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Stackpole Bridge: Rebuilding a Connection to the Past

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STACKPOLE BRIDGE: REBUILDING A CONNECTION TO THE PAST

by

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ABSTRACT

Many historical structures are still appreciated today for their beauty, the skill required to construct them, and how they preserve and complement the natural environment. Aqueducts, buildings, and bridges constructed by ancient civilizations are excellent examples of some of the stone structures that remain standing today that offer tangible ties to the past. Many of these structures foster local pride, create a strong sense of community, and provide economic benefits beyond their physical function.

Some of the most durable historical structures are stone arch bridges, which have been used worldwide for centuries for transportation over terrain that would otherwise be difficult to navigate. Such bridges used materials sourced locally and improved the lives of people in the region. Though not commonly found today in the United States, these bridges are an important link to civil engineering excellence and time-tested craftsmanship.

As communities grow and develop, they often wrestle with the desire to maintain historic structures or replace them in the name of progress. This was the situation for Stackpole Bridge in southern Maine. This bridge, built in the 1840s, is a dry-laid stone arch bridge on Simpson Road in Saco that spans Stackpole Creek. As a masonry bridge, it shows the craftsmanship and skill that is no longer common in many parts of the world. Throughout its service life, the bridge suffered damage from numerous floods from the nearby Saco River and was eventually rehabilitated in 2016, thus preserving its historical significance.

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Historic Value

The National Park Service (NPS) uses the term "historic preservation" to encompass the preservation of a structure as it is, the rehabilitation of historical features of a structure that is deteriorated, the restoration of historic features in structures that have been altered, and the reconstruction of structures to be almost exactly as they existed originally. The benefits of historic preservation efforts include the efficient use of existing resources, the preservation of traditional and skilled methods of workmanship, the addition of character and charm to a community, and the potential to attract further investment in the area (Rabinowitz).

Preserving or rehabilitating historic structures is an efficient use of resources because the existing materials or footprint of the structure can be reused, thus reducing waste and increasing sustainability. Rehabilitation efforts also preserve the old methods of craftsmanship and workmanship that have become less common over the last century. The character and details of rehabilitated structures emphasize the uniqueness of the structure and its community. Moreover, these improvements often lead to further investment in tourism and other business developments which help the community in the long term.

Structures that are preserved can fit into a wide array of categories. A historic structure as defined by the NPS is "a constructed work . . . consciously created to serve some human activity" ("NPS Policy 28: Cultural Resource Management"). This definition encompasses many different types of structures including bridges, buildings, dams, and canals. The National Register of Historic Places generally considers a historic structure to be one that was built about 50 years prior to the present date ("How to List a Property"). It is important to note that though structures that are more than 50 years old are considered historic, only some of these structures typically have significance to local history. These are the structures that are typically rehabilitated or preserved by towns or individuals.

Historic Arch Structures

Stone structures have existed for centuries around the world. They connect us to the past, which is seen through the countless lasting stone structures built by great civilizations throughout history (The Editors of Encyclopedia Britannica). In fact, remnants of stone structures are often all that is left of past great civilizations that have fallen. The ancient structures that are shaped with arches lend themselves to being more durable since they have an efficient use of material.

The most notable and well-known instances of stone arches from great civilizations come from the ancient Roman period. Structures like aqueducts, bridges, and buildings, such as the Colosseum (see Figure 1) and Pont Du Gard (see Figure 2), utilize various arch shapes in their designs. The Colosseum was a center of entertainment for the population of Rome where gladiatorial games and reenactments were held. This structure utilized the keyhole-shaped vaulted arch, also referred to as the Roman arch, that is characteristic of Roman architecture.

Figure 1*. The Colosseum (Design Pics Inc.)*

The Pont Du Gard was built in the first century AD to bring clean water to Nîmes, a city in southern France which was ruled by the Roman empire at the time (UNESCO World Heritage Centre). This structure used two levels of stacked pure compression arches, and small arches across the very top that carried water. Structures like these were incredibly valuable to the vast Roman empire and were designed and constructed for reliability and durability.

Figure 2*. Pont Du Gard (Gallas)*

Another great civilization that employed arches was ancient Greece. Although arches were not as predominant as they were in ancient Roman architecture, arches can still be found in structures built by the Greeks. One such structure is the Stadium Entrance in Olympia (see Figure 3), constructed in the late third century BC, making it over 2000 years old. This is where athletes competing in the ancient Greek Olympics entered the stadium for the games (Cartwright).

Figure 3*. Stadium Entrance in Olympia, Greece (Cartwright)*

One of the oldest stone arch structures that still remains in use today is the Arkadiko Bridge in Greece (see Figure 4), which dates to 1300 BC, making it over 3,000 years old ("This Bronze Age Highway"). This bridge is a primitive stone arch bridge. Its primary function when it was initially constructed was to allow chariots to travel across the rocky slope and water runoff from heavy rain to flow through the arch and along the small riverbed. The Arkadiko Bridge is one bridge that is a part of a Bronze Age highway that connected the Greek cities of Mycenae, Tiryns, Tolo, and Epidaurus ("This Bronze

Age Highway”). Located in a rural area, the bridge was an important link for transportation and trade between villages across the landscape.

Figure 4. *Arkadiko Bridge, Greece (Wikimedia Commons)*

The Arkadiko Bridge is a testament to the lasting nature of both stone as a material and the arch as a design form. This bridge and the aforementioned ancient structures still standing today are tangible examples of the excellence, skill, and practicality of the building methods of ancient civilizations.

Rural Bridges of New England

While its history is not as extensive as ancient Greece or Rome, New England has many long-lasting historic structures that were key parts of the region's development. For most of its history, New England has been a primarily rural region, comprised of small towns that support industries like farming, logging, and manufacturing. Rural areas are defined by the Census Bureau as any population, housing, or territory not in an urban area (“What Is Rural?”). The census bureau also states that rural areas shall have a population density of less than 1,000 people per square mile ("The Urban and Rural Classifications"). As a rural area, New England is divided by many rivers that require bridges to support human interaction and efficient economic development through trade and commerce between towns.

Two of the major bridge types historically used in rural areas of New England are stone arch and timber bridges. Stone and timber are materials that are readily available in rural areas and can last for significant periods of time, creating reliable transport routes. Timber bridges typically do not last as long as stone bridges, but they are easier to build, and tend to have materials that can be sourced in the vicinity of the project site.

