Additional reading

Arch construction

Topics

Introduction

Arches are still used in new building work, but their importance today is closely aligned to reproduction of facades for historical buildings, reproduction of building styles in new development and the maintenance of historical buildings. They are also used in refractory brickwork for high temperature furnaces including brick kilns and glass, steel and nickel furnaces.

The construction of arches remains an important part of apprentice training, especially as the stock of buildings requiring ongoing maintenance continues to grow.

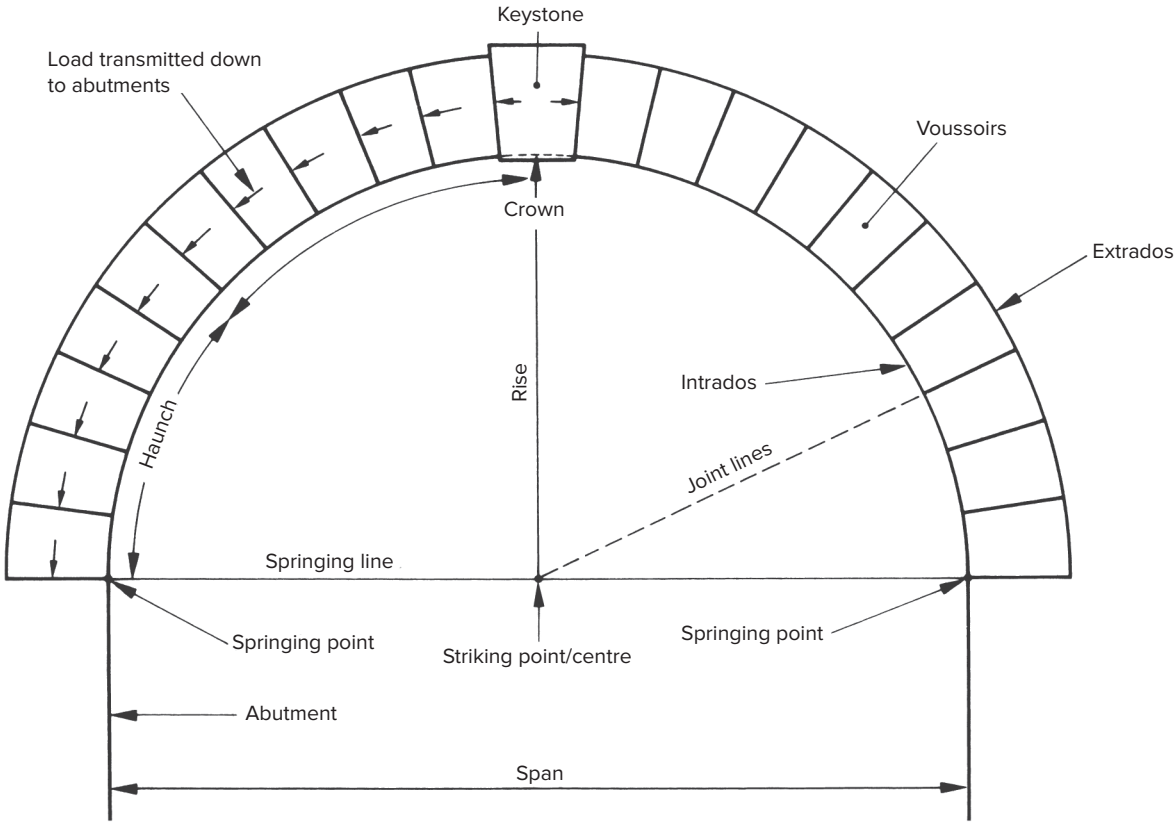
Terminology

The parts of an arch are shown in Figure 1.

TIP As indicated in AS 4773.2: 2010 Masonry in small buildings, the following apply, unless otherwise specified:

- The rise is not less than one-quarter of the span.
- There must be at least 300 mm brickwork above the arch.
- Abutments are no less than the width of the span.

Fig. 1 Masonry arch details



Arch categories

Arches are categorised in the following types:

- *Single-centred arches*–have a single striking point or centre.
- *Multicentred arches*–have more than one centre or striking point.

Fig. 2 (a) Pointed segmental arch; and (b) Semi-circular arch

(a)

(b)

Courtesy of Alister Ford

- *Gauged arches*–constructed with **voussoirs** or arch bricks that are cut or molded to a wedge shape and the joints are parallel.
- *Rough arches*–the voussoirs remain square, causing the joints to be wedge-shaped.

Setting out a rough arch

Before commencing to lay the arch bricks, they should be set out around the arch centre to determine the size of the joints. Alternatively set an arch brick as the key brick and mark a gauge on the intrados (top of the arch centre) from the key brick to either the skewback or the first arch brick laid on the skewback. To draw the actual arch brick, a summering circle the width of an arch brick (76 mm) is drawn around the striking point/arch centre and summering lines are drawn representing each side of the arch brick (Fig. 5).

When the thickness of the joints between arch bricks becomes excessive as the arch face increases in depth, the joints can be minimised by laying the bricks in rings, 110 mm in depth, provided the arch is at least a full brick thick. Alternate rings will have a key joint instead of a key brick (Fig. 6).

