprayed at low pressure (maximum pressure 400 psi).

4.3.1.2 Repointing - Treatment Not Recommended

- Removing non-deteriorated mortar from sound joints and repointing the entire bridge to achieve a uniform appearance.

- Saw cutting or grinding the mortar joints.

- Not hand pointing the final 1½ inches.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and finish.

- Not protecting the finished work from direct sun and rain until the face has cured and hardened.

- Using metal scrapers or brushes or acid and alkali cleaning agents on the bridge.

4.3.2 Repairing Spalling and Delaminated Stones

Spalling refers to the flaking or chipping off of the exterior surface of a stone. Delamination refers to the separation of stones into constituent layers. Spalling and delamination can create gaps in joints, allowing moisture to infiltrate the structure.

No codes in Publication 55 specifically refer to the repair of spalled or delaminated stones. Related BMS Activity Numbers include B744802 (Abutment Repair); C77402 (Wing Wall Repair); A745201 (Culvert Headwall/Wing Repair); and C745203 (Culvert Arch Barrel Repair).

The treatment outlined below applies to one or a small amount of stone. Spalling and delamination over an extensive area may require reconstruction of a component, particularly if there is evidence of water infiltration.

4.3.2.1 Repairing Spalling and Delaminated Stones - Treatment Recommended

- Clean spalled or delaminated areas with a wire brush, compressed air, or low pressure water (maximum 400 psi).

- Cover the spalled or delaminated areas with a mortar mix similar in color to the surrounding stone.

    - Prior to beginning, prepare a 1.5 foot test patch designed to match the color, for review and approval by the job foreman or project engineer.

    - Hand-trowel the mortar on the spalled or delaminated areas; finish to match the finish of the surrounding stone.

- Scribe mortar lines, if necessary, into the area to match the appearance of the existing coursing and mortar.

4.3.2.2 Repairing Spalling and Delaminated Stones - Treatment Not Recommended

- Cleaning the spalled or delaminated area with high pressure water, which can damage the intact portions of the structure and lead to water infiltration.
- Using a mortar mix that does not match the color of the surrounding stone.
- Repairing spalling or delaminated stones with concrete, gunite/shotcrete, or other structurally or historically inappropriate material.
- Not scribing mortar lines into the mortar mix or not matching the appearance of the existing mortar.

4.3.3 Replacing Missing or Loose Stones

This treatment refers to replacing an individual stone or small number of stones. It does not contemplate major repairs, rehabilitation, or restoration of stone work. As with the previous section of this manual, no codes in Publication 55 specifically refer to the repair of missing or loose stones. Related BMS Activity Numbers include B744802 (Abutment Repair); C77402 (Wing Wall Repair); A745201 (Culvert Headwall/Wing Repair); and C745203 (Culvert Arch Barrel Repair).

Missing stones can result in water infiltration. They may also be symptomatic of larger problems with the bridge. The cause behind the missing stone should be thoroughly investigated and noted on Screen AH of Publication 100A, and measures should be taken to correct larger problems, if necessary.

4.3.3.1 Replacing Missing Stones - Treatment Recommended

- Replace missing stones with the original stones, if possible.
- If it is not possible to reuse the original stones, the stones should be replaced in-kind, matching the existing stones in type, size, texture/finish, and color.
- Thoroughly clean the stones and the receiving surface using low pressure water (maximum pressure 400 psi).
- Apply a lining of bedding mortar to the surface of the hole to be filled.
- Carefully reset the stones, ensuring that they are well-bedded; do not jar the masonry already in place.

- Place the stones so that the natural stratification is parallel to the bedding plane.

- After the mortar has cured, repoint using the procedures outlined in Section 4.3.1.1 and a mortar that is compatible with the historic mortar and which matches the historic mortar in color, texture, and finish.

4.3.3.2 Replacing Loose Stones – Treatment Recommended

- Carefully withdraw the stones to be reset to avoid damage to the adjoining masonry.

- Clean off loose mortar.

- Follow the remaining steps outlined in Section 4.3.3.1 above.