***Figure 5**. Babb's Bridge, Maine (Maine Department of Transportation)*

One timber bridge type that is characteristic of New England is the wooden covered bridge, which became increasingly popular in the nineteenth century (see Figure 5). Covered bridges were widely used at this time, since timber was available in the region and was relatively inexpensive for bridge construction. Timber is much lighter than stone or iron, and easier to cut and transport to a project site. Timber also possesses considerable material strength, meaning that it can withstand the loading conditions required of a bridge, thus making it suitable for bridge construction. However, wood is highly susceptible to damage and deterioration from the elements. The roof of a wooden covered bridge acts as a shield for the trusses and roof deck to prevent damage and rot from rain and snow (Bustamante Engineers Staff). Therefore, covering timber bridges allows them to have a longer lifespan. However, timber bridges are vulnerable to vandalism and destruction due to the flammable nature of wood. They are also susceptible to flood damage due to the light nature of wooden structures, which are often partially washed out during extreme flood events. Around one thousand covered bridges were constructed in New England in the nineteenth and twentieth centuries, but only around 200 of these covered bridges remain today (Bills).

Since timber bridges are susceptible to weathering, vandalism, and flood failures, stone arch bridges can be a more suitable bridge alternative. Stone arch bridges have been used throughout New England for centuries. Many of the bridges that still stand today were built between the mid-eighteenth century and mid-nineteenth century. The stones used in bridge construction are typically from a quarry local to the project site. Masons, craftsmen, and builders from the towns nearby would traditionally be the ones to construct the structure, which could last for over one hundred years.

***Figure 6**. Gleason Falls Bridge, Hillsborough, New Hampshire (Salge)*

An example of a stone arch bridge in New England is Gleason Falls Bridge (see Figure 6), built circa 1830 (American Society of Civil Engineers). This bridge was built over rocky ledges and a modest waterfall. Though the impetus for this bridge's construction is not specified, it serves the practical purpose of allowing people to cross over the turbulent waterfall and treacherous ledge safely. Gleason Falls Bridge also frames the picturesque and reflective scene of a stone arch bridge, waterfall, and forest. It is important to consider the aesthetics of structures like the Gleason Falls Bridge so that they can visually harmonize with their surroundings and complement the natural landscape.

FORM AND FUNCTION

Aesthetics of an Arch Bridge

Arches create an elegant, continuous shape that is softer and more pleasing to the eye than a simple post and lintel rectangular shape. While being aesthetically pleasing, the arch form also creates a structure that is strong and enduring and has the capability to cross large distances and create open spaces, all while saving materials.

It is unusual to find timber arch bridges, but one can be observed in the Kintaikyo Bridge in Iwakuni City, Japan (see Figure 7). This arch bridge for pedestrians is a combination of stone and timber that was originally built in 1673 and extensively rehabilitated in 1953 after a severe typhoon struck the area (Iwakuni City Industry Promotion Department). This bridge blends seamlessly with the natural landscape and though it is a man-made structure, it almost functions like a part of the landscape. A unique feature of this bridge is the walkway, which is not flat. Instead, it mimics the surrounding hills by following the shape of the arch, minimizing the amount of material used for construction.

***Figure** 7. Kintaikyo Bridge, Iwakuni City, Japan (GaijinPot Travel)*

Stone arch bridges are more common than timber arch bridges. Stone is a primal, unique, and raw material. It anchors the structure to nature and tethers it to the local natural landscape. Stone used within a structure can also be a mark of the local region since each region has its own native rocks. It is often a sustainable resource because it is typically quarried in the vicinity of the project site. Stone harmonizes with the surrounding landscape, holds a significant connection to historical structures, and creates a timeless look. It evokes a sense of grandeur and durability that connects it to the impressive historical structures of past and present civilizations. Stone is a natural material that is easily and aesthetically combined with other materials for assorted designs. Each stone is different and offers a variety of options for whatever aesthetic look suits the structure and its location.

Figure 8. *Twizel Bridge (Hawkins)*

Twizel Bridge (see Figure 8), located in England, is a shallow stone arch bridge built during the early sixteenth century (Co-Curate). It is a bridge with a high round arch and a single 90-foot span, that was constructed from small stones and arches serenely over the River Till. This bridge was important to the area because it provided a dry crossing over the River Till and aided English troops in battles against Scottish troops (National Transport Trust). Twizel Bridge is a good example of a stone bridge that was created for practical purposes, yet also serves as a beautiful physical link over a geological feature.

Societal Impact of Bridges in Rural Areas

In the United States, approximately 97% of the land mass consists of rural regions ("Rural Roads and Bridges: Why They're Important"). Bridges have been used widely to connect rural communities to one another and to larger towns and cities across the world throughout history. In the past, bridges provided a wider range of job options to local residents in mills or factories, as well as the opportunity to trade goods and services with a larger population of people.

Bridges are a crucial component of the transportation system, ensuring the economic and social links needed to survive in these areas. Geological features like ravines and streams can make it difficult for local residents to interact, gather, travel, and trade. By building bridges, rural communities can share the skills and talents of their residents to create thriving and connected communities. This connection allows for trade and commerce, job availability within various industries, and the potential for tourism. Bridges also provide a local structural landmark that fosters pride within the community.

As the world has grown increasingly connected over the past century, trade and commerce between places that span far distances has risen. This increases the need for reliable transportation infrastructure, making bridges essential for rural communities' economic development. One potential economic impact from historical bridges in rural areas is tourism. Today, visitors are often drawn to rural areas for attractions like farms, outdoor recreation, and exploration of historical sites. Historical bridges and other structures that are preserved and well-maintained can entice visitors to learn about the local history of the town, increasing the potential for rural tourism and economic growth.

The aesthetics of a bridge affect how people in the area feel about their region and the pride they have in their community. Furthermore, infrastructure that is in poor, deteriorated condition can cause a sense of failure or embarrassment for a community, especially when many people travel through it and perceive the deterioration as a reflection of the community. Therefore, bridge maintenance is imperative so that the community pride can be fostered. Thus, bridges are an impactful part of economic stability, allowing rural communities to flourish.

Sustainability

Bridge materials and building techniques have become more technologically advanced over time, making it easier to build bridges across terrain that would otherwise be more difficult to traverse. This allows for shorter routes between places and more efficient travel for individuals as they conduct business and visit family and friends. The advancement in strength and efficiency of new materials has reduced the use of some natural and sustainable materials that have commonly been used in construction in the past.

Sustainability is "the use of natural products and energy in a way that does not harm the environment" (Oxford Learner's Dictionary). When designing a building or bridge, engineers should thoughtfully consider how sustainability can be incorporated in the selection of building materials. Another important design choice is the proximity of the material's origin to the actual project site. It will likely decrease costs if the building materials are from local sources. If that is not the case, there is still value in choosing local materials since the region of the project can be reflected in the structure once it is constructed.

