

# Historic Stone Highway Culverts in New Hampshire Asset Management Manual



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## 1.0 INTRODUCTION

### 1.1 Purpose

This project was undertaken for the New Hampshire Department of Transportation (NHDOT) with the purpose of preparing a preservation plan for historic stone highway culverts determined eligible for listing in the National Register of Historic Places (NR).

Through consultation with stakeholders<sup>1</sup> it was determined that to be effective, the plan should take the form of an asset management manual to be distributed to local and state officials who own or have responsibility for historic stone culverts (culvert owners). The manual should:

- Provide culvert owners, and other citizens, information to aid their understanding of the cultural importance of New Hampshire's historic stone culverts and to support their efforts to identify, maintain and preserve them;
- Provide a practical inspection and maintenance plan with specific actions for culvert owners to take to prevent deterioration and damage to historic stone culverts;
- Provide guidelines for repairing historic stone culverts that comply with the *Secretary of the Interior's Standards for the Treatment of Historic Properties*.



Photo No. 1: The NHDOT Stone Culvert Inventory Project located and documented over 100 historic stone highway culverts across the state.

This project follows the work of the NHDOT Stone Culvert Inventory Project (see Section 6.2 below) undertaken to locate and document stone culverts and then assess their National Register eligibility. This manual is a companion document to the document produced by the Inventory project entitled *National Register of Historic Places Multiple Property Documentation Form: Stone Highway Culverts in New Hampshire, 1750 to 1930*, prepared in 2009 by the New Hampshire Department of Transportation's Bureau of Environment.<sup>2</sup> Information from the documentation pertinent to this manual, including the physical characteristics and history of New Hampshire stone culverts, has been included here, fully or abbreviated as necessary. Copies of that document can be obtained from NHDOT; see the endnote referenced above for ordering information.

## **1.2 Why Preserve Historic Stone Culverts?**

Stone highway culverts are among the earliest and potentially most enduring of highway structures, being built from the era of first settlement down to the late nineteenth and early twentieth centuries, when vitrified clay, concrete, and corrugated metal culverts became available to supplant them. Constructed to prevent the erosion of early roads during times of high water and to avoid the need to ford small streams, stone culverts introduced several of the methods and materials of early bridge building on a small scale. Although often overlooked in the history of transportation, stone culverts represent some of the earliest examples of vernacular engineering in the New England landscape.<sup>3</sup>

### ***New Hampshire's Stone Highway Culverts:***

- Have served as important links in the state's developing road network and possess characteristics associated with early highway design and construction.
- Exhibit a range of stone masonry methods, practices and craftsmanship from vernacular to highly skilled that are now lost in terms of their application to modern culvert construction.
- Provide information about historic stone masonry construction practices through interpretation of their design, materials and craftsmanship and help in the understanding of other stone culverts, stone bridges or other stone structures found locally or statewide.
- Provide information useful to understanding stone slab and stone lintel bridges, a very rare bridge form that are simply longer-span versions of stone box culverts.
- Perform an important function of passing water under roadways in the most long-term and cost-effective manner possible.



- Are potentially eligible for the National Register of Historic Places under Criterion A, for association with events that have made a significant contribution to the broad patterns of New Hampshire's early transportation and development history.
- Are potentially eligible for the National Register of Historic Places under Criterion C, for their embodiment of distinctive physical features and characteristics of type, period and method of construction.
- Are among the most aesthetically pleasing structures built by man and blend harmoniously with New Hampshire's natural landscape.



Photo No. 2: This stone arch culvert (HIL0022) and another similar but larger one only 100 feet away (HIL0023) carry Beard Brook under Gleason Falls Road in Hillsborough, NH. This is a segmental arch – nearly semi-circular – spanning 12 feet. Twelve stone arch bridges and culvert-size bridges (see Photo No. 4) were built in Hillsborough during the 19<sup>th</sup> century.

## 2.0 IDENTIFYING HISTORIC STONE CULVERTS

### 2.1 General Characteristics of Culverts

A culvert is a structure for conveying a stream of water beneath a canal, railway embankment, or road. According to the Oxford English Dictionary, it was in France about 1770 that the term culvert came into use in connection with canal construction and later with railways, highways, and town-drainage. It may have originated from the French words *couloir*, a waterway, or *coulouère*, a channel, or *couler*, to flow. Others consider 'culvert' to be of English origin associated with canal building about 1800.<sup>4</sup>

A culvert according to the Federal Highway Administration is defined as:

"A structure designed hydraulically to take advantage of submergence to increase hydraulic capacity. Culverts, as distinguished from bridges, are usually covered with embankment and are composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert. Culverts may qualify to be considered "bridge" length."<sup>5</sup>

The FHWA's definition of a culvert is only partly applicable to stone culverts. Stone culverts do typically differ from bridges in the three main ways identified by the FHWA: span length, fill over top, and submerged operation. How do these differences apply to New Hampshire's historic stone culverts?

#### *Stone Culvert Length*

The distinction between bridges and culverts, particularly from the standpoint of the structural engineer and those charged with inspecting and maintaining their safety, has generally been based on the span length of the opening. The Federal Highway Administration's *Bridge Inspector's Training Manual* considers structures beneath highways less than 20 feet in span length to be culverts. This definition is based in part on the Federal Highway Act of 1968 that mandated each state to institute a bridge inspection program for bridges 20 feet and longer within the Federal-Aid Highway System. Structures less than 20 feet were typically classified as culverts. However, many state highway departments including the New Hampshire Department of Transportation, define culverts as structures with spans of less than 10 feet, and bridges as structures with spans of 10 feet or greater.

When box culverts exceed a span of 10 feet they are called stone slab or lintel bridges in the states that use 10 feet as the break point. The great variability in the strength of stone, especially when under tension as a beam span, has limited the use of stone by engineers to very short spans in which a large factor of safety could be assumed.

In stone arches the stones are in compression and bridges can be safely designed to span beyond 200 feet. Spans greater than about 30 feet, in particular segmental or elliptical arches of low rise – so-called flat arches – place very large compressive forces on the arch stones and outward thrust on the abutments and have generally been the product of an engineer's calculations.



Photo No. 3: This four-span stone slab structure (Amherst Bridge 159/105) once carried Boston Post Road over Beaver Brook in Amherst, NH. It provides an example of the variability in assigning the term culvert or bridge to certain structures. On the basis of the length of the individual spans, which do not exceed 8 feet, it can be labeled a four-barrel stone box culvert. But with a primary function to convey traffic, the absence of an overlying filled embankment, and most importantly, the need to regularly inspect the structure due to its greater susceptibility to catastrophic collapse than a single channel culvert, it was designated a bridge by NHDOT. This large and very rare example of a stone culvert with more than two spans is now bypassed by a modern bridge.

### *Earth Fill over Stone Culverts*

Culverts, by the FHWA definition, are through embankments and covered by earth fill and therefore designed to carry a large and significant dead load depending on the depth and type of the cover material. Many of New Hampshire's smaller stone culverts under 5 feet span have several feet of earth fill over the top. Whereas many of the larger culverts of both box and arch type have less than 2 feet of fill over top and are really mini-bridges rather than culverts. The nomenclature is not important but the structural differences can be. In buried abutments, the fill overtop and embankment material can play an extremely important role in culvert design: it assists structurally in the culvert's live-load carrying capacity by distributing vertical loads laterally, and it acts as an earthen dam during flood events that exceed the capacity of the culvert and submerge the inlet. Maintaining the integrity of the fill around buried culverts can be crucial to the survival of the stonework of the culvert during floods.





Photo No. 4: This stone arch bridge in Hillborough (HIL023), the companion arch to the one in Photo No. 2, was built with the same materials and techniques but with a longer span and a flatter segmental arch, illustrating the similar characteristics of arch bridges and culverts.

### *Submerged Operation of Stone Culverts*

Some stone culverts, particularly long culverts in high road embankments or causeways, were designed to operate submerged under a head of water pressure. This practice was used both to reduce the cost of long culverts and as a precaution against rare and extreme runoff events from cloudbursts or heavy rain during a heavy snow melt.

There is no evidence that any of New Hampshire's stone highway culverts were specifically designed to operate submerged although some may have been built with the assumption that they would be occasionally inundated.

When the water level rises and submerges the culvert opening two conditions occur that threaten its structural integrity: the embankment acts as a dam and the hydrodynamic characteristics of the water flow through the culvert change from of "flow in an open channel" to those of "flow in a pipe."

The embankment acting as a dam presents several concerns: the type of fill over and around the culvert, the quality of the masonry in the facewalls (or endwalls), and the inlet and outlet design, i.e., the nature of embankment protection such as stone aprons and rip-rap. When a culvert discharges under pressure the intensified force and turbulence of the water can undermine the

outlet channel and scour the abutment foundations if they are not designed for it. The fill is all-important since the embankment can become saturated and swell, allowing the finer particles to wash away until voids and channels open along the exterior of the culvert. In the case of arches, which depend on uniform loading on the arch stones for stability, failure can result fairly quickly as the water pressure pushes the stones into voids in the backing fill. Voids formed behind the walls of the culvert will typically result in the walls bursting under the internal pressure of the water.

## **2.2 New Hampshire's Stone Highway Culverts**

Stone highway culverts in New Hampshire are of two main types, box culverts and arched culverts. Box culverts have vertical stone walls that carry a stone slab spanning the opening. Arch culverts are essentially small versions of stone arch bridges and consist of shaped stones arranged to form an arched opening by wedging against one another.

Based on the current inventory, box culverts outnumber arch culverts roughly ten to one in New Hampshire. This is due primarily to the fact that arches are generally used for longer spans than box structures can achieve and therefore the arches fall into the category of bridges. Both types vary in span and opening size depending on the nature of the watercourse they conduct, vary in length depending on the width of the roadway they carry, and vary in materials, design and workmanship.

Stone culverts were built in locations where permanent or seasonal streams of small volume intersect the routes of range roads, turnpikes and highways. They were also built through causeways across wetlands to equalize the water levels and pressures on each side. In a few occasions where roadways are curbed, small box culverts channel storm water from curbside catch basins under the road to the opposite side.

New Hampshire has attained recognition as the location of some of New England's most skillfully built stone highway structures. Many are built of dry-laid masonry (without the use of mortar) and therefore required a high degree of workmanship to insure structural soundness.

### ***A basic preservation plan for New Hampshire' stone highway culverts will:***

- Encourage the preservation or restoration of existing stone culverts;
- Identify structural and hydrological conditions that may threaten stone culverts;
- Identify repair methods for typical stone culvert failures;
- Encourage the design of bypass culverts or other methods of floodwater management that preserve the structural integrity of stone culverts.

## 2.3 Stone Box Culverts

Box culverts have vertical stone sidewalls across which span stone slabs or lintels that in turn carry fill and the roadway. The sidewalls, or channel walls, are sometimes called abutments in longer span examples that approach bridge size. The slabs or lintels spanning the opening act as beams, tending to bend under their own weight and under the weight of the added loads they carry. The bending stresses are concentrated at the middle of the span where the upper half of the of the beam is under compression and the lower half is under tension. Stone is weak in tension, therefore stone beam spans are very limited and a function of the type and quality of the stone and its thickness.

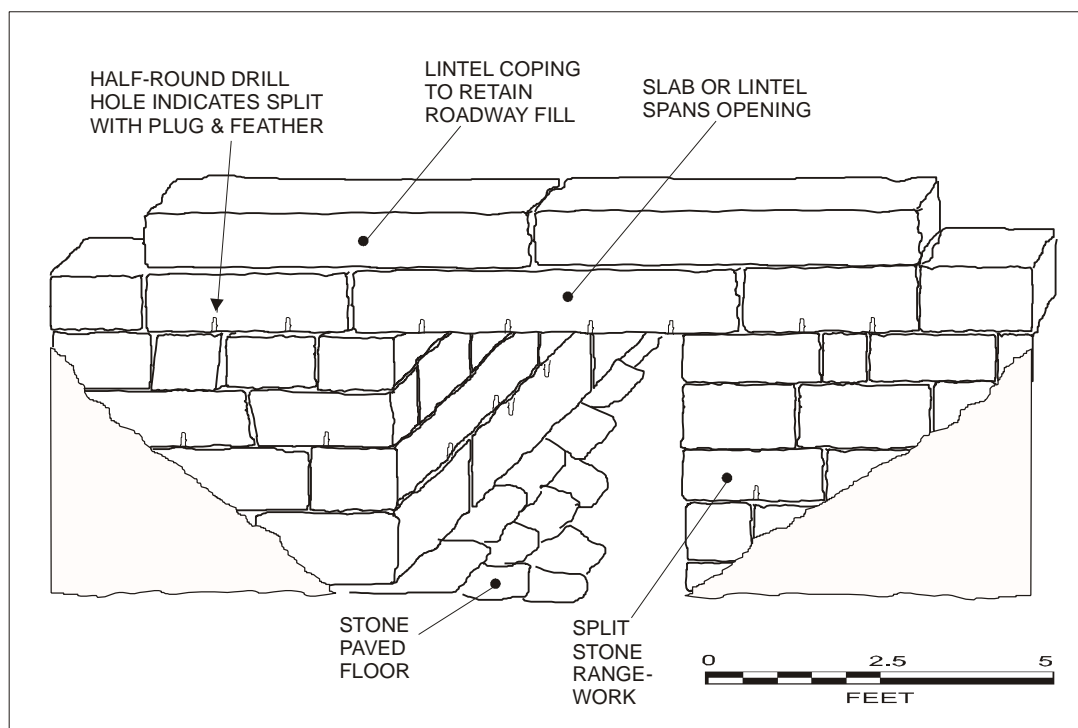


Figure No. 1: Typical 4-foot stone box culvert of split and cut granite quarry stone

The difference between slabs and lintels is their width dimension, lintels being narrower. Length is the stone's longest dimension, usually used to span the culvert opening. Depth is the vertical thickness of the stone. The depth of the stone beam must increase as its length increases in order to maintain the same strength and carrying capacity. Width is the variable that distinguishes slabs from lintels: lintels are commonly as wide as they are deep (square) or nearly so, while slabs may be many times as wide as thick, limited only by the ability to quarry, handle, and transport them. Lintels are typically 8, 10 and 12 inches square since they were used in brick wall construction over door and window openings. Long lintels, generally over 8 feet, may be deeper than wide, for example, a 10-foot lintel might be 12 inches wide by 16 inches deep.



Photo No. 5: This box culvert in Hillsborough, NH (Culvert HIL0019) is of exceptional span with a 10'-6" opening width. It is built with split granite lintel spans and fieldstone walls. The outside lintel seen in the picture is particularly interesting in that it was cut from a quarry face with a slight curve to it, giving the lintel a slight arch shape with thickened ends. While unsuitable for many purposes the builder perhaps saw the structural advantage of such a stone beam for use in this culvert project.

In New Hampshire the average span of stone box culverts identified in the culvert field survey is about 3.5 feet, with the maximum being 11.5 feet and the minimum 1.0-foot. Stone box culverts rarely exceed 10 feet in span and reach lengths over 5 feet only when high quality stone like New Hampshire granite is readily available. In the survey only two box culverts exceeded 10 feet in span: Culvert POR0119 with a span of 11'-7" and Culvert HIL0019 with a span of 10'-6" [Note: Refer to the Culvert Resource Inventory Table in Appendix A for the location and other information on culverts referred to in the text]. Five additional box culverts exceeded eight feet in span. All box culverts over 6 feet in span were of cut stone (ashlar) construction.

When a large culvert opening was needed to handle freshets and flood events, there were two additional ways to increase the total area-of-waterway or opening area other than simply increasing the span: increase the height of the culvert opening or increase the number of culvert openings.

If the roadway was high above the streambed, or could be readily raised in height, then the culvert sidewalls could be increased in height to give the opening a tall narrow rectangular shape rather than the more common square or horizontal rectangle shape.



