Chapter 2

Methods of Kiln Construction

The laying of firebrick in kiln construction is a specialized masonry skill. There are rules that must be followed to ensure a strong, monolithic structure that will function efficiently at high temperatures and be durable.

STRAIGHT-WALL CONSTRUCTION

There are three vital rules in straight-wall construction: (1) An unsupported wall 4 1/2" thick cannot be higher than 3 feet; (2) an unsupported wall 9" thick, tied by alternate header and stretcher courses, cannot be higher than 8 feet; (3) an unsupported wall 13 1/2" thick, tied by alternate header and stretcher courses, cannot be higher than 12 feet.

There are five basic methods of laying straight walls: header course, stretcher course, alternate header and stretcher, rowlock course, and soldier course.

HEADER COURSE

In a header course, bricks are laid lengthwise across the wall with the 2 1/2" x 9" side butting against the next brick (Fig. 2-1). All header courses develop a reasonably stable wall with minimum hot face exposure (4 1/2" x 2 1/2") and the back side of the brick subject to relatively low temperature. Header courses are good for bricks facing near temperature limits.

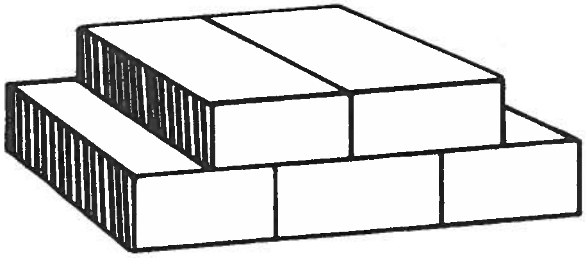

Fig. 2—1: *Header course, with bricks laid across the wall.*

A wall laid mainly of headers, which normally consists of three or four rows of header courses to one row of stretcher courses (Fig. 2-2), has the advantages of an all-header wall but has greater rigidity.

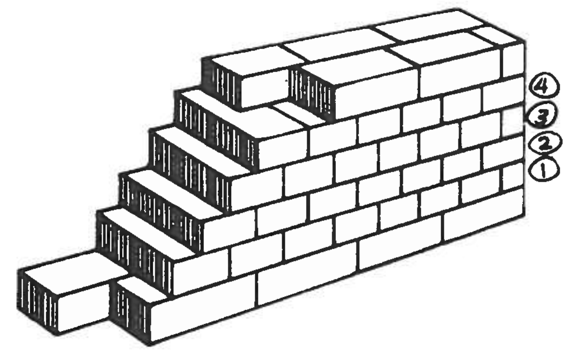

Fig. 2—2: *Alternating four header rows with one stretcher row gives greater rigidity.*

STRETCHER COURSE

Stretcher courses are laid lengthwise, running with the wall so that the 2 1/2" x 9" surface becomes the hot face (Fig. 2-3). An all-stretcher wall is not rigid and is not recommended for over 3 feet in height unless it has other means of support.

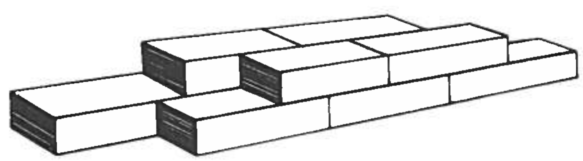

Fig. 2—3: *Stretcher course, with bricks running along the wall.*

A wall laid mainly of stretchers, which normally consists of three to four rows of stretcher courses to one header row, as shown in Fig. 2-4, is a much stronger wall and has an important advantage. In a kiln where bricks are subject to slagging or other erosive action, such as occurs in a wood-fired kiln or salt-glaze kiln, the exterior face can be easily repaired by replacing the 4 1/2" x 9" hot-face brick with another, or a 4 1/2" skin wall (ram mix) tied into the remaining bricks.

ALTERNATE HEADER AND STRETCHER COURSES

Alternate headers and stretchers in walls of 9" and 13 1/2" thicknesses are extremely stable. This is considered good practice in bricklaying.

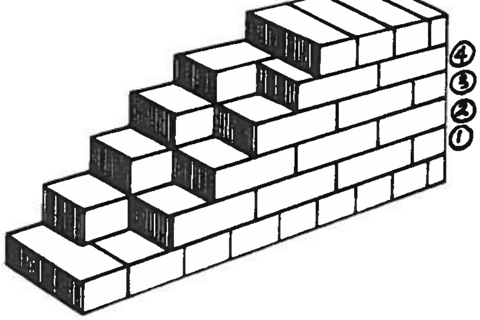

Fig. 2—4: *Alternating four stretchers with one header makes it easy to replace a hot-face brick.*

It is also considered good practice to have alternating joints on each row, which means no joints run in a straight line above each other (Fig. 2-5).

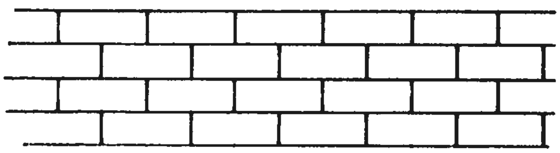

Fig. 2—5: *Alternating joints produce a stable wall.*

This alternate header and stretcher wall is sometimes referred to as "English bond" and is the most common method of construction using dense firebrick. To begin a 9" wall, a 9" x 6" large brick, a 4 1/2" bat and straight bricks are used to set up the joint pattern for subsequent rows (Fig. 2-6).