Fig. 3 Gauged and bonded semi-circular arch

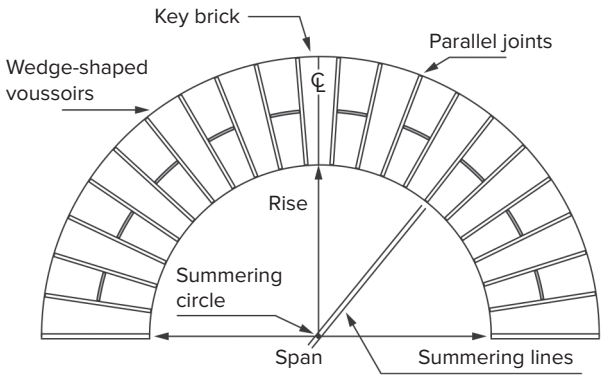


Fig. 4 Rough arch

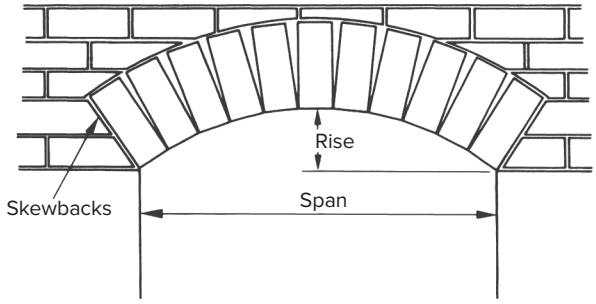


Fig. 5 Setting out the gauge for a rough arch

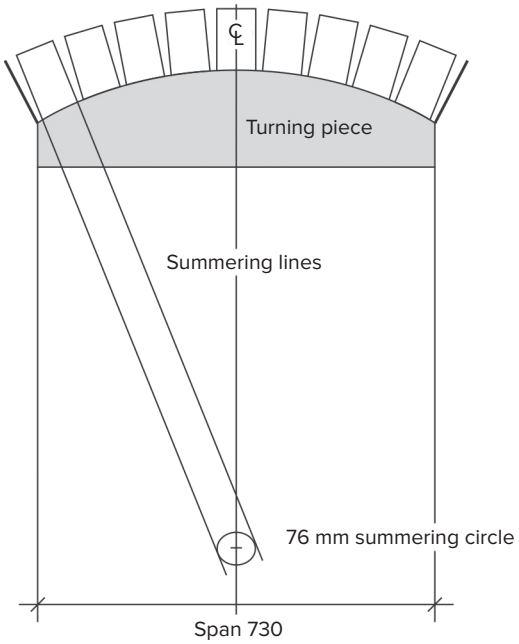
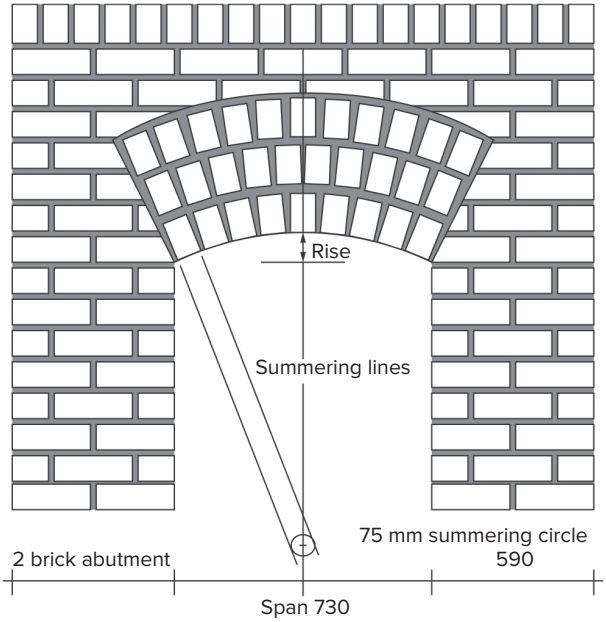


Fig. 6 Rough 110 segmental arch with three rings



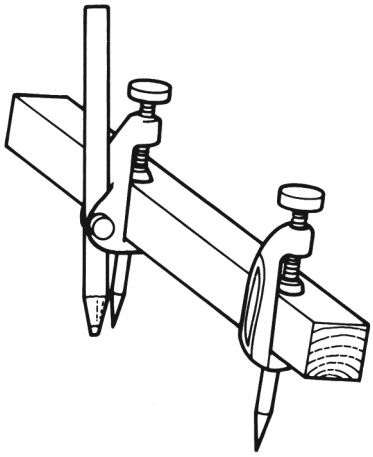
Arch set out

The shape of an arch should be set out accurately on strict geometrical lines. Bending a length of plastic or thin timber to an irregular curve is shoddy workmanship and demonstrates a lack of understanding of one of the most essential skills for all building workers–circle geometry. For a competent building tradesperson, setting out a regular curve or circle is simple but the result is excellence.

TIP When setting out an arch, draw the arch to full size on a sheet of plywood or MDF. The arch centre or turning piece is then made to the same dimensions and can be placed on the arch set out to allow the arch bricks to be checked for accuracy after they have been cut.

The circular lines of an arch can be drawn using trammel heads fixed to a straight edge or long level. An alternative is to use a straight edge with a builder's pencil taped securely to the straight edge and a nail driven through the other end.

Fig. 7 Trammel heads fixed to a timber batten



Semi-circular arch

To draw the intrados of the semi-circular arch, bisect the span *AB* to obtain the radius and the centre; the rise, of course, will be half the span. Extend the radius by the depth of the arch face to draw the extrados.