Photo No.6: A tall narrow box culvert in Tuftonboro, NH, (TUF0007) with a 2'-10" opening width (span) and a 7'-6" opening height. When conditions allow, increasing the area of the opening by increasing the height may be cost effective if lintels or slabs capable of longer spans are not economically available. Note the very large dimension fieldstone that would have required oxen power and perhaps a small A-frame to place. (Also used as cover photo)



Multiple-channel box culverts were built when a large waterway opening was required greater than the opening height or span ability the available stone would allow. The use of stone slabs or lintels to span greater than about 8 feet was usually impractical due to the immense size and weight of the stones required and the hardship in transporting and placing them without hoisting equipment. The use of hoisting equipment increased the project cost, defeated the economy of using readily available stone, and made other culvert materials more attractive. Since stone cannot span greater than 10 or 12 feet in most highway culvert applications, when a waterway opening of that size was needed the practical solution was to simply build two small culverts side by side sharing a center wall.

In rare cases, box culverts with more than two waterway openings – also called channels, cells or barrels – were built. An exceptional example with four channels is Amherst Bridge 159/105, a bypassed historic bridge that formerly carried Boston Post Road over Beaver Brook (see Photo No. 3 above).

Multi-channel box culverts may exhibit a higher level of workmanship because of the need for a continuous center wall between the two channels. Unless the culvert walls bear directly on bedrock, care must be taken to insure a solid foundation for the center wall since it will be subjected to erosion and undermining from two sides. Since the center wall sits in the middle of the watercourse it is also subject to greater water velocities and the force of direct impacts from floating debris during flooding. Multi-channel box culverts built with cut stone often have well squared stones laid with tight joints to insure the greatest area of frictional contact and resistance to movement. Cement mortar may be present to increase the bond between the stones. Those built with fieldstone may use very large stones for the center wall that resist movement by their sheer mass.



Photo No. 7: This is a double box culvert in Fitzwilliam, NH, (FIT0017) with two 6-foot channel openings. It is built with cut lintels and mortared cut-stone channel walls. Culvert channels are sometimes referred to as cells or barrels.

Box culverts may be constructed of fieldstone or rubble, split stone, or cut stone squared and smoothed to varying degrees of finish. The terms fieldstone and rubble implies local loose stone gathered and laid-up as-is with little if any cutting or trimming to improve the fit. Coursed rubble (or fieldstone) walls exhibit an effort by the mason to periodically level off the work to keep the forces in vertical alignment to the greatest degree possible. A chipping hammer is used to roughly shape the more irregular stones. Uncoursed rubble work is randomly laid with no attempt at horizontal coursing and with a large amount of "chinking" – using small stones to fill the irregularly shaped gaps between the larger stones.

The nature of split stone depends on its geology and varies widely by locality and quarry. The homogenous nature of much of New Hampshire granite means that with skill it can be split evenly along straight lines to yield a rough but relatively planar surface. [The splitting methods, by chisel and wedge and then after about 1830 by drilling and using a "plug and-feathers," are described in the preceding discussion of contexts.] Split stone lintels of uniform size and suitable for use without cutting were readily produced in long lengths. Lintels that break are sold as-is in random lengths, the ends squared up by the mason and used to build tight range-work



walls. Split stone used in culverts may also be the product of boulders and ledge outcrops "quarried" by the mason from the immediate area.

Cut stone is typically dimension stone – specified to be of a certain uniform size enabling it to be laid in equal parallel courses known as range-work. Ashlar-work also uses cut squared stone, but of unequal sizes resulting in uneven courses. The term cut stone, as used during the 19<sup>th</sup> century implies hand-cut as opposed to machine cut and includes stone that is squared and dressed using a hammer and a variety of specialized chisels.



Photo No. 8: This box culvert in Albany, NH (ALB0045) has an unusually large area of waterway opening, with a 9'-4" opening width (span) and 8'-0" opening height. The channel walls are built with very large dimension cut stones bedded in mortar, notable for both their length at 25'-9" and their craftsmanship. Note the massive lintel.

Photo No. 9: A double box culvert in Canterbury, NH, (CNT0007) with two 3'-6" wide openings, split stone slab spans and a center wall built with large-dimension fieldstone.



Photo No. 10: This is an example of a typical cut-stone (ashlar) box culvert located in Marlborough, NH (MAR0015). It is of average size (4'-0" opening width), built with split lintel spans, ashlar channel walls and mixed cut and field stone facewalls.





## 2.4 Stone Arch Culverts

The stone arch culvert is rare in comparison to the box culvert, representing only ten percent of the total culverts surveyed and inventoried in this study. The rarity of arched stone culverts is due to their higher cost of materials, skilled labor and special construction methods usually necessary to build them. In the case of refined arches that use cut arch stones, known as *voussoirs*, the size, shape and number of stones needed must be calculated and then each stone carefully cut and fitted. Heavy timber formwork known as centering must be constructed in the streambed in the shape of the finished arch. The arch stones are then erected on the forms and wedged against one another. When the stone vaulting is completed, wedges and blocking supporting the centering are removed allowing it to be lowered and pulled out from the culvert. Since the height and width of the culvert must be large enough to allow for the construction of the centering and its removal, culverts of small dimensions do not lend themselves readily to arched construction. Stone arches are therefore mainly used for culverts for spans exceeding those capable of stone slabs or lintels, generally the range of 10 to 20 feet at which point they may be classified as bridges.

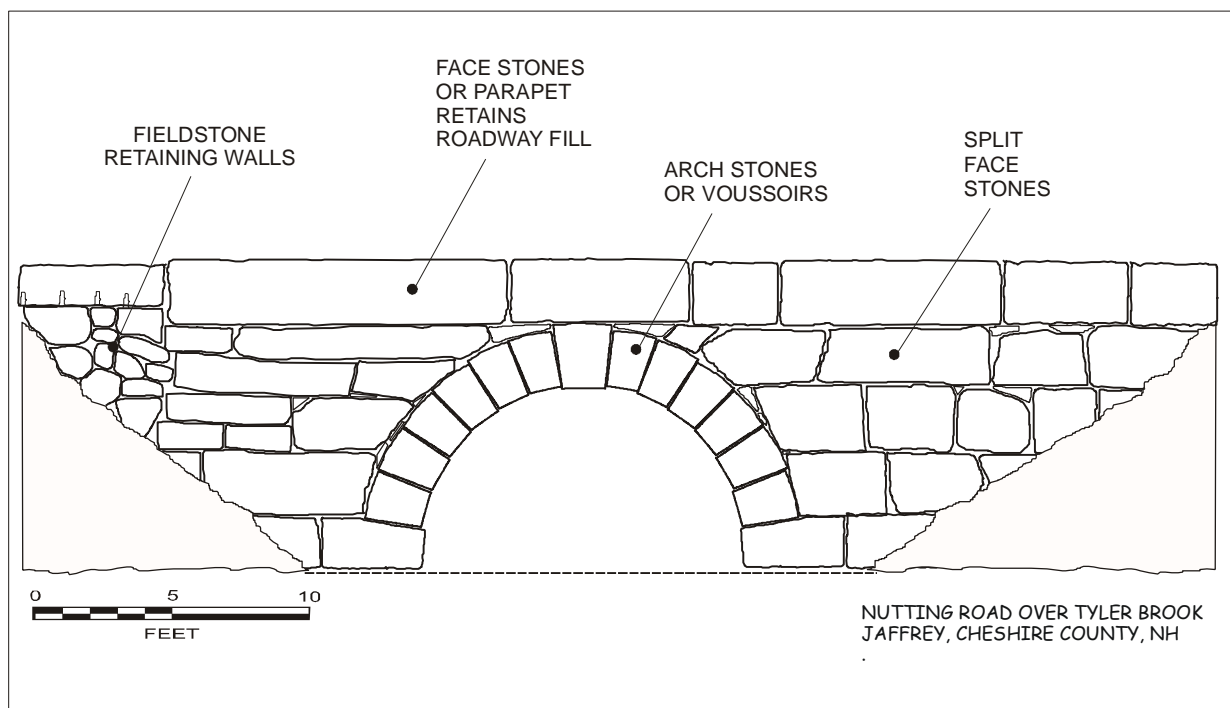


Figure No. 2: Typical stone arch culvert with semi-circular arch of split and cut granite quarry stone.

Most stone arch culverts are semi-circular in shape. Segmental arches are more often found in longer span culverts in the range of 10 to 20 feet. The arches are carried on stone abutments with stone retaining walls typically extending some distance back from the abutments to support the roadway approaches. Above the arch stones are the facewall stones that merge with the retaining wall stones. The area of the facewall to each side of the arch is known as the spandrel wall; the area directly above the arch extending up to the roadway grade is called the facewall or parapet.

Large arched stone culverts and bridges, whether semi-circular or segmental, typically use arch stones that are split and cut with an angle of taper that corresponds to the radius of the arch. The stone at the center of the arch is often somewhat larger than the others and known as the keystone, a shape most are familiar with. These wedge-shaped arch stones are called voussoirs. Smaller stone arch culverts are occasionally built of fieldstone, or rough-split stone, with little or no visible evidence of shaping or tapering. Arched stone culverts are found both dry laid without mortar and mortared, the latter occurring after about 1880 when Portland cement came into common use in the United States.

Stone arch culverts may be constructed of fieldstone or rubble, split stone, or cut stone squared and smoothed to varying degrees of finish. The arch stones are usually cut voussoirs with a high degree of squaring and smoothing. The facewalls are often of split or rough-cut fieldstone; retaining walls are typically fieldstone. Please refer to the preceding description of stone box culverts for a detailed discussion of stone types and methods of splitting and cutting.



Photo No. 11: This is an outstanding "textbook" example of a semi-circular cut-stone arch culvert located in Jaffrey, NH (JAF0464). It displays a very high degree of skilled masonry craftsmanship in the tightly fitted arch stones, enlarged keystone and massive cut facewall stones.

## 3.0 MAINTAINING HISTORIC STONE CULVERTS

### 3.1 General Maintenance Discussion

Culverts are like any other component of a town's highway system, a truck and plow for example: regular inspection and routine maintenance extends the service life and avoids costly repairs. But more importantly, stone culverts are unlike most any other town asset: they don't become obsolete and they can last indefinitely.

#### *Why do historic stone culverts deserve special maintenance treatment?*

Over one hundred stone culverts survive in New Hampshire. All of the state's known historic culverts are estimated to be over 100 years old and many may be 150 years old or older. One might think that if they have lasted this long, subjected to dozens of flood and high water events and thousands of freeze-thaw cycles, they could very well last forever. While it is true that some of the inventoried culverts remain in good and serviceable condition, many more are in need of maintenance and repair, either immediately or soon.

#### *Rust Never Sleeps*

Many of our stone highway culverts are built of high quality native granite, schist, or gneiss that was surface quarried locally or gathered from fieldstone deposits. Although these are some of the most permanent materials on earth, routine and common sense maintenance cannot be ignored.

Anyone responsible for painting steel structures knows the expression "rust never sleeps" meaning that certain naturally occurring chemical reactions like the oxidation of iron operate continuously until complete, i.e., the steel is totally consumed and converted into iron oxide. Rust is not a worry, but other physical, chemical and biological forces of nature that do break down stone culverts also work continuously around the clock.

In the case of dry-laid stonework, maintenance of the earth fill around the culvert is vitally important because the weight and pressure of the fill helps bond the entire mass of stonework together. Mortared stonework is cemented together, but is more vulnerable to water infiltration accompanied by freeze thaw cycles that pry the mortar bonds apart. These are but two examples of the maintenance issues to be discussed in this section.

### 3.2 Stone Culvert Inspection & Maintenance Program

Owners of historic stone culverts are strongly encouraged to adopt a simple *Stone Culvert Maintenance Program* with the goal of maintaining the structural and functional integrity of the culvert as it was originally designed and built. Culverts less than ten feet in span are not inspected by state bridge inspectors and are often ignored by their owners until they become big problems.

#### *Example of a simple culvert inspection and maintenance program:*

- Conduct annual inspection and complete a *Culvert Maintenance Inspection Form* (form provided in Appendix C).
- Conduct curbside inspection of inlet and outlet a minimum of three times a year for culverts with specific problems identified on the annual inspection form.
- Conduct additional inspections and take photographs during high-water events or immediately afterwards.
- Conduct any necessary maintenance as described in the following guidelines.



Photo No. 12: This culvert is located in Litchfield, NH (LIT0010). The 7' span arch is a segment of a circle springing from tall sidewalls. The type is sometimes called a horseshoe arch, but is more correctly known as a stilted segmental arch

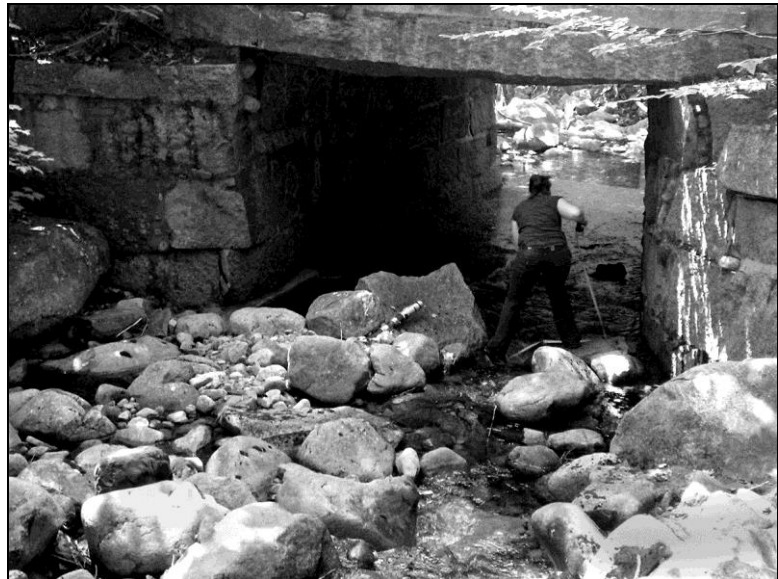


### 3.3 Maintain A Clear Waterway

Maintaining a clear, unobstructed waterway into, through, and out of the culvert is the most important and often the simplest yet most neglected bit of maintenance that can be done. Most of New Hampshire's stone culverts are over one hundred years old and regardless of whether their openings were properly sized at the time they were built, many are undersized for the water they conduct today.

The continual development of our land has created more open and less permeable acreage that in turn has increased the storm water runoff in the watersheds that culverts serve. When the flow capacity of a historic stone culvert is exceeded and it fills with water to the top or worse, operates submerged, damage will occur to some degree and its long-term structural integrity will be further jeopardized. Stone culverts operating at full or excess capacity typically suffer erosion damage at outlet end to some degree.

Photo No. 13: Special efforts may be necessary to maintain a clear waterway. The boulders obstructing the inlet and channel of this large and historically important box culvert must be cleared. They will catch debris and divert and intensify the stream flow up against the sidewalls. [see Photo 8 above for information on this culvert].



When the roadway over a stone culvert is overtopped by floodwaters – essentially the breaching of an earthen dam – the possibility of a dangerous "washout" greatly increases. The roadway to either side of the culvert or the entire culvert itself may collapse and wash out. Many lives have been lost and vast damages to public and private property have resulted from culvert washouts. Even when avoiding the worst, roadway and stone culvert reconstruction will be costly.

A single log or fence post lodged across the inlet opening could trap branches and form a clog during the next freshet that causes a washout. Clogged culverts cause water to backup and erode the upstream banks allowing sediment and boulders to wash into the channel. Boulders and other obstructions in the channel divert the normal flow intensifying erosion and scouring of the culvert foundations, fill and embankments. Stone culverts, like all culverts, must be cleaned of debris to prevent potentially catastrophic damage.

- Inspect culverts on a regular basis for obstructions to the normal flow of water in, through and out the culvert. Plan equipment and manpower needed to clear waterway.
- Remove debris and obstructions from the inlet, channel and outlet. Clear debris, loose branches and logs along the upstream banks to the extent possible.
- Inspect culverts during high water events and maintain a clear flow to the extent safe practices allow.
- Consider the installation of a Debris Control Structure upstream to prevent debris from reaching and clogging the culvert inlet. See Section 5.0 below.