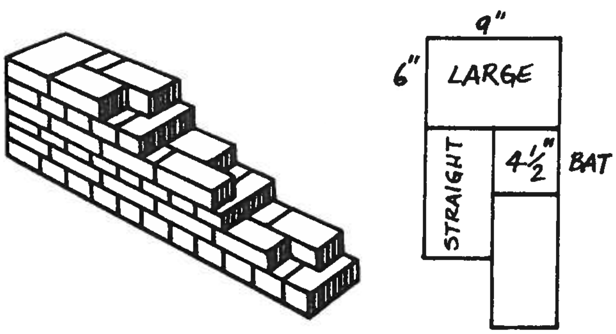

Fig. 2—6: *Layout for base of 9" alternate header and stretcher wall.*

ROWLOCK AND SOLDIER COURSES

In a rowlock course, bricks are laid on their sides (2 1/2" x 9"), side-to-side or end-to-end (Fig. 2-7). In a soldier course, bricks are laid on end (4 1/2" x 2 1/2"), side-to-side or end-to-end (Fig. 2-8).

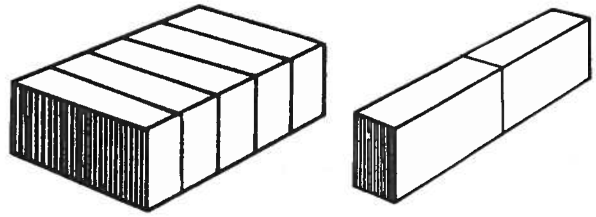

Fig. 2—7: *Rowlock course; (left) side-to-side; (right) end-to-end.*

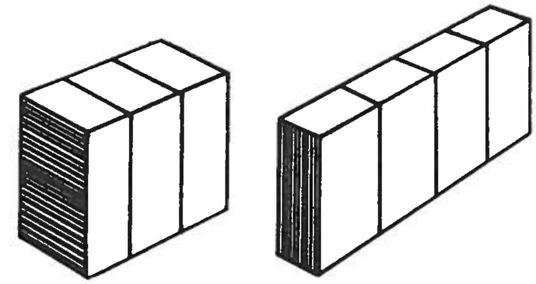

Fig. 2—8: *Soldier course: (left) side-to-side; (right) end-to-end.*

WALL CONSTRUCTION

13 1/2" WALLS

There are three usual methods for laying 13 1/2" walls:

1. One may use standard 9" x 4 1/2" x 2 1/2" bricks with 9" x 6" x 2 1/2" bricks. The 13 1/2" wall (shown in Fig. 2-9) has no joints running through it. Also (shown in Fig. 2-9) alternating header/stretcher with stretcher/header, use 9" x 6" x 2 1/2" brick for staggering joints.

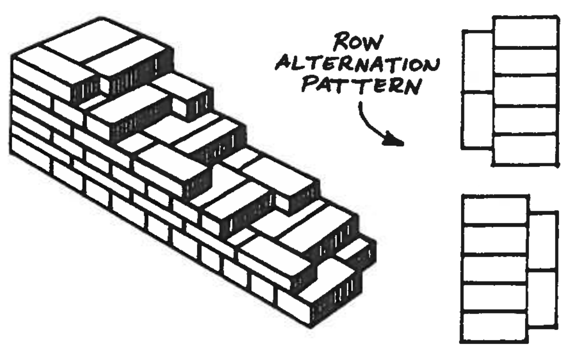

Fig. 2—9: *Method 1 for laying a 13 1/2" wall.*

2. In the second method, the wall is laid with four rows of hot-face stretchers backed by headers, and one row of headers, which, in turn, is backed with stretchers (Fig. 2-10). The advantage of this construction is that is makes for easier repair.

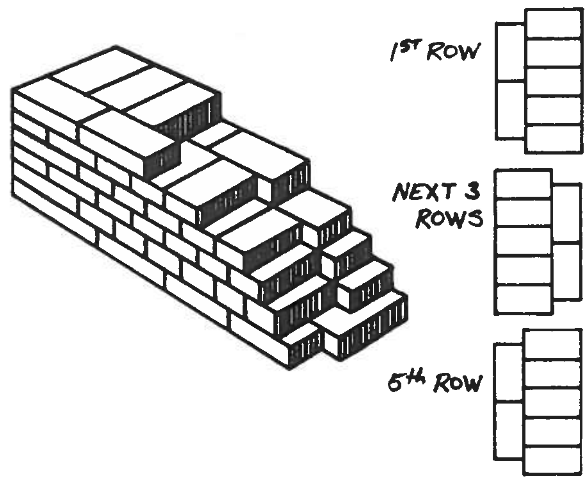

Fig. 2—10: *Method 2 for laying a 13 1/2" wall.*

3. In the third method of laying a 13 1/2" wall, every fifth-row header course has a 13 1/2" brick in it, with alternating joints on each row.

This type of construction makes an extremely stable wall that is easy to repair. It is also good for setting sprung arches.

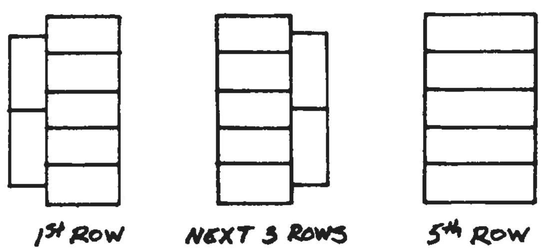

Fig. 2—11: *Method 3 for laying a 13 1/2" wall.*

FLUES

When building flues into the kiln wall, the normal distance between flues will be 9", or one brick. The average size of flues will be one brick standing on end (9" x 4 1/2"). (If using the 2 1/2" brick series, four rows of bricks will cause the flue holes to be 4 1/2" x 10". Three bricks of the 2 1/2" series will be sufficient in almost all cases; however, it is better to err in having flues too large, rather than too small.) All flue holes should be built on a header course, with the flue opening directly above a header (Fig. 2-12). The reason is that the header brick becomes a knockout brick, in case the flue is too small. In building the 9" flue separator, alternate header and stretcher courses should be used.

