BUILDING
Stone Arches

by Peter "Columbus" Annese

Modern tools and ingredients enhance construction of one of the world's oldest headers

I'm a masonry contractor in Truro, Mass. Recently, my crew and I laid a series of stone arches below the wood-framed terrace of a new residence. The deck above was independently supported on structural steel columns that would be concealed within the stonework, so in this case the arches were decorative. Nonetheless, they were traditionally built and totally capable of supporting a structural load. Before trusses, steel beams, and reinforced concrete became commonplace, nothing beat the durability and bearing capacity of a stone masonry arch.

A masonry arch gets its structural quality from wedge-shaped "ring stones" placed in compression around the perimeter. The overhead pressure is redistributed to the ring stones and down to the springer stone at the base of the arch (see "How Arches Work," page 3).

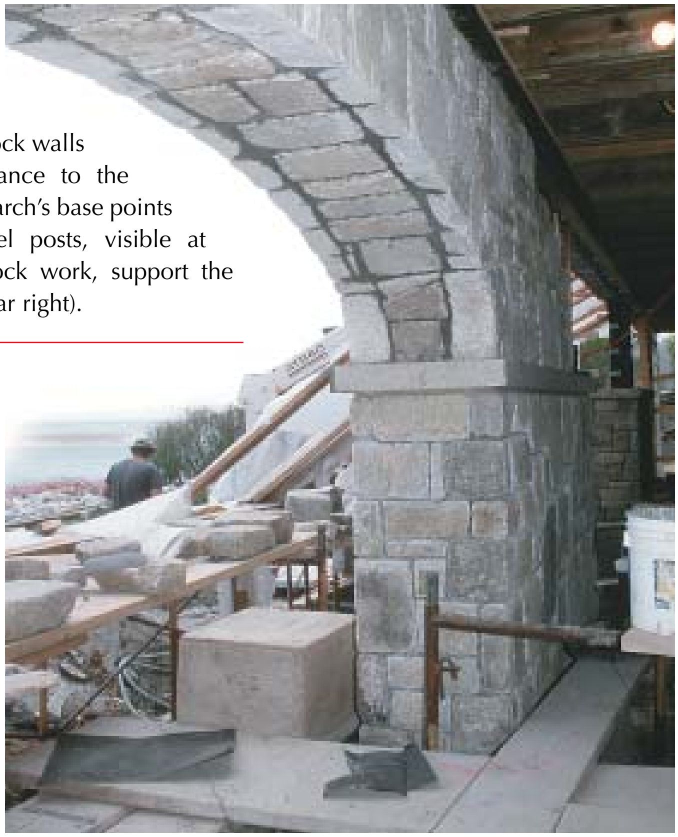


Figure 1. Concrete block walls provide lateral resistance to the outward forces at the arch's base points (right). Structural steel posts, visible at either end of the block work, support the overhead deck load (far right).

I always work from plans prepared by a qualified engineer, so I'm spared the headache and risk of making structural calculations.

On this job, we set a series of elliptical arches between core walls of concrete block built on 12-inch-thick reinforced concrete footings (see Figure 1). We used stainless-steel wall ties, about one per square foot, to provide a strong connection between the concrete and stone. After bringing the veneer up to the specified spring line, we capped it with level granite slabs. The arch construction began at this point.

Enhancing the Stone

We worked this job with quarried granite veneer stone; flat, randomly broken pieces of widely varying size and irregular shape and about 3 to 4 inches thick. The architect specified an ashlar pattern, in which the stone is dressed to have straight geometric lines and is laid in angled patterns. My favorite look in stone masonry is called dry stack, after the original, mortar-free method of laying closely fitted stone. I always work with mortar but back-cut the stone to minimize the face joints. Although the sizes and shapes of the stones appear random, I consider each one for its size and place in the overall pattern and cut it to fit. You have to continually visualize the total installation as you work, which is part of the reason each stone mason's work is distinctive.