Photo No. 14: This culvert is also located in Hillsborough County, in the town of Wilton (WIL0006) and is an exceptional example of an entirely dry-laid segmental arch (nearly semi-circular) built with split and cut stone. Much of the stone was thinly bedded and split readily into thin manageable slabs that could then be easily squared and tightly fitted with a minimum of chinking required. An occasional untrimmed fieldstone is mixed in for economy and speed. Not visible are concrete roadway curbs that support railing posts, a visual but necessary detriment that does not significantly diminish the integrity of the resource.

### 3.4 Prevent Scour

Scour in reference to bridges and culverts means the removal of material by erosion from under and around underwater foundations such as abutments, piers wingwalls and embankments. The undermining of bridge footings and foundations by scour is the leading cause of bridge failure.

The erosional effect of moving water is intensified and focused by obstructions introduced into the stream, either intentionally like abutments and supporting piers, or unintentionally like rocks and boulders that may have fallen in from collapsing banks. Such obstructions not only force the stream into narrower, higher-velocity flow patterns with more power to erode, but they cause cyclonic turbulence cells to form known as vortices. Vortices can be envisioned as small underwater tornados, churning and lifting sediment from around obstructions, nearly always working away to some degree, but dangerously powerful during floods when water depth and velocity increase dramatically. In Photo No. 10, the large boulders accumulating at the mouth of the culvert will cause scouring of the culvert floor during floods and possible undermining of the walls.

Photo No. 15: The center wall of this double box culvert has settled and shifted dramatically at the outlet end due to scour undermining and is now in danger of collapse. Scour is most severe on the downstream side of piers and abutments.



If the culvert stonework is bearing directly on exposed bedrock, particularly hard rock such as the granite or schist forming the bed of many New Hampshire streams, scour is not a concern. But in all other cases, where the culvert stonework extends below the surface of the streambed to an unknown depth and unknown foundation substrate, scour must be considered a serious threat.

- Inspect for scour on a regular basis following guidelines in the FHWA Bridge and Culvert Inspection Manuals. An obstruction to the flow of water increases possibility of scour.
- Special attention must be given to culverts with multiple channels. Like bridge piers, the walls that stand in the stream separating the culvert openings are particularly susceptible to undermining by scour and their collapse will probably result in the complete washout of the culvert.

### 3.5 Prevent Embankment Erosion

Roadway embankment erosion and stream bank erosion both upstream and downstream of a culvert can contribute to culvert damage or failure. Loss of embankment destabilizes culvert stonework, redirects stream flow, and washes sediment, stones and vegetative matter into the stream causing culvert clogging.

Flood events will always result in some degree of erosion that may be impossible to control. A reasonable objective however, is to identify and control factors that are causing or contributing to bank erosion during normal rainfall events that will in-turn help limit the extent of erosion during abnormal events.

Causes of stream and culvert embankment erosion include:

- Obstructions to the waterway that block and increase stream flow, raise stream level or redirect flow into the banks (see above Section 3.3. Maintain a Clear Waterway).
- Roadway runoff not properly collected and directed away from the embankments into erosion mitigation structures (see Section 3.8 Preventing Damage by Roadway Runoff).
- Loss of embankment vegetation by clearing or erosion (see Section 3.7 on Vegetation).

Actions to take to prevent embankment erosion:

- Take immediate steps to control embankment erosion when it is discovered by placing inexpensive temporary soil erosion control systems such as wood chips and staked straw bales.
- Protect embankments subject to erosion with permanent erosion control systems such as erosion control mats or stone armoring. Permanent systems should be designed by a licensed professional engineer.

For information on commercial erosion control mats see:

- Shepley, Brian; Smith, Robert; Jackson, Gerry L. *Market Analysis of Erosion Control Mats. Research Note FPL-RN-0284*. Madison, WI: US Department of Agriculture, Forest Service, Forest Products Laboratory.



### **3.6 Limit Damage by Overtopping**

When a culvert is clogged or of insufficient capacity to the degree that the stream leaves its banks and flows over the top of the roadway (overtopping) an extremely dangerous situation is created. The roadway embankment acts as a dam and becomes increasingly saturated and more unstable the longer the overtopping condition exists, threatening a sudden and catastrophic washout. Alternatively, the water pressure can force channels to open through the fill under the roadway causing the pavement to collapse. Once an open washout channel is established it enlarges at an increasing rate in concert with the volume and velocity of the water passing through it.

The structural stability of stone culverts operating submerged is dependent on the weight of the earth fill above and behind the stonework. This is especially true of arch culverts – and especially those built with roughly fitted arch stones – which derive most of their strength and resistance to movement from the pressure exerted by the overburden. Arch culverts will likely collapse once fill material has been washed away. Large box culverts with massive lintels or slabs spanning the opening are generally less susceptible to uplift and washout when overtopped, but may stand on vulnerable abutments.

Overtopping of historic stone culverts must be prevented:

- Determine which culverts in your district have operated submerged or have been overtopped. Longtime residents in the immediate area should know.
- Develop plan to increase culvert capacity by installing a bypass culvert (see Section 5.1)
- Install erosion control systems on road and stream embankments to a distance of 25' or more from the culvert stonework (see Section 3.5 Controlling Erosion above for description of and reference to suitable erosion control systems.



Photo No. 16: This 3.5' box culvert in Wolfeboro, NH, WOL0026 has split lintel spans and fieldstone walls. The dry-laid masonry is "loosely built," with poorly fitted joints, due to the use of rounded boulders that offer limited bearing surface. Rough work like this is normally chinked and mortared. It stands due to the weight of the overlying fill pressing the stones tightly together from all sides. If the fill is lost, the stones will follow. In this case roadway runoff has washed out and collapsed the facewall on the left.

Photo No. 17: Collapsed roadway over stone arch culvert in Temple, NH caused by overtopping. (Photo courtesy of James Garvin, NHDHR).



### 3.7 Prevent Damage by Vegetation

Vegetation has both negative and positive effects on stone culverts. All vegetation found growing on or within the stonework, including the facewalls and wingwalls, should be considered extremely detrimental to the structural integrity of the culvert. Vegetation on the earth embankments flanking the culvert may be protecting the culvert by anchoring the soil and preventing erosion both due to highway runoff and high water events. The roots of larger vegetation near the culvert may be infiltrating the stonework and posing an apparent or non-apparent threat to the structural integrity of the culvert.



Photo No. 18: Regularly remove small trees and vegetation growing in stonework before it becomes a big problem.

- Inspect culvert stonework and surrounding stream and roadway banks making note of vegetation. Plan equipment and manpower needed for vegetation removal. Take digital photographs.
- Grasses, vines, and ground covers should be left undisturbed up to the edges of the wingwalls or facewalls of the culvert for erosion protection. Small bushes, saplings and small trees help prevent erosion but their roots must not be allowed to infiltrate the stonework.
- Remove all small vegetation from the culvert stonework using hand clippers or rotary string trimmers. Annual removal of small vegetation avoids the cost of more expensive removal methods if vegetation is ignored.
- Small trees, bushes and heavy vines with roots anchored in masonry joints must be removed very carefully to avoid loosening stones. Do not attempt to pull vegetation loose that is firmly anchored in the stonework using leverage or mechanical means. Larger vegetation should be cut off at the stump as close as possible to the stonework. The stump cut should be painted with herbicide to cause the roots to die and disintegrate in place.
- Large trees and bushes should be cleared from embankments to a distance of 15 feet from culvert stonework. Stump cuts should be painted with herbicide and the roots left to disintegrate.
- Professional tree removal service is recommended for heavy tree work but must be closely supervised to insure careful removal of trees without damage to stonework.



### 3.8 Prevent Damage by Roadway Water Infiltration and Runoff

Physical deterioration and damage to stone culverts by roadway water infiltration and runoff generally begins slowly with pavement and curbing failure and increases in rate with each heavy rain until a major failure of the culvert structure occurs. Roadway maintenance crews can conduct or specify the necessary maintenance procedures to prevent the potential for damage by roadway water, as well as make minor repairs to damage already in progress.

Pavement cracks allow water to seep into the fill material surrounding the culvert and behind the facewalls and wingwalls. Saturated fill expands and contracts with the freeze/thaw cycle. Expanding ice exerts tremendous force, known as ice jacking that can result in cracked and displaced culvert stones, loosened or broken mortar joints, bulging walls, separation and enlargement of joints.

Water infiltration through the pavement or along the edges of the roadway gradually washes away the small particles such as sand in the fill material causing settlement of the roadway and a cycle of further cracking and water infiltration.

- Inspect roadway over culverts and culvert approach embankments for potential sources of water infiltration and evidence of runoff erosion. Plan for equipment & manpower needed for maintenance and repairs. Measure linear feet of cracks to be sealed. Take digital photographs.
- Pavement edging over culverts that is broken or lacks curbing may be allowing runoff to directly enter the fill material behind the facewalls. Install low cost asphalt drainage curbing to direct runoff beyond the limits of the culvert stonework.
- Direct runoff into gravel or riprap lined swales or ditches to prevent bank erosion.



Photo No 19: Repair cracked, broken pavement to stop water infiltration. Repair or install curbing to direct runoff away from culvert and embankments.



### 3.9 Prevent Over Loading and Impact Damage

Preventing damage by over loading presents a challenge to owners since load rating and weight limit posting is not required in most cases and determining load limits in advance of damage is a difficult and somewhat subjective exercise. When increased loading can be anticipated, such as the detouring of heavy truck traffic over a minor road with a long span box culvert for example, methods for the protection of the culvert span should be considered. Temporary steel road plates can be set over the culvert to better distribute wheel loads. A permanent reinforced concrete "flyover" slab may be the practical long-term solution.

Photo No. 20: Box culvert in Enfield Center with a series of cracked lintels due to over loading. Repair options are limited to replacement of the fractured members, a problem best avoided by inspection and advance planning.



Impact damage to culverts results primarily from snowplows hitting the curbing or from vehicle impacts to the railings. Culvert facewall stones are sometimes extended above the pavement as parapets or curbing which are particularly vulnerable to plow damage. Due to the narrow width of many culverts, railing posts are often imbedded in the fill facewall, or in the facewall stonework. In such cases wider spacing of railing posts or alternative railing systems is recommended.

Photo No. 21: Impact to the railing over this small box culvert has pushed the facewall stones into the stream resulting in erosion and loss of fill that threatens the overall integrity of the structure.



## 4.0 REPAIRING HISTORIC STONE CULVERTS

### 4.1 Historic Preservation Requirements

Culvert owners making repairs to historic stone culverts using federal or state monies or requiring state agency issued permits are required by law to have their project reviewed and approved by the New Hampshire Division of Historical Resources (NHDHR). Authorization by the NHDHR must be obtained before your project can receive funding or necessary state permits such as a wetlands permit. Information on the applicable federal and state laws governing the state's historic resources including stone culverts can be found on the NHDHR website at <http://www.nh.gov/nhdhr/review/>.

Obtaining approval from the NHDHR to make repairs to a stone culvert is not complicated:

- (1) Adopt a repair plan that respects the historic character and significance of the resource [this chapter will assist you];
- (2) Complete a *Request for Project Review Form* (RPR Form) and submit it to NHDHR. [Form and Instructions available online: <http://www.nh.gov/nhdhr/review/>];
- (3) Attend a meeting with NHDHR staff to resolve any issues and finalize the repair plan [DHR will schedule meeting and notify you].

The following paragraphs provide a basic understanding of some of the historic preservation terminology and concepts you may encounter in your project approval process:

#### *Character defining features*

"Character defining features" is a term used in the field of historic preservation to describe the individual physical components or features of a National Register eligible property that have been identified as contributing to the property's historic significance. These features must be maintained, repaired or replaced using acceptable Treatments for historic properties.

- New Hampshire's stone culverts are relatively uncomplicated structures composed of one material, stone, or two materials, stone and mortar. The stone itself, the way it was worked with hammer and chisel, and the manner in which it was laid-up to form the culvert and wingwalls, constitute the character defining features of a stone culvert.

#### *Treatments*

"Treatments" is another term with special meaning in the historic preservation business. It is derived from *The Secretary of the Interior's Standards for the Treatment of Historic Properties*, federal guidelines that specify how historic properties may be repaired and rehabilitated. The

Secretary's Standards for Rehabilitation (Standards) are a list of general rules to follow for most types of repair work on historic buildings (See Appendix D). These Standards have been reworded by bridge preservation specialists to be more applicable to bridges, but they remain general in scope (See Appendix E). The Standards also include *Guidelines* that give more specific instruction on *Recommended* and *Not Recommended* treatments for the various materials and components of buildings. The guidelines for the treatment of the masonry of a building apply somewhat to stone culverts (See Appendix F). Although the Secretary's Standards are only partly applicable to stone culverts, they provide an understanding of the principles that guide the formulation and choice of acceptable treatments for historic properties.

- Historic stone culverts have a limited number of historic materials and design features, which means a limited number of character defining features and a limited number of suitable treatments.
- Acceptable treatments preserve the historic materials and design of the culvert.
- Respect the materials, methods, and labors of those who came before you. New Hampshire's stone culverts have lasted over 100 years: make every reasonable effort to repair them in their original form. Your efforts will be similarly respected for centuries to come.

#### **4.2 Sources of Culvert Repair Information**

Culvert repair literature specific to stone culverts is very limited. Information has to be gathered from a variety of sources; some are available for download from the Internet, others will need to be obtained through your library by inter-library loan. The most authoritative information on the modern practice of maintaining and repairing culverts is available from two Federal Highway Administration publications:

- *FHWA Culvert Inspection Manual—Supplement to the Bridge Inspector's Manual*. (1986). FHWA Publication Number: IP-86-2. Online at: <http://isddc.dot.gov/OLPFiles/FHWA/006625.pdf>
- *FHWA Culvert Repair Practice Manual Volume 1 (1994) and Volume 2. (1994)*. FHWA Publication Number: RD-94-096. Online at: <http://isddc.dot.gov/OLPFiles/FHWA/010551.pdf>
- *FHWA Culvert Repair Practice Manual Volume 2. (1995)*. FHWA Publication Number: RD-95-089. Online at: <http://isddc.dot.gov/OLPFiles/FHWA/010550.pdf>

Although the FHWA manuals provide valuable information applicable to all types of culverts, information specific to the subject of stone culverts is very limited. Most technical literature on culvert repair deal with the serious and expensive issues of repairing long pipe culverts under

deep highway embankments, many of which are located under post WWII superhighways. These culverts are now big problems: steel, concrete or tile pipes have rusted out, eroded, frost-spalled, otherwise broken down and even collapsed. The great expense of closing the road and digging them up to replace them has created a market for repair-in-place systems.

A great number of the proprietary and non-proprietary culvert repair systems and products have been developed for relining pipe culverts. Essentially all of these systems are unsuitable for use in historic stone culverts. Either they simply are not designed for such use due to the irregularity of the stone work or because they introduce modern materials and diminish the historic integrity of the resource. Fortunately, few of New Hampshire's historic stone highway culverts are buried deep and therefore excavation for proper reconstruction is usually very practical.

Two publications that offer information relevant to stone arch culverts:

- PENNDOT Stone Arch Bridge Maintenance Manual, (October 2007).
- Project Keystone: Stone Arch Bridge Management Plan, (October 2007).

Both of these documents have been useful in preparing recommendations in this report and are available online at <http://www.pastonearch.org/>

The best treatment of stone culvert design and construction in the historical literature is:

- *A Treatise on Masonry Construction*. Ira O. Baker (New York: John Wiley & Sons, 1899).

Books with good discussions of stone masonry materials, tools and techniques are:

- *Audel's Masons and Builders Guide No. 4*. Frank D. Graham (New York: Theo Audel and Co., 1924).
- *The Art of the Stone Mason*. Ian Cramb. Cincinnati, Ohio: Betterway Books, 1992.
- *The Art of Splitting Stone*. Mary and James Gage. (Amesbury, MA: Powwow River Books, 2005).

See the extensive Bibliography in Section 9.0 for additional sources of information



### 4.3 Stone Culvert Repair Guidelines

The majority of repair work will entail resetting individual facewall or wingwall stones that have fallen or reconstructing entire sections of collapsed culvert stonework. Whenever possible, stone culverts should be repaired using the original stones from which they were built.