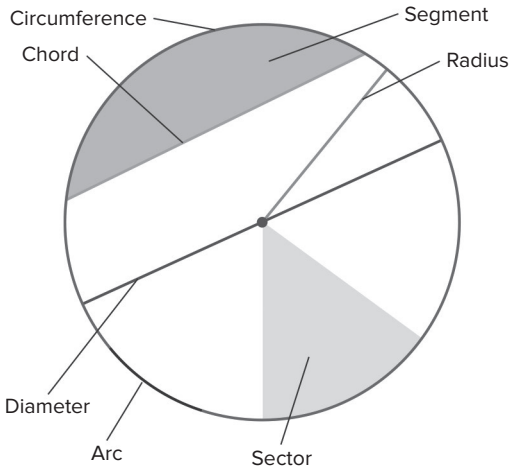
Segmental arches

A segment is that part of a circle bounded by an arc and its chord (see Chapters 3 and 4 Trade Calculations and Measurements and Trade Drawings). When applied to an arch, the segment is described by its span and rise. From this information, the radius of the circle can be obtained so that the curve of the segment can be drawn.

Setting out a segment by calculation

The radius (r) of a segment can be calculated, given the span and rise, and using the following formula:

Fig. 8 Circle geometry



Setting out a segmental arch

The geometrical method to set out a segmental arch is illustrated in Figure 10.

1. Bisect the span *AB* along the springing line at point *D* with a perpendicular line.
2. Continue the centreline down to a point past the estimated centre of the circle.
3. Measure the rise from *D* to *C*.
4. Bisect the lines *AC* and *CB*, with perpendicular bisectors meeting at *E* on the centreline.

5. *AE* then becomes the radius of the curve and will join points *C* and *B*.
6. The depth of the arch face *AF* is added to *AE* to allow the extrados to be drawn from *F*.

TIP The two perpendicular lines that bisect *AC* and *CB* must meet on the centreline otherwise the setting out is incorrect.

$$r = \frac{(\text{½ span})^2 + \text{rise}^2}{2 \times \text{rise}}$$

Example: Calculate the radius of a segmental arch if the span is 2400 mm and the rise is 600 mm.

$$r = \frac{1200^2 + 600^2}{2 \times 600} \text{ or } r = \frac{1.2^2 + 0.6^2}{2 \times 0.6}$$
$$= \frac{1.44 + 0.36}{1.2} = \frac{1.8}{1.2} = 1.5 \text{ m (or 1500 mm)}$$

Fig. 9 Semi-circular arch

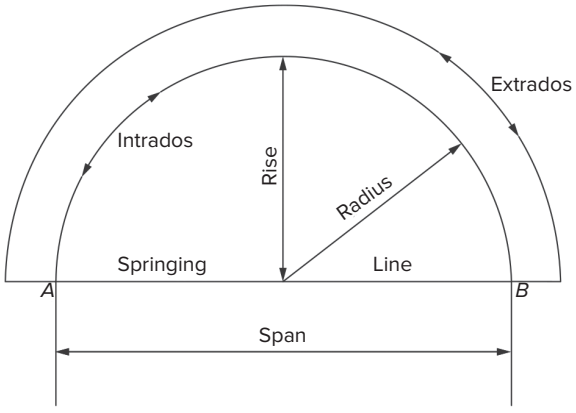
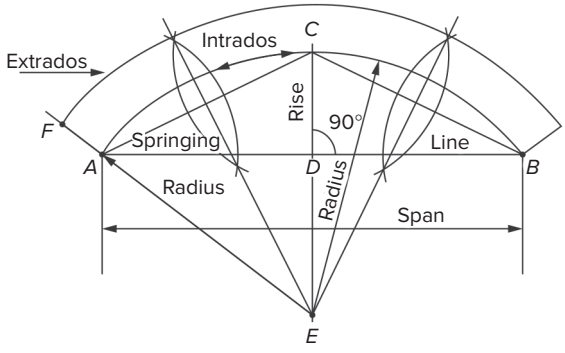


Fig. 10 Geometrical method to set out a segmental arch



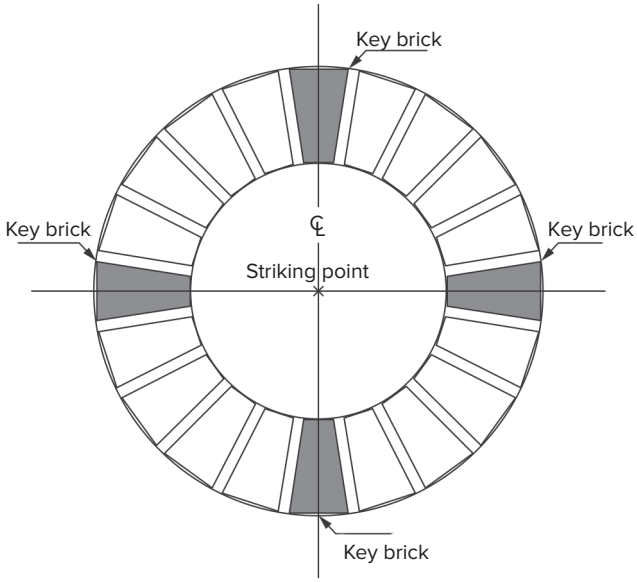
Wheel arches

Wheel arches have been a feature of homes during many periods of Australian architecture such as Old Colonial, Victorian, Federation, Inter-war, Post War and Late Twentieth Century. Wheel arches are set out with four key bricks: two aligned to the horizontal centreline and two aligned to the vertical centerline. Setting out is similar to a semi-circular arch with the exception of the four key bricks.

Setting out

Draw a circle with a specified radius to form the intrados. The diameter is the span. The extrados is drawn by adding the depth of the arch to the radius. The internal circle can be cut out and used to construct the arch centre.