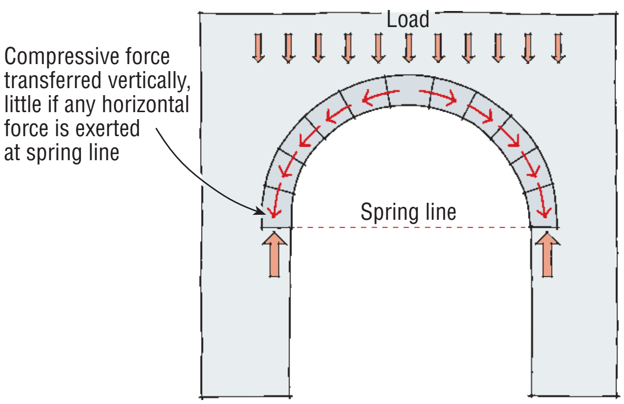
I precut a big stack of 15-pound felt paper into sheets of various sizes and use those to pattern the individual stones. I trace the pattern onto the face of a suitable stone with a lumber crayon or permanent marker. After a few years, you develop an eye for selecting a rough stone that'll require the least amount of cutting, but it's still slow going. Each stone takes an average 10 to 15 minutes of prep before setting it in place. We processed 196 tons of granite and worked a little over a year on this one job. And from all that cutting and dressing, we

How Arches Work

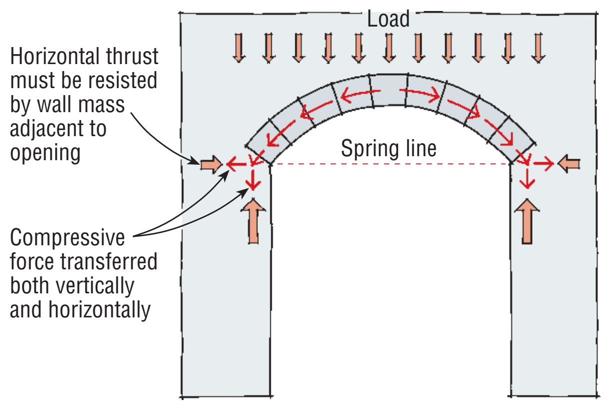
A masonry arch exploits the simple principle that equal and opposing forces cancel one another out. The form of a circle is extremely strong under compression, and, provided its end points can't be displaced, so is any section of a circle. The arch ring is segmented only for practical purposes; in theory, it could be carved from a single piece of stone. And masonry segments need not be wedge shaped, provided that mortar is used to fill the gaps and distribute the compressive forces. Under a load stress, any segment of the arch is in equal compression to all other segments; thus, none is moved out of place. Instead, the stress is transferred to the base of the arch. In a semicircular, or true, arch, this force is directly vertical. Little if any horizontal force is exerted at the base line.

The curvature of an ellipse is flatter than that of a true arch. As an arch is flattened, the line of stress shifts to a horizontal thrust at the spring line. That puts lateral pressure on the base column and places the ground between columns under tension. Without an "abutment" of sufficient mass to resist horizontal movement, the arch will collapse. When arches abut one another in a series, the horizontal forces cancel each other out and transfer vertically to the bearing base or column.

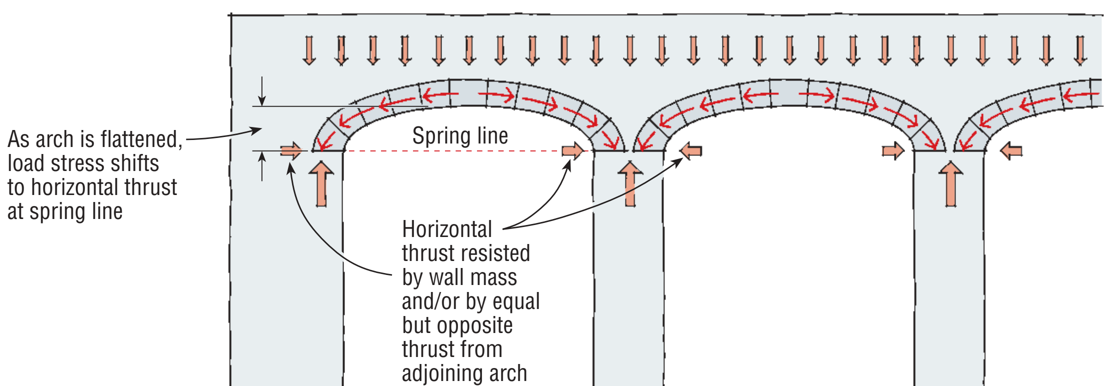
—Dave Holbrook



True Arch



Segmental Arch



Elliptical Arch

hauled away around 78 tons of rubble at the end of the job, a waste factor of about 40% (Figure 2).