Photos and notes taken of impending problems in the course of culvert inspections may provide the information needed to identify what stones belong to the culvert and exactly where they were located, particularly culverts with large, cut, quarried or uniquely shaped stones. On the other hand, a culvert built of small local rubblestone or fieldstone that has collapsed and been scattered about in a rocky stream may be impossible to sort out even with photos.

Before undertaking repairs, read Section 4.4 on Stone Culvert Masonry Methods and Section 4.5 on Historic Culvert Specifications.

#### *Planning the work*

- Identify cause of the problem.
  - Do inspection sheets indicate this is a recurring problem?
  - If so, should temporary repairs be made or is more substantial work justified to correct the problem permanently?
- Determine the skills and tools and materials that will be required.
  - Who can most effectively do the work? Can work be done with in-house labor or will a specialized masonry contractor be required?
  - Is the stonework of exceptional quality? Were historic masonry specifications followed? (see section 4.5 below).
  - Will excavating or lifting equipment be needed?
  - Will pruning saws, shears or clippers be needed to clear vegetation from areas to be repaired?
  - Can existing stone be reused or will stone need to be acquired elsewhere and brought in?
- Determine what permits are required?
  - Contact the New Hampshire Division of Historical Resources at:  
<http://www.nh.gov/nhdhr/review/>
  - Contact the NH Department of Environmental Services at:  
<http://des.nh.gov/organization/divisions/water/>

### ***Resetting individually displaced dry-laid wall stones***

This work can generally be undertaken in the course of maintenance with road crew labor or local masons possessing experience with dry stone wall construction. The work is limited to the restacking of dry-laid wall stones that have become loose, displaced or have toppled from the top of facewalls and wingwalls. Erosion, soil slumping, frost and root jacking are the usual causes. Excavation is generally limited to that done with hand tools including shovel, pick and axe, in order to clear and prepare the original bed and backing area for the wall stones. Hand saws and clippers are used to clear vegetation in localized areas to be repaired.

### ***Rebuilding collapsed facewalls or wingwalls***

When larger sections of the face and wing walls have collapsed a decision will need to be made whether the project will require outside professionals. This work is typically beyond the capabilities of road crews and will require at the minimum the services of a professional mason. Repairs to mortared rubble work and cut-stone work should be performed by a specialized masonry contractor with a demonstrable record of project experience repairing historic stonework such as retaining walls, foundations or bridge abutments.

### ***Rebuilding collapsed box and arch culvert spans.***

Partial or complete collapse of the lintel or slab span stones of a box culvert or the ring stones of an arch culvert creates an emergency situation that usually results in the closing of the road. Repair procedures and methods will vary by town and depend on numerous variables. In addition to a specialized masonry contractor experienced in historic stonework, the work will also require excavation, filling, and road paving. Environmental and historic permitting will be required. A consulting engineer with experience in both historic stonework repairs and culvert sizing and design will need to be retained. Working in consultation with the New Hampshire Division of Historical Resources, the engineer will prepare repair plans and specifications that meet the standards for historic masonry repairs and will oversee the work of the contractors.

#### 4.4 Historic Stone Culvert Masonry Methods

To professional stonemasons, the value of a well-built stone culvert is self-evident. And to any amateur mason who has worked with stone, perhaps built a garden retaining wall, restacked a dry laid bank-barn foundation, or attempted a stone chimney, our finer culverts will evoke a sense of awe. The rest of us can gain a greater appreciation for these potentially eternal structures by seeking them out in the field and by studying the materials and methods of their construction. Those who might be quick to replace a damaged stone culvert with a shiny silver pipe should be open to the possibility of enlightenment.

A brief introduction to the materials and methods of the stone masonry found in New Hampshire's highway culverts follows. For more information, several books on the subject are cited at the end of this section; request them from you local library and soon you will be "siding with stone."

The masonry methods and skills used in constructing New Hampshire's historic stone highway culverts range from rudimentary fieldstone work up to "First-class Masonry" <sup>6</sup> that exhibits the best in materials and workmanship.

In general, arched culverts took greater labor and skill to construct than box culverts, but some of New Hampshire's extraordinary box culverts were clearly built by very skilled professional masons while some fieldstone arch culverts appear to have been built by those without any specific masonry skills.

Photo No. 22: Box culvert of dry-laid fieldstone very randomly laid.



The smaller box culverts of dry-laid fieldstone construction required few tools and in many cases only the skills that many farmers would have acquired through the practice of building fieldstone walls and building foundations. The large flat stones needed for the top of the culvert to span the opening were the same as those found in fields or pried from rock outcrops and set aside for

steps and capping foundation walls. Stone was moved about on an ox-drawn sled known as a stone boat, advanced into position on log rollers and then adjusted into its final resting place with iron pry bars.

Large box culverts and arch culverts with stones larger than what one or two men could place, required the use of a small "stiff-leg" mason's derrick to lift and lower the big stones into place. A local barn builder likely had a small derrick so the presence of big stones does not necessarily mean a "professional" mason was involved. A culvert built of split quarry stone stacked in neat courses may represent the investment of public money, but was still within the abilities of the local builder skilled in many trades. The term "vernacular" is often used to describe the engineering and construction of stone culverts; its derivation is from the Latin *vernaculus*, meaning domestic (not foreign) or indigenous. In other words, New Hampshire born and bred.

An understanding of the materials, methods and tools used to build New Hampshire stone highway culverts will help culvert owners identify how a particular culvert was constructed, how it should be repaired or reconstructed, and who is qualified to make repairs.

### ***Fieldstone***

In New England and other northern areas subject to glaciations, fieldstone generally means stones found in the fields deposited by glaciers, usually well weathered and rounded to some degree. It is often of wide ranging variety, scraped up by the ice from local bedrock or transported all the way from Canada. Farmers moved the stones to the edges of cultivated fields and pastures and piled them to form walls. Fieldstones too big to be move were broken up into rubble, or if of good quality, split and squared up for work that warranted it like foundation corners, bridge abutments and culverts.

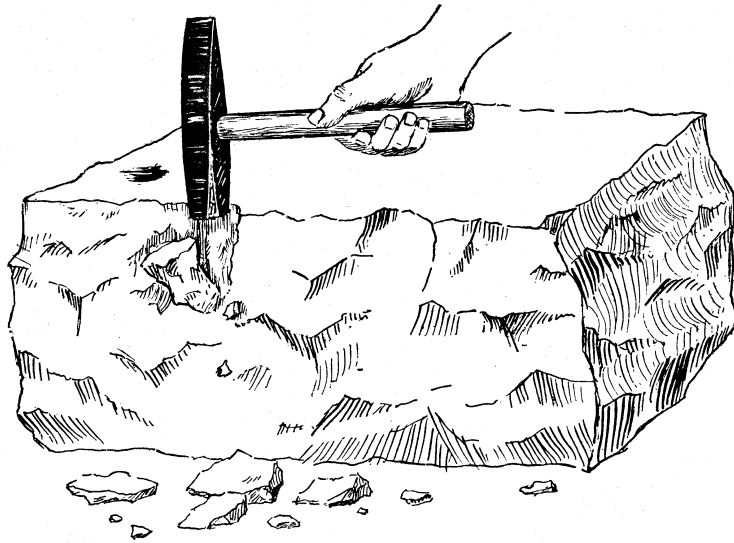
### ***Rubble stone***

Rubble stone is loose broken stone, generally weathered very little if at all, and usually native, such as local quarry tailings, talus, and what can be pried or broken free from rock outcrops. The term random rubble refers to a technique or style of stone wall built with rubble of uneven sizes and shapes, usually bedded in mortar and without attention given to even coursing.



### *Hammer work*

Masonry hammers come in a variety of shapes, weights and head design depending on the intended use. A general purpose hammer with both a square head and chisel head is used for knocking irregular knobs and angles off a stone and roughly trimming to size. Fieldstone, rubble and quarry stone was all rough-worked with the hammer as needed to quickly achieve a better fit or more even bearing. Stones worked with more than a few blows, squared-up or roughly faced are known as *hammer dressed*.



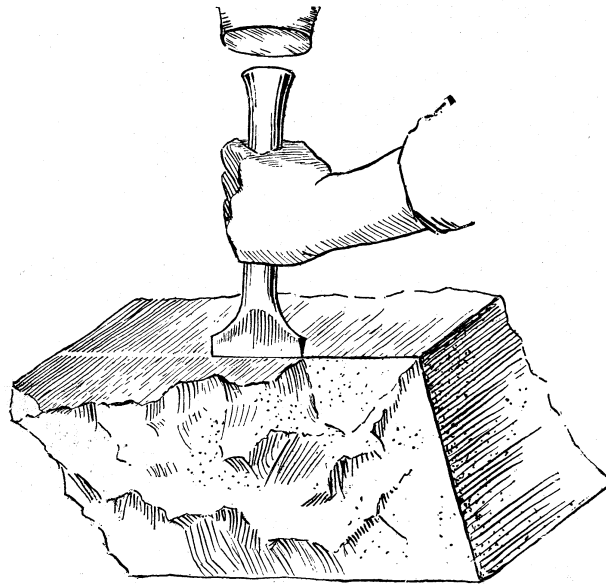
**Figure No. 3:** Hammer squared and dressed stone

### *Cut stone*

The term cut stone usually means that a cutting tool was used to apply straight edges and corners to the stone. In regards to stone used in culvert work, it means cut by hand with a hammer and a variety of specialized chisels. Although mechanized stone saws were introduced in the 19<sup>th</sup> century, their use was limited to cutting valuable softer stones used for decorative purposes like marble, rather than hard foundation stones like granite. \

The term cut stone is sometimes loosely used for any stone that has been shaped and squared, as opposed to rubble or fieldstone, but unless chiseled lines are evident, the term *worked stone* is better suited.

Cut stone is typically dimension stone – specified to be of a certain uniform size enabling it to be laid in equal parallel courses known as range-work. Ashlar-work also uses cut squared stone, but of unequal sizes resulting in uneven courses.



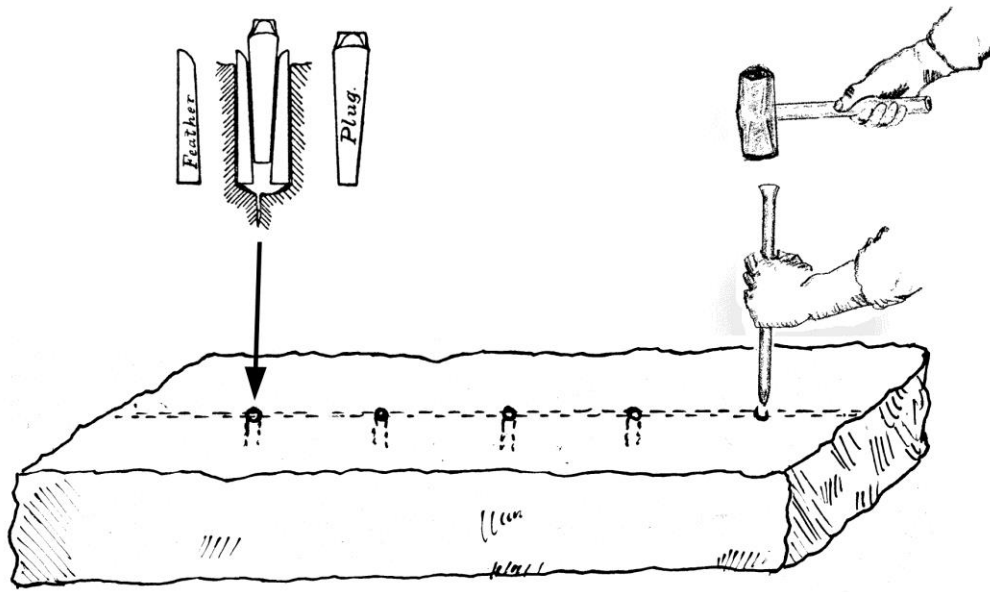
**Figure No. 4:** Cutting stone with a chisel

### *Split stone*

The nature of split stone depends on its geology and varies widely by locality and quarry. The fine grain and homogenous nature of much of New Hampshire granite means that with skill it can be split evenly along straight lines to yield a rough but relatively planar surface. Split stone lintels of uniform size and suitable for use with little or no working were readily produced in long lengths. Split stone used in culverts may also be the product of boulders and ledge outcrops "quarried" by the mason from the immediate area.

Splitting was done with a flat chisel and flat wedges up until the late 18<sup>th</sup> century when drilling round holes and using the "plug and-feather" wedge system came into use. When the split surface is left natural and unworked it is referred to as split faced or quarry faced.

- See *Appendix G, Granite Splitting Tools and Techniques*, to learn how to recognize the differences between the splitting methods.



**Figure No. 5:** Splitting stone with the plug and feather method.

### *Dry laid stone masonry*

Many of the stone culverts are built of dry-laid masonry, meaning the stone was laid-up without the use of mortar. For the purposes of culverts, bridge abutments and retaining walls, dry-laid masonry usually sufficed nicely, although attaining good bearing and tight joints between the stones was more labor intensive requiring continual hammer work.

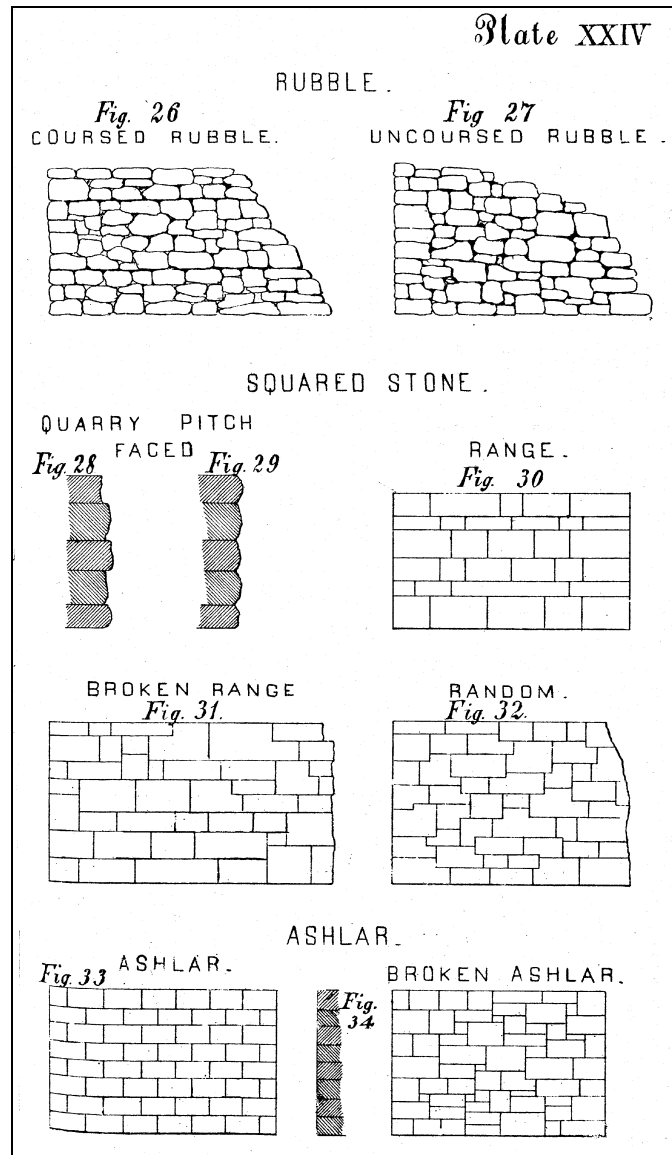
Dry laid walls have benefits. The lack of mortar provided porosity to the structure that allowed water in the backfill to drain out through the faces thereby reducing hydraulic pressure on the masonry and the damaging effects of frost and ice. The lack of mortar also allowed the stones to move slightly, giving the structure an overall flexibility that some argue is an advantage when subjected to excessive live loads, impact loads or vibration that can fracture and pulverize mortar in some cases.

