A SunCam online continuing education course

Fundamentals of Masonry
Part B

by

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Introduction

The science of masonry construction is extensive, thorough, and is the foundation of the profession. But there is an artistic component bounded only by the imagination of the designer and the skilled mason.

Masonry construction has been practiced for thousands of years beginning with the ancient Greeks and the Romans. The "language" of the craft developed over this time. Today we use words that clearly identify pieces and parts of the industry that can bewilder or confound those unfamiliar with them – words such as collar joint, sash block, and Jack arch.

This three course series provides fundamental knowledge about masonry construction for the engineer, architect, contractor, and anyone else who is interested in having a basic understanding of the topic.

Fundamentals of Masonry – Part A explained and simplified the terminology and the fundamental principles of masonry and masonry construction including the nomenclature and history of the subject, and an introduction to the basic principles of wall construction.

Fundamentals of Masonry – Part B continues the discussion of masonry including design and reinforced masonry, some structural elements such as bond beams, lintels, pilasters, and arches and concludes with a section titled "What can go wrong?" with an example of the severe consequences of ignoring the design and construction principles of masonry.

It is fully illustrated with drawings and color photographs and is written in an easy to understand style.

Coming soon **Fundamentals of Masonry – Part C** will discuss additional masonry units including stone and glass, the anatomy of a clay brick street, efflorescence, and additional fascinating (actually, disheartening) damages resulting from sloppy and incorrect masonry construction practices.

Design

All masonry structures and elements, including both reinforced and non-reinforced, must be designed in accordance with the governing building codes and standards to insure safety for all. The design of masonry projects is based on an analysis of the structure to determine the magnitude, the line of action, and the direction of all forces acting on each portion of the building including walls, columns, beams, and other masonry components. The codes and standards assume that all dead, live, and lateral loads and other forces are considered in the design including those resulting from temperature changes, impact, winds and snow, seismic forces, unequal settlement, and combinations of such forces. Those forces or combinations of forces which will produce the greatest stresses are then used for determining the size of the wall, beam, column, and other components, the strength and other properties of the components, and the amount, if any, of reinforcement required.

There are three methods of design for masonry structures. They differ in their assumptions, approaches, and outcomes. Without going into structural theory and the details of the design procedures, the three methods and their philosophy are briefly presented below.

Working stress design (WSD), also known as allowable stress design (ASD). This is perhaps the oldest theoretical design method, and is based on linear elastic theory. This theory assumes that the materials deform (stretch and compress) in a linear manner. This is similar to a rubber band when stretched in that it will return to its original shape without having been permanently deformed. The stresses in the materials are kept well below their ultimate stress. This design method is relatively straight forward and results in a structure that will perform quite satisfactorily over many years with little or no signs of distress due to anticipated loading conditions.

Strength design, also known as ultimate stress design (USD). This theory is based on the fact that materials do not deform in a linear fashion because the stress-strain diagrams in fact are not linear. The stresses in the materials are allowed to reach their maximum design capacity – i.e., reach their failure point less an appropriate factor of safety. Even though the structure while under maximum design loads does not fail (it is structurally safe), it may have deformed significantly enough to be unserviceable in some cases. The deformations often show up in the form of large unsightly cracks and other cosmetic and functional defects. A big advantage of this design method is that it allows for smaller and lighter reinforcement and thinner block and unit sizes, thereby keeping costs to a minimum.

Empirical design is a design based on data derived from observation or experience. These observations have been formalized into a consistent and rational basis for selecting materials, sizes, and strengths. The goal of this design philosophy is to insure the structure will reach an acceptable degree of both serviceability and safety.

The choice of which structural design philosophy to use is based in part on the building occupancy classification, i.e., the more people serviced by the structure, the more conservative or "safer" the design. Also, there are limitations on which design procedure to use, or not use. As only one example from the International Building Code, the empirical design may not be used for any of the following conditions:

1. The design or construction of masonry in buildings assigned to Seismic Design Category D, E, or F, and the design of lateral-force-resisting system for buildings assigned to Seismic Design Category B or C. The limitations are because earthquakes are very unpredictable in their severity.
2. The design or construction of masonry structures located in areas where the 3-second gust wind speed exceeds 110 mph, because of the severity of possible damages caused by higher winds.
3. Buildings more than 35 feet in height that have masonry wall lateral-force-resisting systems because of the higher wind speeds and greater lateral displacement of the structure above that height.

   "In buildings that exceed one or more of the above limitations, masonry shall be designed in accordance with the engineered design provisions of section 2107 (working stress design) or section 2108 (strength design)."

Once the design is complete, it is very important to transfer all of the resultant design requirements for the project to a set of plans and specifications (contract documents) that clearly convey the appropriate information to the masons and inspectors. Errors, omissions, and inconsistencies in this step can have serious consequences. Here are just a few examples:

- Design calculations based on using Type S mortar and specifications calling for Type N mortar because of the differences in strength of the mortars.
- Design calculations requiring vertical reinforcement steel at say, 4-foot centers in a wall. Simply specifying that requirement is not enough if a 3-foot section of wall needs vertical reinforcement also. How would the contractor know to place the steel in the 3-foot section?
- Calculations based on using high strength concrete masonry units (CMU's) where the standard ASTM specifications call for standard strength units, again because of the strength differential between the units.

Of all problems occurring in masonry construction, design errors occur in only about 10% of the cases. The rest, approximately 90%, occur because of construction errors usually involving water intrusion. Some examples:

- Not placing vertical steel in the proper position in the cores of the units which allows cracks to open up under design stresses, thereby allowing water to enter.

- Plugging weep holes with mortar droppings causing backup of moisture in the wall.
- Inadequate mortar between units preventing proper bonding of units allowing water to penetrate the wall.
- Using grout in a bond beam that is too dry or contains aggregate that are too large to properly bond to the steel thus causing structural damage.

Proper and complete design, plan and specification preparation, and inspection of the contractors' work are the basis for successful masonry construction.

Reinforced Masonry

Reinforced masonry is masonry construction containing steel reinforcement embedded in the mortar joints or grouted cores in such a manner that the component materials act together to resist applied forces.

NOTE: *Terms like grout, bond beam, pilaster, etc. will be discussed later in this course.*

Concrete masonry units and clay masonry units (clay bricks) are structurally sound in and of themselves. However, when they are used to construct some familiar projects these same masonry units need structural help to perform their intended functions. Here think warehouses, big box retail stores, large storage buildings, high rise buildings, and other load bearing structures including walls, pilasters, bond beams, retaining walls, and structures built in high wind areas and areas where high seismic forces can be expected, etc. Both CMU's and clay bricks are typically reinforced to resist design loads requiring structural properties which can't be economically built using non-reinforced masonry.

Vertical and horizontal steel reinforcing bars are placed in masonry walls to resist bending stresses due to lateral forces, usually wind and seismic. Wind can apply either pressure or suction, therefore bending in both directions must be considered. Reinforcing steel is lapped a minimum of 16-inches to develop tensile stresses in the steel without exceeding the allowable bond stresses. Deflections are checked to keep them below the maximum allowable.

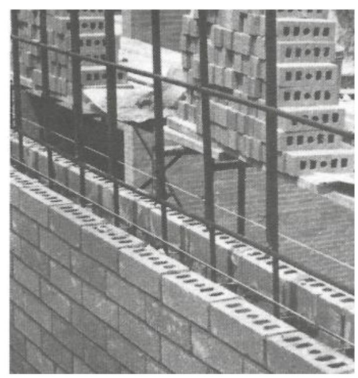
Early on, the design of load bearing masonry construction was based on empirical design analysis. The empirical design method effectively limited the height of buildings to 6 or 7 stories high. Anything higher was uneconomical to build. In the late 1960's, after much research had been done, the basis for design changed to working stress design. The change in design criteria more than doubled the height of economically competitive buildings. Design procedures are straight forward for a practicing structural engineer familiar with reinforced masonry. And, of course, the design must be done in accordance with all applicable building code rules and regulations.

In its simplest form, a reinforced CMU wall will have vertical reinforcing steel placed in cores of the block and filled with grout. Horizontal steel will also be placed within the concrete block at regular intervals vertically, sometimes as often as every other course, and grouted in place. The structural reinforcement will provide a very high resistance to bending stresses both in the vertical and horizontal directions, resistance to shear forces in the wall, and a high load bearing capacity to support the weight of building and wall above.

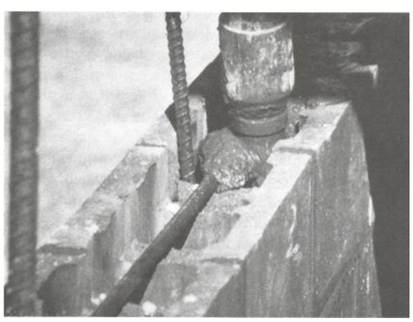
Reinforced brick masonry (RBM) is different in many ways from the conventional brick veneer used in cavity walls. The most important difference is the concept of grouting the brick masonry.

There are key two points when using RBM. First, the brickwork is the permanent formwork for the grout. It must be built to allow proper placement of reinforcing and grout. Second, the quality of workmanship has a significant impact on the final strength of the structure. Unfilled mortar joints and out of plumb construction can have serious effects on the final strength of the reinforced brick masonry.

The placement of the reinforcing steel is of critical importance in developing the masonry wall strength. Wire ties and other spacing devices are used to maintain proper positioning of the steel to keep it within tolerances prior to adding the grout material.



Reinforced brick masonry typically consists of either of two common methods. In the first method, shown in the photo on the right, reinforcing steel bars are placed in the collar joint, the space between two wythes of brick masonry. The collar joint is then grouted full. The photo shows a reinforced clay brick wall ready for grout.



The photo on the left shows an example of the second method. A single wythe of clay brick with large hollow cores (similar to concrete masonry units) that align vertically are used. Vertical steel is set in place and the hollow bricks are placed over and around the steel. As the wall is laid up, horizontal steel is placed in bed joints or in continuous bond beams made by removing portions of the webs connecting the face shells. The cores containing reinforcing steel are then grouted full. The photo also shows a reinforced clay brick wall being grouted.

Girders are large sized beams. Reinforced brick masonry girders consists of brick masonry in which steel reinforcement is embedded so that the resulting horizontal member is capable of resisting loads which produce compressive, tensile, and shear stresses. The principles of design for reinforced brick masonry girders and beams are the same as those commonly accepted for reinforced concrete flexural members and similar formulae may be used.

Grout

Grout is a cementitious material that is used in reinforced masonry construction. Most commonly, grout is used to encompass or surround reinforcing steel placed in masonry construction to bond that steel to the masonry.

Grout is made with the same ingredients as concrete – water, aggregate, and Portland cement. Grout is different from concrete in several ways. Concrete is made with a course aggregate. Grout is made with sand or p-fill aggregate. Concrete is made with a minimum of water and placed in non porous forms. Grout is made with much more water and placed in often very porous masonry units. The water cement ratio is critical for concrete. It's not that important for grout because much of the excess water in grout is quickly absorbed changing the water cement ratio from a high to low value. As the water is absorbed by the porous masonry forms, grout will shrink a bit. Concrete does not shrink when placed in the non porous forms.

Grout is similar in looks to both mortar and concrete. Concrete is a stiff mixture. Mortar has a "buttery" consistency. Mortar will stick to the underside of a trowel. It is impossible for grout to do so. Grout should be sufficiently fluid to flow into all the cracks and crevices in the masonry and completely surround and cover the reinforcing steel leaving no voids.