It's worth remembering that stone masonry requires a large staging area for material storage and processing, for a long time. You may think you've got adequate parking for all the other trades, but with stone work going on, you may be surprised. Sometimes I have to park off site, too.

Figure 2. An ashlar pattern requires each stone to have straight, man-made edges and be laid in a close-fitting, angular design. The waste factor runs as high as 40%, producing a considerable pile of rubble as the work progresses.

Forming an Arch

Although a stone arch is ultimately self supporting and load bearing, it doesn't start that way. The shape of the arch is first created by laying the stone over a precise wood form provided, in our case, by the GC. I've probably laid a hundred arches over the years without ever repeating the same radius. But you never know; I find the forms too nice to toss and have a sizable collection in my storage yard. The typical form is made from a pair of plywood or solid lumber face panels that describe the arch. The face panels are spread and reinforced with framing, built to the approximate finished wall thickness. The top of the form is covered with narrow planks or bendable plywood to support the stone as it's laid.

The form is set to span between bearing points and is elevated slightly on wood spacers and beveled shims. Pulling the shims and spacers makes the form easy to remove later (Figure 3).

Figure 3. Wood shims under the arch form ensure easy removal later. The author relies on the builder to construct the form.

The arch ring is built of individual ring stones, typically wedge shaped, that follow a radial pattern from the center of the arch opening. I usually attach a length of mason's line to pivot from the center of the bottom edge of the form and pull it across the ring stone blank like a chalk line to mark the radial lines. The arch ring is laid out one stone at a time, working from one side, then the other, toward the center. I do the spacing and proportions pretty much by eye unless a strict, formal geometry is specified.

The top of the arch is closed with a keystone that locks the construction together. With the keystone in place, the form can be removed and the arch will stand independently. When working with mortar, we leave the form in place for an initial curing period of at least four days. Mortar not only binds the stones but also fills gaps and distributes stress, adding even more strength to the arch.

On this job, the architect stipulated that the ring stones should not be different in shape or pattern from the "spandrel" — the general vertical facing above and around the arch. That made me a little uneasy, so I still worked a wedge in among the ring stones wherever I could. Most stone arches are deeper than the thickness of the ring stones. But filling the underside, or soffit, of the arch follows similar principles, relying on compression between the stones and mortar for structural integrity.

I back-cut the soffit stones on all edges to minimize the face joint and laid them face down on the form. Back-cutting also created wedge-shaped spaces between the stones, which I filled with mortar. After the mortar hardens, the soffit's compressive strength and structural performance are like that of the ring stones. Before setting each soffit stone, I spread sand on the form to protect the face from mortar staining. And because the joints can't be raked out while the mortar's still green, I filled them with a 1/2 inch of dry sand to displace the mortar. When the form was pulled, the sand spilled out, leaving a recessed joint (Figure 4).

On its own, Portland cement–based mortar would do an adequate job of holding the stones together. But in pursuit of the mason's tradition of building for eternity, I leave no stone unturned. Every bonding face gets a liberal brushing of Silpro Weld-O-Bond Plus, a water-based latex bonding agent formulated to bond Portland cement to a variety of surfaces (Figure 5).

Until the cement begins to set up and stiffen — from 1 to 2 hours or longer — some of the face stones are wobbly and easy to dislodge. When working a short run, I could be forced to stop laying up

Figure 4. The underside, or soffit, is laid between the ring stones. Mortar and masonry rubble fill the void behind the face stones. As he places each stone, the author spreads sand on the form and packs a layer into the joints before the mortar (left and below left). The sand helps keep the finished face clean and falls out when the form is pulled, leaving recessed joints. Only minor pointing is needed to finish (below).

Figure 5. Although Portland cement forms a naturally strong bond with stone, the author brushes all mating surfaces with an acrylic binder to improve adhesion.

until the cement hardens. Instead, temporary shims and wire twists allow me to continue stacking stone without the downtime (Figure 6).