4.3.3.3 Replacing Missing or Loose Stones - Treatment Not Recommended

- Replacing missing stones with stones that do not match the existing stones in type, size, texture/finish, and color.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and, finish.

- Repairing with concrete, gunite/shotcrete, or other structurally or historically inappropriate material.

4.3.4 Removing Concrete, Gunite/Shotcrete, or Other Historically Inappropriate Exterior Coatings

This refers to the process of removing concrete, gunite/shotcrete, or other historically inappropriate exterior coatings. These coatings can trap moisture, making the mortar susceptible to frost damage. Frost damage can cause cracks in the gunite/shotcrete and in the bridge mortar, leading to further water penetration and freeze/thaw damage.

4.3.4.1 Removing Concrete, Gunite/Shotcrete, or Other Historically Inappropriate Exterior Coatings - Treatment Recommended

- Remove the exterior coating using hand tools and small pneumatic-powered chipping hammers, exposing the natural stone faces. The work should be done carefully to avoid damaging, loosening, or working loose the underlying stones.

- Continuously monitor surrounding surfaces to ensure that the coating is not delaminating and potentially detaching, which could cause the sudden collapse of a large section of the coating and injury to the workers.

- Should any stones behind the exterior material become loose or fall out, replace them using the procedures outlined in Section 4.3.3.

- Following the removal of the exterior coating, the surfaces should receive a light abrasive blast cleaning (below 400 psi) to remove any remaining film and chisel marks. The process should be stopped if the cleaning damages the newly exposed stones. Sand blasting can quickly disfigure soft stone surfaces.

- After cleaning, all surfaces should be rinsed with low pressure water (maximum 400 psi) and a natural bristle or synthetic brush. Plain water used for cleaning should be tested for minerals that may cause staining. Demineralized water should be used.

- If repointing is necessary, follow the procedures outlined in Section 4.3.1.1.

4.3.4.2 Removing Concrete, Gunite/Shotcrete, or Other Historically Inappropriate Exterior Coatings - Treatment Not Recommended

- Removing the exterior coating with tools other than hand tools and small pneumatic chipping hammers.

- Using high-pressure water to wash the stones following the removal of the exterior coating.

4.3.5 Repairing/Rehabilitating Damaged or Missing Parapets and Coping

The parapet height and shape are character-defining elements of a stone arch bridge. Parapets are also one of the most frequently damaged parts of a stone bridge, primarily due to vehicle impact. Coping stones are also frequently missing, which can lead to water infiltration, or they have been replaced with nonhistoric and inaccurate concrete replacements. In some instances, stone parapets have been removed and replaced with historically inappropriate treatments, such as reinforced concrete safety shaped barriers or metal beam guiderails.

Publication 55, Chapter 5 does not contain a BMS Activity Number for stone masonry parapet repair and replacement. In conducting the work, the following procedures should be followed.

4.3.5.1 Repairing/Rehabilitating Damaged Parapets and Coping – Treatment Recommended

- Rebuild damaged parapets with the original stones, if possible.

- If it is not possible to reuse the original stones, the stones should be replaced in-kind, matching the existing stones in type, size, cut, texture/finish, and color.

- The repaired section should replicate the coursing of the original section.

- When rebuilding damaged parapets, follow the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

4.3.5.2 Restoring Missing Parapets and Coping - Treatment Recommended

- If restoring a missing parapet involves the replacement of existing, nonhistoric railings, a design exception may be necessary before proceeding with the work.

- Restore a missing parapet or section of a parapet and coping based on documented evidence, such as an intact parapet, historic photographs or plans, or an intact parapet on another bridge constructed at approximately the same time.

- Use in-kind material that replicates the historic appearance in type, size, texture/finish, cut, and color.

- Recreate the coursing of the historic parapet and the appearance of the coping.

- When restoring the missing parapets, follow the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

4.3.5.3 Restoring Missing Parapets and Coping Stones - Other Acceptable Treatment

- Using stone-faced reinforced concrete or reinforced concrete scored to replicate stone. This should be undertaken only when mandated by engineering and safety standards.