Because of the differences in water content, concrete can reach compressive strengths of up to 10,000 psi, whereas, grout with its higher water-cement ratio seldom reaches a compressive strength much above 2,500 psi (after curing in the porous masonry forms).

The photo on the right shows a concrete block wall being built with vertical reinforcing steel bars placed in regularly spaced cores. The entire vertical cores with the steel bars will later be filled with grout. Horizontal reinforcing bars are also laid in concrete masonry units and encased in grout to create beams, e.g., lintels and bond beams. Grout is also used to fill voids in masonry construction to add stability and resistance to cracking. Grout can also increase fire ratings, security, acoustical performance, blast resistance, thermal storage, and anchorage capabilities.

The specifications define two types of grout – fine and coarse. Fine grout contains sand, which is smaller than 3/8 inch in diameter, as its only aggregate. Coarse grout allows pea gravel, which is smaller than ½ inch in diameter, in addition to the sand. Mix proportions for grout are shown in the table on the next page. Hydrated lime, which helps in sealing very small cracks, is added to the mixture, when necessary. The specifications do not recognize any appreciable compressive strength differences between fine and course grout. The differences are in the ease of placement – fine grout can be placed in smaller openings than coarse grout.

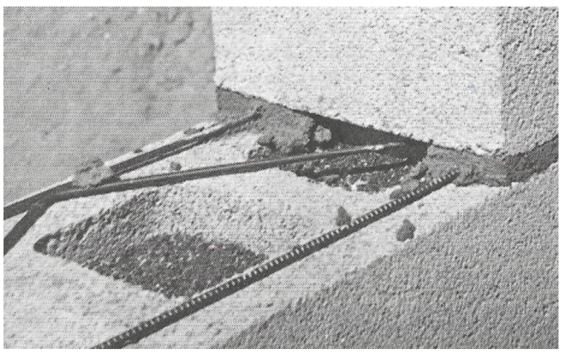
Grout (Proportions by Volume)				
Type	Portland Cement	Hydrated Lime	Sand	Pea-gravel
Fine	1	0 to 1/10	Not less than 2 ¼ and not more than 3	0
Course	1	0 to 1/10		1 to 2

Grout is placed into masonry construction either by pouring by hand from a bucket or by pumping. The photo shows grout being pumped into a lintel, containing horizontal reinforcing bars, above an opening for a window. When vertical cores of block are to be filled with grout, the cores must be constructed so that a continuous, unobstructed opening of the proper size is maintained for proper placement of reinforcement and grout. The higher the pour, i.e., the higher the completed wall before the pour begins, the larger the unobstructed opening must be. For example, a 12 foot pour using fine grout requires a clear opening of 2-1/2 x 3 inches. Using coarse grout, the opening required is 3 x 3 inches. A one foot high pour requires 1-1/2 x 2 inches for fine grout, and 1-1/2 x 3 inches for coarse grout. Reference tables exist to aid in determining the minimum size of opening required for different heights of pour.

Additives can be added to the grout mixture to affect the properties of the grout. For example, where shrinking can't be tolerated, an admixture can be added to the grout to make it a non-shrinking grout. Admixtures can also be used to slow the curing process, to speed up the curing process, and to plasticize the mix (reduce the water content while still maintaining a high flow consistancy). Additives containing chlorides should not be added to grout mixtures because the chlorides may corrode the reinforcing steel and may also contribute to efflloresence in the wall.

Wire Joint Reinforcement

Wire joint reinforcement was originally developed to control vertical masonry wall cracking caused by thermal or moisture expansions or contractions. Wire joint reinforcement is a cold drawn wire product. It consists of two or more longitudinal wires connected with cross wires forming a ladder (photo on previous page) or a truss (photo below) design. The wires have a minimum tensile strength of around 80,000 psi, right up there with common steel reinforcing bars. Wire joint reinforcement is manufactured in various widths and usually in 10' and 12' lengths. The wire joint reinforcement is designed to fit in the 3/8-inch thick horizontal mortar joints of masonry walls as shown in the photo on left. The wires in the joint reinforcement vary in size from 0.1205-inch diameter (11 gage) to ¼-inch in diameter. The longitudinal wires are slightly deformed (just visible in the photo below) to better "grip" the cured mortar.



The wire joint reinforcement performed very well in its original role controlling vertical masonry wall cracking. It is now also commonly used as (1) a metal tie system for bonding together adjacent masonry wythes (thicknesses) of walls and (2) as a structural steel reinforcement to increase masonry's resistance to bending, shear, and direct stresses.

Wire joint reinforcement is typically placed at 8, 16, or 24-inch spacing vertically, i.e., every course, every other course, or every third course. Wire joint reinforcement increases a wall's resistance to bending in the horizontal span by providing steel on the tension side of the wall, but does not improve its strength in the vertical span. The value of wire joint reinforcement in the horizontal span depends on three main variables – bonding pattern of the masonry, the size of the wire, and the strength of the mortar.

The **bonding pattern** is important in an unreinforced CMU wall. For example, an 8" thick CMU wall with no wire joint reinforcement in stacked bond pattern has about 40% of the horizontal bending strength of the same wall laid in running bond pattern with no reinforcement. However, by putting horizontal wire joint reinforcement at 16" vertically (every other course) in the two different bond patterns, each wall has an increased resistance to horizontal bending stresses to the same value – 120% of the wall laid in running bond pattern with no reinforcement. The running bond pattern wall increases its strength by 20%. The stacked bond pattern wall increases its strength three-fold (3 x 40% = 120%). Placing the reinforcement every course increases both walls to 160% of an unreinforced CMU wall laid in running bond pattern.

The **size of the steel wires** used in the wire joint reinforcing also has an effect on the amount of horizontal bending strength of a masonry wall. For example an 8-inch CMU wall reinforced every 16-inches vertically has an allowable moment of 2650 in-lb/ft^2 with wire joint reinforcement made with 9 gage wire (0.1483 inches diameter). When the wire joint reinforcing is made with 3/16-inch diameter wire (0.1875 inches diameter), the allowable bending moment is increased to 4285in-lb/ft^2 – just over a 60% increase in resistance to bending moments. The size of the wire was the governing factor.

The **strength of mortar** used in constructing a wire reinforced steel CMU wall affects its resistance to horizontal bending. For example, using the same size wire (9 gage) for the longitudinal members of the wire reinforcing steel, and placing the wire reinforcing in every joint of a test panel, when Type N mortar (1,100 psi compressive strength) was used, the wall had about 160% the resistance of an unreinforced wall. Using Type S mortar (3540 psi compressive strength), the resistance was about 220% of an unreinforced wall. In fact, the resistances to horizontal bending did not increase above about 160% for Type N mortar for any increase in size of wire used. The strength of mortar was the governing factor.

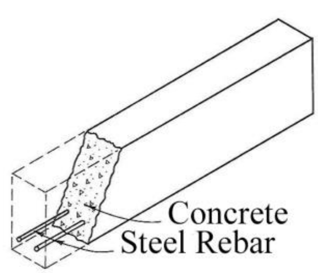
Horizontal wire joint reinforcing is normally placed in the two or three joints immediately below the top of the wall, and in the first and second joints above and below openings. The wire joint reinforcing above and below the openings should extend either 24-inches past the opening or to the end of the wall, whichever is less. Wire joint reinforcing need not normally be placed within 24-inches of a bond beam. Wire joint reinforcing should be lapped at least 6-inches when placed in the horizontal joint and wire joint reinforcing should not be continuous through an expansion joint.

Openings in Masonry Walls

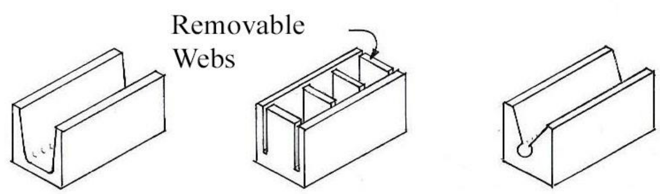
All openings, big and small, in masonry walls must have some sort of support for the masonry above them. This support is usually in the form of a header – a beam of some sort that spans the opening to support the weight of the wall and any loads above it. In masonry construction, this beam is called a **lintel.**

Depending on the type of masonry units and other factors, lintels may be precast or cast-in-place concrete, reinforced concrete masonry, or structural steel.

A **precast or a cast-in-place concrete lintel** is simply a concrete beam, reinforced with steel reinforcing bars (rebar) in the bottom. Precast concrete means the beams are of a standard size, made in a concrete beam manufacturing facility and are available for purchase by the mason, ready for placement above the opening, and immediately ready to carry loads. Cast-in-place concrete means that a wooden form is built over the opening in the wall, steel rebar are placed in the proper location in the form, and concrete is then placed in the form. After the concrete cures the forms are removed and the lintel is ready to carry loads.

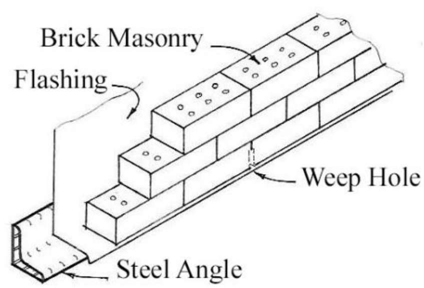


A **reinforced concrete masonry lintel** is a cast-in-place beam whose forms are built with specially shaped concrete masonry units. These units are variously called lintel units, lintel blocks, or bond beam masonry units. They can also be standard masonry units with removable, depressed, cut out, or grooved webs.



The reinforcing is standard steel reinforcing bars. And the bonding material is grout, NOT concrete. Note that the word "concrete" in reinforced concrete masonry lintel refers to the masonry units which are being reinforced – they are concrete masonry units – CMU's. To construct a reinforced concrete masonry lintel, lintel blocks must first be laid across the opening on a support system, i.e., must be shored up in place. Then the reinforcing steel bars are placed and the grout added. After the grout cures, the wood shoring is removed leaving a lintel that perfectly matches the surrounding masonry in both bond pattern and surface texture. The lintel is then ready to support loads. Reinforced concrete masonry lintels are often preferred over precast lintels because they match the wall masonry.

A **structural steel lintel** is a steel member, often an angle, and is mostly used in brick and stone masonry construction. Steel angles are simple to design, easy to obtain, and are readily installed. It is one of the most common lintels used in brick masonry walls. If the wall is a cavity wall, as is commonly used in residential and smaller commercial construction, the loads on the lintel are often only the dead load of the steel lintel plus the weight of the brick masonry in the load triangle above the opening (more on that in a bit).



There are advantages and disadvantages to each type of lintel.