To control the lay-up, I stretched a reference string line across the spandrel, offset an inch from the face to avoid irregularities in the stone surface.

Figure 6. Mortar is slippery when wet. Shims and wire twists stabilize individual stones until the cement hardens.

Cutting Stone

A $7\frac{1}{4}$-inch wormdrive saw equipped with a diamond blade is my primary stone cutting tool. I've modified ours with a length of plastic tubing attached to a mini sump pump that douses the blade with a continuous trickle of lubricating water (Figure 7). Even cutting with water, we burn through at least a couple of blades a week. If bought individually, diamond blades go for about \$90 each. I buy them by the case, which cuts the price to about \$60.

After back-cutting the stone, I "rock," or roughly bevel, the edges to soften the saw-cut appearance, using a maul and cold chisel or a masonry hammer (Figure 8, next page). Rocking can be further refined to a more natural-looking surface by "thermaling," or finely flaking the rocked edge with an acetylene torch. That would have been a good way to add a few more months to this job.

Figure 7. The author's saws are modified with a pump-fed water tube to lubricate the stone during cutting. Dry-cutting is also possible but drastically shortens blade life.

Mortar

I work with modern cement mortar, using ratios of Portland cement, lime, and sand that produce a mix with extremely high compressive strength. I add plasticizers to reduce the need for water, which can weaken the bonding strength of the mortar. Over time, every stone mason develops a personal mortar recipe. Mine calls for 15 shovels of sand, half of a 94-pound bag of Portland, two shovels of masonry cement, and one shovel of lime. I add about 24 ounces (or two paper coffee cups) of Silpro C-21 (Silpro, 800/343-1501, www.silpro.com), an acrylic plasticizer, to a five-gallon bucket of clean, potable water, which brings the mortar to a workable consistency.

Weather protection. Cement mortar is sensitive to freezing. If ice crystals form in the mix before the cement can fully hydrate and set, the mortar may be weakened. Ice expands 9% beyond its liquid state and can forcibly separate the binder (cement) and aggregate (sand), making the mortar crumbly. Calcium chloride can be added to the mix as a setting accelerator; I use Simpson's Winter Ad-Mix (William S. Simpson Co., South Easton, Mass.; 508/230-0900), a liquefied form of calcium chloride. The Ad-Mix has no adverse effect on the mortar itself. But calcium chloride is suspected of causing corrosion in nonstainless metal wall ties and reinforcing steel, so if there's a concern, don't use it.

Figure 8. "Rocking" the cut edges with a chisel or masonry hammer gives the stone a more natural look.

It's best to maintain the mortar at above-freezing temperatures of 40°F minimum for the period of setting, at least 48 hours. One simple way to make sure there's no frost or frozen aggregate in the mortar is to use hot water in the mix, but heating water isn't practical on site. In really cold spells, we'll sometimes heat the sand before mixing the mortar, by tenting it under a tarp and blasting it with a propane-fired salamander. Completed work has to be protected from freezing overnight and during the initial 48 hours of curing. Insulating "thermal tarps" are made for this purpose, the heat supplied by a portable electric heater. This is an effective method for protecting limited areas of newly completed work. But it's a waste of time having to thaw a wet and frozen pile of stone and sand in the morning before you can get to work. In order to keep the work moving ahead in all weather, we set up a temporary enclosure over the general work area (Figure 9). Pipe scaffolding and furring lumber make a handy framework for the reinforced poly membrane canopy that we use (A.H. Harris, Newington, Conn.; 860/665-9494, www.ahharris.com). I used to use cheaper, woven poly tarps for the canopy, but the translucent membrane is much more durable and doesn't block the daylight. The poly comes in 100-foot rolls from 10 to 40 feet wide and costs $45 per 1,000 square feet. With a couple of salamanders blasting away, we're able to stay relatively warm, dry, and busy.

Figure 9. The crew constructs a temporary shelter of pipe scaffold, lumber, and poly sheeting over the primary work area. Propane-fired heaters keep the materials and masons above the freezing mark in cold weather.

Peter Annese *operates Columbus Stone Masonry in Truro, Mass.*