One example of a sustainable material that has been used historically in New England is granite. Granite is an excellent choice of building material to use in the construction of stone arch bridges because it is able to resist the negative effects from freeze-thaw cycles. It is also less susceptible to erosion and weathering ("The Choice of Stone for Stone Arch Bridges"). Granite is a good example of a building material that can be used to reflect the geology of the region around a project site if it is quarried nearby.

The durability of the material is an important sustainability consideration. It is better to spend more money now on a quality, durable material and have it last for a long period of time, than to choose a lower quality material that is less expensive but will have to be replaced multiple times over the course of the structure's life. Historically, building materials were sustainable, because they were often natural materials that were sourced locally and could be easily reused for other projects if the structure were no longer needed. These natural materials also have a lack of synthetic chemicals and substances that can be found in materials like paint and asbestos, which can cause harm to the builders and users of the structure, as well as the environment (National Center for Healthy Housing). This is one reason why masonry arch bridges are such long-standing, well-loved structures that are used around the world.

ENGINEERING OF MASONRY ARCH BRIDGES

Arch Components

Arch bridges are compression structures where the downward force of the structure keeps all the elements securely in place. When the arch is a typical semicircle shape, the load acts on the bridge foundation with both a horizontal and vertical component. When the arch is keyhole-shaped with vertical walls and a semicircle arch on top, the load acts the same way as for a semicircle arch, but it is then transferred to the walls and into the foundation.

Stone arches follow a specific element nomenclature. The interior of the arch shape is called the intrados, while the exterior is called the extrados. Intrados and extrados come from the Latin *intra*, meaning "within" and *extra*, meaning "outside" and the French *dos*, meaning "back" (Merriam Webster Dictionary). The stone blocks that form the arch are called voussoirs. The central voussoir is referred to as the keystone of the arch and is typically the last stone placed in the arch. The springline is the distance between the bottom abutments of the arch, and is also referred to as the span of the arch. The apex is the center point at the top of the arch that defines the rise of the arch, or maximum opening height (Florida Department of Transportation). The opening of the springline and the rise of the arch constitutes the hydraulic opening, which dictates the river's depth and speed as it passes through the bridge.

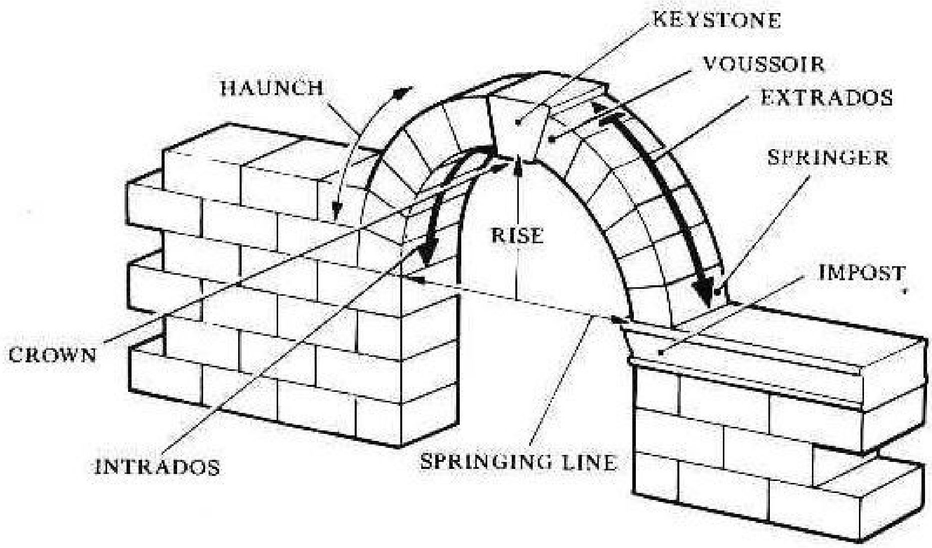

Figure 9. *Components of arch (Spodek)*

Design

The downward force of the bridge material, also referred to as self-weight, forces the voussoirs together in compression. This means that forces are pushing against the members of the arch and compressing them together, instead of pulling them apart or making them behave in tension. This is what makes arch structures stable and efficient. If loads are applied symmetrically along the springline, the arch is in pure compression. If the loads are not applied symmetrically along the springline, parts of the arch could be in tension if the self-weight of the structure is not significant. However, this is rarely the case for old stone arch bridges since they were constructed with heavy materials and small hydraulic openings, making them behave as pure compression structures.

The maximum probable structural load that a bridge experiences has increased over time. Pedestrian traffic, horses, carriages, and carts were the loads that bridges endured for centuries. These are examples of live loads. Live loads are loads that move over a structure and are not static. There has historically been no set standard for the live load that a bridge needed to be able to carry. However, the invention of the automobile paved the way for the innovation of vehicles to serve a variety of needs and to carry significant loads. This caused engineers to develop standards for the heaviest load that bridges can withstand repeatedly. The most recent development for the bridge live load standard was in the early 1990s. The selected American Association of State Highway and Transportation Officials (AASHTO) live load vehicle is the HL-93 truck, with three variable axles and a total load of 72,000 pounds (Kaplan). There is also a tandem load, with two closely spaced axles equivalent to a total load of 50,000 pounds (Kaplan). In addition, there is a lane live load that implies a uniform load of 640 pounds per linear foot over the full span of the bridge (Kaplan). Bridges built today must be designed for a combination of the HL-93 vehicle, the tandem load, or the lane live load. Note that extreme events are the design standard currently, not the usual service loads that were designed for in the past. All states in the U.S. have a maximum legal vehicular weight limit of 80,000 pounds (Kaplan).

Construction Methods

There are two typical ways of constructing stone structures. One way is to use a mortar between stones as they are laid in place, which is referred to as wet-laid. Another option is dry-laid, meaning that the stones are placed on each other without the use of mortar.

Generally, stone arch bridges are built in phases and utilize some sort of formwork to create the arch shape. First, foundations are built up to the level of the base of the arch. Then, temporary formwork in the shape of the arch is placed in the location of the arch for the materials to be laid on during the arch's construction. Stones for the arch are either cut to create a curve to follow the arch shape, or they naturally possess the curve of the arch. The stones for the arch are placed as designed and if wet-laid construction is being used, mortar can be applied before or after the voussoirs are placed. The formwork is then removed, and the remaining construction of the bridge is carried out. This may include building higher walls and filling them in to a certain height to create a road or path for transportation use over the bridge. ("Building a Stone Arch Bridge").