Since dry masonry does not require mortar it can be laid up in the winter providing the foundations are set before the frost and below the frost line. Dry laid walls are easier to repair. In a severe washout more of a mortared wall may come down since it is all bonded together.

### *Mortared stone masonry*

Stone culverts are also built with mortared masonry using squared stone, fieldstone and rubble. The use of dry laid or mortared masonry seems to be due to the method in which the particular mason worked and the materials readily available. Simple lime mortars required the addition of a

natural hydraulic cement in order to be resistant to breakdown by water. Natural cement based mortar was expensive up until the mid-to late 19<sup>th</sup> century when Portland cement manufacture was fully underway in the US. The use of cement mortar to fill the gaps between stones provided a uniform bearing between stones and bonded the entire structure together solidly. Stones no longer needed to be so precisely squared and smoothed which saved labor and offset the cost of the mortar.<sup>7</sup>



**Figure No. 6:** Stone masonry wall construction methods. From J.R Croes, *Nomenclature of Building Stones and of Stone Masonry*, 1877.



## 4.5 Historic Stone Culvert Specifications

It was not until the late 19<sup>th</sup> century that written descriptions and specifications for the construction of stone culverts came into print, and then they were primarily for railroads. Railroads had the engineers, the money and the incentive to perfect the design and construction of culverts. Compared to highway culverts, railroad culvert washouts were especially deadly and expensive. Unlike a wagon, trains could not stop in time to avoid going in the hole and with often high fills over culverts, the plunge frequently had fatal consequences. By the turn of the century detailed specifications for railroad culverts were in use, such as those reproduced at the end of this section from 1904.

The earliest specifications for stone *highway* culverts found in a search of the literature for this report date from 1886. Specifications for New Hampshire highway culverts appeared in state reports about ten years later during the rush to build better roads. Information on the materials and methods of stone culvert construction in New Hampshire prior to that time comes from visual inspection of existing culverts or early town records.

- Inspection of collapsed culverts can provide valuable information about historic construction practices. Detailed photographs of washed out culverts should be taken as soon as possible.
- A wealth of undiscovered information about the state's stone culverts undoubtedly exists in town records. Research undertaken on a local level could greatly expand the knowledge of early construction practices.

Historic specifications for stone culverts can help in preparing repair contract specifications for damaged culverts:

- ca. 1835: In the Contoocook River Valley there was a concentration of small stone arch bridges built beginning about 1835 when a double-arch bridge – the first in New Hampshire – was erected in the town of Henniker. A consulting engineer, Isaac C. Flanders of Lowell, Massachusetts, prepared detailed construction specifications for the two forty-foot spans that included the dimensioning, squaring and finishing of the arch stones, the minimum overlap of the joints (six inches) and the length of the foundation stones (ten feet), to name a few.<sup>8</sup>
- ca. 1844: A box culvert built under Coleman Road in Auburn about 1844 with a clear span of 8 feet used seven stone lintels for the top of the culvert, each measuring 24-27 inches wide, 10-18" deep, and 9-11 feet long.<sup>9</sup>
- 1886: "A point too often neglected in constructing a gravel road is the consideration of the proper size and position of the culverts. Stone culverts must be built of good-sized, well-shaped quarry stone, 6-8" thick, 2 feet wide with

parallel beds, laid dry, making walls 2 feet thick. No space in joints not to exceed 1 inch, and exposed stones at ends of culverts to be squared and pitch-faced."<sup>10</sup>

- 1898: William B. Howe of Concord gave the following guidance on the construction of culverts in New Hampshire:<sup>11</sup>

When more waterway than a thirty-six inch pipe is needed, a stone culvert is required. If good stone is easily obtained near the site of the proposed culvert, it should be built of large, roughly squared stone laid in cement mortar. Lime mortar should not be used in culvert masonry. If the horizontal opening in a culvert exceeds about four feet it is probable that a rough-cut arch culvert would be cheaper than a box culvert, as the increased expense of suitable covering stones would more than pay for the rough work in the arch and the larger dimensions required in the side walls. In the absence of a quarry or large boulders from which suitable stone can be quarried, a culvert can be built of field stone if care is used in selecting and laying them in good cement mortar.

- 1905: New Hampshire's newly appointed State Engineer Arthur W. Dean developed standard specifications for grading and improving town roads with state aid monies. His list of specifications for stone masonry work for culverts:

- all stone shall be free of structural defects;
- selected stone, roughly squared and pitched to line, shall be used at all angles and ends of walls;
- stones shall be at least 6 inches thick;
- stone shall be laid in full cement mortar beds;
- length of the stretchers shall not exceed three times the rise;
- width of stretchers shall not be less than the rise or less than 12 inches;
- at least one-fourth of the stone in the face shall be headers, evenly distributed throughout the wall;
- all stones shall break joints six inches or more;
- no joint on the face shall be more than two inches;
- end walls shall be capped with stone roughly squared extending across the entire width of the wall;
- stone culvert bottoms, when specified on the plans, shall be rammed to a firm bearing and uniform surface and the joints filled with cement mortar; etc.

Note: Dean specifies stone to be bedded in cement mortar. Before mortar is used for repair work it should be determined if the original work was dry laid or laid in mortar and follow suit accordingly.

- 1904: Culvert specifications from *A Treatise on Masonry Construction* (Baker, 1904).

**First-class Masonry** will consist of quarry-faced ashlar [see §§ 200-07] laid in horizontal courses having parallel beds and vertical joints, of not less than ten inches (10") nor more than thirty inches (30") in thickness,—decreasing in thickness regularly from the bottom to the top of the wall,—laid flush in cement mortar of the quality hereinafter specified. Each course must be thoroughly grouted before the succeeding one is laid.

**Size of Stones.** *Stretchers* must be not less than two and one half feet (2½) nor more than six feet (6') in length, and not less than one and one half feet (1½) in width, nor less in width than one and one half (1½) times their depth. *Headers* must not be less than three and one half feet (3½) nor more than four and one half feet (4½) in length—where the thickness of the wall will admit of the same,—and not less than one and one half feet (1½) in width, nor less in width than they are in depth of course.

**Cutting.** Every stone must be laid on its natural bed. All stones must have their beds well dressed, parallel and true to the proper line, and made always as large as the stone will admit of. The beds and sides of the stone must be cut, before being placed on the work, so as to form joints not exceeding one half inch (½") in width. No hammering on a stone will be allowed after it is set; but if any inequalities occur, they must be pointed off. The vertical joints of the face must be not less than eight inches (8") in from the face, and as much more as the stone will admit of. All corners and batter lines must be run with a neat chisel draft one and one half inches (1½") on each face. The projections of the quarry face beyond the draft lines must not exceed four inches (4"), and in the side-walls of tunnels this projection must not exceed two inches (2").

**Bond.** The masonry shall consist of headers and stretchers alternating. At least one fourth of it shall consist of headers extending entirely through the wall, and every header shall be immediately over a stretcher of the underlying course. The stones of each course shall be so arranged as to form a proper bond—in no case less than one foot (1')—with the stones of the underlying course.

**Backing.** The backing shall be of good-sized, well-shaped stones, laid so as to break joints and thoroughly bond the work in all directions, and leave no spaces between them over six inches (6") in width, which spaces shall be filled with small stones and spalls well grouted.

**Coping.** All bridge-seats and tops of walls will be finished with a coping course of such dimensions and projections as may be ordered by the engineer, dressed and cut to a true surface on top and front edges, in conformity with diagrams for same which will be furnished by the engineer.

**Foundation Courses.** All foundation courses must be laid with selected large flat stones, not less than twelve inches (12") thick, nor of less superficial surface than fifteen (15) square feet.

**Second-class Masonry** [§§ 208-12] will consist of broken range rubble of superior quality, laid with horizontal beds and vertical joints on the face, with no stone less than eight inches (8") in thickness—unless otherwise directed by the engineer,—well bonded, and leveled as well as can be without hammer-dressing. No mortar joint shall exceed three quarters of an inch (¾") in thickness. All corners and quoins shall have hammer-dressed beds and joints; and all corners and batter lines shall be run with an inch-and-one-half (1½") chisel draft. At least one fourth (¼) of the stones in the face must be headers evenly distributed through the wall.

Bridge-seats and tops of walls shall be coped in the same manner as specified for first-class masonry. Stones in foundation courses shall be not less than twelve inches (12") thick, and shall contain not less than twelve (12) square feet of surface.

**Third-class Masonry** will consist of good substantial rubble [§§ 213-17] laid in cement mortar. All stones shall be perfectly sound, and sufficiently large to make good, well-bonded, strong work; and shall be laid on their natural beds, in the most substantial manner, and with as much neatness as this description of work admits of. The stones in the foundations must be not less than ten inches (10") thick, and shall contain not less than ten (10) square feet of surface; and each shall be firmly, solidly, and carefully laid.

**First-class Arch-culvert Masonry** shall be built in accordance with the specifications for first-class masonry, with the exception of the arch sheeting and the ring-stones. The rings shall be dressed to such size and shape as the engineer shall direct. The ring-stones and sheeting-stones shall not be of less thickness than ten inches (10") on the intrados, and shall be dressed with three eighths inch (¾") joints, and shall be of the full depth specified (by drawings or otherwise) for the thickness of the arch. The joints must be made on truly radial lines, and the face of the sheeting-stones must be dressed to make close joints with the center. The ring-stone and sheeting-stones shall break joints by not less than one foot (1').

The wing walls shall be neatly stepped, in accordance with the drawings furnished, with selected stones of the full width of the wing and of not less than ten inches (10") in thickness, no stone being covered less than eighteen inches (18") by the one next above it; or the wing shall be finished with a neatly capped newel at the end, and a coping course,—as may be selected by the engineer. The parapet shall be finished with a coping course of full width of parapet, with such projection as may be directed by the engineer, the stone to be not less than ten inches (10") thick.

**Second-class Arch-culvert Masonry** shall be of the same general character and description as second-class masonry, with the exception of the ring-stones and the arch sheeting. The former shall be dressed as specified for first-class arch-culvert masonry. The latter shall consist of selected stones of the full depth of the arch, and shall have a good bearing throughout the thickness of the arch, and shall be well bonded. No stone shall be less than six inches (6") in thickness on the intrados.

**Box-culvert Masonry** will be good rubble [see §§ 213-17], neatly laid up with square-shaped stones of a size and quality satisfactory to the engineer. The end parapet walls and also the side walls for three feet (3') from the ends shall be laid in good cement mortar. When box culverts are ordered to be laid up entirely in cement mortar [see § 214], they will be classified as third-class masonry, and must conform to the specifications for the same.

The covering-stone for all box culverts shall be not less than ten inches (10") in thickness, and must have a good, solid, well-leveled bearing on the side walls of not less than fifteen inches (15").



Photo No. 23: Remarkable workmanship exposed by the partial collapse of this stone arch culvert on the former Cheshire Railroad line in Westmoreland NH (Photo courtesy of James Garvin, NHDHR).



## **5.0 ALTERATIONS**

To be eligible for the National Register, stone highway culverts must retain integrity of location, design, setting, materials, workmanship, feeling and association. The types of integrity that embody most of the character defining features of stone highway culverts are those associated with design, materials and workmanship. Integrity can be diminished by natural causes such as damage and deterioration, or by alterations made to the culvert by man.

Alterations that introduce new materials or change the overall design and workmanship such as widening, reconstruction with concrete or lining with pipe or other materials will almost always have an adverse affect on the historic integrity of a stone culvert.

Pointing dry-laid stone masonry with mortar or re-pointing original mortar joints with new incompatible Portland cement mortars has been a common and misinformed practice in the past and can lead to more problems than it solves. Less common alterations include those made to the roadway above, such as the introduction of concrete curbing or railing structures, or the construction of a bypass culvert to reduce or divert water flow through the historic culvert.

Roadway and bypassing alterations may have a greater impact on the historic feeling of the resource and less of an impact on the design and workmanship of the culvert's structural stonework. The degree of loss of integrity in these cases and the suitability of alteration methods and materials must be carefully evaluated on a case-by-case basis.

### **5.1 Increasing Area of Waterway with Bypass Culvert**

When a stone culvert operates submerged or is overtopped during floods and the waterway is not obstructed in any way, then the culvert can be considered under sized. Very few stone highway culverts were designed to operate submerged. Even if a particular culvert has been observed operating submerged on repeated occasions without overtopping it can be assumed that it is causing erosion and unseen damage. Careful monitoring and inspection of the culvert is warranted while planning to relieve the pressure on the culvert by constructing a bypass culvert.

A culvert is undersized when the cross-sectional area of the opening, known as the area of waterway, is smaller than the cross-sectional area of the stream of water trying to pass through it. The problem may be due to the culvert being inadequately sized for the job by the designer/builder, or a result of increased runoff in the watershed served by the culvert.

In the past, meaning the twentieth century, undersized stone culverts were torn out and replaced by larger concrete pipe culverts. The culvert stone was often reused for the facewalls, wingwalls, curbing, or armoring the stream or road banks.

- Removing, enlarging, or otherwise altering historic stone culverts is no longer an acceptable means of increasing the capacity or area of the waterway.
- Installing a bypass or relieving culvert to side of a historic stone culvert is an acceptable means of increasing waterway capacity if care is taken to limit the physical and visual changes to the culvert and its setting.

The terms bypass culvert or relieving culvert are typically interchanged to mean a new culvert installed near the old culvert to carry a portion of the excess flow during flood events. In some cases the bypass culvert may be designed to take over as the primary channel, in other situations they are set at a slightly higher grade to take flow only during high water, "relieving" the work of the stone culvert.



**Photo No. 24:** This arch culvert in Temple NH (TEM0002) was washed out by flood waters and reconstructed using the original stone. A pipe bypass culvert was installed to the side of the arch to increase the flow capacity. Bypassing causes some loss of integrity of setting, feeling and association but may not substantially diminish the culvert's most important characteristics providing the majority of its functional stonework is left undisturbed and unaltered.

### *Sizing culvert openings*

Sizing the bypass culvert opening or determining the "required area of the waterway" as it was usually called in the historic literature, was done either on the basis of field measurements and observations or with the use of an empirical formula. Regardless of the method used, the necessary area of the waterway was a function of variables that were – and are today – difficult to quantify. Designing on the basis of data gathered from field observations and measurements

was considered "by far the best for permanent work," and consisted of "observing the high water marks on contracted channel openings which are on the same stream and as near as possible to the proposed culvert."<sup>12</sup>

The following diagram, from the FHWA *Culvert Inspection Manual* identifies the factors that must be considered in calculating the amount of runoff that a culvert must handle:

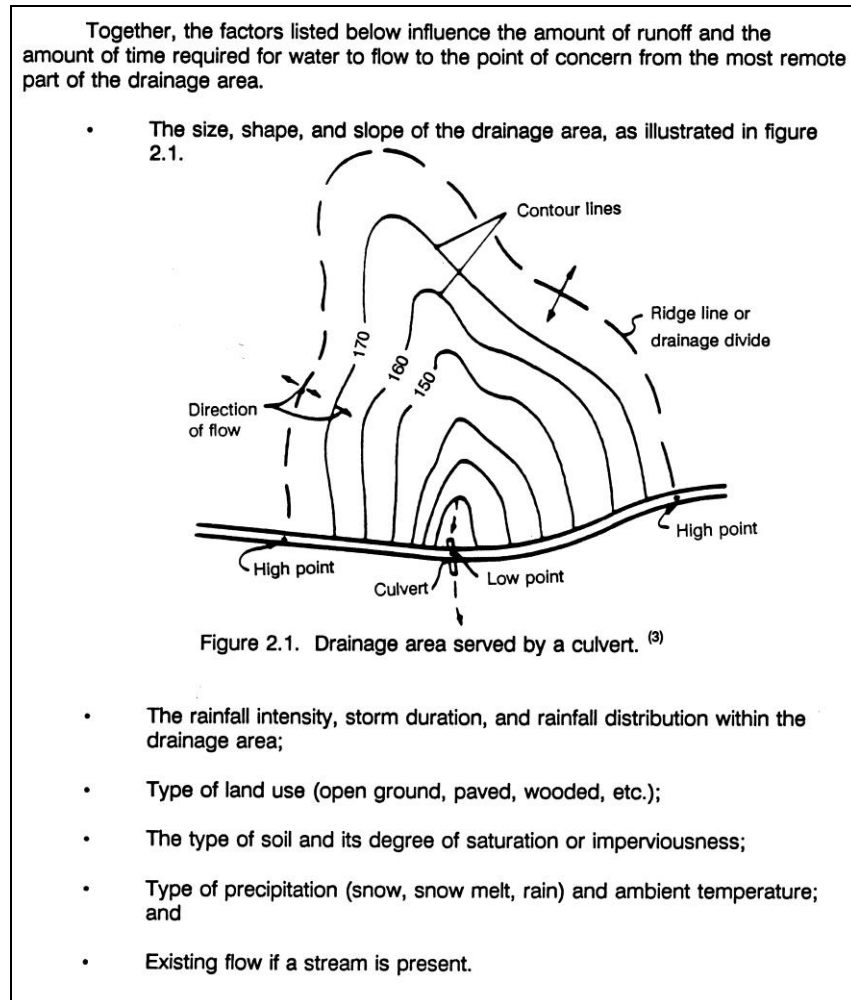


Figure No. 6: Runoff area. Source: Report No. FHWA-IP-86-2, July 1986, p. 2-2.