  The final appearance should be based on documented evidence, such as an intact parapet, historic photographs, plans, or an intact parapet on another bridge constructed at approximately the same time.

  The stone facing should replicate the color, size, texture/finish, coursing, and cut of the bridge.

Score joints and finish point as described in Section 4.3.1; the mortar should match the existing mortar in color, texture, and finish.

4.3.5.4 Parapets and Coping - Treatment Not Recommended

- Repairing damaged parapets with concrete, gunite/shotcrete, metal guiderails, or other structurally or historically inappropriate material.

- Repairing or restoring parapets with stones that do not match the existing stones in type, size, texture/finish, cut, and color.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and, finish.

- Recreating a parapet not based on an intact parapet or other historical evidence.

- Using synthetic stone.

- Not documenting the repair or restoration.

4.3.6 Repairing/Rehabilitating Damaged or Missing Spandrels

Spandrels act as retaining walls for the fill material that supports the roadway. Common problems include bulging spandrels, rotating spandrels, and spandrels that have separated from the arch barrel. Typically, spandrel problems are the result of poor drainage with related freeze-thaw lateral forces, excessive pressure from the fill forcing the wall(s) outward, or a combination of these conditions. When the Inspection Report describes a spandrel that is severely bulging, out of plumb, or partially or completely collapsed, the repairs should address the root causes of the problem as well as the basic wall repair. Spandrel problems should receive a high repair priority. Not correcting the problems and the sources of the problems can result in "*sidewall blowout*," where all or part of a spandrel collapses, with attendant damage to the roadway, parapet, arch ring, and arch barrel.

In addition to these problems, spandrels on some stone arch bridges have been subjected to historically inappropriate treatments, such as the use of gunite/shotcrete, long-term shoring with *gabions*, or replacement of stone with concrete.

Currently, spandrel wall repairs are generally identified by BMS Activity Number A745201, Culvert Headwall Repair. It is recommended that Publication 55 be revised to assign a separate BMS Activity Number to the repair of stone arch bridge spandrels.

Repairing and reconstructing spandrel walls should only be done at the direction of a professional engineer. In most cases, the repairs can be accomplished by a team led by a skilled mason. However, the determination of the cause(s) and possible complication with the arch itself should be the purview of an engineer.

Prior to beginning any spandrel wall repair or reconstruction, the need for temporary shoring should be considered. The wall may appear to be stable at the start of work, but further demolition or unbalanced placement of the stones may require the construction of falsework to support the wall until the final, stable configuration is reached. Shoring must be designed by a professional engineer. Environmental concerns should also be considered, especially when performing work within the waterway.

Please note that all of the following repairs should also include installation of drains to eliminate water-related forces acting on the wall.

4.3.6.1 Repairing/Rehabilitating Spandrels – Treatment Recommended

Repairing/Rehabilitating Spandrels Without Excavation

- Remove the section of the spandrel in need of repair. Consult the engineer or engineering report for the extent and sequencing of the demolition and rebuilding process.

  The parapet wall should also be checked and should be removed and reset if the spandrel walls become or appear to be unstable or unsafe.

- Rebuild the spandrel by resetting the original stones, if possible. If it is not possible to reuse the original stones, replace the stones in-kind, matching the existing stones in type, size, cut, texture/finish, and color. Replicate the original coursing of the spandrel.

- Rebuild following the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

Installing Tie Rods or Anchors Without Excavation

- If the wall deterioration is not too far advanced, installing grouted tie-backs is one potential treatment. While this treatment can be a permanent solution, it is recommended here as a temporary solution to hold a spandrel or section of spandrel in place and slow further movement until a more comprehensive solution can be enacted. The tie rods should be designed by a professional engineer.

- Drill into the spandrel wall and pressure grout the tie rods or anchors into the spandrel and the fill behind the spandrel. The exterior tie plate should be made as unobtrusive as possible to appear consistent with the era of original bridge construction.