In the United States, masonry arch bridges were typically dry-laid throughout the early nineteenth century (Citto and Woodham). Most mortars that were available during the mid-nineteenth century and prior were made of a rough mixture of some combination of lime, shells, natural cements, clay, or animal hair (Mack and Speweik). However, when lime mortar was used, it often did not hold up well in harsh weather conditions. Thus, dry-laid stones were still preferred for most construction in New England, though lime mortar can occasionally be seen in historic stone arch bridges. In the late nineteenth century and the early twentieth century, hydraulic cements were developed, which began the widespread method of wet-laid stones. Portland cement was imported to the United States in the late nineteenth century, then it began to be manufactured in the U.S for use as an additive in mortar (Mack and Speweik). This allowed mortar to be more reliable and suitable for stone arch bridge construction in the twentieth century.

Although the use and development of mortars improved the performance of some bridges, issues like weathering still provided challenges to bridge durability. Weathering can cause stones and mortars alike to disintegrate, causing some of the arch elements to pull away from the arch barrel of the bridge (Garrity). Additionally, cracks in masonry can form due to considerable tensile strains that occur as a result of heavy, uneven live loads. These cracks can grow and connect with each other if significant weathering occurs, which can contribute to the failure of the structural integrity of a bridge. Weathering is a natural process that occurs simply because the bridge is located outdoors and has constant contact with the elements.

Rehabilitation and Replacement

As some older masonry structures have deteriorated and become overstressed, they have been replaced with reinforced concrete structures, the main reason being that concrete structures are less expensive to build than masonry ones. The material of concrete itself is often cheaper than extracting natural masonry blocks, and the skilled labor to construct the structure costs less than a mason. Though concrete is a more affordable material to use and more versatile material to shape than stone masonry, replacing existing masonry structures with concrete ones is not always the best choice. Masonry's historical character, lack of corrosion, durability, and sustainability balance out the differences between the two materials.

Concrete is a mixture of cement, water, stone aggregate, sand, and admixtures. Reinforced concrete is concrete that contains steel rebar in order to provide additional tensile reinforcement and strength to the material. A similarity between today's stone masonry and reinforced concrete is that Portland cement is a component of the mortar used to lay masonry and is also used in concrete mixes. Masonry has been used as we know it today for thousands of years, whereas reinforced concrete is a fairly modern material.

The first widespread use of reinforced concrete occurred in France and England around 1850 (Herff College of Engineering). French builder, Francois Coignet built several houses from concrete that used iron rods in the floors to contain the walls. Joseph

Monier patented reinforced concrete garden containers around the late 1860s and later patented reinforced beams and columns for roads and railways (Herff College of Engineering). The use of reinforced concrete did not become more regular in construction until after 1879, when German builder G.A. Wayss purchased Monier's patent rights and spread the use of reinforced concrete (Herff College of Engineering).

Both masonry and reinforced concrete have good qualities that make them desirable for use in construction. However, there are some downfalls to these materials to consider. Concrete is prone to cracking, especially when subjected to overloading and to consistent freeze-thaw cycles, as is common during New England winters (The Constructor). The process of mixing the concrete affects its final strength. Masonry structures are costly to rehabilitate because they require specific materials to match the stone that already exists in the structure. Additionally, repair of masonry requires a skilled stonemason to do the work, especially if the structure is historical, which can be challenging to find for some projects. However, masonry structures do not have the potential for rebar corrosion like reinforced concrete structures.

Both building materials can be sustainable. Masonry is sustainable because stones can be reused almost endlessly for a variety of purposes once the structure is no longer needed. Concrete is somewhat less sustainable than masonry, though it can be processed, and parts of the processed concrete can be reused in new concrete mixes.

Though concrete structures are durable and economical to construct, masonry structures have merits that should not be overlooked because of cost savings. Stone masonry structures typically hold significant local history and can garner investments in historic preservation in their communities due to their beauty and uniqueness. In the long term, there can be greater value found in rehabilitating existing historic stone masonry structures than in completely replacing them with more cost-effective concrete structures.

CASE STUDY: STACKPOLE BRIDGE

Site Location

Stackpole Bridge was built in 1848 and is located in southern Maine in the city of Saco (see Figure 10). It is a dry-laid, stone arch bridge spanning Stackpole Creek, with an arch that has a springline opening of seven feet and a rise of 18 feet. The full width of the bridge, including the walls, is approximately 50 feet and it carries two-way traffic.

During the nineteenth century, Saco had a large mill and farming community. This area was rural with a large mass and was home to many small and large farms with fields, crops, and livestock. The area has remained rural, though it does not have the same volume of farms as it once did. There are rolling hills, fields, and patches of forest in the vicinity. Stackpole Bridge was placed in its location over Stackpole Creek because the steep ravine and creek that separates the land was difficult to cross without the aid of some sort of bridge. There was a bridge that preceded Stackpole Bridge, located slightly upstream of the current location of the Stackpole Bridge. Based on the era of construction, this was likely a timber bridge which allowed nearby residents to engage in the local commercial, social, and agricultural activities of the time.

Figure 10. *Stackpole Bridge after rehabilitation*

Societal Aspects

Stackpole Bridge was important for local traffic since the bridge connected the rural community to the downtown commercial area of Saco. In the town center along the Saco River, there were several mills and other industry buildings that functioned as sawmills and textile mills (Hardiman). The raw materials for the mills needed to be transported into the city from the surrounding rural regions. Farming was a primary activity in this area as well, so the bridge linked farmers to downtown Saco, allowing them to transport goods and produce to town easily. The farms around Stackpole Bridge supplied wheat to the local region and to nearby cities, such as Boston, making the bridge critical for local and interstate commerce (*Stackpole Bridge: The Story in Stone*).

The connection of the rural area to the downtown was integral for rural residents of Saco so that they could access the city center efficiently. If the bridge did not exist in its location, residents would only be able to access the center of Saco by traveling seven miles out of the way through the neighboring town of Buxton to reach downtown Saco. Though the journey is easier today with the use of cars than it would be when Stackpole Bridge was originally built, the additional time required to travel the long way to town would likely discourage residents from going as often as they would otherwise. This could impact the rural community's integration with the rest of Saco, the local economy, and other neighborhoods.

Original Construction

In 1847, a bridge warrant was signed by neighbors who lived in the vicinity of Stackpole Bridge. Parts of the previous bridge had washed out many times in the past when Stackpole Creek flooded, prompting city representatives to request a new, more durable bridge to be constructed over the creek. On February 23, 1848, selectmen from the City of Saco requested the city to build a new bridge over Stackpole Creek (*Stackpole Bridge: The Story in Stone*). This bridge was constructed from dry-laid stone, using materials from local sources, such as quarries near the farms in the vicinity. The stones that were used in the construction of Stackpole Bridge were likely quarried, then rolled down the hills to the site of the bridge. Granite blocks from these quarries were used to construct the bridge, which was built on ledge. The arch of the bridge had a seven-foot span and an 18-foot rise to the arch apex, making the arch have a fairly small hydraulic opening (Wathne). It is probable that local workers and craftsmen were the laborers who built the bridge. The bridge cost approximately $700 to $800 in 1848 (*Stackpole Bridge: The Story in Stone*). This is equal to a cost of approximately $26,000 to $30,000 in 2023, assuming a 2.1% inflation rate (Webster).