- Determining the required area of waterway and designing bypass culverts for stone culverts must be done by a registered professional civil engineer with experience in stream hydraulics, runoff and drainage calculations, and culvert design.

### ***Additional information***

*Hydraulic Design of Highway Culverts, Second Edition.* Publication No. FHWA-NHI-01-020, September 2001, Revised May 2005. Federal Highway Administration and National Highway Institute, Sponsors. Available online at <http://isddc.dot.gov/OLPFiles/FHWA/015808.pdf>

*Sizing of Highway Culverts and Bridges: A Historical Review of Methods and Criteria.* Bruce M. McEnroe, University of Kansas and Kansas Department of Transportation. Report No. K-Tran: KU-05-4, February, 2007. Available online at: <http://www.t2.unh.edu/nltapa/Pubs/Culvert%20Technologies%20List.pdf>

## **5.2 Installing Debris Deflectors**

Stone culverts that are repeatedly prone to clogging with debris may be candidates for the installation of debris control structures upstream of the inlet. Culverts that operate at or near their capacity during high water or those that would be particularly vulnerable to damage from submergence or overtopping should also be considered.

The use of a debris deflector to protect a historic stone culvert has not been tried yet in New Hampshire, so design and installation will initially require careful consideration on a case-by-case basis by the various permitting and funding agencies.

Please refer to the descriptions, diagrams and photographs of various types of debris control structures presented in the comprehensive FHWA technical document cited below.

### ***Additional information***

*Debris Control Structures Evaluation and Countermeasures.* Hydraulic Engineering Circular No. 9. Publication No. FHWA-IF-04-016. September 2005. Available on line at <http://www.fhwa.dot.gov/engineering/hydraulics/pubs/04016/index.cfm>

## 5.3 Increasing and Decreasing Live Loading

### *Overbridging*

Since culverts are short span structures, there are possible opportunities to span over the structure with thin precast concrete decking, bridge plank, steel plate or other types of engineered thin-section deck span. The feasibility of overbridging depends on the ability to transfer the overbridge loads to suitable bearing points, either on pilings, new hidden abutments, or the existing stone abutments. The increase in the height of the roadway grade to accommodate the thickness of the overbridging deck requires consideration during the feasibility analysis.

An engineered overbridging system can:

- lessen or remove the loading on structurally weakened stone culverts;
- increase the load rating on a culvert;
- be designed to have no adverse effect on the historic character defining features of the culvert.

### *Stone Arch Reinforcing Systems*

Arch reinforcing systems that introduce new materials to the exterior of the stonework or that are otherwise visible such as shotcrete and reinforced concrete overlays adversely affect the historic integrity of the culvert and are not acceptable.

A system that has been approved for historic stone arch bridges and may prove suitable for larger arched culverts is the tensioned cable and grout anchor system called Archtec, manufactured and installed by Cintec International based in Newport, Wales, UK, with a US office in Washington DC. The proprietary system is installed entirely within the fabric of the structure, leaving no visible change to the structure. The system has recently been used to reinforce historic stone arch highway bridges in Massachusetts.

Information on the Archtec system is available at  
<http://www.cintec.com/en/applications/Archtec/index.htm>

## 5.4 Railings and Guardrails

Careful consideration must be given before installing railings or guardrails along the roadway over culverts. Railing posts anchored in or near the culvert stonework, including the facewalls and wingwalls, pose a threat to the integrity of the culvert during installation and by displacement from vehicle impacts. Culverts with fill overtop deep enough to properly anchor rail posts and accept impact displacement without injury to the stonework are good candidates for railing installation. Culverts with shallow fill overtop are not candidates for post-supported railing systems. Cable systems with breakaway posts may be adaptable to shallow-cover culverts. Floating railing systems anchored independently beyond the limits of the culvert stonework and fill is the preferred system. The use of a concrete curb beam to anchor rail posts



(see photo below) may introduces a harsh and adverse visual alteration, but may be justifiable from a structural and safety standpoint in certain circumstances.

- Railings that do not adversely affect the physical or visual historic integrity of the culvert or pose a structural threat to the stonework are permitted.
- Culverts with fill overtop: posts must not be driven in; great care must be taken not to disturb culvert stonework when digging and setting posts.
- Culverts with shallow fill overtop generally do not accept traditional post-supported railings but can be equipped with special railing systems.



Photo No. 25: A heavy reinforced concrete curb/parapet has been cast-in-place across the top of the facewall of this culvert in Wakefield (WAK0010) with the dual purpose of providing a strong anchorage for the railing and a curb capable of redirecting tire impacts back into the travel lane. By eliminating the need to anchor the railing posts into the facewall, the culvert is protected from damage that could result from a forceful impact. The curb or cap beam helps consolidate and protect the top of the facewall from loosening due to erosion and vibration and could be an acceptable alteration in situations such as this.

## 6.0 HISTORIC STONE CULVERT PRESERVATION INITIATIVES

### 6.1 Public and Private Preservation Efforts

Efforts are well underway to identify, commemorate and preserve New Hampshire's rare stone culvert collection on a statewide basis by the NHDOT, and on local and regional levels by individual towns and non-profit organizations. These efforts are becoming part of the groundswell of interest and initiatives nationwide to preserve historic bridges of all types. [Note that some of the projects listed below refer to stone bridges but include large stone culverts in the 10 to 20 foot span as they were defined for this study].

The New Hampshire Department of Transportation in cooperation with the New Hampshire Division of Historical Resources has established a strong tradition of respect for its historic bridges of importance, preserving those that can be saved and carefully documenting those that cannot. The many writings and talks on the importance of the state's historic bridges by NH State Architectural Historian (and bridge historian) James Garvin has stimulated many of these preservation initiatives.

- **NHDOT Stone Highway Culvert Inventory, Historic Registration and Asset Management Project.** This statewide project, of which this manual is a part, began as a result of the flooding in the southwest part of the state in 2007. The project is discussed below.
- **Hillsborough.** The Town of Hillsborough is very proud of its group of stone arched bridges. In 2003 the American Society of Civil Engineers designated “Five Stone Arch Bridges, Hillsborough, New Hampshire” as National Historic Civil Engineering Landmarks on the basis of a nomination submitted by Frederick C. Rhyner, P. E., of the New Hampshire Section, ASCE. The town obtained a state historical marker in 2006, placing it at one of these bridges (see photo below). The bridges are mentioned on the Hillsborough Chamber of Commerce website, and there is a printed brochure with a map locating the bridges.
- **Boscawen.** The Town of Boscawen conducts walking tours of its town forest, which feature several old roads and a couple of stone culverts that are pointed out on the tour.
- **Warner.** The Town of Warner has organized an effort to find, list and map stone structures, beginning with abandoned stone building foundations – referred to as cellar holes – and now including stone culverts.
- **Lyme.** The Town of Lyme, Lyme Historians have also begun to find, list and map cellar holes and stone culverts.
- **Society for the Protection of New Hampshire Forests.** David Anderson, education director for The Society for the Protection of New Hampshire Forests, includes stone culverts in the walking tours of the Society's lands allocated in Newbury, Stoddard, and elsewhere in the state.

- Connecticut River Joint Commissions.** The Connecticut River Joint Commissions promotes historic bridge pride in their region several ways:
  - (1) Historic bridges are described on the Commissions website at <http://www.crjc.org/heritagebridges.htm>.
  - (2) Guides to historic bridges are posted on the Connecticut River Byway website for heritage-oriented tourists at <http://www.ctrivertravel.net/history.htm>.
  - (3) Historic bridges are depicted on Connecticut River Byway literature.
  - (4) Participation in permit review through the NH Rivers Management and Protection Program. This work has led to strong support from our local river subcommittees and from CRJC for historic bridge rehabilitation rather than replacement including Stratford Maidstone Bridge, Monroe-McIndoe Falls Bridge, Lebanon Route 4 Bridge, Orford's Samuel Morey Bridge, and Chesterfield Brattleboro Bridge.
  - (5) Partnership grants for historic bridge protection, such as a grant to Haverhill for fire protection for the Bath-Haverhill Covered Bridge.
- Steel Bridge Preservation Projects:** The Town of Jackson has preserved a historic pin-connected pony truss on a trail along Wildcat Brook. The towns of Hancock and Greenfield, N. H. have preserved a historic pin-connected 1906 pony truss bridge over the Contoocook River as a pedestrian crossing. A major effort is now underway to preserve the bypassed Chesterfield-Brattleboro steel arch bridge over the Connecticut River.

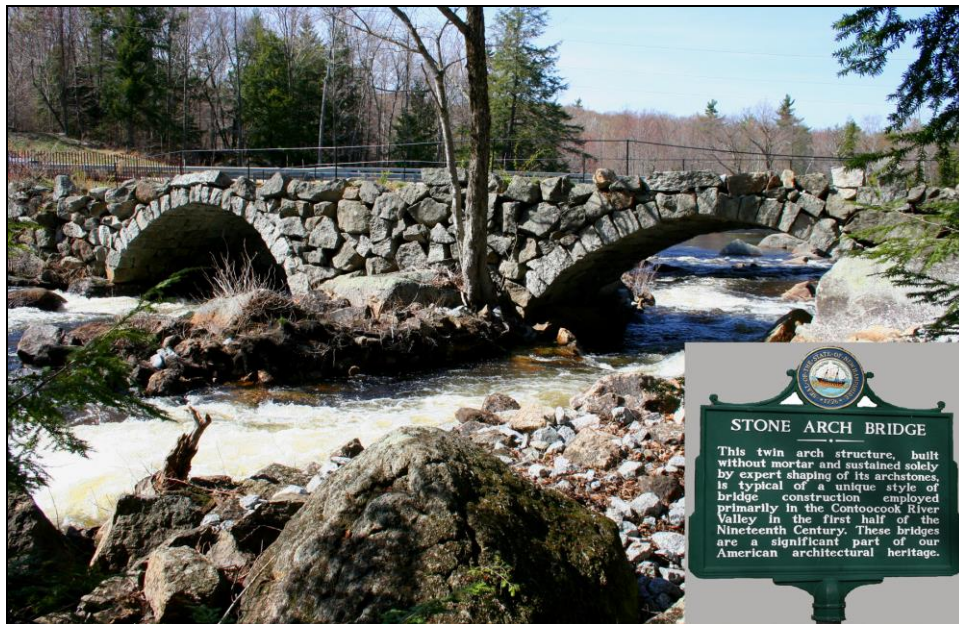


Photo No. 26. This Twin Stone Arch Bridge with segmental arches, cut arch stones and fieldstone facewalls is located in Stoddard, NH, spans the North Branch of the Contoocook River near the Antrim town line. It is now bypassed by a new bridge and preserved in a small public roadside park visible from Route 9. A historical marker (inset) commemorates this important historic artifact.

## **6.2 Contribute to the Ongoing Stone Culvert Inventory Project**

New Hampshire's Town Road Agents, NHDOT District Engineers and Maintenance Crews and all others are encouraged to help locate and inventory the many stone culverts that are known to exist under the state and local roads but have not yet been photographed and inventoried.

How you can help:

- Determine if the stone culverts you know of are listed in the Stone Culvert Resource Inventory Table in Appendix A. If not:
- Complete and mail the Stone Culvert Location Form provided in Appendix B. The form is pre-addressed on the reverse side; simply make a 2-sided copy of the form, fill out the location information, fold and mail.

The purpose of the Culvert Inventory Project was to identify stone highway culverts in New Hampshire built prior to 1958 (fifty years of age or older) that possess characteristics qualifying them for listing in the National Register of Historic Places (NR). The findings are used by the New Hampshire Department of Transportation (NHDOT) to aid in the planning and performance of culvert maintenance, repair and replacement. The findings are also be used by the New Hampshire Division of Historical Resources (NHDHR) and cooperating federal agencies such as the Federal Highway Administration (FHWA) and the Federal Emergency Management Agency (FEMA) to make decisions about the eligibility of stone culverts for listing in the National Register of Historic Places.

A field survey of stone culverts was conducted by the NHDOT in 2007. Culvert locations were identified from the DHR Survey and Review and Compliance files, responses to a email list-serve notification sent out to state offices and road agents, a hydrology study of the Ashuelot River conducted by The Nature Conservancy, a search of the DOT bridge database (known as PONTIS), and from a DOT water quality study in the southern section of the state.

A specific objective of the study was locating and mapping culverts; in the field, culverts were measured, photographed, and sketched. Information regarding the location of the culvert was collected, including the UTM, GPS, street, and crossing of the culvert, and compiled on a special resource inventory form developed specifically for the project.

The goal of the fieldwork was to establish an understanding of how these stone structures fair under flood conditions, to determine what appropriate alterations may be necessary, and to understand how the design and construction of these structures has changed over time.

## **7.0 HISTORICAL BACKGROUND OF STONE CULVERTS**

[Note: this section is condensed from the *National Register of Historic Places Multiple Property Documentation Form: Stone Highway Culverts in New Hampshire, 1750 to 1930.* ]

Culverts are believed to have originated with man's desire to drain away surface water to claim swampy land for cultivation and may date back several thousand years. About 600 BC Etruscan engineers built a narrow open channel with masonry walls through Rome to drain a low-lying swampy area into the Tiber and claim the land for what would become Forum Romanum. Parts of it survive today and serve as an example of early stone arch culvert design. Archaeological remains indicate the Romans drained their arable lands in Europe and England with both open and covered drains.

When low swampy areas are crossed with roads on earthen causeways, culverts provided a means of equalizing the level of the water on either side, thereby preventing the causeway from acting as a dam and becoming saturated, soft and unstable. Early American roads typically skirted wetlands due to the cost of building a filled road. Turnpikes and other roads built by subscription or otherwise well funded were an exception and usually followed as straight a line as economically possible. Railroads on the other hand, typically crossed wetlands since maintaining a flat even grade or following a straight line provided operating efficiencies that offset the initial cost of "fills."

Although the basic design of stone box and stone arch culverts developed from the ancient practices of stone post-and-lintel and stone-arch construction, their refinement was an outgrowth of the building of the railroads. The design and sizing of culverts based on the mathematical analysis of the particular structural and hydraulic requirements of a given situation, was almost exclusively developed by the railroads in the late 19<sup>th</sup> century. The lessons learned by the railroad engineers shaped the design of the highway culverts and bridges that followed.

### **7.1 Stone Slab Bridges and Culverts**

A stone box culvert consists of a stone slab, or series of slabs in parallel, spanning between two stone channel walls. Structurally, the slab functions as a simple beam, one of the oldest forms of human building. In architecture, a beam supported at each end to create a roof or opening in a wall is known as post and lintel, post and beam, or column and beam construction. Surviving stone examples that have been accurately dated are usually of roughly shaped stone, Stonehenge in England, built 3800 years ago, being perhaps the best-known example. The Greeks elevated column and beam construction to an art form, exemplified by the Parthenon, built c. 448 BC.