Installing Tie Rods With Excavation

- If the fill material can tolerate a vertical excavation cut, install the tie rods continuously between the spandrel walls by digging a trench between the spandrel walls.
- Drill into the spandrel wall to set the exterior anchors/plates, which should be as unobtrusive as possible to appear consistent with the era of original bridge construction.
- If complete excavation is necessary, a reinforced concrete wall could be constructed on the interior of the parapet face to anchor the tie rods and eliminate the need for exterior anchors/plates.

Repairing/Rehabilitating Spandrels With Excavation

- Excavation of fill material, and the removal, design, and rebuilding of a spandrel wall or wall section should be undertaken only under the direction of a professional engineer.
- Excavate and remove the fill material. Excavation of fill material from a large section of the spandrel should be done carefully to ensure a uniform and symmetrical distribution of deadload to keep the arch in place. The repair will likely require the use of falsework to support the arch during the repair work.
- Remove the section of the spandrel in need of repair. Consult the engineer or engineering report for the extent and sequencing of the demolition process.
- Rebuild the spandrel by resetting the original stones, if possible.
- If it is not possible to reuse the original stones, replace the stones in-kind, matching the existing stones in type, size, cut, texture/finish, and color.
- Replace the fill material and install a drainage system in accordance with Publication 408, Sections 613 and 674 and Publication 55, Chapter 9.
- Rebuild following the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

4.3.6.2 Restoring Missing Spandrels or Spandrel Sections – Treatment Recommended

- Restore a missing spandrel or spandrel section based on documented evidence, such as an intact spandrel, historic photographs, plans, or an intact spandrel on another bridge constructed at approximately the same time.

- Use in-kind material that replicates the historic appearance in type, color, size, texture/finish, and cut.

- Remove the section of the spandrel to be restored. Consult the engineer or engineering report for the extent and sequencing of the demolition and rebuilding process.

- Replace fill (if necessary) and install drainage in accordance with Publication 408, Sections 613 and 674 and Publication 55, Chapter 9 to relieve water penetration and pressure from fill compacting.

- Recreate the coursing of the historic spandrel. Rebuild following the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

4.3.6.3 Spandrels – Treatment Not Recommended

- Repairing spandrels with concrete, gunite/shotcrete, or other structurally or historically inappropriate material.

- Repairing or restoring spandrels with stones that do not match the existing stones in type, size, texture/finish, cut, and color.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and finish.

- Recreating a spandrel not based on an intact spandrel or other historical evidence.

- Repairing or restoring spandrels without installing proper drainage.

- Using synthetic stone.

- Using gabions as long-term repair solutions.

- Not documenting the repair or restoration.

4.3.7 Repairing/Rehabilitating the Arch Ring and Arch Barrel

The arch ring (also known as the voussoir arch) and the arch barrel are character-defining elements of a stone arch bridge. They are also the main structural elements of the bridge, supporting the load and transferring the forces to the substructure elements. Failure of the arch means the structural failure of the bridge. Every effort should be made to preserve the material and workmanship of the arch ring and arch barrel. Common problems encountered with arch rings and barrels include cracking, missing stones, and historically inappropriate repairs, such as the use of gunite/shotcrete or concrete as repair material. Frequent sources of the cracking and missing stones include water penetration or spandrel wall movement.

Arch barrel repair work is usually described by BMS Activity Number C745203, Culvert Barrel Repair (Publication 55, Chapter 15), which applies to reinforced concrete structures. It is recommended that Publication 55 be revised to assign a separate BMS Activity Number to the repair of stone masonry arch rings and arch barrels.

Severe arch barrel deterioration is the most difficult repair to undertake with a stone masonry arch. *Repairs and reconstruction of arch rings or barrels should only be undertaken at the direction of a professional engineer. Depending upon the scope of repairs, they may be accomplished by a team led by a skilled mason. However, the determination of the cause(s) and possible complications with the arch ring and barrel should be the purview of a professional engineer.*

Prior to beginning any arch barrel repair or reconstruction, the need for temporary shoring should be considered. The barrel may appear to be stable at the start of work, but further demolition or unbalanced placement of the stones may require the construction of falsework to support the arch until the final, stable configuration is reached. Shoring must be designed by a professional engineer. Environmental concerns should also be considered, especially when performing work within the waterway.