Since the bridge is located over a creek, it experienced several floods over the years. During those floods, sediment became lodged in between the stones, causing concern among some residents that there was damage to the bridge. In the early twentieth century, mortar was applied to parts of the bridge in an effort to fix some damage to the bridge caused by the flooding.

The aesthetic design of Stackpole Bridge resembles traditional and classical Roman architecture through the use of an arch since it is a stable and well-established type of structure. Additionally, it may have been inspired by stone arch bridges located in Scotland and England, countries from which many people in the area had emigrated. Those familiar with stonework in the area understood that the arch is also a very stable structure. Arches had been used regionally in forts around New England and in buildings in Boston. The use of an arch in the bridge design linked the bridge to a vast historical lineage.

The design of the bridge is intriguing because a wider, semicircle arch would have required less work and material. However, the narrow keyhole-shaped arch that was used acts as a dam with a spillway. This means that the small hydraulic opening of the arch was likely chosen in an effort to slow the flow of water under the bridge, due to the seasonal nature of the creek.

When Stackpole Bridge was initially constructed, it was only for pedestrian, horse, carriage, and wagon use. Vehicles were limited to wagons and carriages that were not as big and could not hold as much weight or cargo as modern cars and trucks can. Even if a cart was carrying a load of wood or stone, the weight of it was a fraction of a modern truck carrying wood or stone today. There were few formal bridge load specifications in the mid-nineteenth century in the United States. However, one engineer in 1846 designed a suspension bridge that carried highway traffic in Pittsburgh, Pennsylvania, and he specified that the bridge should hold the weight of four six-horse teams loaded with 104 bushels of coal and the weight of 100 head of cattle (Kaplan).

Over the past several decades, AASHTO has specified several bridge loading conditions that have increased with each new specification. Today the heaviest individual vehicle weight used for bridge design is the HL-93 truck ("Load Rating Guide"). The significant change in loads on Stackpole Bridge over the course of 160 years contributed to the overstress of the bridge. The bridge was built to last a long time, but it was not built to withstand constant loads that were much heavier than the common methods of transportation at the time of construction.

Events Leading to the Closure

In the early 2000s, the Maine Department of Transportation reviewed Stackpole Bridge because the city thought it needed to be replaced, since there were visible signs of structural distress. The inspection revealed that a temporary steel structure made with columns and girders located underneath the arch would be a satisfactory temporary fix (see Figure 11). However, in 2001 this steel structure caught debris from floodwaters which flowed through the arch and entangled the steel girders, causing problems with the bridge to accelerate (*Stackpole Bridge: The Story in Stone*). Over time, water from floods had flushed any sand or gravel that was in between the stone in the bridge. Additionally, larger live loads from increasingly heavy vehicles crossing the bridge caused the sides to bulge out. In 2002, traffic over the bridge was limited to one lane because the bridge continued to deteriorate (Maine Preservation). Also in 2002, a report from the Maine Department of Transportation recommended that Stackpole Bridge be monitored for maintenance and repair (Graham).

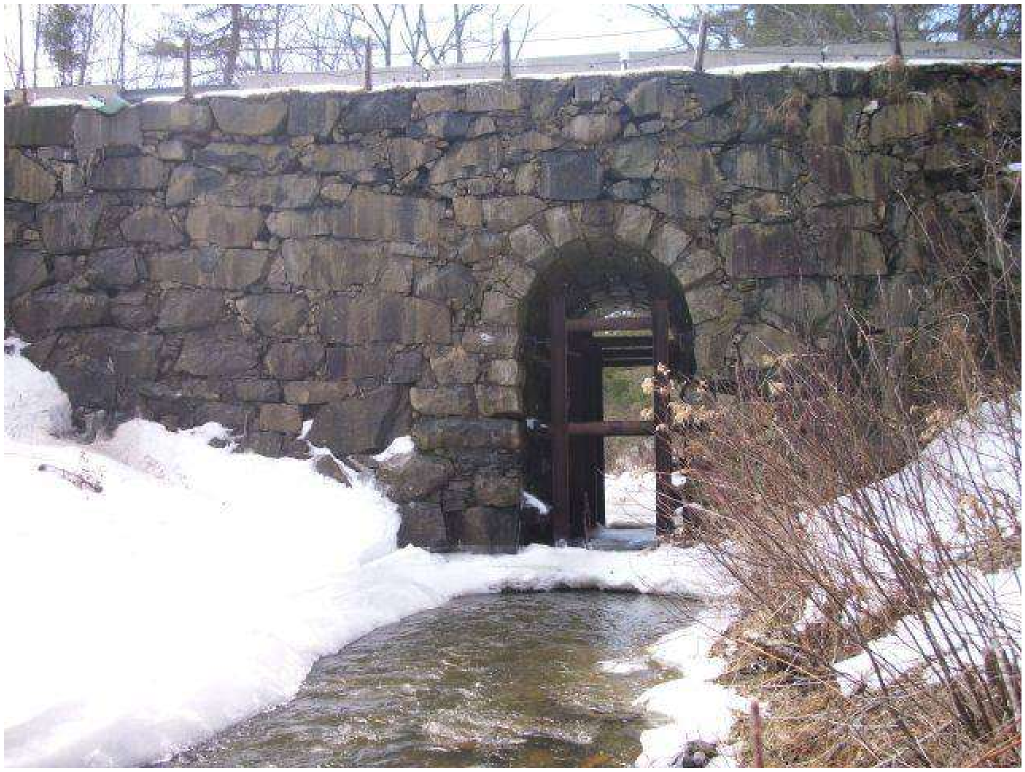

Figure 11*. Steel structure in the arch of Stackpole Bridge prior to rehabilitation (Maine Preservation)*

On Patriot's Day in 2006, there was a severe spring storm which caused significant flooding around Southern Maine. In Stackpole Creek in Saco, the water rose quickly and flooded completely over the arch of the bridge, reaching about two yards below the road level of the bridge. Debris from the floodwaters likely got caught in the cross-bracing of the steel structure. This contributed to the further deterioration of the bridge and caused increasing concern among city officials and the neighboring residents.

The residents who lived near Stackpole Bridge were passionate about the history, significance, and legacy of the bridge and could tell that something would need to be done in order for the bridge to continue functioning properly. In 2007, they created a group called the Friends of Stackpole Bridge to educate people about the bridge and advocate for the bridge to be rehabilitated ("About Friends of Stackpole Bridge").