Fig. 11 Wheel arch



TIP Bonded wheel arches must have a stretcher face for the four key bricks and therefore are gauged in multiples of eight. Wheel arches that are not bonded are gauged in multiples of four.

Establishing the correct gauge

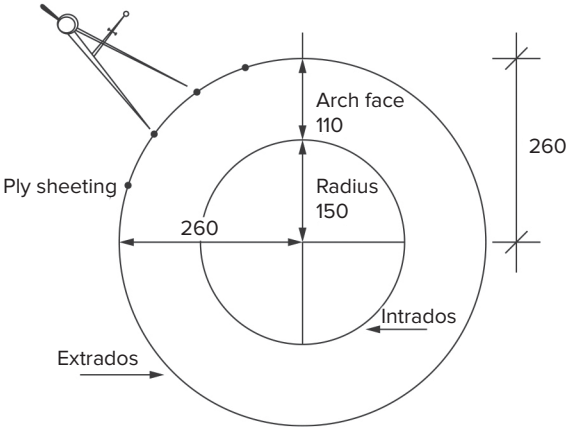
Calculate the circumference of the extrados using πD and divide by 86 mm (76 mm + 10 mm). This figure is then adjusted allowing for combinations of four or eight for bonded wheel arches, to determine how many arch bricks are required. The extrados length can now be divided by the number of voussoirs required to determine the actual size of each voussoir and the joint between them.

This example is based on a span of 300 mm and a single ring with a 110 mm face depth, and a circumference of extrados C = πD

- C = 3.14 × (300 + 110) = 1287
- 1287/86 mm (brick depth 75 + 10 mm joint) = 14.97 arch bricks–say 16 arch bricks
- 1287/16 = 80.44 mm including a joint
- Allowing for an 8.44 mm joint results in an arch brick 72 mm wide at the extrados.

The same method can be used to calculate the width of the arch brick at the intrados.

Fig. 12 Establish the correct gauge



Steps

- Set out arch full size on a sheet of ply
- Establish gauge by dividing quadrant into multiples of 4 + 1
- Gauge cannot be greater than 86 mm
- Deduct joint size from divider measurement for width of arch brick at extrados

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- Deduct joint size from divider measurement for width of arch brick at extrados.

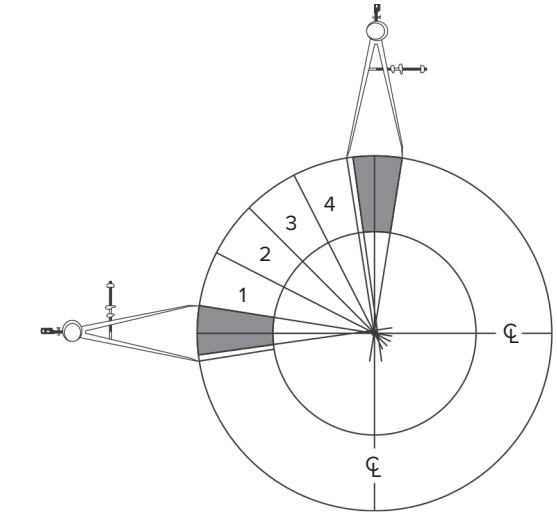
Step 1

- Draw 2 key bricks centrally on each centreline by extending lines from the extrados to a 10 mm summering circle.
- Mark out the gauge between the key bricks around the extrados starting from the side of one key brick and finishing on the same side at the other.

Step 2

- Start from a key brick and set out the remaining joints between each arch brick around the extrados.
- Extend lines from the extrados to the summering circle.
- Repeat process for remaining quadrant.

Fig. 13 Steps for setting out the gauge for the top half of the arch



Step 1

- Draw 2 key bricks centrally on each centreline by extending lines from the extrados to a 10 mm summering circle
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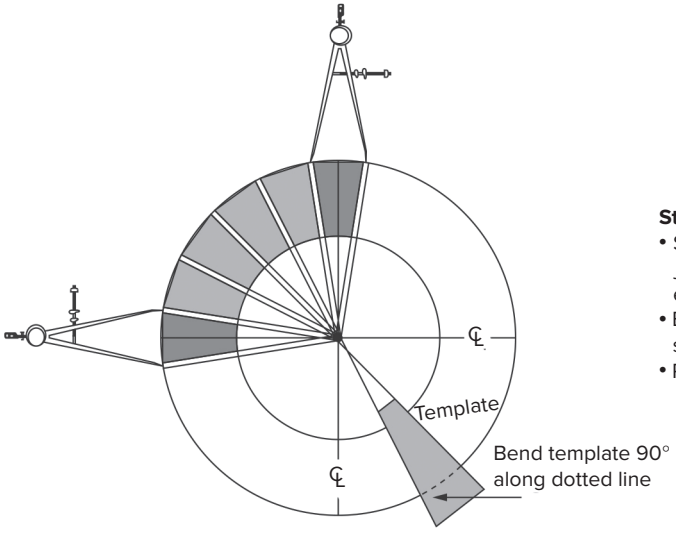


Step 2

- Start from a key brick and set out the remaining joints between each arch brick around the extrados
- Extend lines from the extrados to the summering circle
- Repeat process for remaining quadrant

Constructing the wheel arch

To construct a wheel arch:

- A vertical centreline is set out on a timber head.
- A short piece of timber batten or plywood approximately 100 × 200 mm is fixed through its vertical centreline to the centreline on the timber head.
- The timber head is then set up above the location for the arch so that the vertical centreline of the arch is aligned to the vertical centreline on the plywood or batten.
- The horizontal centreline of the arch is then drawn through the vertical centreline to provide the centre of the arch.
- A timber trammel measuring 20 × 10 × the required length is fixed through its centreline and the centre of the arch. The distance from the arch centre to the point of the trammel must equal the radius plus the depth of the arch face plus 10 mm for a joint.
- Drive a nail into the end of the trammel to form a point.
- The trammel is used to mark the bricks that will be cut to form the inverted section of brickwork that the lower section of the wheel arch is laid into.