4.3.7.1 Repairing Longitudinal Cracks in the Arch Barrel – Treatment Recommended

<u>Repairing Longitudinal Cracks Without Excavation</u>

- If water is escaping through the crack, prior to beginning the work take the following steps:

  Improve drainage as outlined in Section 4.1.2 to relieve water penetration and pressure from fill compacting.

  Seal any cracks between the roadway and the parapets and repair any holes in the deck, as described in Section 4.1.2.2.

  If water no longer escapes through the crack, repair the crack.

- Repairing longitudinal cracks using mortar injection:

  Remove all mortar, debris, and contaminants within the crack using hand tools, small pneumatic power chisels, air blasting, low-powered water, or vacuuming.

  Attach mortar injection ports into or onto the crack and affix with mortar. Place the end-most ports at the end of the crack to ensure complete filling of the crack. Space additional injection ports as needed.

To permit maximum flow, position injection ports on the wider section of the crack and at intersections, if any.

For cracks less than ¼ inch wide, space the injection ports no wider than 2 feet apart; for cracks ¼ inch wide or greater, space the injection ports 3 feet apart.

After the injection ports have been installed, seal the crack opening using stone patching mortar.

Begin injection at the wider end of a horizontal crack or at the lowest point of a sloping or vertical crack. Secure to the feed line a positive displacement pump capable of maintaining a consistent, uninterrupted pressure of 5 psi to the first port. Monitor the adjacent areas to assure that the pressure injection doesn't move the stones. If it does, stop immediately.

Initiate a flow of mortar with casein added by one to three percent the weight of the lime to promote fluidity and re-solidification. Continue the flow until mortar exits from the adjacent port. Temporarily plug the adjacent port and continue the flow to achieve maximum penetration.

Temporarily stop the injection process, remove the feed line, and seal the port. Attach the feed line to the adjacent port and repeat the procedure along the crack until the last port is filled.

Once the mortar has cured, carefully remove the injection ports and fill the holes with mortar.

4.3.7.2 Repairing/Rehabilitating Arch Rings and Arch Barrels with Excavation - Treatment Recommended

Repairs and reconstruction of arch rings or barrels that require the excavation of fill should be undertaken only at the direction of a professional engineer. Prior to beginning any excavation, the need for temporary shoring should be considered. The barrel may appear to be stable at the start of work, but further demolition or unbalanced placement of the stones may require the construction of falsework to support the arch until the final, stable configuration is reached. Shoring must be designed by a professional engineer. The following procedures should be observed during the course of repairs to respect the historic nature of the bridge.

- If voussoirs and arch barrel stones are cut and precisely gauged, they should be numbered and photographed prior to beginning rehabilitation work; where possible, they should be replaced as originally constructed.

- If possible, use the existing stones to repair/rehabilitate/restore the arch.

- If it is not possible to reuse the original stones, the stones should be replaced in-kind, matching the existing stones in type, size, cut, texture/finish, and color.

- Rebuild following the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

- Fill material should be consistent with the guidelines of Section 4.3.8.

4.3.7.3 Repairing/Rehabilitating Arch Rings and Arch Barrels with Excavation – Other Acceptable Treatment

- After installing falsework and excavating the roadway fill, install a reinforced concrete saddle or slab against the *extrados* of the arch.

  A saddle should be cast directly onto the existing extrados to ensure composite action. It should be bonded to the substructure to ensure that the thrust is transmitted there. To reduce induced shrinkage stresses, the saddle should be thoroughly cured; it may also be necessary to cast the arch segmentally.

  A professional engineering analysis should be conducted to ensure that the abutments are capable of carrying the additional dead load of the saddle.

  Where the substructure cannot take the additional thrust, a concrete slab can be built, with the substructure providing the necessary support.

- Fill material should be consistent with the guidelines of Section 4.3.8.