CURVED WALLS

Curved walls are found in domed, downdraft, and beehive kilns. The reason curved walls are used is that they are much stronger and more stable than a straight wall. The curve creates a wedging action, which keeps the brick from falling inward. The only limiting factor on height is the compression strength of the bottom bricks. This is why many early kilns with walls 18-22 1/4" thick (in some cases up to 3 to 5 feet) could carry the thrust of the dome without reinforcing supports.

Materials choices for curved walls:

— 4 1/2" wall thickness-circle (arch brick can be used, but is not recommended)

— 9" wall thickness-key (or combination of circle and key brick)

— 13 1/2" and greater wall thickness-key (or combination of circle and key brick; wedge bricks not recommended)

Curved walls are laid with the same alternating joints straight walls (Fig. 2-13).

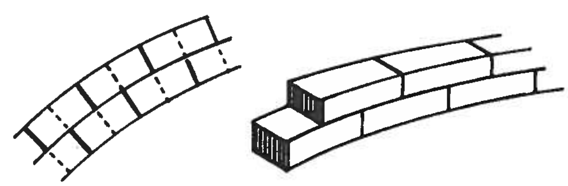

Fig. 2—13: *Joints are alternated in curved wall construction.*

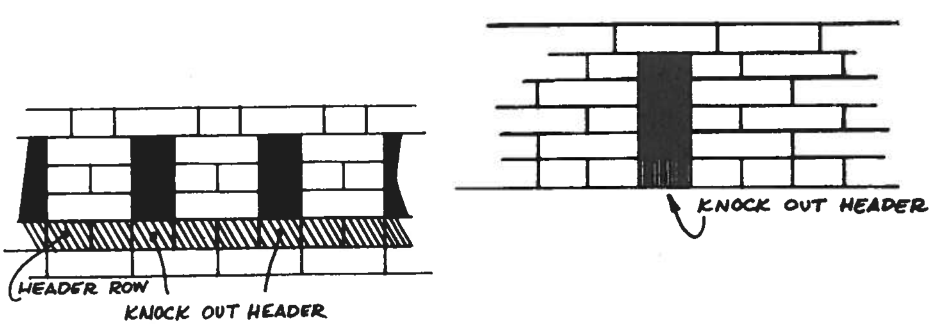

Fig. 2—12: *All flues are built on header courses.*

DIVISION OR COMMON WALLS

A division wall is the common wall between two chambers. In a normal chamber wall, the temperature drops from the inside out, whereas a common wall may be subject to hot-face temperature on both sides. Thus, the division must be made of good quality refractory material. The common wall also supports the thrust of two arches (Fig. 2-14).

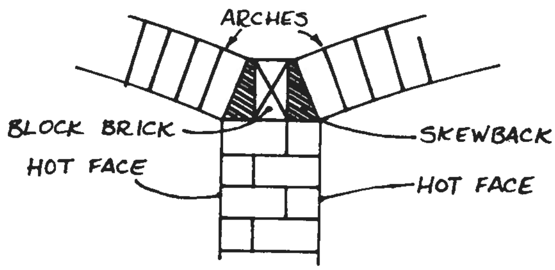

Fig. 2—14: *A common wall supports the thrust of two arches and has two hot faces.*

It is good practice to build common walls 4 1/2" greater in thickness than the ordinary kiln wall; and a common wall should never be less than the width of the two skewbacks used.

ARCHES

SPRUNG ARCHES

Kiln arches perform two duties — forming roofs for the kiln chamber and forming doors and openings. Sprung describes the arch of a cylinder, and is the most common arch used in kiln building.

The arch rests on a skewback on both ends. Skewbacks determine the arch rise and tie the arch to the wall (Fig. 2-15). The force of the arch is down and out against the walls. If the skewbacks fail, the arch will move; therefore, the walls and skewbacks must be rigidly constructed. Standard sizes have been developed for arch, wedge, and key bricks, because dense firebricks are molded to size and fired, thus they cannot be easily machined. These special sizes are called No. 1, No. 2, and No. 3, and, when used by themselves, turn a circle. Arches are built using a combination of No. 1, 2, and 3 bricks with straights to turn almost any given circle. For the combinations of arches and straights in a given radius, see Estimating Firebrick Arches in Appendix.

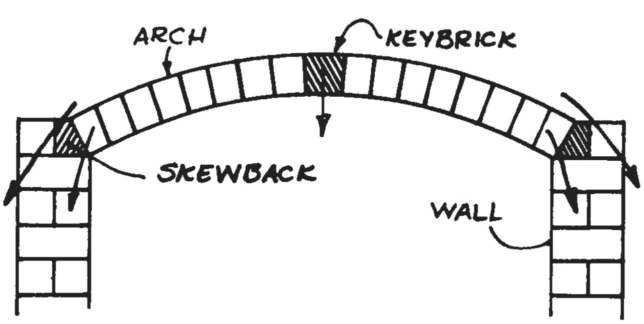

Fig. 2—15: *An arch rests on skewbacks, exerting its force down and out.*

The following list gives shapes and combinations of brick for the arch thickness specified:

— **4 1/2"**: Arch brick, or combination of arch and straight.

— **6 3/4"** or 7 1/2": Large 9" arch, or combination of large 9" arch and large 9" straight.

— **9"**: Wedge brick, or a combination of wedge and straight. (Construction of key brick, or combination of key and straight, is not common, as the load is placed on the narrow face. This construction is only used when special conditions make it desirable.)

— **Over 9"**: Necessarily constructed of special wedge brick. However, 13 1/2" wedge bricks are standard from some manufacturers.

There are four major types of sprung arches: Bonded arches, ring arches, ribbed arches, and straight arches.

Bonded arches. The bonded arch is the most commonly used arch and is considered the best. The joints are staggered, tying the whole arch into a single unit (Fig. 2-16). If one or several bricks fail in a bonded arch, the bricks on either side absorb the load and the arch remains in place.