Fig. 14 Setting up a trammel

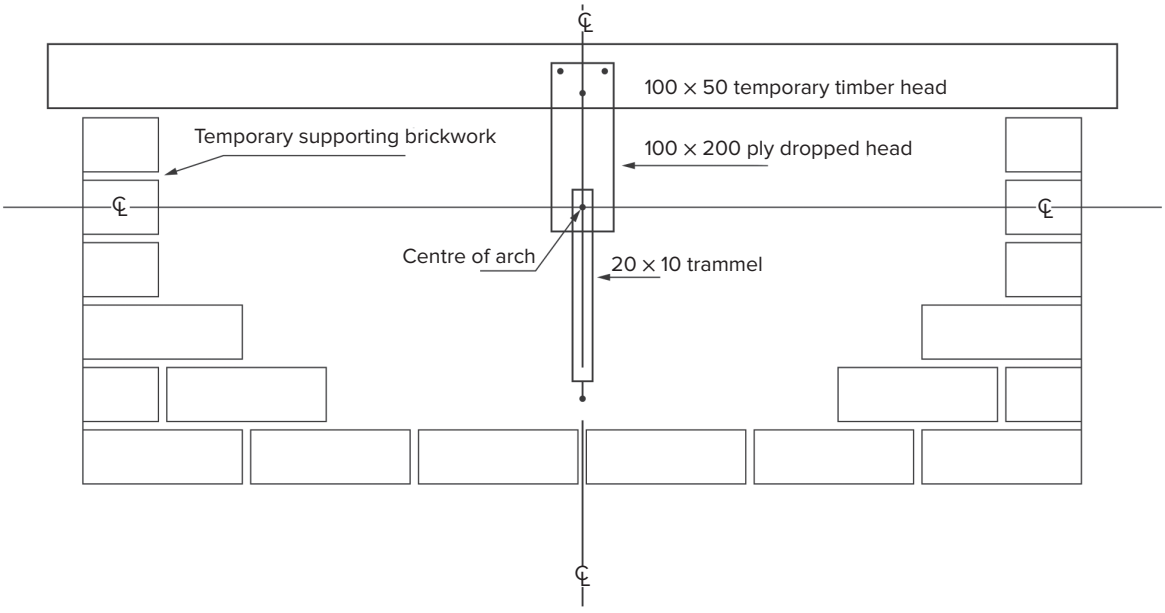
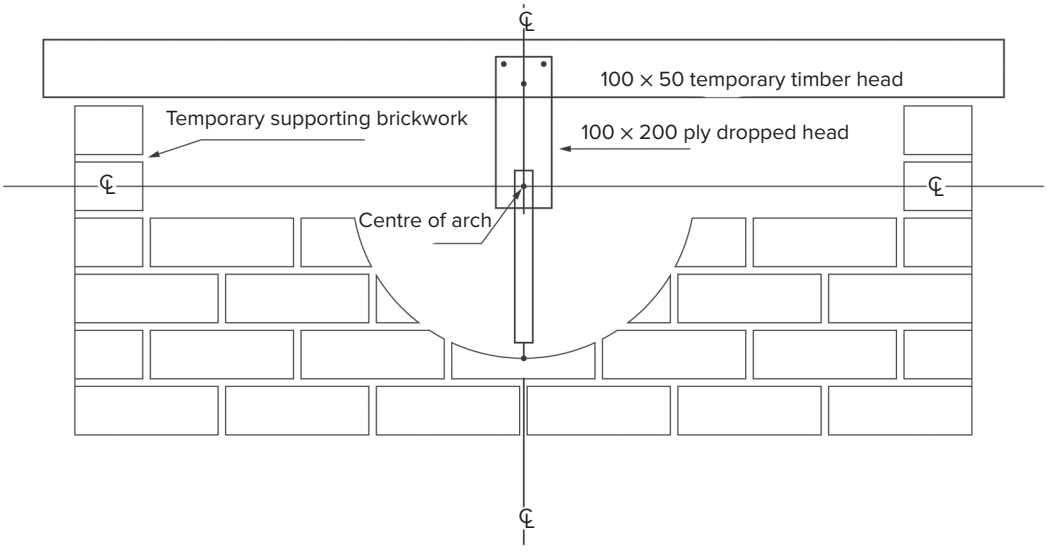
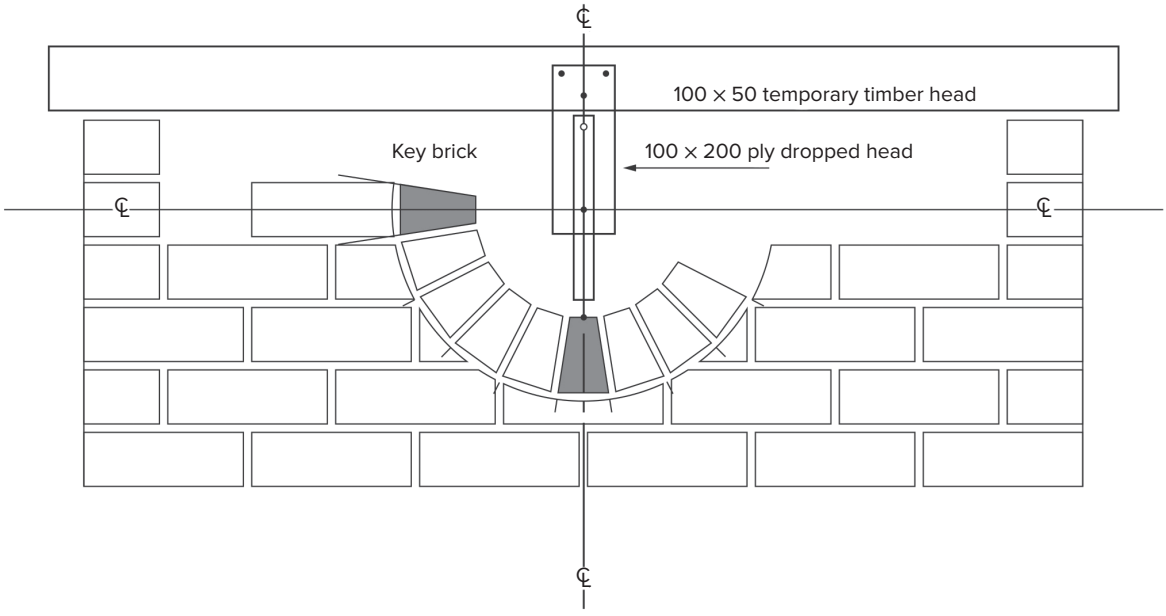