4.3.7.4 Restoring Arch Rings and Arch Barrels - Treatment Recommended

- Restore a missing arch ring/barrel or section of an arch ring/barrel based on documented evidence, such as an intact section of the arch ring/barrel, historic photographs, plans, or an intact arch ring on another bridge constructed at approximately the same time.

- Use in-kind material that replicates the historic appearance in type, color, size, texture/finish, and cut.

- Remove the section of the arch to be restored. Consult the engineer or engineering report for the extent and sequencing of the demolition and rebuilding process.

- Replace the fill material and install a drainage system in accordance with Publication 408, Sections 613 and 674, and Publication 55, Chapter 9.

- Recreate historic coursing. Rebuild following the General Guidelines for Repairs as Outlined in Section 3.5, the procedures for laying stone as outlined in Section 4.3.3.1, and the repointing procedures outlines in Section 4.3.1.1.

4.3.7.5 Arch Rings and Arch Barrels - Treatment Not Recommended

- Repairing arch rings/arch barrels with concrete, gunite/shotcrete, or other structurally or historically inappropriate material.

- Repairing or restoring arch rings/barrels with stones that do not match the existing stones in type, size, texture/finish, cut, and color.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and, finish.

- Recreating an arch ring/barrel not based on an intact section of the arch ring/barrel or other historical evidence.

- Using synthetic stone.

- Not documenting the repair or restoration.

4.3.8 Fill Material

Historically, stone arch bridges were generally filled with earth or other sub-grade material excavated from the bridge site. *Fill material is not a character-defining element of a bridge.* Replacing fill material with engineering fills can help improve drainage, particularly if *geotextile material* is layered in with it, and can assist in correcting problems with spandrels and arch rings. Decisions on the type of fill to be used when repairing or rehabilitating a bridge should be based on such factors as improved drainage and engineering needs. Improving fill material is both cost-effective and consistent with the goals of historic preservation.

4.3.8.1 Recommended Replacement of Fill Material when Repairing, Rehabilitating, or Restoring a Bridge

- Fill material should be replaced in accordance with the procedures of Publication 408, Section 613. If geotextile material is added to improve drainage, the procedures of Publication 408, Section 735 should be followed.

- *Flowable fill cement* and geotextile material are alternative fill materials.

- Fill should be placed in lifts that are designed to avoid unbalanced conditions that could lead to the collapse of the arch.

4.3.9 Abutments, Piers, and Wing Walls

The correction of foundation-related problems is critical to preserving stone arch bridges. Uncorrected scour problems can potentially result in the collapse of a stone arch bridge. The increased risk of undermining (scour) due to higher flood peaks and generally inadequate, by today's standards, foundation depths can doom a bridge if not corrected. Softened foundations can lead to arch problems that threaten the entire structure. Wing walls are also often the victim of vehicle impact when drivers run off the roadway.

Repairs and reconstruction of substructure elements should only be undertaken at the direction of a professional engineer. Depending upon the scope of repairs, they may be accomplished by a team led by a skilled mason. However, the determination of the cause(s) and possible complications with substructures should be the purview of a professional engineer.

4.3.9.1 Repairing/Rehabilitating Substructure Elements – Treatment Recommended

Repairs and reconstruction of substructure elements should be undertaken in accordance with BMS Activity Number B77402 in Publication 55, Chapter 14 (PennDOT 2002). In order to respect the historic character of the bridge, the procedures should be supplemented by the guidelines outlined below.

- Rebuild substructure elements with original stones, if possible.

- If it is not possible to reuse the original stones, the stones should be replaced in-kind, matching the existing stones in type, size, cut, texture/finish, and color.

- The repaired or restored section should replicate the coursing of the historic substructure element. Rebuild following the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.

4.3.9.2 Substructure Elements - Treatment Not Recommended

- Repairing substructure elements with gunite/shotcrete or other structurally or historically inappropriate material that traps moisture.

- Repairing or restoring using stones that do not match the existing stones in type, size, texture/finish, cut, and color.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and finish.

- Using gabions as a long-term repair solution.

- Using concrete jacketing as a long-term repair solution.

- Not documenting the repair or restoration.