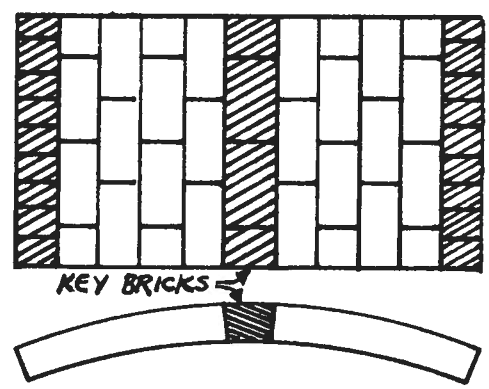

Fig. 2—16: *Joints are staggered in a bonded arch.*

Ring arches: The ring arch is, as the name implies, one where each row of bricks across the arch is a ring of brick (Fig. 2-17). If one brick in the ring fails, the whole ring drops. It is difficult to replace a ring of brick. I used a ring arch on a chamber kiln and found that, during firing, the rings expanded open almost 1/2". Perhaps if the kiln had been tied together with steel, it would have helped. A bonded arch, however, doesn't have this problem. The main advantage of a ring arch is the ease of laying, especially when using a combination of standard shapes.

Ribbed arches: The ribbed arch is primarily used in open-hearth furnaces. The ribs give the arch stabil-

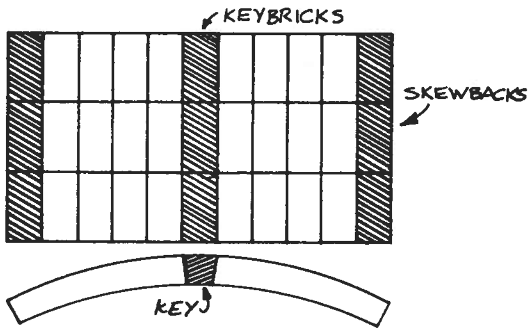

Fig. 2—17: *Ring arches expand during fire and, if one brick fails, the whole ring fails.*

ity and strength after the intermediate bricks have eroded (Fig. 2-18).

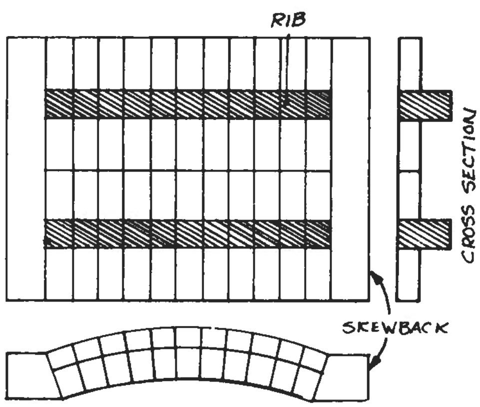

Fig. 2—18: *Ribs provide stability and strength against erosion.*

Straight arches: The straight arch is a bonded arch made with standard 9" x 4 1/2" x 2 1/2" straight bricks and is used when one doesn't have arch brick available or when one wants to produce a freeform arch (see Fig. 2-19).

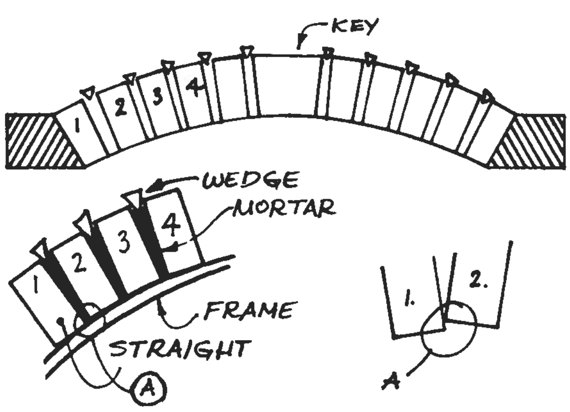

Fig. 2—19: *Proper laying and wedging technique for a sprung arch.*

The important factor in using straights to make a sprung arch is to set the corners of the brick carefully (see Fig. 2-19, point A). Brick 1 is laid onto the arch frame. The inside edge of brick 2 must be above and touching the outside edge of brick 1. In other words, each brick acts as a lip for the brick on top of it. The arch is laid from both sides simultaneously, then the key brick is cut to fit. The arch is sprung off the form by starting at the bottom and working up both sides, driving wedges (bits and pieces of small refractories) into the gaps between the brick rows and spreading them apart, while driving the bottoms into a tighter fit. If, however, one over wedges or drives too big a wedge too deep, it will part the bricks on the bottom. This could also result in weakened brick. When mortaring the arch bricks, care should be taken to apply the mortar in a wedge form, thus helping to set up the proper wedge.

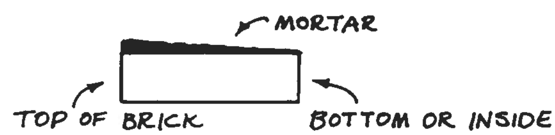

Fig. 2—20: *Applying mortar to form a wedge.*

The key brick must be pounded down below its neighboring bricks, thus ensuring a strong key (Fig. 2-21).

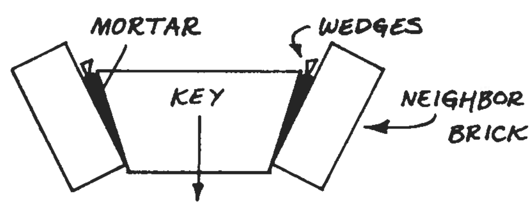

Fig. 2—21: *The key should be forced below neighboring bricks.*

SUSPENDED ARCHES

A suspended arch is mechanically held together and supported in place, and does not tie directly into the side walls. The support is usually a metal framework fitting into holes or grooves, or around specially shaped bricks, and held together by rods, pipe, tee bar, and so forth (Fig. 2-22). The most common thicknesses for suspended arches are 4 1/2" and 9".