Fig. 15 Cutting in the invert



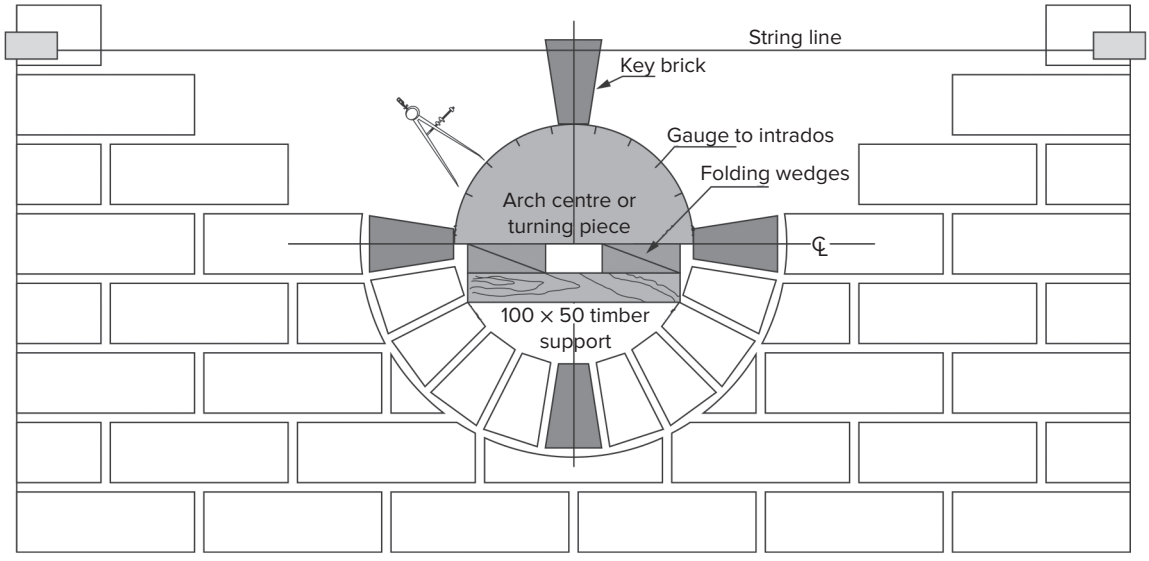
- The point of the trammel is used to determine the shape and size of each creeper cut, taking into account the joint between the arch bricks and the creeper cut (Fig. 15).
- The arch gauge is marked around the two bottom quadrants by gauging between the location of the lower key brick and the two key bricks on each side.
- The trammel is shortened by 120 mm (110 face + 10 mm joint) to provide the line and shape of the intrados.
- As the arch bricks are laid, they must be checked to the end of the trammel for alignment to the intrados and for alignment to the centre of the arch (Fig. 16).
- Remove temporary timber head when lower section (invert) is completed.