4.3.10 Scour Protection

Substructure failure due to channel scour can cause a catastrophic collapse of a stone arch bridge. The substructure consists of unconnected blocks of stone masonry. Compared to a reinforced concrete foundation, the stone masonry foundation is much less likely to span over an area being undermined due to scour. Once a section of stones begins to settle into the undermined area, continuity is lost and an accelerated loss of stones is likely to occur. If unchecked, this could eventually result in loss of support to the arch barrel and collapse of the superstructure.

Scour action can be the result of several different conditions.

- Deposits in the channel can restrict flow and cause increased velocity in the remaining channel opening.

- Upstream horizontal channel movement may redirect the flow from parallel to the substructure to being directed into the substructure at a significant skew. This results in greater turbulence and scouring action around the unit.

- A period of unusually severe precipitation could generate high volumetric flows and result in channel scour.

- General scour over a long period of time could deepen a significant length of the channel, which would include the bridge structure.

Scour repairs should be considered if a scour hole is significantly deeper than the average streambed depth, the channel alignment has been altered, the footing is exposed due to scour, or if the footing becomes undermined due to scour. Scour remediation, if installed below the water surface, would not be considered an intrusive repair and a repair scheme could be developed using methods used for a non-historical bridge. When scour has been noted on BMS AW Screen and maintenance has been recommended on AH Screen, the required repairs should conform to Chapters 14 and 16 in Publication 55. Maintenance would likely consist of one or more of the following items:

- Underpin Undermined Footing; Chapter 14, BMS Activity Number: E744803.

- Repair or Construct Streambed Paving; Chapter 16, BMS Activity Number: A745301.

- Construct Rock Protection; Chapter 16, BMS Activity Number: B745301.
- Fill Scour Hole; Chapter 16, BMS Activity Number: C745301.
- Remove Vegetation/Debris; Chapter 16, BMS Activity Number: ECREMVG.
- Remove Deposits; Chapter 16, BMS Activity Number: ECREMDP.

4.3.11 Decorative Features

Decorative elements, such as stringcourses, finials, and pilasters, add an aesthetic component to the bridge and can become character-defining elements in their own right. Therefore, in most cases, decorative treatments should be respected in the course of completing repairs, rehabilitations, or restorations.

4.3.11.1 Repairing/Rehabilitating/Restoring a Decorative Feature – Treatment Recommended

- Repair or restore a damaged or missing decorative element based on documented evidence, such as an intact decorative feature, historic photographs, plans, or an intact feature on another bridge constructed at approximately the same time.
- Rebuild using the original stones/material, if possible.
- If it is not possible to use the original stones/material, use in-kind material that replicates the historic appearance in type, color, size, texture/finish, and cut.
- The repaired/restored section should replicate the historic appearance. Rebuild following the General Guidelines for Repairs outlined in Section 3.5, the procedures for laying stone outlined in Section 4.3.3.1, and the repointing procedures outlined in Section 4.3.1.1.
- Document the repair or restoration through documentary and photographic evidence.

4.3.11.2 Repairing/Rehabilitating/Restoring a Decorative Feature – Treatment Not Recommended

- Recreating a decorative feature not based on an intact feature or other historical evidence.
- Recreating a decorative feature that does not replicate the color, size, texture/finish, and, if appropriate, coursing and cut of the historic appearance.

- Repointing using a mortar that is not compatible with the historic mortar and which does not match the historic mortar in color, texture, and, finish.

- Using synthetic stone.

- Not documenting the repair or restoration.

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APPENDIX A

GLOSSARY OF TERMS

GLOSSARY OF TERMS

Abutment - A masonry mass which receives the thrust of an arch, vault, or strut.

Arch Barrel - The stones that form the arch ring.

Ashlar - Masonry composed of rectangular units of stone, generally larger in size than brick and properly bonded, having sawn, dressed, or squared beds and joints laid in mortar.

Bed - The horizontal mortar layer between stones.

Belt Course - see Stringcourse.

Buttress - An exterior mass of masonry set at an angle or bonded into a wall which it strengthens or supports.