Figure 12. *Stackpole Bridge when it was closed in 2013 (Maine Preservation)*

In 2013, Stackpole Bridge was fully closed to all traffic due to its severely overstressed condition (see Figure 12). City officials began discussing more seriously what should be done to make the bridge usable and safe. A committee was formed by the Saco Public Works department, Fire Department, and the residents who lived near Stackpole Bridge to discuss the options for the bridge.

<u>Community Debate</u>

The discussions and debate within the community related to the decision of whether to replace or rehabilitate Stackpole Bridge were often tense (*Stackpole Bridge: The Story in Stone)*. Though the people in the debate were opposed to each other, they were all residents of the same city and were fighting for what they believed would be the best option for the citizens of Saco. Tension in the debates formed because each side's stance on the issue was founded based on cost, economic factors, and their own personal convictions regarding the importance of historic structures.

The replacement of the entirety of Stackpole Bridge was an attractive alternative because it would be a fairly low-cost option that would also completely update the bridge so that it met today's standards for structural safety. The people who advocated for the bridge replacement wanted the original bridge to be entirely replaced with a standard precast concrete structure that would act as a box culvert over the stream. This would require full demolition of Stackpole Bridge and diminish the historic and aesthetic value of the bridge. Those who advocated for replacement saw the bridge as a service that was not being provided to the residents, and wanted to remedy the situation as quickly, inexpensively, and safely as possible. This group of people was primarily concerned about the seven-mile detour that residents had to take through Buxton to reach the center of Saco once Stackpole Bridge was closed in 2013. Others who desired replacement simply had no interest in rehabilitating a historic bridge, stating that the bridge was, "just a pile of rocks with no historical significance" (*Stackpole Bridge: The Story in Stone*).

Opponents of the replacement were concerned that replacing the bridge instead of rehabilitating it would disregard the historical lineage and legacy of Stackpole Bridge. Rehabilitation would be a more sustainable option because original materials from the bridge would be reused in the preservation of the structure. Those who advocated for bridge rehabilitation valued the history of Stackpole Bridge itself. They saw the bridge as a symbol and physical manifestation of Saco's past. It was also a visual reminder of the local history which provided a connection to the people who had lived and worked in the area in past centuries. Rehabilitation advocates wanted to educate the population about the history of the bridge and to put it into historical context within the town (Tobias). Many advocates of the bridge rehabilitation worked together to bring in historians, hold lectures, and ensure that local newspapers covered the story of Stackpole Bridge. They also contacted the city council members to inform them of the necessity of rehabilitating the bridge, though some council members "showed no interest at all" (Tobias).

Referendums

Over the course of the discussion surrounding the bridge, there were three different Public Works directors, three mayors, and many city council members. Some people had no interest whatsoever in the project and just wanted the solution that would be the most inexpensive and most efficient. There were also concerns about money because people did not want significant tax increases; they wanted to spend the least amount of tax money possible on Stackpole Bridge. The Friends of Stackpole Bridge remained steadfast in advocating for bridge rehabilitation. In an effort to secure enough funding so that a resolution could be reached for Stackpole Bridge, the city held two different referendums on bridge bonds. In a 2013 referendum, a proposed $1.7 million bond failed, but in 2014 voters approved a more modest $990,000 bond (*Stackpole Bridge: The Story in Stone*).

Final Bridge Construction

The project was put out to bid by the city of Saco in 2015. The plans and specifications for the project allowed companies to choose if they wanted to propose replacement or rehabilitation. Regardless of whether Stackpole Bridge was replaced or rehabilitated, it needed to be able to carry modern structural loads and be perfectly functional for the city of Saco.

The company that had the lowest bid proposed the total replacement of Stackpole Bridge with a new concrete structure for about $860,000 (Sutherland). However, this company never signed a contract for the project due to legal and insurance issues, so the city had to determine how to proceed.

The people in the community who sought to rehabilitate the bridge instead of replacing it had received letters from national and international organizations touting the local historical importance and uniqueness of Stackpole Bridge. After lengthy workshops and meetings during the summer and fall of 2015, on December 21, 2015, the city council took a final vote to support rehabilitation of Stackpole Bridge. At this meeting, the Saco city council voted five to two to allocate an additional sum of money to the 2014 $990,000 bond to cover the cost of the lowest bid the city received for rehabilitation of the bridge.

The final award of the contract went to CPM Constructors, a Maine general contractor from Freeport, for $1.2 million (Ouellette). While the original proposal envisioned a new bridge deck supported by micropiles driven into the structure, analysis of the rubble inside the bridge required the contractor to adjust their approach. They proposed the blended rehabilitation of the existing Stackpole Bridge. This included retaining the existing arch (see Figure 13) and addressing internal structural issues by using a partial concrete structure within the existing bridge dimensions, while keeping the exterior stone façade of the bridge virtually unchanged (see Figure 10).

Figure 13. *Stackpole Bridge during rehabilitation (Friends of Stackpole Bridge)*

Construction of the bridge started in the summer of 2016 and continued through the winter until the bridge was completed in the summer of 2017. As part of the revised approach by the contractor, the stones of the bridge were taken apart piece by piece, while the complete arch remained in place. The stones were marked and stored by their original location for proper placement in the rehabilitated structure. A cast-in-place reinforced concrete structure was constructed around the remaining arch to create a stable bridge superstructure (see Figure 13). The original steel bracing from the early 2000s was left in place during construction to aid as formwork, and it was fully removed prior to the completion of the rehabilitation. Precast concrete pieces provided a skeleton for the rehabilitated bridge walls. The original stones were then used as a façade for the bridge, serving no structural function, but maintaining the look of the historic Stackpole Bridge.

The reuse of the original stones was a sustainable and cost-effective option that also preserved the historical value of the bridge’s exterior design.

Results of Rehabilitation

The original Stackpole Bridge that was constructed in 1848 had been eligible to be listed in the National Register of Historic Places as a historic structure (Tobias). Though the rehabilitated structure reused the visible original stones from the bridge and maintained the form and historic appearance from the original, the National Register of Historic Places did not consider the bridge to be a historic structure anymore due to the interior rehabilitation improvements with modern materials (Gotthelf).

However, the residents and citizens of Saco still considered Stackpole Bridge a valuable historic landmark, since the arch remained original and the historical appearance was preserved. After rehabilitation, a plaque was mounted by the bridge honoring the original builders and the effort to save the bridge.