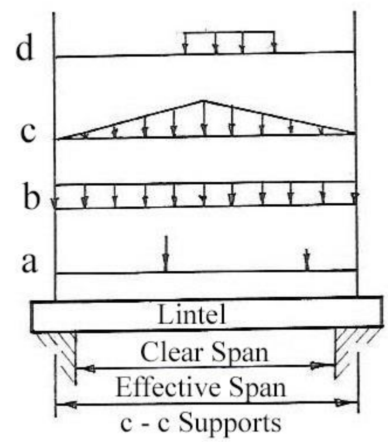
Type of Lintel	Advantage	Disadvantage
Precast concrete	Delivered ready to use Requires no shoring Supports loads immediately	Can be heavy – may need equipment to lift Does not match CMU in texture and finish
Cast-in-place concrete	No equipment needed to lift	Requires shoring Must cure before loading Does not match CMU in bond pattern, texture, and finish May have shrinkage problems

Reinforced concrete masonry	No equipment needed to lift Matches CMU's in bond pattern and surface texture	Requires shoring Must cure before loading
Steel angle	No equipment needed to lift Quick to install Supports loads immediately	Must maintain (periodic painting) May have differential movement between masonry and steel

As with any beam, the lintel design process begins with the determination of the loads to be carried. Once the loads to the beam are determined, the bending moments and shears in the lintel are calculated using straight forward structural analysis. After that, depending on the type of lintel being used, i.e., concrete, masonry, or steel, the appropriate design criteria is used to complete the design of the member. For this <u>Fundamentals of Masonry</u> course, we will limit our discussion to the determination of the loads on the member. By doing this, we will see some of the special properties of masonry that make it unique. All lintels follow a similar procedure.

Lintels are usually assumed to be simple span beams that support point loads and uniformly distributed loads, both live and dead, along their length. Axial loads carried by lintels are negligible and not considered.

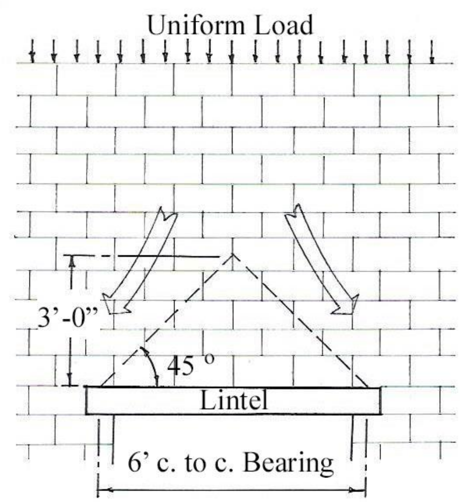
Usually these loads can be grouped into one of the four types shown in the drawing: a – point loads, b – uniformly distributed loads acting over the entire span, c – triangular loads with apex at mid-span acting over the entire length of span, and d – uniformly distributed loads acting over a portion of the span. Each load individually will create bending moments and shears in the beam. The designers will then superimpose the results of these individual loads to determine the overall shears and moments in the lintel.



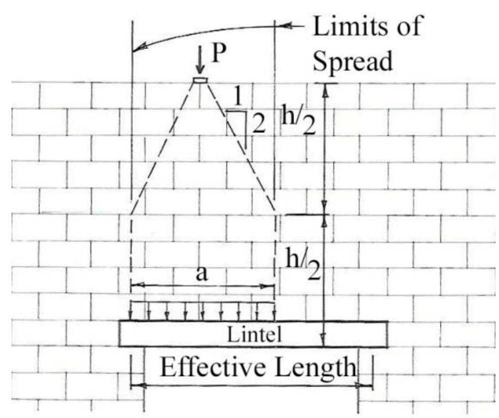
Point loads are simply individual loads that act directly on the lintel. Examples are floor joists and roof trusses that bear directly on the lintel.

Uniformly distributed loads acting over the entire span are loads with a constant weight per foot and cover the entire span. Examples of uniformly distributed loads over the entire span are the dead weight of the lintel itself and the weight of the masonry wall above the lintel. In residential construction and other lightly-loaded structures, the loads from the floor joists or rafters may be considered as uniformly distributed when the height of the masonry between the lintel and the load bearing is a relatively small distance – in the order of 1/3 to1/2 of the joist spacing.

Triangular loads with apex at mid-span acting over the entire length of span are specific loads created by arching action of the masonry above the lintels (see drawing). When masonry is laid in a running bond (overlapping) pattern an arch will form over an opening in the wall. This arching action will support the wall above the arch with no supporting structural member across the opening. Studies show that the load area within this arch can be assumed to take the shape of a triangle with the two sides sloping at a 45º angle with the horizontal. When a sufficient height of masonry wall is structurally continuous above an opening, arching action will carry the dead weight of the wall and superimposed loads outside the triangular area. In that case, the lintel need only be designed to support its own weight plus the masonry within the triangle. This triangular shaped masonry wall is the load that creates this "triangular load with apex at mid-span acting over the entire length of span". Remember, this arching action only occurs for concrete block and brick masonry laid in a running bond pattern. Concrete and brick masonry laid in a stack bond pattern will transfer ALL the weight and loads above the lintel directly to the lintel – a much more severe loading condition. This would then be a uniformly distributed load as discussed above.



Uniformly distributed loads acting over a portion of the span are often generated by large point loads acting on the wall above the lintels (see drawing). Relatively heavy concentrated loads (P) from beams, girders and other horizontal members framing into the wall (and not bearing directly on the lintel) can be handled in a simplified manner. Here is an example using the Working Stress Design (WSD) method for a reinforced concrete masonry lintel. Other design methods are similar. The point load, P, is assumed to be transferred downward from the apex of a triangle with 2:1 side slopes. The maximum spread of this load distribution triangle is limited by code. The governing criteria for the limit of spread of the load are: 1) one-half of the wall height; 2) encountering an expansion joint; 3) reaching the end of the wall; and, 4) being adjacent to an opening, whichever provides the smallest length of load delivered to the lintel. In the drawing, neither side slope encounters an expansion joint, another opening, nor the end of the wall; therefore the width of the spread, length a, is governed by one half the wall height above the opening. As it turns out in this case, simply by looking at the diagram, 100% of the point load would be delivered to the lintel in the



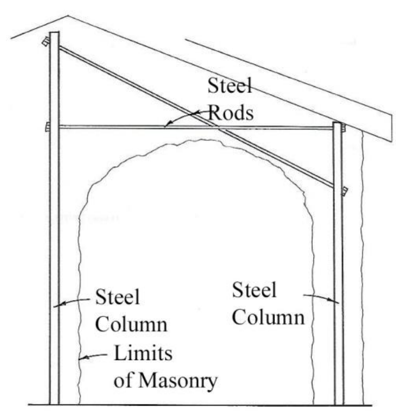
form of a uniformly distributed load of magnitude of P/a # per lin-ft, or perhaps kip/lin-ft. This uniformly distributed load of length a acts over the portion of the lintel as shown.

The arching action that supports the wall and loads above the apex of the triangular shaped area will produce relatively large horizontal thrusts at the base of the triangle. It is very important that there is enough masonry mass (or, length of wall) at each side of the opening to resist these horizontal thrusts. Arched openings near other openings and corners of a building can be problematic because of the horizontal thrust in that direction.

A story. Years ago, when I was doing a lot of design work, Bruno, the owner, wanted to put a chalet style addition to his pizza restaurant in West Lafayette, IN. He wanted an arched opening into the entryway of the new addition. The exterior of the new addition was going to be a nice looking stone masonry which works just fine for creating an arch. Notice, in the photo, that the entrance door itself sits back about four feet from the face of the arch. It is a sheltered foyer. The arched opening was located at the corner of the building and was going to support a portion of an attic floor load and a portion of the roof load.

This part of Indiana can get some pretty heavy, wet, snow loads during the winter months, plus the attic was going to be used for storage, so there was going to potentially be a relatively large horizontal thrust at the base of the arch that would bear at the corner of the building. There would be very little masonry mass to resist this horizontal thrust. I drew it up, as he wanted it to look, and simply mentioned to him that there would have to be a horizontal structural member across the top of the opening – at the base of the arch – to take the horizontal thrust of the arch. He immediately said that was unacceptable. I suggested it could be as simple as a steel rod across the opening. No. How about a good looking chain of some sort? No! He was adamant. What to do? What to do?

I fussed with the problem for a few days and came up with the idea that we would just "bury" a structural steel framework into the masonry veneer to carry the horizontal thrust at the corner of the building. I went back to Bruno and let him know that there would be a nice arch over his new entryway with nothing under it. He was a happy man.



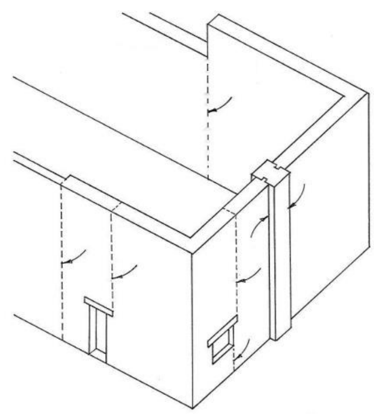
The structural system (see drawing) was two square steel columns with "X" bracing (actually tie rods) across the top of the opening, encased by the masonry arch and building corner column. The outward thrust of the loads on the arch kept the cross bracing in tension so rods were appropriate (no compression forces in the bracing). **End of story**.

PS – About 20 years later we were developing River Market Shops on that corner and we bought his property and removed the building to allow construction of the new building. Too bad – it was still a solid building.

Design tables for allowable shear and resisting moment values for a wide variety of simply supported lintel designs are available for the selection of the proper concrete beam, reinforced masonry unit, or steel beam for an opening. Selection of the lintel is based on the span of the opening and the bending moments and shears developed by the loads above the opening. And, of course, design and construction of lintels should conform to all applicable building code and specification requirements.

Control Joints

Control joints in masonry walls are used to control vertical cracking in the wall by providing stress relief at specific locations along the length of the wall. They allow horizontal movement of the wall due to changes in moisture and temperature. Control joints actually separate the masonry wall vertically into sections, or panels, allowing the wall panels to shrink or expand independently.

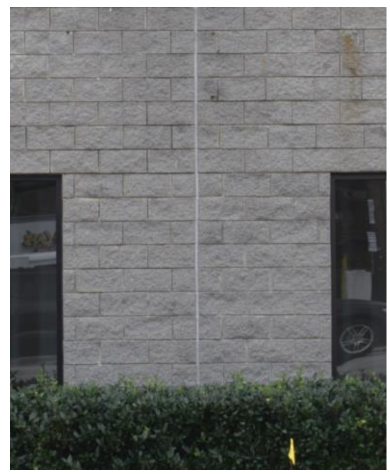


Vertical control joints are placed in masonry walls (shown by arrows in the drawing) where cracking due to stress concentrations are expected to occur. Some typical locations for vertical control joints include:

- Changes in wall height.
- Changes in wall thickness.
- A column or pilaster.
- One or both sides of wall openings.
- Construction joints in foundations, roofs, and floors.
- Additions to an existing building.
- Regular locations to break up a long expanse of wall with no openings.
- Other locations where other stress concentrations are likely to occur.

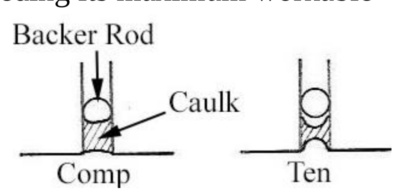
Control joints are usually easy to spot from the exterior of a building. They show up as a vertical line on the face of the masonry wall. The two photos on the next page show a construction joint in both a clay brick masonry veneer wall and a concrete block masonry wall. The control joint in the photo on the left shows a control joint extending from the bottom to the top of the clay brick masonry veneer wall. It creates a complete separation of the wall panel on the right from the wall panel on the left. This control joint is, as are all exterior control joints, weather tight – the joint is sealed with a high quality caulk or other sealant. The photo on the right shows a control joint in a concrete masonry wall. It too is sealed with caulk.