The idea of using stone slabs resting on stone walls (abutments) and piers to bridge a watercourse must also be many thousands of years old, but surviving examples are difficult to date. Where slabs of stone were readily available, primitive man undoubtedly muscled them into a resting place atop other stones to bridge small streams. The earliest of England's famous



"clapper" bridges are believed to date to the late Bronze Age. They consist of massive granite slabs resting on piers of roughly stacked stones. The name clapper derives from the Anglo-Saxon word 'cleaca' meaning, "bridging the stepping stones." The most famous is Post Bridge in Dartmoor, England built about 1000 BC which has four granite slabs 15' long and 6' wide, each weighing in excess of eight tons.<sup>13</sup>

The Anping Bridge in the Fujian (also spelled Fukien or Fu-Chien) Province of China consists of a series of granite slabs, some as large as 35 feet long and 2.5 feet thick. It dates to about 1000 AD and is over a mile in length overall. A later example by 12<sup>th</sup> century Fujian builders is the Lo-yang Bridge with a single slab span of 70 feet, perhaps the longest stone span ever built.<sup>14</sup>

The English and other early immigrants with stone masonry skills apparently introduced the first stone slab bridges to America. Stonemasons built stone slab bridges intuitively. They assessed the character and strength of the available stone and determined the thickness necessary to span a certain distance on the basis of experience and perhaps limited testing. Determining the safe limits of stone to span openings cannot be precise. It is a natural substance of great variation in composition and imperfections such as hairline cracks can often not be seen. While stone has great strength in compression, it has little tensile strength, and a beam must have great tensile strength in its lower half to span wide openings. Reinforced concrete beams and slabs with lines of steel rods placed near the bottom to resist tensional forces were introduced to bridge building at the end of the 19<sup>th</sup> century and effectively eliminated further use of stone slabs or lintels for large culverts and short span bridges.

## **7.2 Stone Arch Bridges and Culverts**

The Etruscans were the first to put large voussoir arches into common use in building construction, and the Romans who followed them in time were the first to employ the voussoir arch in bridge building. The era of Roman stone arch bridge building spans from about 241 BC to about 200 AD.<sup>15</sup> The Romans used only semi-circular arches, the Pons Palatinus (181 BC) with 80' spans being an early monumental example.<sup>16</sup> The segmental arch, representing only a segment of a circle, has a span greater than its rise and provides a larger opening with less material and labor than a semi-circular arch. Segmental arches occur very rarely in culvert spans less than ten feet, but are fairly commonly found in spans between ten and twenty feet where their use is typically associated with the need for a wide waterway opening in a low embankment.

In Europe, French and English engineers advanced the art and scientific principles of stone arch bridge construction during the 17<sup>th</sup> and 18<sup>th</sup> centuries and built many beautiful long, low arches with spans in excess of 100 feet. In the United States an age of great stone arch railroad bridges began with the advent of the steam railroads. Massive stone viaducts composed of a series of tall semi-circular arches – works of man unrivaled since the days of the Roman Empire – were erected by American railroads beginning in the 1830s.

But the advances in large stone arch bridge technology had little to do with the small arches used for highway culverts and short span bridges – they continued to be designed and built by the rule-of-thumb practice established by masons rather than in accordance with the emerging mathematical theories of arch behavior.

### 7.3 Highway Culverts

The evolution of the stone highway culvert follows the progress of road and highway development. It begins with the early stone arch and post and lintel construction being adapted for bridges and advances through the 19<sup>th</sup> century with the building of improved cart roads and railroads, finally reaching a high degree of efficiency by the end of the century with the advent of mechanized stone quarrying. Upon reaching the pinnacle of their development, the use of stone culverts came to an abrupt end with the introduction of inexpensive reinforced concrete and corrugated steel pipe culverts. In rocky environs like New England, especially New Hampshire where excellent quality granite and able stone masons remained affordable, the building of stone culverts persisted into the early 20<sup>th</sup> century as a practical alternative to the other less permanent types.

The history of stone highway culverts has received little scholarly attention and 19<sup>th</sup> century engineering literature mentions them only in general terms like typical or standard suggesting their features of design should be common knowledge. Historians have apparently ignored them because of their commonness and relative insignificance compared to monumental stone bridges.

According to the Oxford English Dictionary, it was in France about 1770 that the term culvert came into use in connection with canal construction and later with railways, highways, and town-drainage. "It has been conjectured to be a corruption of the French words *couloir*, a waterway, or *coulouère*, a channel, gutter, or any such hollow, along which melted things are to run', or *couler*, to flow. On the other hand some think 'culvert' an English dialect word, taken into technical use at the epoch of canal-making."<sup>17</sup>

Much has been written on the European founders of modern road design, namely the French engineer Pierre-Marie-Jerome Tresaguet who worked in the late 18<sup>th</sup> century, and Thomas Telford and John L. Macadam, both Englishmen, who worked in the early 19<sup>th</sup> century. Although the design principals of all three men largely hinged on the importance of proper road drainage, their writings apparently do not discuss the proper design of culverts.

In New Hampshire in the mid-to-late 18<sup>th</sup> century, early roads known as range roads were laid out in some areas of the interior along straight property lines coinciding with the edges of a range of square or rectangular parcels of land.<sup>18</sup> After the American Revolution newly established state governments encouraged private enterprises to construct toll roads known as turnpikes. The first New Hampshire turnpike corporation was chartered in 1796 and by 1810 fifty turnpikes had been incorporated in the state. The first bridges and culverts along the range roads and turnpikes would have been mostly of timber construction with perhaps the occasional use of dry-laid stone

where conditions warranted it and field and rubble stone were readily available. When the timber structures rotted or were washed out many were undoubtedly replaced with stone.

Early 19<sup>th</sup> century highway culverts of both stone box and stone arch construction have been documented in New Hampshire. An arched opening through a stone causeway was built at High Bridge in New Ipswich in 1819.<sup>19</sup> During the 1830s and 1840s there was a marked increase in the use of split stone and quarried granite for bridge and culvert building in New Hampshire. This trend has been attributed to the introduction of the plug drill and plug-and-feathers method of splitting stone and the need to replace vulnerable wooden bridges with permanent ones of stone.<sup>20</sup>

Beginning in the 1830s, a few arched granite highway bridges were built in southern New Hampshire under the supervision of engineers from major manufacturing centers.<sup>21</sup> In the Contoocook River Valley there was a concentration of small stone arch bridges built beginning about 1835 when a double-arch bridge – the first in New Hampshire – was erected in the town of Henniker. In Hillsborough alone twelve stone arches were built, six of which remain.<sup>22</sup> In Auburn, Rockingham County, a stone box culvert with a span of approximately 8 feet was constructed under Coleman Road about 1844. The culvert was determined eligible for listing in the National Register and documented in 2002 prior to its removal.<sup>23</sup> Another early stone box culvert that is no longer extant was the Dame's Brook Culvert, formerly located on West Milton Road in Farmington. It was an eight-foot culvert with an attributed date of 1857 and like the Coleman Road Culvert consisted of a series of parallel lintels with fill over top.<sup>24</sup>

By the late 19<sup>th</sup> century an increasing number of papers and textbooks were appearing on the subject of road construction and the need for proper drainage.

It is very bad policy to make culverts of wood, unless indeed they are so situated as to be constantly under water; the cost of replacing them after the embankment and road has been built over them is disproportionately great. They should be made of stone, or brick; lately of vitrified stoneware, or cement drain-pipe, oval or egg-shaped, has been used to advantage in their construction.<sup>25</sup>

A point too often neglected in constructing a gravel road is the consideration of the proper size and position of the culverts. Stone culverts must be built of good-sized, well-shaped quarry stone, 6-8" thick, 2 feet wide with parallel beds, laid dry, making walls 2 feet thick. No space in joints not to exceed 1 inch, and exposed stones at ends of culverts to be squared and pitch-faced.<sup>26</sup>

In some localities good stone is plentiful and cheap, and this fact, with perhaps other local considerations, will sometimes make it seem best to reject the use of pipe and to construct a stone culvert. In nearly every case rough rubble masonry will answer every purpose.<sup>27</sup>

During the 1890s the nationwide movement for better roads resulted in a great many papers regarding the importance of drainage in road design and the accompanying need for proper culverts.<sup>28</sup> Progressive states passed road legislation, Massachusetts in 1892 and New York in 1893, that created a county highway system with engineers in each county responsible for road

improvement. New Hampshire would not pass similar legislation until 1905 but beginning in 1897 the New Hampshire Board of Agriculture did begin holding annual "Institutes" on the need for more and better roads. Several papers presented at the 1899 convention covered the methods of road drainage and construction of culverts practiced in New Hampshire.<sup>29</sup>

New Hampshire's State Aid Highway law of 1905 required towns to make annual appropriations for highway improvements and created the post of state highway engineer.<sup>30</sup> In the first year \$80,000 in State Aid went to the towns for widening, reducing steep grades, and constructing permanent culverts, underdrains and side ditches.<sup>31</sup> Newly appointed State Engineer Arthur W. Dean developed detailed specifications for stone culverts (see Section 4.2 below).

As the 20<sup>th</sup> century progressed, the gap between the cost of concrete and pipe culverts compared to more costly stone culverts continued to grow. Some textbooks no longer included any mention of stone as a choice. In New Hampshire where there was a combination of harsh environment, continued availability of cheap quarry stone and conservative highway engineers that favored the tried and true, stone persisted as a material for culvert construction. The figure below shows the New Hampshire Highway Department's use of granite for the walls and floor of a 4-foot box culvert in combination with a reinforced concrete slab span.<sup>32</sup> This design took advantage of the properties of each material: stone is better able to resist the effects of water and ice than concrete; reinforced concrete is strong and predictable in tension.

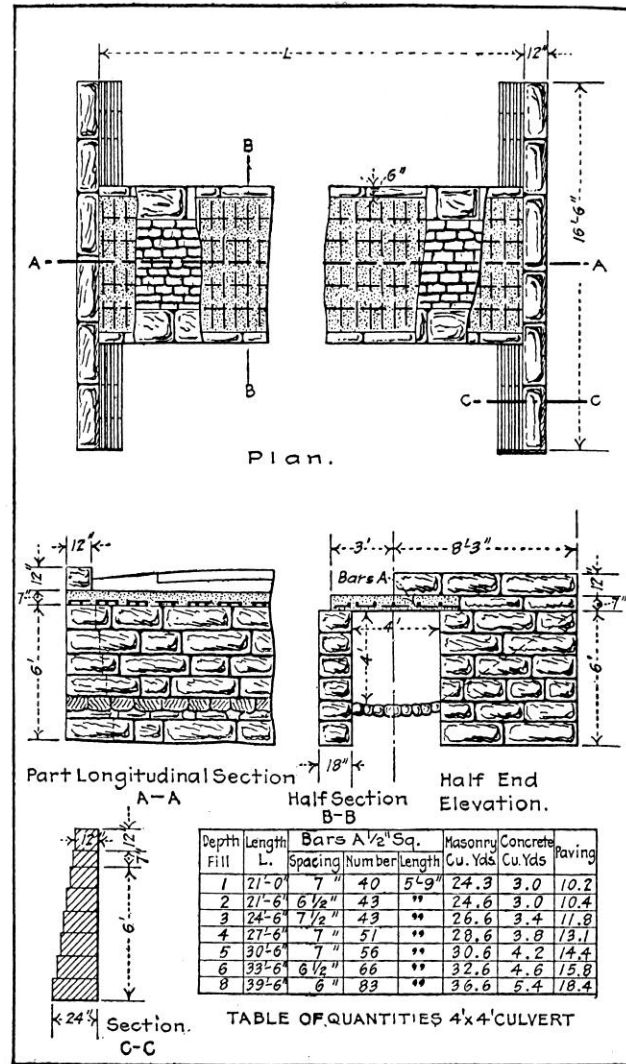


FIG. 64.—Typical masonry culvert. State of New Hampshire.

Figure No. 7: Standard design stone box highway culvert with reinforced concrete span used by the New Hampshire State Highway Department in the early 20<sup>th</sup> century.

## 8.0 NOTES

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- <sup>1</sup> Representatives of the NHDOT Bureau of Environment, NHDOT Bureau of Bridge Design, New Hampshire Division of Historical Resources, and various towns participated in discussions.
- <sup>2</sup> *National Register of Historic Places Multiple Property Documentation Form: Stone Highway Culverts in New Hampshire, 1750 to 1930*. Prepared by Richard M. Casella, Historic Documentation Company, Inc., Portsmouth, RI, for the New Hampshire Department of Transportation, Bureau of Environment, Concord, NH, September 1, 2009. Copies may be obtained by written request to Joyce McKay, Bureau of Environment, NH Dept. of Transportation, 1 Hazen Drive, Concord, NH 03302
- <sup>3</sup> "Proposal and Scope of Work for Statewide Planning and Research Project: Asset Management for Stone Highway Culverts, New Hampshire, Dating to 17<sup>th</sup> to 20<sup>th</sup> Centuries." Prepared by NHDOT by James Garvin, Joyce McKay and Nadine Peterson. February, 2007.
- <sup>4</sup> Oxford English Dictionary, 1989.
- <sup>5</sup> U.S. Department of Transportation, Federal Highway Administration. *Bridge Inspector's Reference Manual*. (2002).
- <sup>6</sup> In the late 19<sup>th</sup> century, masonry work was assigned a classification based on the quality of construction: First-class masonry, Second-class masonry, Third-class masonry, First-class Arch-culvert masonry, Second-class Arch-culvert masonry, and Box-culvert masonry. See discussion in Section 4.6.
- <sup>7</sup> Portland cement was patented in 1824 by Joseph Aspin, an English bricklayer who named it for its resemblance to a high quality quarry stone from Portland, England. It was first used in mortars and concrete in applications where hydraulic characteristics were needed. For more on hydraulic cement mortars see: Frank E. Kidder, *Kidder-Parker Architects' and Builders' Handbook*. (New York: John Wiley & Sons, Inc., 1904):194-195; Baker, *Masonry Construction* 1904, pp. 51-53;
- <sup>8</sup> James L. Garvin, "Notes on the Origins of Arched Stone Bridges in the Contoocook River Valley of New Hampshire," (November 20, 2004). Manuscript on file at New Hampshire Division of Historical Resources, Concord.
- <sup>9</sup> New Hampshire Historic Property Documentation No. 504, "Coleman Road Culvert, Auburn, NH." July, 2002. On file at New Hampshire Division of Historical Resources, Concord.
- <sup>10</sup> Charles C. Brown, "Gravel Roads," *Engineering News and American Contract Journal* 15 (April 24, 1886): 262.
- <sup>11</sup> The papers presented at the Board of Agriculture's 1899 Institute on Good Roads are published in: N.J. Bacholder, *Report of the New Hampshire Board of Agriculture from October 1, 1898 to January 1, 1901*. (Manchester, NH: Arthur E. Clarke Public Printer, 1901). Howe's paper, cited in the text, is on pages 481-488.
- <sup>12</sup> Webb, 1900, p. 205.
- <sup>13</sup> Eric deMare'. *The Bridges of Britain*. (London: B.T. Batsford Ltd., 1954): 36-37.
- <sup>14</sup> *Ibid.*, p. 36.
- <sup>15</sup> Jean-Pierre Adam, *Roman Building Materials and Techniques*. Translated by Anthony Mathews. (Bloomington, Indiana: Indiana University Press, 1994): 162.
- <sup>16</sup> Conde B. McCullough, and Edward S. Thayer, *Elastic Arch Bridges*. (New York: John Wiley and Sons, Inc., 1931): 6.
- <sup>17</sup> Oxford English Dictionary, 1989.
- <sup>18</sup> James L. Garvin, "Range Roads." In *Old Stone Wall* (Newsletter of the New Hampshire Division of Historical Resources, Concord, NH), Spring 2002.
- <sup>19</sup> James L. Garvin, "Notes on the Origins of Arched Stone Bridges in the Contoocook River Valley of New Hampshire," (November 20, 2004). Manuscript on file at New Hampshire Division of Historical Resources, Concord.
- <sup>20</sup> *Ibid.*
- <sup>21</sup> *Ibid.*
- <sup>22</sup> The six remaining bridges are: 1. Sawyer Bridge, 2 arches, bypassed beside Route 202; 2. Second Turnpike Bridge or Bridge at Fuller's Tannery, 2 arches separated by causeway, Hillsborough Lower Village; 3. Carr-Jones Bridge over Beard's Brook, 2 arches; 4. Gleason Falls Bridge over Beard's Brook, one arch; 5. Bridge north of Gleason Falls over Beard's Brook, 2 arches separated by long causeway; 6. Tuttle (?) Bridge, now underwater off Breezy Point, Jackman Reservoir or Franklin Pierce Lake. The bridge at Hillsborough Bridge, built in 1893 by Ward and Douglass of Barre, Vermont, is a mortared bridge and is not included among the dry-laid spans discussed here.