Fig. 16 Laying the invert



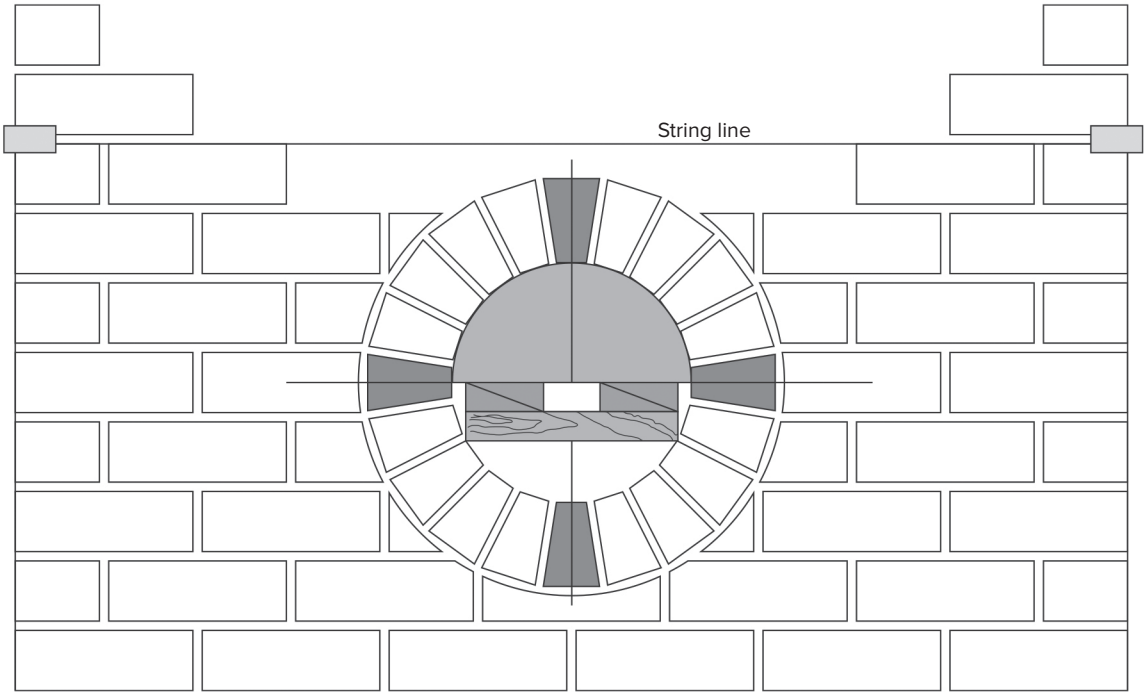
- Set up arch centre or turning piece so that arch centre is aligned to the horizontal centreline.
- Set out location of remaining key brick and gauge arch brick spacings along the top of the arch centre (intrados).
- Build up corners and commence laying arch bricks to a string line to maintain alignment (Fig. 17).
- Set the last three bricks in place without joints to check gauge and make final adjustments to joints.
- Lay the last three arch bricks including key brick, ensuring joints are even and full and that each brick sits squarely on the arch centre.

Fig. 17 Gauging the upper semi-circle



- Mark creeper bricks by measuring from a tight string line to the arch extrados and allowing for the correct size joint between the cut brick and the extrados.
- Cut and lay creeper bricks to a string line (Fig. 18).

Fig. 18 Laying the upper semi-circle

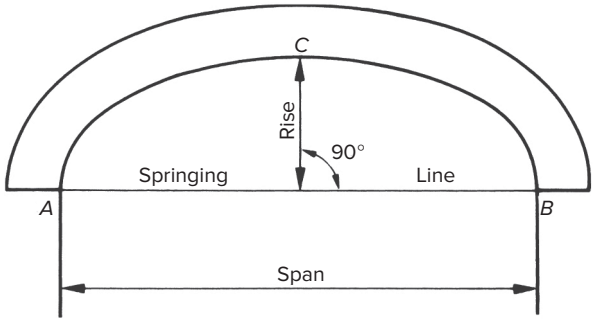


Gothic arches

Gothic arches are a group of pointed arches that originated in France and became a prominent feature of northern European architecture. A typical example is the *equilateral arch* (Fig. 20).

The arcs forming the arch spring from two centres which lie on the springing line. In the example shown in Figure 19 they are the actual springing points. Other arches in the group are the *lancet arch* (Fig. 21) and the *obtuse* or *depressed arch* (Fig. 22) where the rise is varied by altering the position of the centres along the springing line.

Fig. 19 Semi-elliptical arch



Segmental Gothic arch

The segmental Gothic arch is set out in a very similar way to the previous gothic arches but the striking points are below the springing line and are located when the centerline of the span for each separate segmental curve is drawn until it strikes the abutment on the opposite side of each segmental curve (Fig. 23).