The design of control joints depends on many factors including, but not limited to, fire resistance rating, lateral loads on the wall (including wind, earthquakes, etc.), shrinkage of the materials, amount and types of horizontal reinforcement in the wall, height and thickness of the wall, etc. Also, placement of the control joint in the wall may affect the load distribution. For example, placing a control joint next to a lintel will eliminate arching action from occurring. In such a case, the lintel must be designed to carry the entire load above it including any concentrated loads. Normally horizontal joint reinforcement should be discontinued at the control joint unless it is required for structural purposes.



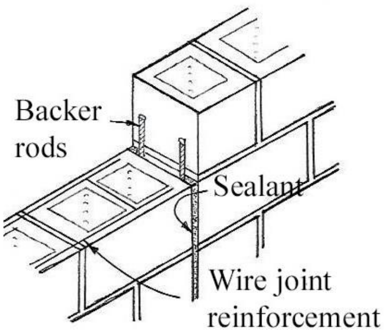
Control joints are constructed by eliminating the vertical mortar joint and sealing the space while also accommodating small movements. The joint is made weather tight by using backer rod and a high quality sealant such as caulk both inside and outside of the completely built wall. Backer rod is a round, flexible, very lightweight length of polyethylene foam ranging in size from about 1/4 –inch to over an inch in diameter – photo on the left.

Caulk joints use backer rod to keep the depth of the caulk from exceeding its maximum workable depth into the masonry joint. The sealant does not bond to the backer rod which insures that the sealant adheres to only two sides during the compression and tension of the joint (drawing on the right). Doing so allows the caulk to expand and contract to its maximum ability. The caulk, if adhered on three sides, will not expand properly under tension – it will likely tear.



Standard Control Joints

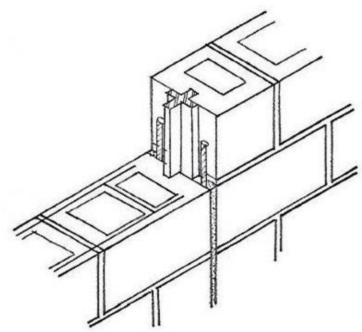
The standard control joint is constructed by simply eliminating the mortar in the joint and sealing both sides with backer rod and caulk. See drawing on next page. When transfer of lateral loads



between two wall panels is not critical, and fire resistance is not a controlling design feature, the standard control joint is constructed to simply provide longitudinal movement and stress relief at specific locations. Notice in the drawing that any wire joint reinforcement used for the sole purpose of controlling shrinkage cracking in the wall should be discontinued at the control joint location.

Joints with Preformed Gaskets

Preformed gaskets can be used as a shear key (a structural term used to denote the ability to transfer loads) to transfer out-of-plane loads across a control joint from one wall panel to the next. The gaskets are molded rubber compounds or PVC compounds. The drawing on the right shows a cross shaped preformed gasket. Other preformed shapes are available, all of which use a concrete block specially formed with a vertical groove in the end –block typically used for the jambs of windows or doors – called a jamb block, or sash block.



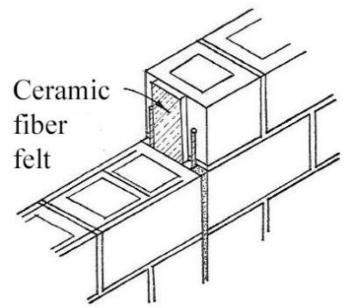
Manufacturers of the preformed gaskets generally list allowable horizontal load transfer limits for design purposes. Preformed gaskets also will meet some fire resistance requirements. For example, the joint shown in the drawing above and the photos below will meet the requirements of a two-hour fire resistive rating.

In the following series of photos, a cross shaped preformed gasket is used in the construction of a control joint. The building happens to be a new car wash under construction where the wall is continuous – i.e., no openings. In the left photo the preformed gasket has been placed in the wall in the first course of block and subsequent courses are laid to fit. A sash unit, being held by the

mason in the center photo, which accommodates the flanges of the gasket, is used to construct the joint. In the right photo notice the clean vertical joint in the wall being maintained by the mason during the construction. The control joint will be sealed later against the sash block, which has a square, flat end and nicely accommodates both backer rod and sealant.

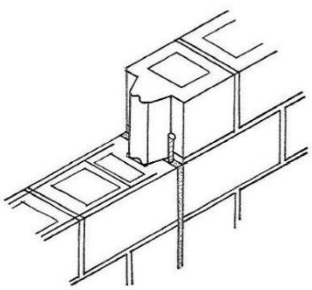
Joints with Ceramic Fiber Felt

Ceramic fiber felt is used in control joints where fire resistance is a controlling design factor and when the transfer of lateral loads between the two wall panels is not critical. This joint in the drawing on the right is the standard control joint with a ceramic fiber felt material in the joint cavity. This joint has a 4-hour fire resistive rating.



Joints with Special Unit Shapes

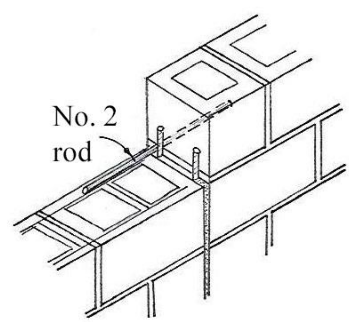
Special unit shapes are concrete masonry units with shapes that are capable of transferring lateral loads across control joints by incorporating a shear key in the design of the block, and provide a fire rating resistance. The drawing on the left shows one type of shear key.



Different units with other shaped shear keys are also used in transferring the loads across the joint, depending on the height of the wall, the spacing between the joints, the severity of the loading conditions, and the fire resistance rating required. When mortar is placed in the joint between the backer rod and the shear key – being careful not to pack it in too tightly causing a bond between wall panels – this joint will meet the requirements of a four-hour fire resistance rating.

Control Joint Reinforcement

Control joint reinforcement can be used when out-of-plane (lateral) load transfer is required between two panels on either side of a control joint as shown in the drawing on the right.



A No. 2 smooth steel bar is placed in the horizontal mortar joint at intervals in the wall – the spacing vertically depending on the design parameters. One end of the rod should be greased or otherwise made incapable of bonding to the mortar, to allow for horizontal movement between the two panels on either side of the joint. When wire joint reinforcement is used in a wall solely for the purpose of controlling shrinkage cracking, it is common to use this method of constructing a control joint. As mentioned before, the wire reinforcement when used only to control shrinkage cracking must be discontinued at the joint location to allow the wall to move horizontally.

For long walls without openings or other points of stress concentrations, the control joints should be installed to break the wall into a series of isolated panels. The length of each wall panel depends on the height of the wall and the amount of horizontal reinforcement (bond beams and/or wire joint reinforcement) placed in the wall. Common maximum control joint spacing is in the range of 25-feet to 60-feet. In earthquake zones, where CMU walls are heavily reinforced, the amount of wall reinforcement – bond beams and vertical steel rods – is usually sufficient so that no control joints are necessary.

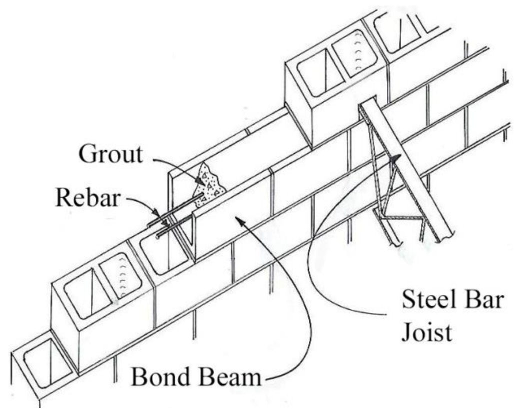
Control joints are also used for separating structural units or dissimilar materials that may have different rates of expansion or contraction. Control joints may be the only method used to control vertical cracking in a wall, or they may be used in combination with bond beams and wire joint reinforcement.

The photo below shows a control joint at the connection of a new building to an existing building – actually two additions and three control joints! Can you find all three control joints? The answer is coming up soon. The original building was a one-story building on the right in the photo. It has a stone masonry veneer. The first addition was a second floor on the original building plus a one story addition containing an entrance door. Notice that the stone on the first addition does not perfectly match the stone on the original building – it just "sort of" matches the original stone veneer. It is usually undesirable aesthetically when adjacent materials just "sort of" match. When the second addition was added, they went with a complimentary looking masonry veneer – clay brick in an appropriate color.

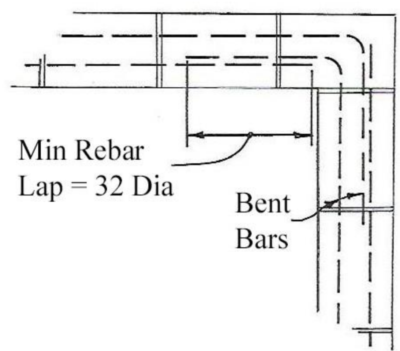
Now, the three control joints are: 1) a visible control joint between the original building and the first floor addition with the door, 2) between the first and second additions between the stone and the brick, and 3) from the left upper corner of the door to the top of the first addition. Without the three control joints, a vertical crack would probably appear at these locations. The photo on the right shows a close-up of the control joint between the first and the second additions. The weather tight sealant is a flexible, pre-formed (folded) piece of rubber compound, sized to fit the width of the control joint. The preformed rubber is used in place of caulk. One other thing, there is no way to tell from the outside view what kind of control joint was constructed – whether it was constructed to just allow for horizontal movement, whether or not it allows for transfer of lateral loads across the joint, or whether or not is has a fire rating.

Bond Beams

Bond beams are beams integral with a concrete masonry wall. While bond beams can be designed to carry vertical loads like lintels, their primary purpose is to resist flexural stresses in the transverse horizontal direction. Bond beams are also used as a means of vertical crack control by resisting longitudinal horizontal tensile stresses in masonry walls. Bond beams are constructed in exactly the same manner that reinforced concrete masonry lintels are constructed – with specially shaped block laid continuous in a course, with structural steel reinforcing bars placed horizontally in those blocks, and the blocks filled with grout. When the grout cures, the bond beam is able to resist horizontal and vertical loads. Of course, the reinforcement for bond beams should be sized to satisfy the structural requirements



Bond beams are continuous along a wall in lengths up to 60 feet as well as continuous around corners. The drawing shows a plan view of the reinforcing steel around a corner in a bond beam. Bond beams often encircle an entire building. They are, however, not usually continuous through expansion joints. When only one bond beam is used in a wall it is usually placed in the top course, or next to top course. Multiple bond beams can also used in a wall – placed as often as every other course.



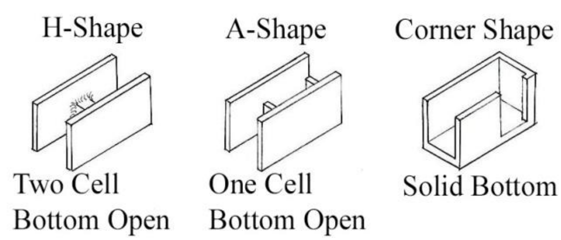
Some other examples of where bond beams are used:

- In foundation walls and retaining walls to prevent overloading from lateral pressure either from the earth backfill or heavy equipment operating too close to the top of the wall.
- In masonry swimming pools – usually every other vertical course – and in the top course.
- Over heavy doors in masonry buildings – to distribute impact loading over a larger portion of the wall than immediately adjacent to the door. Slamming a heavy door may produce cracking at mortar joints.
- In the course of masonry directly under the support beams of a floor or roof loading, such as the steel bar joists in the photo, to distribute concentrated loads over the wall length and thickness.