Coping - A protective cap, top, or cover of a parapet; may be flat, but often sloping or curved to shed water so as to protect masonry below from water penetration.

Coursing - The pattern in which stones are laid, generally composed of levels and risers.

Delamination – The separation of stone into constituent layers.

Efflorescence - A powdery crust that forms on stone or brick due to the presence of water or soluable salts.

Extrados – The exterior curve of an arch.

Finish Pointing - In the repointing process, the process of placing the final 1 ½ inches of mortar.

Flowable Fill Cement - A cementitious slurry consisting of fine aggregate or filler, water, and cementitious material(s) capable of filling all voids in irregular excavations and hard to reach places. Used primarily as a backfill in lieu of compacted earth or material.

Gabion - A basket or cage filled with rocks and used primarily to support abutments and piers.

Geotextile Material - A woven or nonwoven, porous industrial polymer fabric that allows water to flow through but which traps small aggregate particles.

Joint - The vertical mortar layer between stones.

Keystone - A wedge-shaped piece at the crown of an arch that locks the other pieces into place.

Levels - Straight, long lines of stones.

Look-out - On a stone arch bridge, a decorative portion of a structure, usually projecting from the spandrel, from which to afford a view.

Mortar - A plastic mixture of cementitious material (such as plaster, cement, and lime) with water and fine aggregate that hardens.

Parapet - A low wall or railing to protect the edge of a bridge.

Pier - An intermediate support for the adjacent ends of two bridge spans.

Pilaster - An engaged pier or pillar; generally constructed as a projection from the spandrel wall or a bridge.

Pointing - The material used as the final treatment of mortared masonry joints; also the act of troweling in the material.

Rehabilitation - The process of returning a property to a state of utility, through repair or alteration, which makes possible an efficient contemporary use while preserving those portions and features of the property that are significant to its historic, architectural, and cultural values.

Repair – A corrective measure or corrective measures or task(s) intended to return a specific defect or deterioration to a functional or near original condition or state

Repoint - To remove mortar from between the joints of masonry units and replace it with new mortar.

Restoration - The act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period.

Retempering – The process of adding water to mortar in order to remoisten it; the process should be avoided.

Risers - Stones that rise above a level.

Rubble Stone - Rough stones of irregular shapes and sizes generally not laid in regular courses into a wall or foundation.

Scour - To remove the material beneath a bridge substructure by a current of water; undermining.

Sidewall Blowout - The process where bridge fill material creates pressure on the spandrels, causing all or part of the spandrel to collapse, often along with attendant damage to the roadway, parapet, arch ring, and arch barrel.

Spalling - The flaking or chipping off of the exterior surface of a stone.

Spandrel - The space between the exterior curve of an arch and the roadway.

Squared Stone Masonry - Construction in which squared stones of various sizes are combined in patterns that make up courses.

Stringcourse - A horizontal band of masonry, generally narrower than other courses, extending across the spandrel wall and parapet of a bridge.

Towers - On a stone arch bridge, a decorative feature sometimes located at the ends of the bridge.

Vapor Permeability – the ability to move moisture from the interior of the structure back out into the atmosphere.

Voussoir - A wedge-shaped masonry unit forming one piece of an arch or vault.

Wing Wall - The retaining wall extension of an abutment intended to retain the side slope material of an approach roadway embankment.

APPENDIX B

ESTIMATED REPAIR/ REHABILITATION COSTS FOR STONE ARCH BRIDGES

ESTIMATED REPAIR/REHABILITATION COSTS FOR STONE ARCH BRIDGES

A stone arch bridge repointing contract let in 2005 and effective for 2005 and 2006 contains the following costs associated with stone arch bridge repair:

Pressure Mortar Applicator with Operator: $250/hour

Pressure Mortar Pointing: $16/linear feet

Hand Mortar Pointing: $16/linear feet

Stone Masonry Reconstruction: $750/cubic yard

Installation of Weep Holes: $140/each

Mobilization for Emergency Bridge Repairs: $100/call

Water Pollution Control: $9,000/bridge