The advantages of using a suspended arch are readily seen in top-loading electric or gas kilns. Repair to these arches is quite easy, unless sidewall bracing is required. Also, it is easy to accommodate thermal expansion, both horizontally and vertically, which reduces break-causing stress in the bricks.

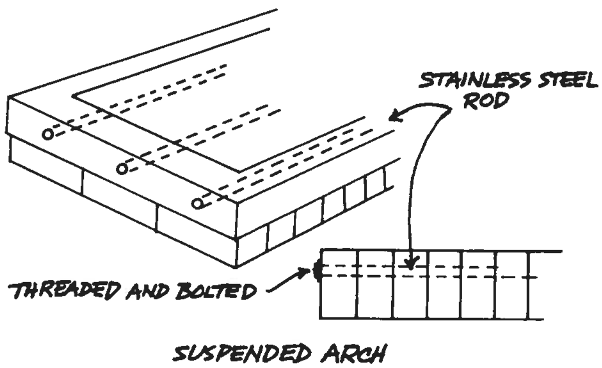

Fig. 2—22: *Metal framework for a suspended arch.*

The disadvantage is that it usually costs more for the additional metal framework and connection rod assembly than is the case with a sprung arch.

CORBEL ARCHES

A type of arch seldom mentioned is the corbel. This particular arch can be used to span portholes or flue holes where other lintel shapes are too small (Fig. 2-23). Use the corbel arch to span up to 24".

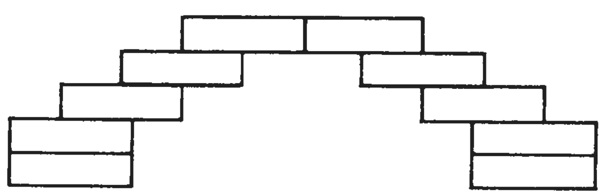

Fig. 2—23: *Corbel arches can be used to span flues or portholes.*

I have seen small, 10- to 16-cubic-foot kilns with corbel arches. This is not a good practice for the following reasons: (1) structural instability; (2) the uneven inside surface causes irregular heating and flame turbulence; (3) bricks are subject to greater erosion; and (4) the design is generally poor.

FRAME CONSTRUCTION

To begin building an arch, one must have a wood frame, which can be constructed in a number of ways. The first method produces a one-use arch form that is good for freeform arch construction (Fig. 2-24). Another method produces a reusable arch form for standard skewback arches (Fig. 2-25).

To make an arch support for a standard skewback arch using a featheredge, you need to know two things: the span (the distance between the two supporting walls) and the rise of the arch (Fig. 2-26). A featheredge will give a rise of 1 1/2" per foot of span.

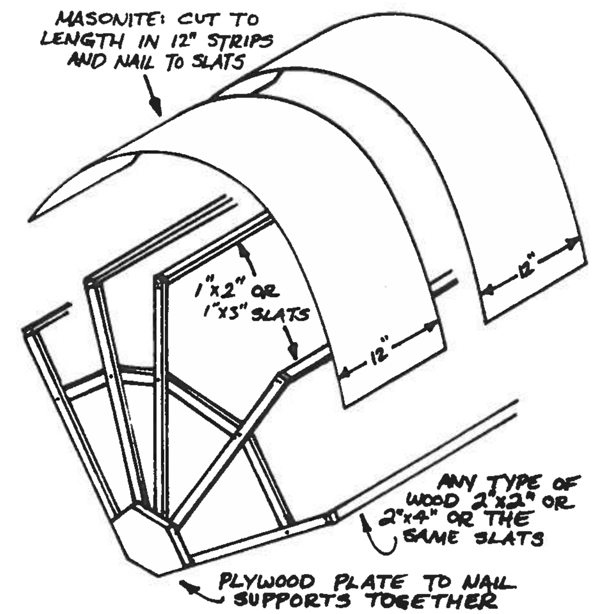

Fig. 2—24: *Building a one-use arch form.*

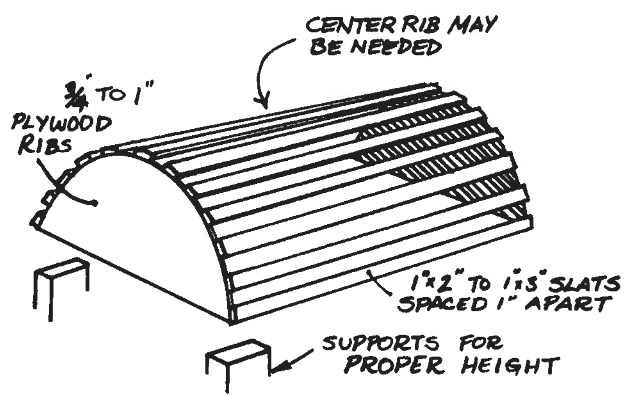

Fig. 2—25: *Building a reusable arch form.*

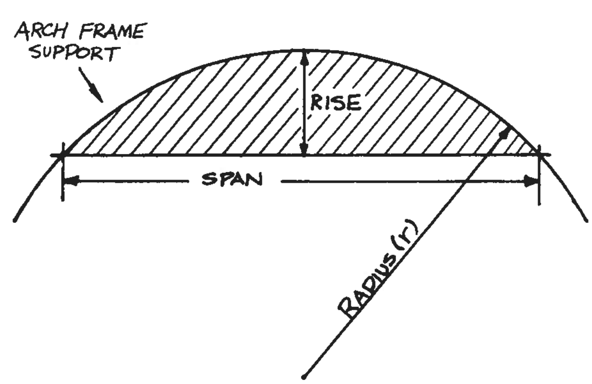

Fig. 2—26: *Support for a standard skewback, using a featheredge.*

Use this formula to find the radius of the circle:

$$1.0625 \times span = radius\ (r)$$

A catenary arch usually has a rise-to-span ratio that exceeds the 1 1/2"-3" range considered good practice. The catenary arch is formed by first deciding upon the span, then forming the curve with a perfectly flexible, inextensible cord suspended by its end (Fig. 2-27). The catenary arch is self-supporting. It contains the walls and sprung arch all in one curve.