- To eliminate the need for separate lintels above openings where the head of the opening falls at the bottom of the bond beam course.

- To prevent or minimize vertical crack development. The bond beam offers resistance to horizontal movement of an area 24 inches above and below its location in the wall. Therefore, bond beams located four feet apart helps control vertical cracking in the entire wall height.

Where vertical steel must pass through a bond beam as in, for example, fully reinforced masonry construction where the vertical steel is at 8" on center, the bond beam is constructed of H-shaped block which has no bottom in either core as shown in the drawing. Where vertical steel is placed intermittently, say at 16", 24", or 48" on centers, A-shaped lintel blocks with no bottom in one core, are used where required to allow the vertical steel to pass through. Where vertical steel will not be used in the wall, the bond beam is built with bond beam or U-shaped units having a solid bottom. At corners the corner shaped block is used. A portion of the block is cut away to allow for continuity of the reinforcing steel bars and the grout.



Pilasters

A pilaster is a vertical structural member built of masonry and is a part of a masonry wall. It has a uniform cross section throughout its height and can serve as a vertical beam, a vertical column, or both. Pilasters are bonded or keyed to the masonry wall, and may be flush or projected from one or both wall surfaces.

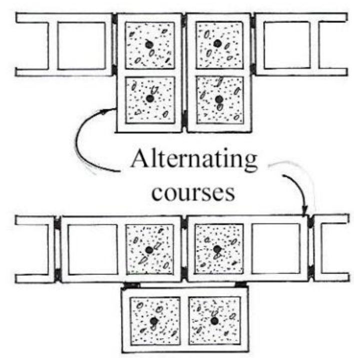
To create a pilaster that acts structurally as a vertical beam – one that supports little or no vertical load other than its own weight – it must be "supported" at each end, both the top and the bottom. The top of the pilaster is supported horizontally at the roof or floor above, and the bottom of the pilaster is supported horizontally at the foundation or floor below. Horizontal (lateral) loads are loads that act perpendicular to the wall, such as a wind load. The wind blows on the adjacent wall panels and the horizontal forces are transferred from the walls to the pilaster via connections, usually tie bars. These loads are in turn transferred to the roof or floor above and the foundation or floor below.

Pilasters that serve as a vertical column rest on a foundation and support a vertical load. The loads are usually in the form of concentrated loads acting at the top of the pilaster, e.g. a beam or girder. Both horizontal and vertical loads can act on the same pilaster. Building codes require at least four vertical steel bars in pilasters, among many other requirements depending on their intended use and magnitude of the supported loads. The structural design of pilasters can be complex.

Masonry pilasters are typically classified as either bonded pilasters or unbonded pilasters. A bonded pilaster – as in bond pattern of the masonry wall – is a masonry pilaster that is built integrally with the masonry wall and firmly attached to the wall as any other masonry unit in that wall. An unbonded pilaster is a masonry pilaster that is not built integrally with the masonry wall. Also, a masonry pilaster can be a combination of the two where one side of the pilaster is bonded to the wall and the other side is not bonded to the masonry wall. To accommodate longitudinal shrinkage of the wall, at least one side of the pilaster must be unbonded to the wall, i.e. a control joint is installed. Unbonded pilasters have at least one control joint on one wall panel. They can also have two control joints, one on each wall panel.

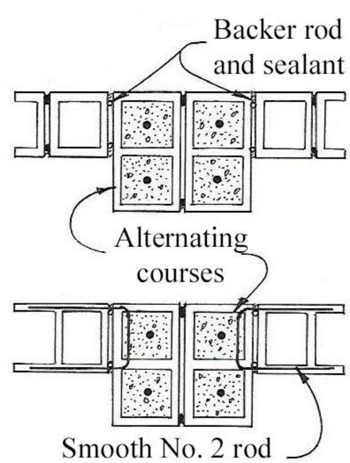
Bonded Pilasters

Bonded pilasters are used when a sufficient amount of horizontal steel is incorporated into the wall to prevent horizontal shrinkage cracking in the wall. Since the need for control joints are eliminated, bonded pilasters can be used. The top two drawings show a typical construction method for incorporating bonded pilasters into a masonry wall using standard concrete masonry units. Bonded pilasters are very good at transferring lateral loads from the adjacent wall panels to the pilaster which acts as a vertical beam. The lateral loads are then transferred to the roof system at the top and foundation at the bottom of the pilaster. The bonded pilaster is constructed using normal mortar joints between masonry units.

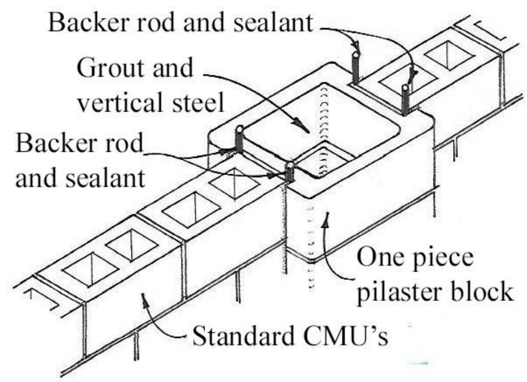


Unbonded Pilasters

Unbonded pilasters are used when a control joint is necessary at that location to control vertical cracking in the masonry wall. The lower two drawings show an unbonded pilaster with one control joint on each side. The control joints at the unbonded pilaster shown must be capable of transferring lateral load from the wall panels to the pilaster while still allowing longitudinal horizontal movement of the wall due to moisture and temperature changes. To transfer the lateral loads from the walls to the pilaster, bent steel dowels are inserted into the mortar joints, usually every other course. Each leg of the dowel is greased or otherwise prevented from bonding to the encasing mortar or grout into which it is embedded. Backer rod and sealant, or caulk, is used to allow longitudinal horizontal movement between the walls and the pilaster.

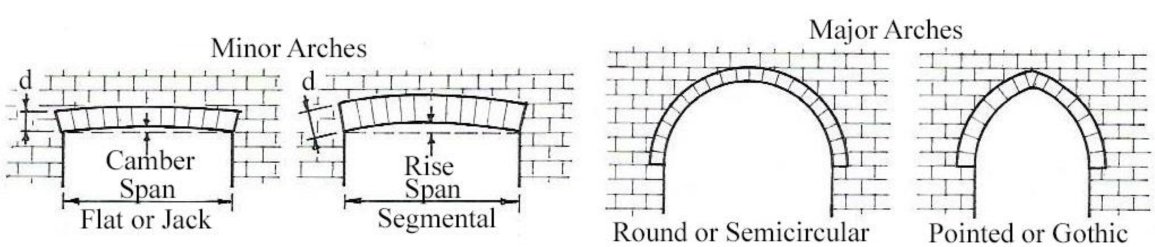


Special Shaped Pilaster Block
Often pilasters are constructed using specially shaped concrete masonry units. The drawing shows a typical one-piece pilaster block with control joints at both sides of the pilaster. There are other specially shaped pilaster blocks that are used for constructing pilasters – including this exact same shape except in two half-blocks. This pilaster is a vertical column only. The joints between the pilaster and the wall panels are sealed with backer rod and sealant and are not capable of transferring lateral horizontal forces from the wall panels to the column. If lateral load transfer were required, "U" shaped steel dowels would be used to transfer lateral loads from the wall panels to the pilaster as shown in the unbonded pilaster drawing on the previous page. Longitudinal movement is permitted between the wall panels and the pilaster by greasing or otherwise preventing the legs of the steel dowels from bonding with the mortar.



Arches
A masonry arch is a vertically curved, rigid, compressive, typically non-reinforced structural member spanning two points of support. It is built integrally with a masonry wall and is made of solid masonry units with full mortar joints. It is commonly built with a uniform cross section with a smooth, continuous curve making it easily adaptable to many architectural styles and applications. A masonry arch may also be built flat, or nearly flat, using specially shaped masonry units or specifically placed units.

Arches are classified as either minor or major. Minor arches have a span of six feet or less and a rise-to-span ratio not exceeding 0.15. For example, at a rise-to-span ratio of 0.15, the maximum rise for a 6-foot span minor arch would be (0.15 x 6-feet) = 0.9-feet, or about 10-3/4 inches. Major arches are those with spans greater than 6-feet or rise-to-span ratios greater 0.15. If this same 6-foot span arch had a rise greater than 10-3/4 inches, it would be classified a major arch.



The Flat or Jack arch has what is called a camber instead of a rise. A camber is a very slight bend in the member. In the case of a minor arch, it would be in the order of about an inch or less. The Segmental arch has an actual rise of a few inches, not to exceed 10-3/4 inches.

The most common arch loadings are uniformly distributed loads over the entire length of an arch, and concentrated loads acting at the center of the span. Both loading conditions must have a sufficient amount of masonry wall above the arch to properly support the loads. Arches are very good at supporting uniformly distributed vertical loads acting along the full span of the arch. Of course, if both loading conditions are acting on the same arch, the results of the forces generated by the loads must be combined. To load an arch unsymmetrically defeats its use as a natural load-carrying structure.

The magnitudes of the loads arches carry are similar to those of lintels. That is, because of the arching action of the masonry wall construction above the arch (with masonry laid in running bond pattern), an arch need only support that triangular area of the wall formed by a triangle with sides forming a 45^{o} angle with the horizontal.

Loaded arches generate a relatively large horizontal thrust at its supports. This horizontal thrust at the arch supports is large for two reasons. First, the arch itself, even though it only carries a relatively small load its shape is conducive to producing large outward horizontal thrusts. And, second, the weight of the masonry wall above the triangular area also creates a horizontal thrust (as discussed in the Lintel section) separate from that of the arch. The sum of these thrusts is relatively large.

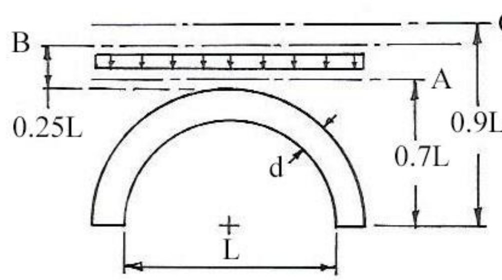
The usual governing design condition for an arch supporting only a uniformly distributed load (the most common case) is the compressive strength of the masonry units. At failure, the masonry units will be crushed. The governing design conditions for a concentrated load applied to the center of an arch will 1) usually induce bending stresses and fail the arch by causing a portion of the arch to incur tensile stresses, or 2) perhaps be shearing between adjacent masonry units in the arch.

To give an idea of some of the governing design conditions, let's take a look at one special case –a semicircular arch with the radius equal to half of the span = 0.5L, located in a clay brick veneer wall. We'll consider first, a single uniformly distributed load acting on the wall above the arch, and then second, a single concentrated load acting on the wall directly above the center of the arch. These are a few of the many specific, individual, calculations and considerations necessary to properly design a specific type of arch.

The following assumptions apply to an arch carrying only a uniformly distributed load. See the drawing on the next page.

- There must be a minimum amount of masonry above the arch. No superimposed loads are permitted below line A located at 0.7L above the horizontal axis of the arch.