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- <sup>23</sup> New Hampshire Historic Property Documentation No. 504, "Coleman Road Culvert, Auburn, NH." July, 2002. On file at New Hampshire Division of Historical Resources, Concord.
- <sup>24</sup> New Hampshire Individual Property Inventory Form FAR0015, "Dame's Brook Culvert, Farmington, NH." September, 1999. On file at New Hampshire Division of Historical Resources, Concord.
- <sup>25</sup> Clemens Herschel, "The Science of Road Making," *Engineering News* 4 (June 2, 1877): 148.
- <sup>26</sup> Charles C. Brown, "Gravel Roads," *Engineering News and American Contract Journal* 15 (April 24, 1886): 262.
- <sup>27</sup> Ontario Legislative Assembly. "Stone Culverts," Sessional Papers (No. 36) Legislature of the Province of Ontario, (1894): 51.
- <sup>28</sup> In 1890 C. Frank Allen, a member of the Boston Society of Civil Engineers published a comprehensive paper entitled "Roads and Road Building" that elicited wide ranging discussion on the specifics of the road bed design but little comment on culverts. The California Roads Convention of 1892 included numerous papers on the need for good roads including one by W.E. McClintock of the Massachusetts Highway Commission. See "Good Country Roads" *Engineering Record* 29 (December 23, 1893): 58.
- <sup>29</sup> The papers presented at the Board of Agriculture's 1899 Institute on Good Roads are published in: N.J. Bacholder, *Report of the New Hampshire Board of Agriculture from October 1, 1898 to January 1, 1901*. (Manchester, NH: Arthur E. Clarke Public Printer, 1901). A paper by Willaim B. of Concord (pp. 481-488) discusses cuverts in some detail. See the *National Register of Historic Places Multiple Property Documentation Form: Stone Highway Culverts in New Hampshire, 1750 to 1930* for a more extensive discussion.
- <sup>30</sup> See: Chapter 35, Laws of 1905. Also see: James L. Garvin. *New Hampshire Good Roads Projects, 1904-2004*. Manuscript on file at New Hampshire Division of Historical Resources, dated July 23, 2003.
- <sup>31</sup> State of New Hampshire. *First Biennial Report of the Governor and Council and of the State Engineer Relative to Highway Improvement*. Concord: State of New Hampshire, 1906:11,19.
- <sup>32</sup> Harger and Bonney, *Handbook for Highway Engineering*, 1927, p. 22.

## 9.0 BIBLIOGRAPHY

- Adams, W. T. "Line Your Old Culverts and Save Them." *Roads and Streets* 99 (September 1956): 83-84.
- Adam, J. P. *Roman Building Materials & Techniques*. Translated by Anthony Mathews. Bloomington: Indiana Univ. Press, 1994.
- Agg, T.R. *American Rural Highways*. New York: McGraw-Hill Book Company, 1920.
- Aitken, T. *Road Making and Maintenance: A Practical Treatise for Engineers....* Philadelphia: J.B. Lippincott Co., 1900.
- Allen, Frank C. "Roads and Road Building." *Journal of the Association of Engineering Societies* 10 (May 1891): 223-258.
- American Association for Highway Improvement. *The Official Good Road Year Book of the United States*. Washington, DC: Published by author, 1912.
- American Concrete Pipe Association and John G. Hendrickson. *Hydraulics of Culverts*. 1964.
- American Railway Bridge and Building Association. "Culverts." *Proceedings of the Eight Annual Convention of the American Railway Bridge and Building Association* 8 (1898): 88-89.
- "A Non-Obstructible Water-Way." *Engineering News* 21 (June 22, 1889): 564.
- "Arch Culvert Plans, Canadian Pacific Railway." *Engineering News* 21 (April 6, 1889): 302.
- Armco Drainage Products Association. *Handbook of Culvert and Drainage Practice*. Middletown, Ohio: Armco Drainage Products Association, 1937.
- Bacholder, N.J. *Report of the [New Hampshire] Board of Agriculture from October 1, 1898 to January 1, 1901*. Manchester, NH: Arthur E. Clarke Public Printer, 1901.
- Baker, Ira O. *A Practical Treatise on Masonry Construction*. New York: John Wiley & Sons, 1899.
- . *A Treatise on Roads and Pavements*. New York: John Wiley & Sons, 1910.
- Bateman, John H. *Introduction to Highway Engineering*. New York: John Wiley and Sons, Inc., 1947.
- Berg, Walter S. *American Railway Bridges and Buildings, Official Reports, Association of Railway Superintendents, Bridge and Buildings*. (Chicago: B.S. Wasson & Company, 1898.)
- Blanchard, Arthur H. and Henry B. Drowne. *Text-Book on Highway Engineering*. New York: John Wiley and Sons, Inc., 1914.
- Blanchard, Arthur H. *Elements of Highway Engineering*. New York: John Wiley and Sons, Inc., 1915.
- Brown, Charles C. "Gravel Roads" *Engineering News and American Contract Journal* 15 (April 24, 1886):261-263.
- Buel, Albert W. "The Merits and Permanency of the Masonry Arch Bridge." *Engineering Magazine*, 17 (April, 1899):23- 44.
- Byrne, Austin T. *A Treatise on Highway Construction*. New York: John Wiley and Sons, 1896.
- Cain, William. "The Stone Arch." *Engineering News* (March 15, 1894): 214-215.
- Chamier, George, "Capacities for Culverts and Flood Discharge." *Engineering News* 41 (January 26, 1899): 61-62.
- Concord, City of. *Forty-third Annual Report of the Receipts and Expenditures of the City of Concord for the Year Ending December 31, 1895*. Concord, NH: Ira C. Evans Printer, 1896.
- Condit, Carl W. *American Building Art, The Nineteenth Century*. New York: Oxford University Press, 1960.
- "Cost of Masonry in Detail." *Engineering News* 20 (December 8, 1888): 446.
- Cramb, Ian. *The Art of the Stonemason*. White Hall, VA:Betterway Books, 1992.

- "Culvert Formulas." *Engineering News* 23 (January 11 1890): 37.
- Dawson, W. B. "Masonry Arches for Railway Purposes." *Canadian Society of Civil Engineers Trans* 1 (May 31, 1888): 210-229.
- deMare', Eric. *The Bridges of Britain*. London: B.T. Batsford Ltd., 1954.
- Elliott, C.G. "Road Improvement." *Engineering News and American Contract Journal* 15 (March 13, 1886): 161-163.
- "The Revival of the Stone Arch." *Engineer*, (June 21, 1901): 638-639.
- Finch, James Kip. "Transportation and Construction, 1300-1800." In *Technology in Western Civilization, Volume I*. Melvin Kranzberg and Carroll W. Pursell, Jr., Editors. New York: Oxford University Press, 1967.
- Folsom, Charles W. "Railroad Washouts." *Journal of the Association of Engineering Societies* 5 (1885-1886): 304-308.
- Forbes, R. J. "Roads to c.1900." In *A History of Technology, Volume IV*. Charles Singer, E. J. Holmyard, A. R. Hall and T. I. Williams, Editors. New York: Oxford University Press, 1958, pp. 520-547.
- Franklin [N.H.]. *Annual Report of the Municipal Government of the City of Franklin for the Financial Year 1915*. Franklin, NH: Published by P. F. Fitzpatrick & Son, 1916.
- Gage, Mary and James. *The Art of Splitting Stone*. Amesbury, MA: Powwow River Books, 2005.
- Garvin, James L. "Granite Splitting Tools and Techniques." (no date). Manuscript on file at New Hampshire Division of Historical Resources, Concord.
- . "Notes on the Origins of Arched Stone Bridges in the Contoocook River Valley of New Hampshire." (November 20, 2004). Manuscript on file at New Hampshire Division of Historical Resources, Concord.
- . "Range Roads." *Old Stone Wall* (Spring 2002). [Newsletter of the New Hampshire Division of Historical Resources].
- . *New Hampshire Good Roads Projects, 1904-2004*. (July 23, 2003). Manuscript on file at New Hampshire Division of Historical Resources, Concord.
- Gift, Amy, and Bill Smith. *Culvert Study Report*. Jefferson City, Mo: Dept. of Transportation, Research, Development and Technology, 2000.
- Gillette, Halbert P. *Handbook of Cost Data for Contractors and Engineers*. New York: Myron C. Clark Publishing Co., 1910.
- Goldthwait, J. W. "Old Range Roads in New Hampshire." *New Hampshire Highways* (December, 1930): 1-7.
- . "Six Old New Hampshire Turnpikes." *New Hampshire Highways* (July, 1932): 4-6.
- "Good Country Roads." *Engineering Record* 29 (December 23, 1893): 58.
- Graham, Frank D. *Audels Masons and Builders Guide No. 4*. New York: Theo Audel and Co. 1924.
- Greene, Francis V. "Roads and Road-Making." *Harpers Weekly* 33 (August 10, 1889): 633-636.
- Harger, Wilson G. *The Location, Grading and Drainage of Highways*. New York: McGraw-Hill Book Company, 1921.
- Harger, Wilson G. and Edmund A. Bonney. *Handbook for Highway Engineers*. New York: McGraw-Hill Book Co., 1927.
- Haupt, Lewis M. *Essays on Roadmaking and Maintenance and Road Laws*. Philadelphia: Univ. of Pennsylvania Press, 1891.
- Herschel, Clemens. "The Science of Road Making." *Engineering News* 4 (June 2, 1877): 148+.
- Hill, E.D. "Arch Culvert and Steam Shovel Work, I. D. & S. Railway." *Engineering News* 21 (June 8, 1889): 523-525.
- Hirst, A.R. "Bridges and Culverts for Country Roads." *Engineering News* 70 (October 9, 1913): 729-730.

Hollister, Soloman C. "Culverts." in *Reinforced Concrete and Masonry Structures*. G.A. Hool and W.S. Kinne, Editors. New York: McGraw-Hill Book Co., 1924.

"How to Determine Size and Capacity of Openings for Waterways." *Engineering News* 38 (October 21, 1897): 267.

International Correspondence School Staff. *Culverts and Tunnels*. Scranton: International Textbook Company, 1940.

Johnson, Dave, and John Zollars. *Culvert Renewal Final Report*. Maplewood, MN: Physical Research Section, Office of Materials and Research, Minnesota Dept. of Transportation, 1992.

Johnson, E. R. "The Improvement of Country Roads in Massachusetts and New York." *Annals of the American Academy of Political and Social Sciences* 5 (September 1894): 269-271.

Jones, Rudard A. "The Origin of the Voussoir Arch." *Civil Engineering*, April, 1941, pp. 259-260.

Kidder, Frank E. *Kidder-Parker Architects' and Builders' Handbook*. New York: John Wiley & Sons, Inc., 1904

Low, Emile. "Maximum Spans of Box Culverts." *Engineering News and American Contract Journal* 14 (July 25, 1885): 55.

Luten, Daniel B. "The Design of Arch Culverts." *Engineering News* 45 (June 13, 1901): 435.

McCullough, Conde B. and Edward S. Thayer. *Elastic Arch Bridges*. New York: John Wiley and Sons, Inc., 1931

McRaven, Charles. *Building With Stone*. Pownal, VT: Storey Books, 1989.

"Minor Structures; Canadian Pacific Railway." *Engineering News* 20 (December 29, 1888): 500-501.

New Hampshire Railroad Commissioners. *Fifty-third Annual Report of the Railroad Commissioners of the State of New Hampshire, 1897*. Manchester, NH: Arthur E. Clarke Public Printer, 1898.

New Hampshire Department of Transportation. "Proposal and Scope of Work for Statewide Planning and Research Project: Asset Management for Stone Highway Culverts, New Hampshire, Dating to 17<sup>th</sup> to 20<sup>th</sup> Centuries." Prepared by NHDOT by James Garvin, Joyce McKay and Nadine Peterson, February, 2007.

Ontario Legislative Assembly. "Stone Culverts." *Sessional Papers (No. 36) Legislature of the Province of Ontario* (1894): 51-52.

Page, Logan Waller. *Roads, Paths and Bridges*. New York: Sturgis & Walton, 1912.

Ruddock, Ted. *Arch Bridges and Their Builders, 1735-1835*. London: Cambridge University Press, 1979.

Spaulding, Frederick P. *A Text Book of Roads and Pavements*. New York: John Wiley and Sons, 1902.

"Standard Pipe Culverts; Kansas City & Omaha R.R." *Engineering News* 18 (October 22, 1887): 300.

"Standard Wooden Box Culverts and Cattleguards." *Engineering News* 21 (January 12, 1889): 26.

State of New Hampshire. *First Biennial Report of the Governor and Council and of the State Engineer Relative to Highway Improvement*. Concord: State of New Hampshire, 1906.

Suplee, Henry, H. "The Strength and Failure of Masonry Arches." *Engineering Magazine* 13 (September 1897): 861-871.

Swain, G. F. "The Stability and Strength of the Stone Arch." *Van Nostrand's Engineering Magazine* 23 (October 1880): 265-276.

Swift, A.J. "Some Methods of Meeting the Ordinary Requirements of Railroad Maintenance." *Engineering News* 25 (May 30, 1891): 522-524; (June 6, 1891): 548-549.

"The Revival of the Stone Arch." *Engineer* (June 21, 1901): 638-639.

Thornton, C. I. *Culvert Pipe Liner Guide and Specifications*. Lakewood CO.: U.S. Federal Highway Administration Central Federal Lands Highway Division, 2005.

- Trautwine, John C. *The civil engineer's pocket-book, of mensuration, trigonometry, surveying, hydraulics ... etc.* New York, J. Wiley & Sons, 1885.
- Turner-Fairbank Highway Research Center. *Culvert Repair Practices Manual*. McLean, VA: U.S. Dept. of Transportation, Federal Highway Administration, Research and Development, Turner-Fairbank Highway Research Center, 1995.
- Turner, Roland; Goulden, Steven L., Editors. *Great Engineers and Pioneers in Technology*. New York: St. Martin=s Press, 1981.
- Tyrrell, H. G. *Concrete Bridges and Culverts, For Both Railroads and Highways*. Chicago: The M.C. Clark Pub. Co., 1909.
- Tyrell, Henry Gratten. *Bridge Engineering. A Brief History...* Evanston, Illinois. Published by Author, 1911.
- U.S. Department of Transportation, Federal Highway Administration. *Bridge Inspector's Reference Manual*. (2002).
- Webb, Walter L. *Railroad Construction, Theory and Practice*. New York: John Wiley and Sons, 1900.
- Whitman, E. A. "Drainage of Country Roads." *Journal of the Association of Engineering Societies* 18 (April 1897): 278-283.
- Whittle, Charles L. "Ancient and Modern Highways." *New England Magazine* 17 (February 1898): 749-765.
- Whitney, Charles S. *Bridges: A Study in Their Art, Science, and Evolution*. New York: W. E. Rudge, 1929.
- Williams, Clement C. *Design of Masonry Structures and Foundations*. New York: McGraw-Hill Book Company, Inc., 1922.
- Wood, Frederick J. *The Turnpikes of New England*. Boston: Marshall Jones Company, 1919.

## 10.0 PREPARERS

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