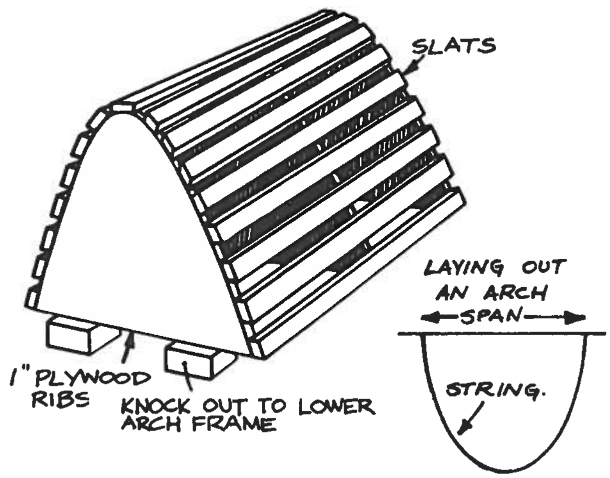

Fig. 2—27: *Building a self-supporting catenary arch.*

DETERMINING ARCH

Because a standard featheredge can be used as the skewback, the minimum rise for an arch is usually 1 1/2" per foot of span. Anything less can result in structural difficulty. The maximum rise has generally been set at 3" per foot of span. The greater the rise of the arch per foot of span, the sturdier the arch will be. I have raised an arch with a 6" rise per foot of span with very good results, so no hard-and-fast rule can be applied.

When using dense bricks, standard-size arch, wedge, and key brick can be used in combination with straights to turn any given radius. Insulating bricks, however, are sized and shaped after firing to a given radius, thus simplifying construction and increasing strength because of the radius involved. Standard shapes can be used, which reduces the cost.

DOMES AND CROWNS

Domes and crowns differ from sprung arches in that an arch describes a portion of a cylinder, while a dome or crown describes a portion of a sphere. A crown describes two sphere arches that meet at dead top center, but originate from different axes. A dome has a single radius (See Fig. 2-28). A crown generally has a flue in the top, while a dome is usually plugged. The rule of thumb for the rise of domes and crowns is 2 1/2"-3" per foot of span. Bricks are laid the 4 1/2" way.

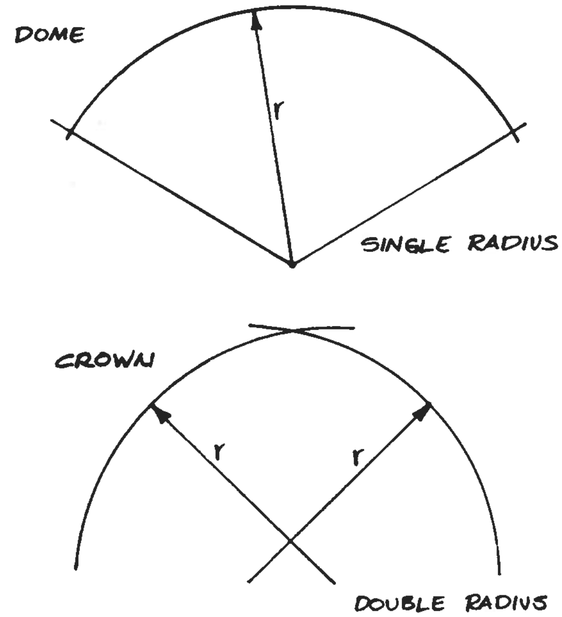

Fig. 2—28: *A dome or crown describes a portion of a sphere.*

EXPANSION JOINTS

During the heating and cooling of a kiln, firebrick will expand vertically and horizontally along a wall, and at a 90° angle to the wall. Each foot of refractories along the wall will expand from 1/16" to 3/32" when heated and cooled. If a kiln is built without an allowance for expansion, the bricks will destroy themselves through mechanical and structural spalling. In many cases, kilns with steel frameworks have been built with no tolerance for expansion and contraction. The walls have buckled, sagged, and cracked, and the frame has bent and bowed.

In free-standing kilns, such as a chamber kiln, expansion joints are not used, except perhaps when the side wall is fitted to the arch. Corner joints and joints where the common wall ties into the side wall are mortared with just a bit more space between bricks. The walls are then free to expand as a structural unit, since they are not tied by steel. If such a kiln is reinforced with tie rods, the rods should be bolted taut when the kiln has reached temperature. This allows for normal expansion.

In an enclosed steel frame, or when a kiln is backed by rigid steel, the bricks must be given proper expansion joints (Figs. 2-29 and 2-30).

Figure 1/16" gap per 1 foot of wall. If the kiln wall is 5 feet long, then the gap should be 5/32" on each end. However, do not have the expansion joint going through the wall but built into the corner joint (Fig. 2-31).