The rehabilitation of Stackpole Bridge has allowed the community in the rural area of Saco to flourish and receive new investment. The Ecology School, a hands-on learning center for people of all ages to learn about the environment, farming, conservation, and the natural world, bought property next to the bridge after construction was complete. Their River Bend Farm campus, which was founded in 2020, is located on Simpson Road just north of Stackpole Bridge (The Ecology School). If the bridge had not been rehabilitated, the school may not have purchased the property, because it would have been cut off from the rest of the city of Saco and would have required much longer commute times. Additionally, Saco Bay Trails opened a new trail along Stackpole Creek called the Mary Merrill Trail that highlights the historic Stackpole Bridge (Saco Conservation Commission).

During this rehabilitation process, the Friends of Stackpole Bridge led the education effort to convince city officials and voters of the historic value of Stackpole Bridge to the community. Their efforts are a great example of how a group of people can affect change in their corner of the world by gathering together and advocating for something that matters to them. By preserving the historic appearance of the bridge, the people of Saco can find value in its history and unique character.

CONCLUDING REMARKS

Stackpole Bridge is an example of a historic structure that has been rehabilitated to retain its structural integrity and its historic significance to the city of Saco. The rehabilitation of historic structures signals the interest and pride a community takes in its history and origins. Inga Browne, a member of the Friends of Stackpole Bridge wrote the following words as Saco was debating between rehabilitation and replacement of Stackpole Bridge:

> "The bridge does not exist in isolation. Most Saco residents support our local schools teaching some examples of classic literature…since these rich stories promote empathy and historic context for our current world. Stackpole Bridge is no different as a living historic artifact that embodies form and function in a rustic yet bold civil engineering landmark….And let's not forget, Stackpole Bridge is a city-owned structure, open and accessible to all" (Browne).

The rehabilitation of Stackpole Bridge shows respect for the people of the past who used their skills and traditional methods to create a bridge that the community could rely on. Historic structures tell the story of the town, the people, the history, and the skills of those who lived there that may otherwise be forgotten.

BIBLIOGRAPHY

"About Friends of Stackpole Bridge." Friends of Stackpole Bridge. Facebook, July 13, 2012. https://www.facebook.com/stackpolebridge/.

American Society of Civil Engineers. "Five Stone Arch Bridges." *Https://Www.asce.org/About-Civil-Engineering/History-And-Heritage/Historic-Landmarks/Five-Stone-Arch-Bridges*, www.asce.org/about-civil-engineering/history-and-heritage/historic-landmarks/five-stone-arch-bridges.

Bills, Joe. "The Best Covered Bridge in Every New England State." *New England*, 16 Mar. 2022, newengland.com/today/travel/new-england/the-best-covered-bridge-in-every-new-england-state/.

Browne, Inga. "Saco's Stackpole Bridge Is Literally History Etched in Stone." *My Secret Maine*, 6 Dec. 2015, mysecretmaine.bdnblogs.com/2015/12/06/maine-news/stackpole-bridge-community/.

"Building a Stone Arch Bridge." *Stone Arch Bridges*, 21 June 2019, stonearchbridges.com/2019/06/21/building-a-stone-arch-bridge/#:~:text=They%20are%20built%20parallel%20to.

Bustamante Engineers Staff. "Why Are Covered Bridges Covered?" *Www.bustamanteengineers.com*, 12 June 2020, www.bustamanteengineers.com/why-are-covered-bridges-covered.

Cartwright, Mark. "Olympia." *World History Encyclopedia*, 2 July 2012, www.worldhistory.org/Olympia/.

Citto, Carlo, and David Woodham. "Evaluating Existing and Historic Stone Arch Bridges." *Structure Magazine*, May 2015, www.structuremag.org/?p=8500.

Florida Department of Transportation. "Bridge Maintenance Reference Manual." *FDOT*, www.fdot.gov/maintenance/bmrm.shtm.

Garrity, S.W.. (2015). The complex engineering design challenges of masonry arch bridge rehabilitation. https://www.researchgate.net/publication/303619345_The_complex_engineering_design_challenges_of_masonry_arch_bridge_rehabilitation/citation/download.

Gotthelf, Liz. "Stackpole Creek Bridge Project May Proceed despite Loss of Historic Status." Press Herald, 2 July 2016, www.pressherald.com/2016/07/02/stackpole-creek-bridge-project-may-proceed-despite-loss-of-historic-status/.

Graham, Gillian. “Saco Council Allocates Money to Restore Historic Stackpole Bridge.” *Press Herald*, 22 Dec. 2015, www.pressherald.com/2015/12/22/saco-city-council-allocates-money-to-restore-historic-stackpole-bridge/.

Hardiman, Thomas. “History of Saco’s Mill District Factory Island.” *Www.sacomaine.org*, www.sacomaine.org/community/mill_district.php#:~:text=The%20region.

Herff College of Engineering. “History of Concrete.” *Www.ce.memphis.edu*, www.ce.memphis.edu/1101/notes/concrete/section_2_history.html.

“How to List a Property - National Register of Historic Places (U.S. National Park Service).” *nps.gov*, National Parks Service, 2019, www.nps.gov/subjects/nationalregister/how-to-list-a-property.htm.

Iwakuni City Industry Promotion Department. “History of the Kintaikyo Bridge.” *Https://Kintaikyo.iwakuni-City.net/En/Data.html*, kintaikyo.iwakuni-city.net/en/data.html.

Kaplan, Linda. “AASHTO Vehicle Live Loading.” *Structure Magazine*, Apr. 2020, www.structuremag.org/?p=15753.

“Load Rating Guide.” Maine Department of Transportation, Apr. 2015. https://www.maine.gov/mdot/publications/docs/guides/MaineDOT_Load_Rating_Guide_April_2015.pdf

Mack, Robert, and John Speweik. *Repointing Mortar Joints in Historic Masonry Buildings*. Oct. 1998. https://www.nps.gov/orgs/1739/upload/preservation-brief-02-repointing.pdf.

Merriam Webster Dictionary. “Extrados.” *Www.merriam-Webster.com*, www.merriam-webster.com/dictionary/extrados.

National Center for Healthy Housing. “Potential Chemicals Found in Building Materials.” *Nchh.org*, 2010, nchh.org/information-and-evidence/learn-about-healthy-housing/building-products-materials-and-standards/chemicals/.

National Transport Trust. “Heritage Locations.” *Www.nationaltransporttrust.org.uk*, www.nationaltransporttrust.org.uk/heritage-sites/heritage-detail/twizel-bridge-northumberland.

“NPS Policy 28: Cultural Resource Management.” *Www.nps.gov*, 16 Aug. 2002, www.nps.gov/parkhistory/online_books/nps28/28chap8.htm#:~:text=Resource%20Definition.