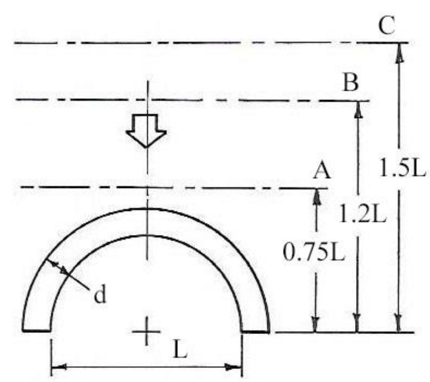
- If arching action occurs in the brick masonry wall above the arch (typically in running bond), any superimposed uniformly distributed loads above line C located at 0.9L above the horizontal axis of the arch may be ignored**.**
- Only the uniform loads applied between the two lines A and B (the masonry between the top of the arch and 0.25L) are considered in the design of the arch. Note that depending on the thickness of the arch, line B may be above line C.



- The portion of the wall that resists the horizontal thrust of the arch is assumed to be rigid, i.e., no horizontal movement.

The following assumptions apply to only an arch supporting a concentrated load applied at the centerline of the span:

- There must be a minimum amount of masonry above the arch. No superimposed concentrated loads are permitted below line A located at 0.75L above the horizontal axis of the arch.



- If arching action occurs in the brick masonry wall above the arch (again, typically running bond pattern), any concentrated load acting above line C located at 1.5L may be ignored.
- Only the concentrated loads applied between line A and line B located at 0.75L and 1.2L respectively, are considered in the design of the arch.
- Concentrated loads occurring between line B and line C located at 1.2L and 1.5L respectively may be divided by the span of the arch (length L) and considered as a uniformly distributed load.
- The portion of the wall that resists the horizontal thrust of the arch is assumed to be rigid, i.e., no horizontal movement.

There are other conditions and restrictions that are used in the design of any arch that take into account:

- Loads applied in combination, i.e., both concentrated loads and uniformly distributed loads applied at the same time.
- The width of the arch, e.g., a roadway bridge is obviously much wider than a brick veneer arch in a wall.
- The determination of horizontal thrust and the mass of adjacent wall to resist this thrust.

- The overturning moment – if any – at the supports.
- The resistance to overturning which is a function of overall axial load in the arch, the wall shape and bond pattern.
- Steel reinforcing in the wall, if any.

Masonry arches can be varied and complex design problems.

All arches are constructed in the field in essentially the same way. A formwork or supporting system – usually wood – in the shape of the proposed arch is first built and placed in the location of the future arch. The masonry units are then placed in the arch, beginning at the bottom and progressing upward. At the top center of the arch, a keystone block is finally laid which locks the pieces together.

Keystone *The central wedge-shaped stone of an arch that locks its parts together: Something that is the central supporting element of a whole.*

Often the keystone is ornate in some fashion, and can also serve as an architectural feature. Other times the keystone unit is identical to the arch units. The masonry wall units may, or may not, be laid at the same time as the arch units. The photo above left shows a window with an arch made of six curved limestone units with a center wedge shaped keystone block. Until the keystone is placed the arch had no structural value. The mortar joints in the limestone arch are barely visible in the photo. The area under the arch and above the window is a cementitious plaster coating over a wood backing and serves no structural function.

The photo on the right shows an arch made with clay brick units. A wooden form was first built and shored in place. Then the brick were laid on the form beginning at the ends and working toward the center of the arch. Until the last brick was laid in the center of the arch, the arch had no structural value. Its keystone unit is simply another clay brick.

The photo on the left shows two carpenters working on the nearly completed wooden form for the clay brick arch.

The photo on the right shows an arched canopy leading to the entrance of an ambulatory surgery center in Lafayette, IN. It is an example of using a structural steel framing system with a brick veneer finish. The clay brick veneer must be able to support its own weight. The underside of the entrance canopy is nicely finished with wood.

The photo on the left is another nice masonry arch over an entrance to a basement recreation area in a Michigan State Park. Notice the three courses of clay brick composing the arch.

Here are two more examples of masonry arches above windows. The photo on the left seems to just be a simple lintel. In fact, because its supports do not bear directly downward on supporting masonry, but rather "push out" on the wall, it is considered a Flat or Jack arch. The photo on the right shows an example of a Segmental arch. It too "pushes out" at its supports, plus it also has a keystone block. The clay brick between the limestone supports and the keystone block slope to match the angle of the support blocks. These are both located on the Purdue University campus in West Lafayette, IN. College campuses are great places to see a variety of nice arches.

The four story building shown on the left is a good example of using arches as load bearing structural supports. The red clay brick exterior on the left side of the building is a load bearing solid masonry wall with multiple arched openings above the windows. Wooden floor joists bear on the 18-inch thick masonry walls above the arches. My partners and I bought this building and did a historical renovation converting the former warehouse space into Class A professional offices. We were proud to have received a Historica1 Preservation Award for the project.

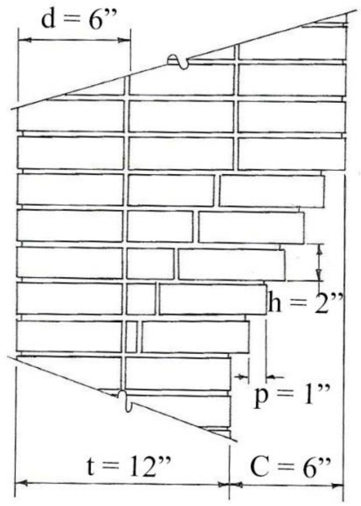
Arched masonry bridges are an entirely different design problem, but with the same aesthetically pleasing result. The loads are much greater than in residential and commercial buildings, and the loads are not often symmetrical. Notice the very large support abutments required to resist the horizontal thrusts. There are many nice looking and interesting masonry arch bridges in the State and National Parks systems.

Corbelling

> **Definition. 1.** *The building of a corbel.* **2.** *An overlapping arrangement of bricks or stones in which each course extends farther out from the vertical of the wall than the course below.*

A **corbel** is essentially a shelf or ledge constructed by laying successive courses of masonry that project <u>out</u> from a wall, pier, or column. A corbel can be used as a structural device to support a cornice or an arch, or as an architectural feature. **Racking** is the term used when successive courses of masonry are stepped <u>back</u> from the face of the wall. Racking back is used to reduce the dimension of the wall to the desired thickness.

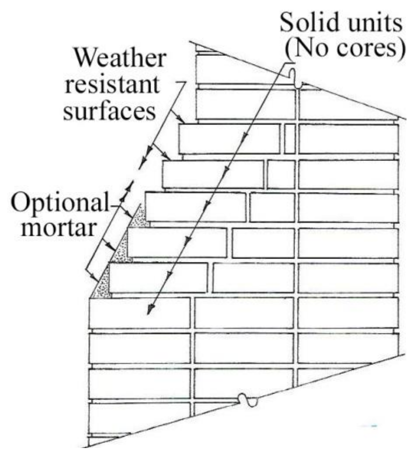
There are certain building code limitations to corbelling, i.e., constructing a corbel. Using the drawing as a guide, the maximum total corbel projection, C, from the face of the wall cannot exceed one-half the thickness of the wall. If the wall thickness, t, is 12-inches, the maximum total corbel projection is $C = \frac{t}{2} = 12"/2 = 6"$.



The projection, p, of each individual masonry unit in the corbel is limited to the lesser of two dimensions: either p equals one-third of the nominal unit bed depth, d, of the masonry unit plus the thickness of one mortar joint (d = 6” in the drawing), or p equals one-half the nominal unit height, h, of the individual masonry unit plus the thickness of one mortar joint (h = 2’ in the drawing). In this case, the maximum projection of each individual corbelled unit will be the lesser of:

$$p = {d}/{3} = {6"}/{3} = 2" \quad \textbf{OR} \quad p = {h}/{2} = {2"}/{2} = 1"$$

Obviously, 1” is less than 2”, therefore the maximum overhang of each individual corbelled course is p = 1”.



Racking on the other hand, has no structural limit on the amount of offset of each individual unit. However, the racked unit above should only be set back a distance that allows a full mortar bed under the end of the racked unit and NOT expose a core in the unit below. The preferred construction technique includes using solid masonry units in the exposed racked area with weather resistant surfaces. Note that when using weather resistant units the absorption rate of water by the bricks from the mortar is decreased, causing a weak bond between units. Adding a compatible bonding agent to the mortar insures a proper bond between the units. An optional mortar wash along the racked faces is sometimes also used.

The photo on the right is an excellent example of what can be done with corbels. Here is a building that is well over 100 years old and, even though it is showing some signs of weathering, it is still a beautiful example of skill and craftsmanship of the masons that did the work so many years ago.

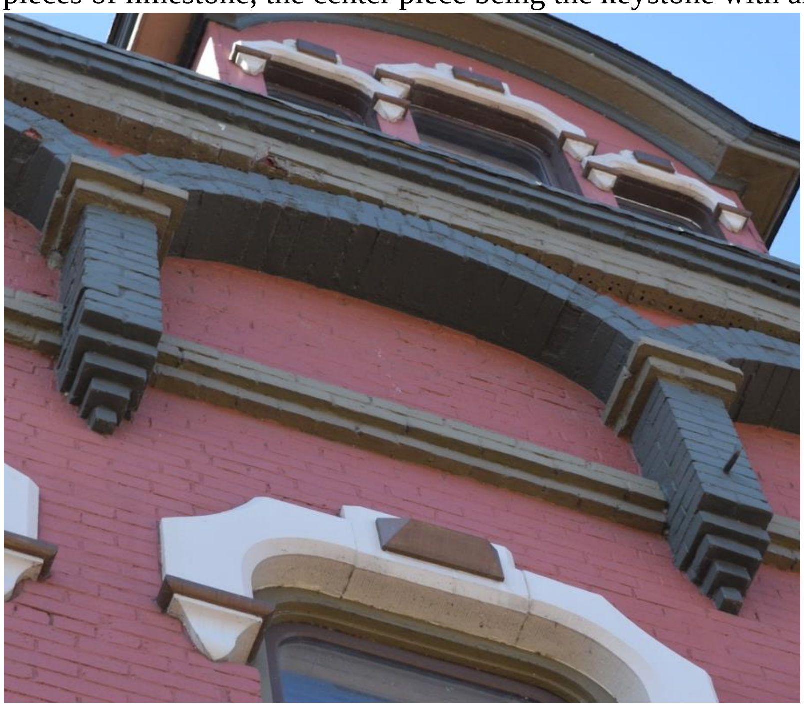
Beginning at the top of the window is a nice segmental arch made using clay bricks laid in the soldier position. Next up the wall is the first corbel.

It is a course of brick laid skewed to the wall with only the corners visible – a nice architectural touch. Notice that the projection is within maximum allowable limit for a corbel. Above that corbel the entire face of the wall is held out away from the main wall. The wall is sitting on top of the corbel shelf of angled bricks. Keep in mind that the main wall below where the corbelling begins is several wythes thick, at least three, maybe four wythes at this height up the wall, allowing for a total corbel of half that thickness.

Continuing up the wall is a series of quoins – rectangular sections – corbelled again. Above the quoins, the wall, which is now the parapet of the building, is again corbelled once for a total of two courses. Then another two courses are each corbelled. Finally, the top course of brick is laid along the top of the wall. This photo was taken in a very old, very small town in southern Michigan. Small towns are good places to find unique examples of corbelling.