In an insulating firebrick kiln within a steel framework, the expansion joint can be eliminated

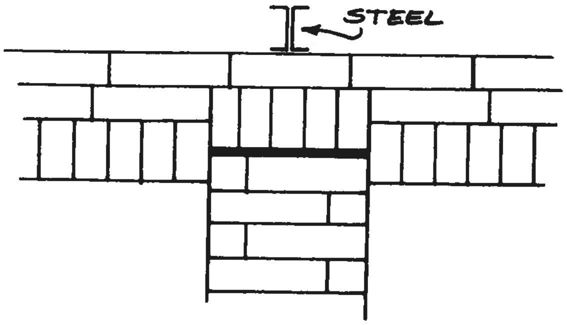

Fig. 2—29: *Division wall expansion joint (hard bricks).*

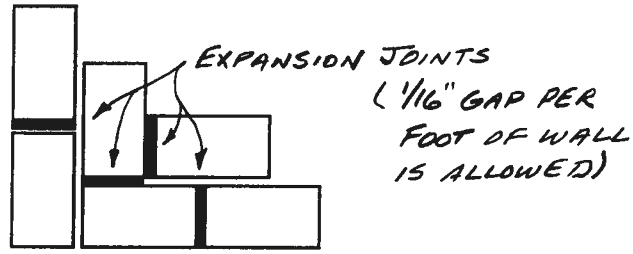

Fig. 2—31: *A gap of 1/16" per foot of wall is allowed. The gap can be filled with a 1/4" fiber pad mortered to the brick end.*

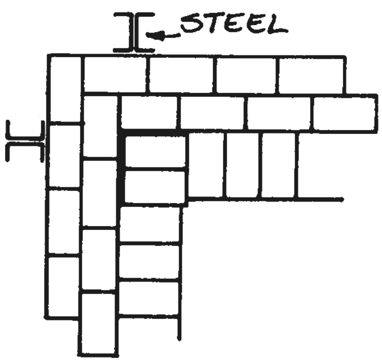

Fig. 2—30: *Floating corner expansion joint (hard bricks). Note that only the 9" hot-face row requires an expansion joint, which is filled with expansion-joint board or a ceramic-fiber filler.*

completely with walls under 4 feet and less and have a flexible wall backing like sheet metal or expanded steel mesh (Fig. 2-32). Wall lengths of over 5 feet can, and in most cases should, use 1/4" fiber pads mortared to the end of the brick when building the corner joints. However, 5-feet wall lengths in a flexible frame, if built properly (not too tight or wedged into the frame), can get by with no expansion joints. Walls well over 5 feet long use vertical expansion cuts in the wall, filled with a ceramic fiber product such as wool, strip, blanket, or board (Fig. 2-33).

SKEWBACKS

Arch stability is dependent upon the rise and thickness of the arch and structural support of the skewbacks. Skewbacks can be built from the standard 9" series shape. A rise of 1 1/2" per foot of span is obtained when the skewback is formed by standard 9" featheredges of the 2 1/2" series. A rise of 1.608"

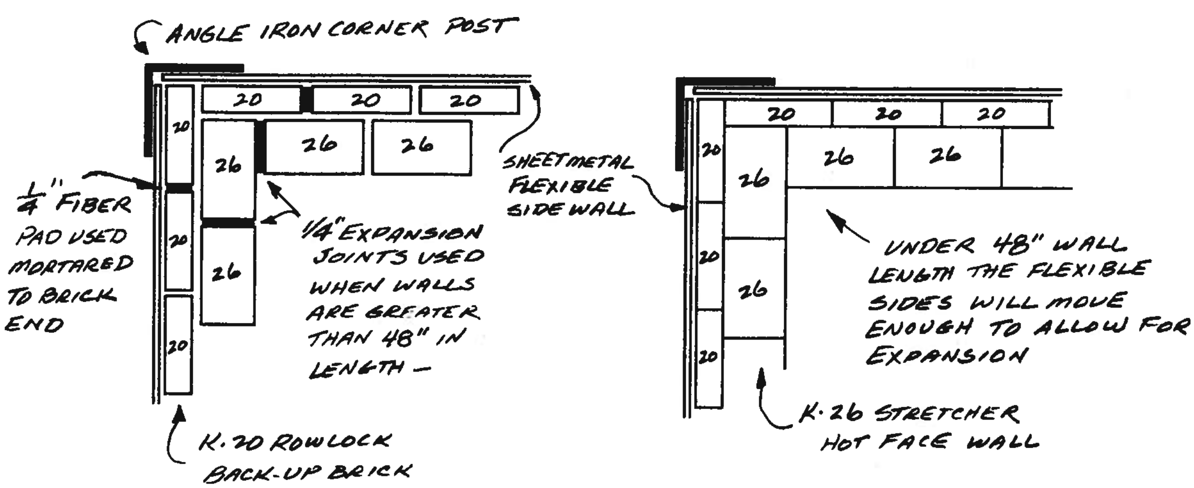

Fig. 2—32: *Expansion joint is eliminated in an IFB kiln with steel framework, with a wall 4" or less.*

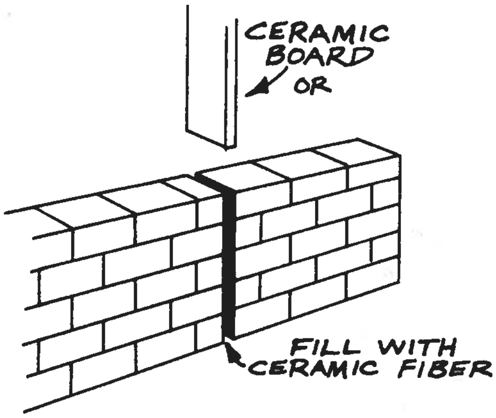

Fig. 2—33: *Vertical expansion cuts are filled with ceramic board or fiber.*

(19/32") per foot is obtained when the included angle of the arch is 60°. Special skewbacks for arches with included angles of 60° are available in sizes 4 1/2" thick, 9" thick, and 13 1/2" thick (Fig. 2-34). A rise of 2.302" (2 5/16") per foot is obtained when standard 9" side and end skews of the 2 1/2" series are used.