Ouellette, Timothy. “Stackpole Bridge Proposal.” CPM Constructors, 2015. file:///C:/Users/amorr/Downloads/Stackpole%20Bridge%20Proposal.pdf

Oxford Learner's Dictionary. “Sustainability.” *Oxfordlearnersdictionaries.com*, 2022, www.oxfordlearnersdictionaries.com/us/definition/english/sustainability.

Rabinowitz, Phil. “Encouraging Historic Preservation.” *Ctb.ku.edu*, ctb.ku.edu/en/table-of-contents/implement/physical-social-environment/historic-preservation/main.

“Rural Roads and Bridges: Why They’re Important.” *U.S. Bridge*, 17 July 2020, usbridge.com/rural-roads-and-bridges/.

Saco Conservation Commission. “Celebrating the Rich Natural Legacy of Saco.” *ArcGIS StoryMaps*, 18 Mar. 2022, storymaps.arcgis.com/stories/208b5b5185a34bb3916192ea187a805d.

Stackpole Bridge: The Story in Stone. Directed by Patrick Andrew Bonsant, New Directions Media, 2018. http://www.newdirectionsmedia.com/media/videos/stackpole_bridge_the_story_in_the_stone.

Sutherland, Kevin. “Saco City Council Meeting and Workshop Items.” July 2016. https://cms1files.revize.com/sacome/7.11.16.pdf

“The Choice of Stone for Stone Arch Bridges.” *Stone Arch Bridges*, 17 May 2019, stonearchbridges.com/2019/05/17/the-choice-of-stone-for-stone-arch-bridges/).

The Constructor. “What Is Reinforced Concrete? Uses, Benefits, and Advantages.” *The Constructor*, 21 Oct. 2019, theconstructor.org/concrete/reinforced-concrete-uses-benefits-advantages/35976/.

The Ecology School. “Mission.” *The Ecology School*, theecologyschool.org/about.

The Editors of Encyclopedia Britannica. “Arch.” *Encyclopedia Britannica*, 17 Nov. 2008, www.britannica.com/technology/arch-architecture.

“This Bronze Age Highway Has the World’s Oldest Bridges That Are Still in Use Today.” *Earthlymission.com*, 27 July 2021, earthlymission.com/bronze-age-highway-oldest-bridges-mycenae-arkadiko/.

“The Urban and Rural Classifications.” Geographic Areas Reference Manual. https://www2.census.gov/geo/pdfs/reference/GARM/Ch12GARM.pdf

Tobias, Lori. “Restoration, Not Replacement Chosen for Maine’s Historic Stackpole Bridge: CEG.” *Www.constructionequipmentguide.com*, 25 Jan. 2017, www.constructionequipmentguide.com/restoration-not-replacement-chosen-for-maines-historic-stackpole-bridge/32420. Accessed 26 Apr. 2023.

UNESCO World Heritage Centre. "Pont Du Gard (Roman Aqueduct)." *UNESCO World Heritage Centre*, whc.unesco.org/en/list/344/.

Wathne, John. "Final Stackpole Creek Bridge Report." Structures North, 2012. https://cms1files.revize.com/sacome/Public%20Works/Stackpole%20Creek/g.pdf

Webster, Ian. "Inflation Calculator." *Www.officialdata.org*, www.officialdata.org/us/inflation/1848?amount=800.

"What Is Rural?" *www.nal.usda.gov*, www.nal.usda.gov/rural-development-and-communities/what-is-rural.

BIBLIOGRAPHY: FIGURES

Design Pics Inc. "Colosseum," *National Geographic*, images.nationalgeographic.org/image/upload/t_edhub_resource_key_image/v1652340658/EducationHub/photos/colosseum.jpg.

Friends of Stackpole Bridge. "Stackpole Bridge during Rehabilitation," Facebook, 27 Sept. 2016, scontent-ord5-1.xx.fbcdn.net/v/t31.18172-8/14445098_1111319818914863_2574402997274646085_o.jpg?_nc_cat=108&ccb=1-7&_nc_sid=9267fe&_nc_ohc=knK0mX0JRsEAX9kSQCq&_nc_ht=scontent-ord5-1.xx&oh=00_AfCmLfrI25c8cgFbO75cJQToO2EdeZCSe884sQJnhyKm1g&oe=645BEC1E.

GaijinPot Travel. "Kintaikyo Bridge," *GaijinPot Travel*, travel.gaijinpot.com/kintai-kyo-bridge/.

Gallas, Karel. "Pont Du Gard, Nîmes, France," *Encyclopedia Britannica*, 26 Apr. 2021, cdn.britannica.com/56/112156-050-E0CDD0A3/aqueduct-Pont-du-Gard-Roman-France-Nimes.jpg.

Hawkins, Simon. "Twizel Bridge, England," *Fabulousnorth.com*, fabulousnorth.com/twizel-bridge/.

Kratochvíl, Zdeněk. "Arkadiko Bridge, Mycenaean, Late Helladic Age," *Wikimedia Commons*, Oct. 2020, commons.wikimedia.org/wiki/File:Arkadiko_bridge,_mycenaean,_Late_Heladic_age,_202418.jpg.

Maine Department of Transportation. "Babb's Bridge, Windham/Gorham, Maine," *Maine Department of Transportation*, www.maine.gov/mdot/historicbridges/_assets/img/coveredbridges/babbs/pic6.jpg.

Maine Preservation. "Closure of Stackpole Bridge in May 2013," *Mainepreservation.org,* images.squarespace-cdn.com/content/v1/5978aeae2994ca3b035c44cf/1546896239201-GEBGBU9GA4H4F688U1G8/Stackpole+Bridge+construction+May+2013.jpg?format=1500w

Maine Preservation. "Steel Structure in the Arch of Stackpole Bridge prior to Rehabilitation," *Mainepreservation.org*, images.squarespace-cdn.com/content/v1/5978aeae2994ca3b035c44cf/1546896236715-2SMW95E5NLEPM8NAUYSK/from+FB+2.jpg?format=1500w.

Morrison-Ouellette, Abigail. “Stackpole Bridge in 2022 after its rehabilitation,” 2022.

Salge, Jim. “Peak Color Surrounds the Historic Stone Arch Bridge at Gleason Falls in Hillsboro, NH,” *Jimsalge.com*, www.jimsalge.com/img-get/I0000XzzaYI_7_XA/s/880/880/Peak-Color-at-Gleason-Falls.jpg.

Spodek, Joshua. “Components of an Arch,” *Joshuaspodek.com*, 13 July 2019, joshuaspodek.com/beware-arch-problems.

“The Krypte, Which Was the Official Entrance to the Stadium of Olympia,” *Worldhistory.org*, July 2012, www.worldhistory.org/img/r/p/1000x1200/426.jpg.webp?v=1678729806.

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