This last photo is of a building directly across the street from the building in the previous photo in the same small town. The masonry work is even more artistic than the last. Before we begin, let's give the colors of the building names to help us see some of the special features of the impressive craftsmanship. Let's use red for the main wall color, brown for the arch keystone feature, grey for the horizontal features and blue for the arches and columns. Of course those are not the correct color names, but those will do for us to more easily follow along with the narrative.

Beginning at the lower window, the corbelled arch directly above the window is made of three pieces of limestone, the center piece being the keystone with an understated architectural flair.



The central focus of the architectural designs of the front of the building is the blue corbelled arches – including the blue supporting corbelled columns. The blue columns begin with a single masonry unit corbelled out at the bottom. Four courses of corbelling above are then used to expand the size of the column in three directions to the desired dimensions. The full sized column extends upward where its top has a corbelled cap – the grey units. Self supporting arches are then constructed using appropriate formwork to support the masonry units until the capstone unit is in place. In this case the capstone unit is simply the last unit placed in the arch to make it structurally sound. The bricks in the arch are laid in the rowlock, or bull header, position to match the depth of the columns. The horizontal thrust of each arch is resisted by the thrust of the adjoining arch.

After the arches are completed, the formwork is removed and the masonry wall is continued up to the underside of the arch. The red wall above the arches is a wythe or two thicker than the main wall of the building. Above that red wall is a grey horizontal corbelled feature three courses high. Notice the holes on the underside of the grey protrusion. They are the "dark spots" on the underside of the bricks – hard to see in the photo. Those are cores in the bricks from the brick manufacturing process. Being open from the bottom is ok because water does not enter into the wall. These three courses are then topped with three more courses – in blue – with each course corbelled again to the top of the wall. The entire wall is then capped with a sheet metal cap – the edge can be seen along the top of the wall. Notice also the grey horizontal corbelled feature extending between the lower portions of the corbel columns.

You may be wondering if perhaps much of the corbelling is protruding beyond the maximum limits of the building codes, i.e., half of the wall thickness. First, that is impossible to tell from the outside because there is no way to know exactly how thick the masonry wall is. And, second, there were no codified building rules and regulations in effect in this area when this building was built well over 100 years ago. Well, then, how did the builder and designer know it would be safe to have protrusions this large if there were no building codes? Because, this is an example of an empirical design, which was the method used before we had written, codified building codes. Empirical design is where the design is "based on data derived from observation and experience" as previously discussed in the design section of this course. Obviously this designer and builder knew the extent of safe corbelling from experience – because, again, this building is well over 100 years old.

Above all of that sits the top feature of the building architecture, a single room perhaps, or maybe a gable protrusion from the building roof, probably unoccupied now. This building has been recently restored to bring it back to its original splendor. Saving old buildings is a worthwhile use of the time and resources needed to accomplish the task.

The next photo shows a common example of racking. A fireplace was built in the exterior wall of the home with a flue extending up to the top of the building. The fireplace is wider than the flue, so it is not necessary to maintain the fireplace width to the roof. Hence, racking back to the width required for the flue is most appropriate. Because racking was chosen on only one side of the structure, the flue from the top center of the fireplace was sloped (to the left in the photo) to keep the hot gasses centered in the masonry enclosure.

The final photo shows using corbels strictly as an architectural feature on the side of a brick

masonry building. There is no other practical use for the corbelling other than to add some texture to an otherwise plain, ho-hum masonry wall. It works. Three of the four corbellings are triangular in shape. They are constructed using individual bricks set at an angle to the wall. The bottoms of the corbels are corbelled out and the tops of the corbels are racked back. The fourth corbel is rectangular in shape, corbelled at the bottom, racked at the top. It is used to provide architectural interest at a safety overflow channel for excess water on the flat roof of the building. The overflow is not expected to be used except in an emergency situation – such as a partially plugged drain during severe rain. The parapet walls each end on either side above the rectangular corbel. Notice that the designers also stepped down the left portion of the top of the parapet to give some added relief to the wall of the building. And notice too, that they used limestone caps on the parapets.

Flashings, Copings, and Caps

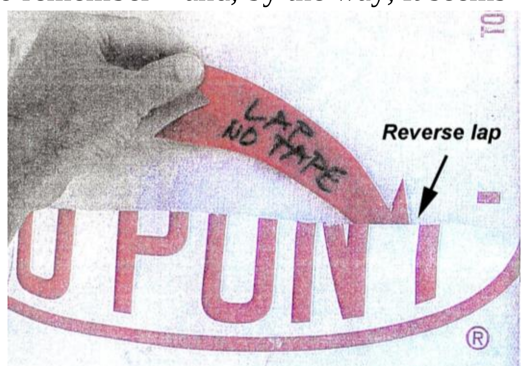
Preventing water penetration through a wall is one of the major considerations of masonry design and construction. Water through an exterior wall can cause deterioration of wood framing, insulation, and interior finishes. Almost all water penetration problems are construction issues.

It is nearly impossible to prevent ALL water and moisture from passing through a single wythe masonry wall – for example through the single course of brick on a wood framed, brick veneer home. However, several lines of defense have been developed that, when properly executed, have proven to be quite effective at preventing the water and moisture from reaching the vulnerable parts of a building – sheathing, framing, interior finishes, etc. The most important of these, and, unfortunately, probably the most commonly constructed incorrectly, are flashings, copings, and caps.

Flashings

The primary purpose of flashings is to collect and divert moisture that has entered into and through a masonry wall. Flashing was introduced in Fundamentals of Masonry – Part A as a component of a cavity wall system. Proper flashing allows water that penetrates the brick veneer to travel down the backside of the brick and exit the cavity through weep holes in the brick appropriately placed at the bottom of the wall cavity.

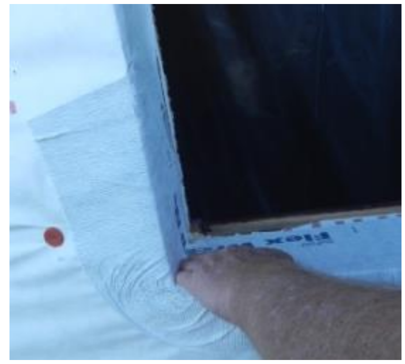
Flashings can be made of many different materials including copper, stainless steel, galvanized steel, EPDM materials, bituminous membranes, and several proprietary products such as DuPont™ Tyvek® Water Resistant Barriers (WRB) and others. Flashings should be made of durable and long lasting materials, and be properly constructed. The cost of repair of improperly installed flashings is almost always very high. Often the entire masonry veneer must be removed from the wall to get to the improper flashings. Once the flashings are repaired or, most likely, replaced, the masonry veneer must then also be replaced.



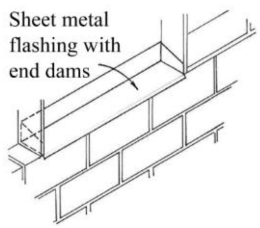
When installing flashings, the most important concept to remember – and, by the way, it seems silly to have to point this out, but here it is anyway – is to overlap separate pieces of flashings and water barriers in the direction of water flow. The upper piece overlaps on top of the lower piece, to prevent water flowing, due to the downward force of gravity, in behind the lower flashing, i.e., between the flashing and the wood substrate. This downward over lapping is called **shingling**. "Water runs down hill" is normally the rule of thumb to keep in mind. I personally prefer the reference to rain pants and boots – "If you tuck your rain pants into your boots, your feet will get wet." That's called a reverse lap. A **reverse lap** directs water behind the piece below, guaranteeing that any wood behind the lower piece will eventually incur water damage. The photo on the right shows a reverse lap in a residence under repair for water intrusion that caused damage to the interior. The worker that installed this wrap obviously had no idea of the fundamental principles of flashings.

The procedures for installing flashings properly are generally similar for all openings – overlap properly and seal all openings against entry of moisture. We'll use a residential/small commercial type window installation to illustrate the proper procedure for flashing an opening in a wall. Successful flashings around windows follow prescriptive procedures. There are many details that must be done properly. Messing up any one of them can cause a leak in the building envelope. The building envelope is everything outside of the building frame that keeps the inside dry, including: water resistant barrier, siding, windows and doors, roof, etc. It is necessary to seal the frame of windows to the building as well as keep water from getting to the sheathing at the interface of the window frame and the wall.

First, the wood sheathing covering the wood structural framing of the building is wrapped in a WRB, which in this case happens to be DuPont™ Tyvek® WRB. There are other proprietary products on the market that will also do the job. It is applied by wrapping the entire structure with the WRB, applying the lower layer first, then the layer above to achieve proper shingling (usually 6" overlap) and attaching using proper fasteners, and carefully following all installation procedures. The wrap is then cut at the openings and wrapped around the window jambs as can be seen on the top of the photo on the right on the next page. A portion of the wrap at the top of



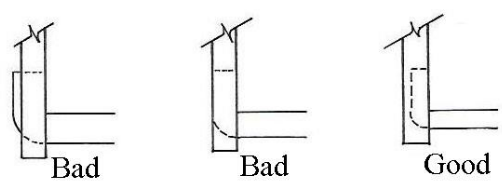
the window is cut and folded out of the way until after the window is installed as shown in a later photo. Next a sill sealer is applied being sure to include proper end dams at each side, again as shown in the photo on the right. The end dams insure any water that gets behind the window will not drain off the side but rather flow down and out from under the window. Also notice the red plastic "washer" on the fastener used to attach the wrap. The washer prevents the wrap from tearing and also seals the penetration made by the fastener to prevent the entrance of moisture.

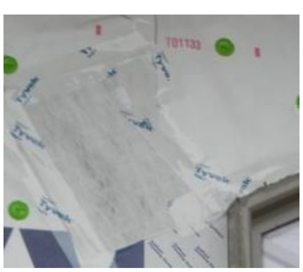


There are other ways to construct proper end dams. The drawing on the left shows one made of sheet metal. It is important to solder all joints properly to prevent any leakage.

The photo on the right shows the window being placed in its opening. Notice the wrap folded up across the top of the opening. It will be unfolded, trimmed to fit the curvature of the window, and be sealed over the top flange of the window on completion of the installation. In the photo on the left the window has been caulked around the perimeter flange prior to placing into the opening. Notice that the bottom flange of the window is not caulked. If water does somehow get behind the flanges, it must be allowed to drain to the bottom and exit out onto the sill sealer and drain downward.

The window flanges are next sealed against the WRB using special sealing tape. The tape is applied to the jambs first (the bottom of the window is not taped) and extends up past the top corner of the window. The drawing on the right shows the proper placement of the lower end of the vertical tape over the sill sealer and end dam. The next photo shows the top flap of the wrap had been brought down over the top flange of the window. It has been trimmed to fit the profile of the window top, and then taped using sealing tape to the top flange. The vertical and diagonal cut edges of the WRB that were made to fold the flap up are then taped to seal them against water penetration as shown. When done properly no water will enter through or





around the window opening. When done improperly, it's almost guaranteed to leak at some point. It is important to follow all instructions of the manufacturers of the WRB carefully and to the letter to prevent water intrusion into and through the building envelope.

The photo on the left shows a rectangular opening, in this case a door, properly taped at a top

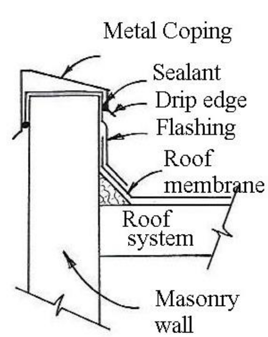
corner. Notice that the top piece of tape completely covers the top edge of the vertical piece of tape. This is done to insure no moisture gets behind the vertical tape. When the installation is complete, any water that penetrates the exterior masonry veneer and reaches the exterior of the water resistant barrier above the opening will flow downward, and in every instance, flow over all laps and continue down the wall to the weep holes for exit – all because of the shingling of the wrap and proper installation of the sealing tape.