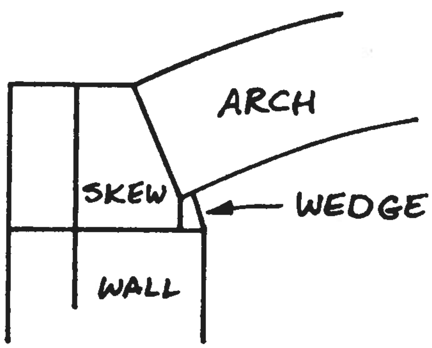

Fig. 2—34: *Special skewback for 60° arch.*

The skewback is the structural member that transmits the stress of the arch to the supporting wall, and to the framework, if any. When the skewback, wall, and arch form an acute angle, steel supports must be used to hold the stress of the arch and the skewback in place (Fig. 2-35A). In Fig. 2-35B, the angle is greater and the arch stress is brought down the slanted wall. It remains self supporting.

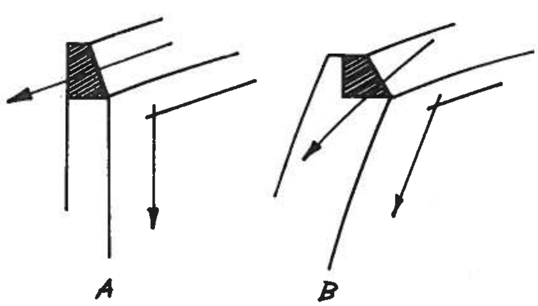

Fig. 2—35: *Distribution of stress created by the arch.*

The placement of the skewbacks is very important to the success of the arch. If straight bricks are used to build a skewback, the lip of the throw brick (first brick off the skewback) should be resting on the wall (Figs. 2-36 and 2-37).

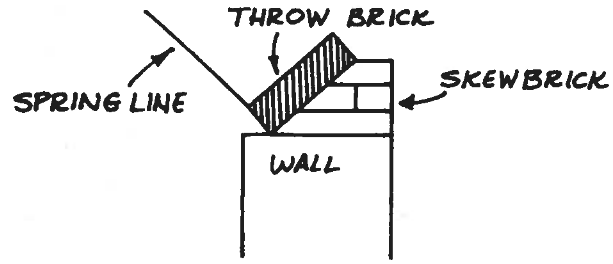

Fig. 2—36: *Lip of the throw brick must rest on the wall.*

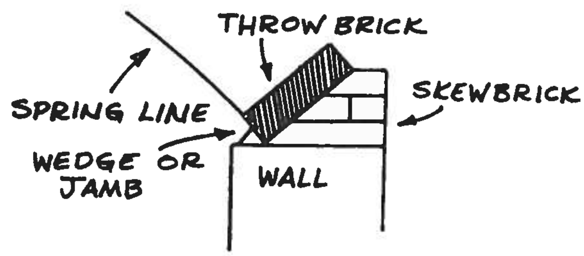

Fig. 2—37: *A wedge fits under the throw brick.*

In both these cases, the throw brick catches the wall. In Fig. 2-37, a wedge or joint (specially cut to fit) fits under the throw brick. The reason for catching the throw brick on the wall is to prevent slippage. It is considered bad practice to have the spring line of the arch flush with the wall (Fig. 2-38).

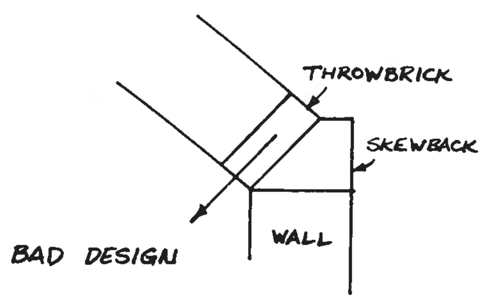

Fig. 2—38: *In this poor design, the spring line of the arch is flush with the wall.*

RAW CLAY CONSTRUCTION

Raw bricks are made in a single or multiple wood-press mold. A long wood trough can be made with piano hinged sides with sizing slots for the cutting wire to slide through to cut the brick sizes. The

Fig 2—39: *Brick making in trough mold, cut and sun dried.*

mold should be at least as long as the kiln width. Clay is packed into the mold, then sliced, the sides dropped and the bricks removed to dry. Various sizes can be made to conform to the kiln's dimensions. When the bricks are bone dry, they can be laid using soft fireclay brick mix as the mortar to level and seal the joints. The mortar is not in a troweling or dipping consistency, but soft, soft clay. Then follow the same construction techniques as using regular brick.

In the illustrated six-chamber raw brick kiln built in 1971 by Richard Hotchkiss, Rimas VisGirda and a workshop group used a Lincoln 60 fireclay base (50 percent — a California fireclay, at Lincoln, California) and coarse sand (50 percent) for the brick clay. Three sizes of raw clay blocks were made: 9" x 10" x 18", 9" x 10" x 9", and 9" x 5" x 5". The kiln was started with the uppermost chamber 6, building up the front and back walls to the desired height, an arch form was installed. At the same time the arch was being laid, the lower chamber front wall was begun and the process continued down to the first chamber. Since the blocks are dry, they could be readily shaped by an axe to follow the curve of the arch form and to make the key block row. Generous amounts of soft mortar were used to level, tilt and seal the joints of the blocks. Each successive arch was strapped with rope to keep from spreading until the next arch was finished which buttressed the upper arch. The side walls were bricked in leaving a door on one side and stoke holes and spy holes on both sides. Average chamber size was 5' x 5' x 6' tall. As each chamber was finished, a fire was started in them to dry them out, and the two upper chambers were being fired to bisque before the rest of the kiln was finished. The chimney was built with commercial firebricks to 12' and then 18' of a scavenged piece of hydraulic water pipe was placed on the brick work. Caution must be taken in the initial firing so as not to blow out the blocks from a rapid temperature increase. The kiln is still being fired by Hotchkiss and Tom Orr.

Fig 2—40: *Start of straight wall with flue holes.*