It's interesting to note that very old masonry buildings did not contain any flashing, and yet they didn't leak. This was because they were built with multi-wythe walls. Even though water will pass through a single wythe, it cannot penetrate completely through a solid brick wall that is at least three courses thick. The maximum depth of wind driven rain into solid masonry construction is in the range of four to six inches. Masonry walls thicker than that are too thick for the moisture to pass completely through. Hence, no leaking. And, no need for flashing.

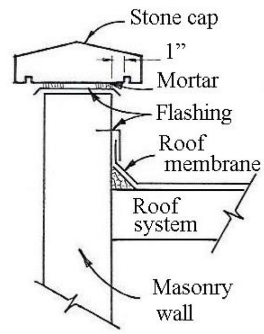
Copings and Caps

Copings and caps are masonry units or other materials used to finish off the top of a wall, pier, chimney or pilaster to protect the masonry below from water penetration through the top. Copings and caps used as flashings for wall tops generally serve a different function from flashings used elsewhere in the structure. The prime function of copings and caps is the <u>prevention</u> of the entry of water into the wall. Collecting and discharging the water is a secondary, but still important function. The terms coping and cap are interchangeable. They both describe the same thing.

Copings always have a sloping top surface to allow water to drain off. If the wall is a parapet wall above the roof of a building, the discharge slope is toward the roof to prevent excessive moisture from running down the outside face of the masonry building. Sometimes, if the cap is a coping block, limestone for example, the cap will have a peak down the center and slope both ways – with a drip edge on each side. All copings and caps contain a drip edge to deter the water from flowing directly down the wall.



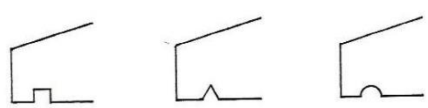
The coping shown in the drawing on the right is made of sheet metal. It could also be made of stainless steel, galvanized steel, copper, or a similar product. The cap is placed over a layer of standard flashing material that prevents any water that inadvertently leaks through the cap from entering the top of the wall. The top of the cap slopes downward toward the roof to discharge water. Notice the drip edges on either side of the coping material. The drip edge is formed on a sheet metal cap by turning out the edge of the metal 1/4-inch. This forces the water to move away from the wall and drip off without necessarily touching the wall. The cap fits completely over the parapet wall and down the sides a few inches. In other cases, if the parapet wall is taller above the roof and covered with a smooth material such as a rubber or EPDM membrane, water can migrate up the wall about three-inches between the cap material and the wall membrane due to surface tension. In those cases, the coping side should extend down the side wall at least 4 inches. Notice that in that case water would be migrating uphill, against the force of gravity.



If the coping is a masonry product, i.e., limestone, precast concrete, etc, the cap will extend past the faces of the wall as shown in the drawing on the right. In either case, a drip edge is cut into the bottom of the stone at least 1-inch from the face of the wall.

The photo on the left shows an exterior masonry column base with a cast-in-place concrete cap. After the form was built, but before the concrete was placed, a one-half inch diameter half-round piece of wood trim was placed in the bottom of the form to form the drip edge. The photo on the right shows the completed cap from the underneath showing the drip edge. The drip edge is on all four sides of the cap. It is placed just over one-inch away from the face of the stone to prevent water from running back along the underside of the cap and draining down the stone wall. Water will not travel horizontally across a properly made drip edge.

Other shapes of drip edges are also common – such as those shown in the drawing on the right.



Brick masonry can be used as the cap or coping material. For example, the photo on the right shows brick placed in a rowlock position as the sill for a window. In effect, the sill is the cap for the masonry wall below. When brick in a rowlock position are used as copings, they should be sloped at least 15° minimum to shed water (as they are in the photo). The lowest

point of the brick acts as the drip edge and should be 1–inch minimum from the face of the wall. This one is a bit short of the 1-inch minimum. Great care should be taken to insure that all bed and head joints are completely filled with mortar.

What Can Go Wrong?

When competent designers and skilled masons follow the proper principles of masonry construction, projects are built correctly. Many examples in these two courses, Fundamentals of Masonry – Part A and Part B, have included buildings that are well over 100 years old. They are structurally sound, dry, and still very aesthetically pleasing to the eye. Some masonry buildings however are not fit for occupancy in only five or ten years after being built. Why is that?

Let's complete this course by taking a look at one component of a failed masonry construction project from discovery through resolution. It was a water issue.

The building was built less than ten years earlier. The owner was a small local business. Large groups frequently gathered for social events in the building. The building had large open spaces, several upscale offices, and was very nicely finished on the interior. It was a one-story building, with a stone masonry veneer over a wood frame. It was perfect for the business and it looked beautiful.

The owners first noticed there was a slight musty, moldy odor in a room from time to time. They put a portable dehumidifier in the room. It mostly worked. The odor disappeared during dry spells of weather. However, after each fairly heavy rain, the odor returned. They contacted the builder. He stripped the wall paper from the inside of the wall in that area and found some dark stain on the drywall. It was mold and it was causing the odor. His solution to the problem was to treat the drywall with a liquid product that prevents mold growth, and then repaint the wall.

When that fix didn't solve the problem the builder next said that there were no weep holes in the masonry wall in that area to allow water drainage from between the sheathing and the back of the masonry veneer. His solution was to simply drill holes in the masonry veneer near the bottom of the exterior wall (photo on right). That didn't solve the moisture problem either because no thru-wall flashing had been originally installed nor was there a cavity between the masonry veneer and the wood sheathing. The builder finally said the warranty period for his work had expired and it was no longer his problem. Bad feelings developed, and legal action followed, including an investigation by an expert.

The expert's report cited several specific issues with the construction of the masonry veneer, including several instances of improper flashing installation, no proper weep holes, improper drainage space behind the stone veneer, improper installation of the window sills, and lack of quality masonry work. These all contributed to the mold growth and its odor.

Now, let's take a closer look at just one of the issues – the improper installation of the single window sill shown in the photo on the right. We'll look at the errors of installation, the results of those errors, and how the moisture problems of the entire building were resolved.

In our discussion of copings and caps in this course, we noted that a window sill is considered a cap on the masonry veneer below the window. The function of the sill is to protect the masonry from water penetration by sealing the top of the wall, providing a slope to drain the water away from the window, and to provide a drip edge to allow the drain water to fall to the ground without necessarily washing over the masonry.

Brick laid in a rowlock pattern is an effective and attractive way to construct a proper window sill. To function properly the top of the cap should slope at a 15^{o} angle to allow water to drain away from the window. A brick window sill should also extend out from the masonry wall a minimum of one-inch to allow the bottom corner of the bricks to act as a drip edge for the runoff. All the window sills on this building violate those two main principles – sloping top and overhang with a drip edge.

The photo on the left shows the brick sill and a hand level to indicate the direction of slope. Not only does it <u>not</u> slope downward away from the building, it actually slopes downward <u>toward</u> the building. Notice the bubble in the center of the hand level is to the left, the indication of a downward slope toward the right, toward the window. Any water that hits the sill will be directed toward the window. Any slight error in the flashing of the window will allow water to enter at the window and onto the wood sheathing.

Also, as can be seen in the photo on the right, there is no overhang for the brick sill. The face of the brick sill is flush with the veneer. Consequently, there is no drip edge on the bottom of the cap. The result of this critical error is that any water that manages to run away from the window will drain directly down the exterior face of the masonry wall and pass through any cracks in the masonry – like the one in the photo. This just increases the potential for water damage in the wood framing system.

A small hole was cut through the wall under the window from the inside of the building. Luckily there was a cabinet under the window allowing the hole to be in an inconspicuous place. The photo on the left shows a moisture meter being used to check the moisture content of the plywood sheathing on the outside of the wood frame structure and behind the masonry veneer. Normal moisture amounts in wood framing range from zero to around 10 to 12 percent, or so. Although it is a bit blurry, the photo shows a reading of over 60% moisture in the plywood. This excessively high moisture reading is indicative of large amounts of water penetrating the veneer and bypassing any flashings, thereby getting to the plywood. The plywood sheathing is soaked.

The major contributors to the intolerable condition were the improper installation of the window sill and the window flashing. The window flashing was reverse lapped over the bottom flange of the window. This error allowed water to literally flow behind the water resistant barrier and directly on to the face of the plywood sheathing. This condition allowed rain water to soak the sheathing every time it rained.

The photo on the right shows an area of plywood that is totally decayed under the window, exposing fiberglass wall insulation. This is the type of damage typically resulting from the regular entrance of rain water. Remember, this building was not even ten years old.

To correct this and all the other construction errors, the entire exterior stone masonry veneer and water resistant barrier were first removed from the building. All plywood sheathing was inspected and the water damaged areas were removed and replaced as were the appropriate windows and doors. A few wood studs were also water damaged to the point that they needed to be removed and replaced necessitating appropriate repairs to affected portions of the interior finishes.

The photo on the right shows an area of a wall with the exterior plywood sheathing and the wall insulation removed. The studs and back of the interior drywall were treated with a commercial product that prevents the growth of mold and seals any mold spores that may have still been on the stud and drywall surfaces. New insulation and sheathing was installed. This was followed with new water resistant barrier and flashings. Finally, the entire stone masonry veneer was replaced. Luckily the nearby quarry still had a supply of the original stone. It was identical to the removed stone.

In addition to the poor quality workmanship, there were design errors. The plans prepared for the construction of the building were poorly done and incomplete. For example, the plans had no flashing details for openings in the walls, and no detail for the proper installation of the rowlock brick window sills. And, finally, there was no competent inspector working for the owner to oversee the construction to help guard against such mistakes.

The repair was very expensive. Not including legal fees the owners spent about $300,000 in 2012 dollars. This was simply an unnecessary expense. It brings to mind an old saying “Why is there never enough time to do it right, but always time to do it over?” Doing it right the first time is certainly less expensive than the cost to do it over. This was a bad situation for the owner of this less than ten year old building. Nuts. ☹

On a happier note, the repair work was successful. There are no leaks, the building is beautiful, and the owners are pleased with the results.

In the next course, **Fundamentals of Masonry – Part C**, we will take a look at some other examples of improper design and construction practices; show and discuss other masonry products, including glass block; and other construction methods and techniques such as what is involved in completing a clay brick masonry street.

Credits
(And Where to Learn More)

BIA
The Brick Industry Association (especially the *Technical Notes*).
Reston Virginia, 22091.
www.bia.org
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NCMA
National Concrete Masonry Association (especially the *NCMA – TEK* notes)
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IBC
International Building Code,
International Code Council,
5203 Leesburg Pike, Suite 600
Falls Church, Virginia 22041-3401
(703) 931-4533

PCA
Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60077
(847) 966-6200

MCAA
Mason Contractors Association of America
1481 Merchant Drive
Algonquin, IL 60102
(800) 536-2225

Recommended Practice for Engineered Brick Masonry, November 1969
Structural Clay Products Institute
1750 Old Meadow Road
McLean, Virginia 22101

Building Construction Materials and Types of Construction, Sixth Edition, 1987
John Wiley & Sons, Inc.