Fig. 20 Equilateral arch

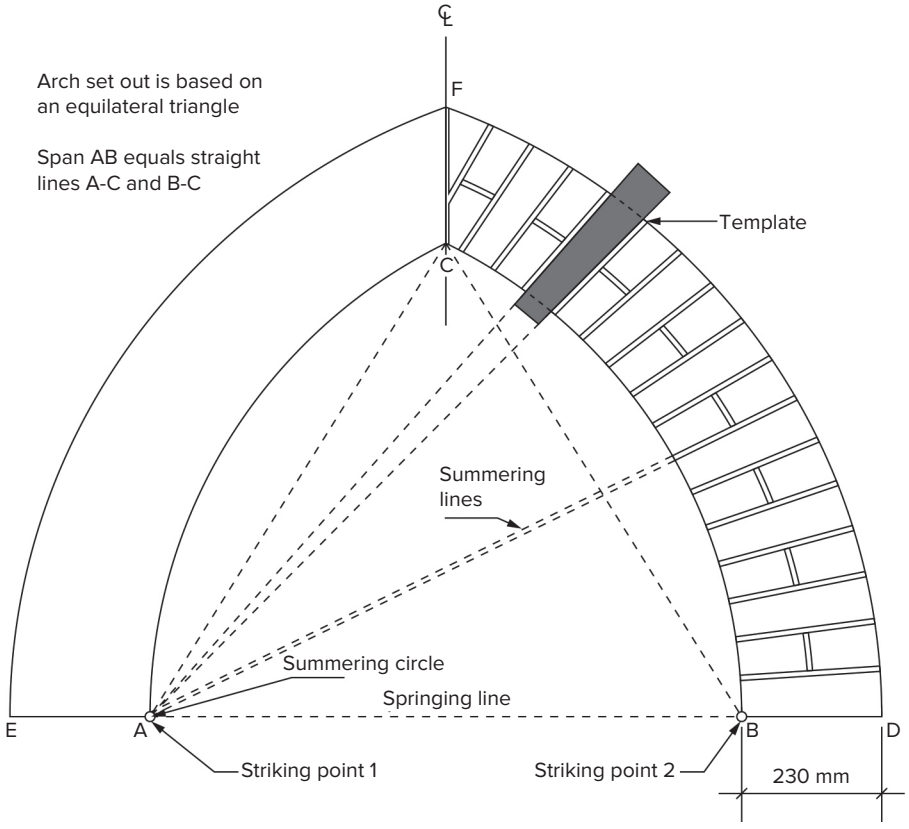


Fig. 21 Lancet Gothic arch

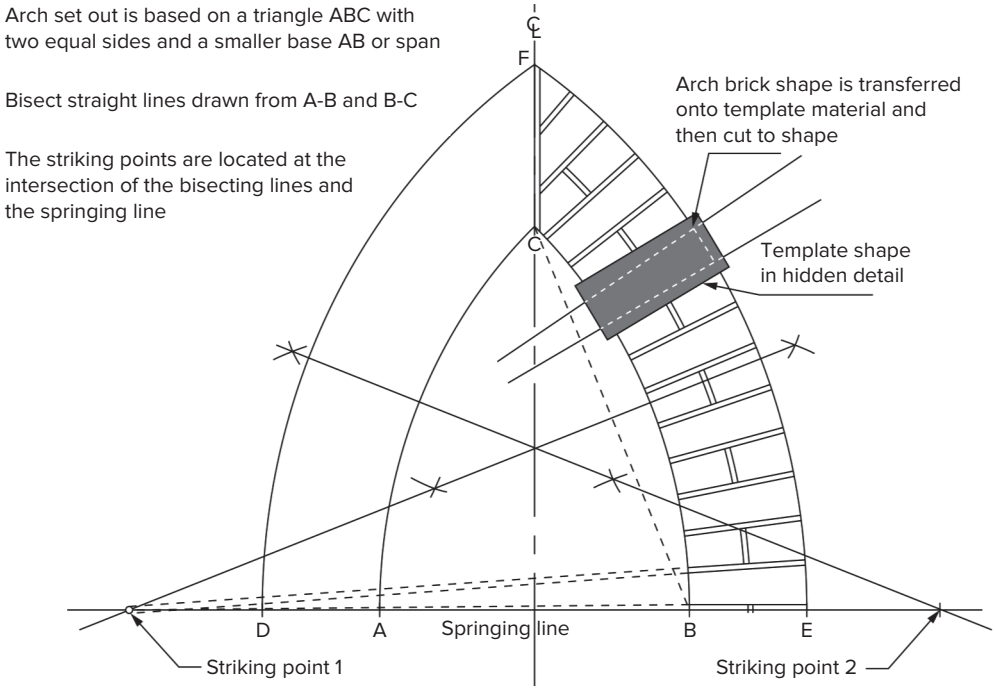
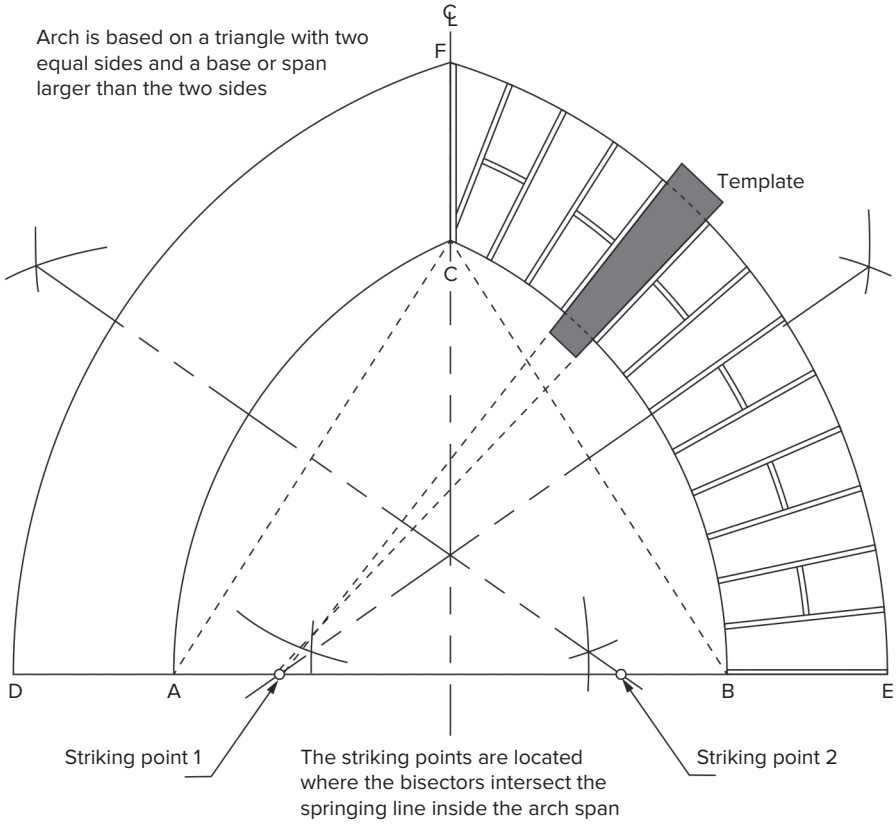


Fig. 22 Depressed Gothic arch



Tudor (or four-centred) arch

The Tudor arch, or the four-centred arch, is a later development of the Gothic arch; as the name implies, the curve of the arch is drawn from four separate centres (Fig. 24).

Three-centred arch

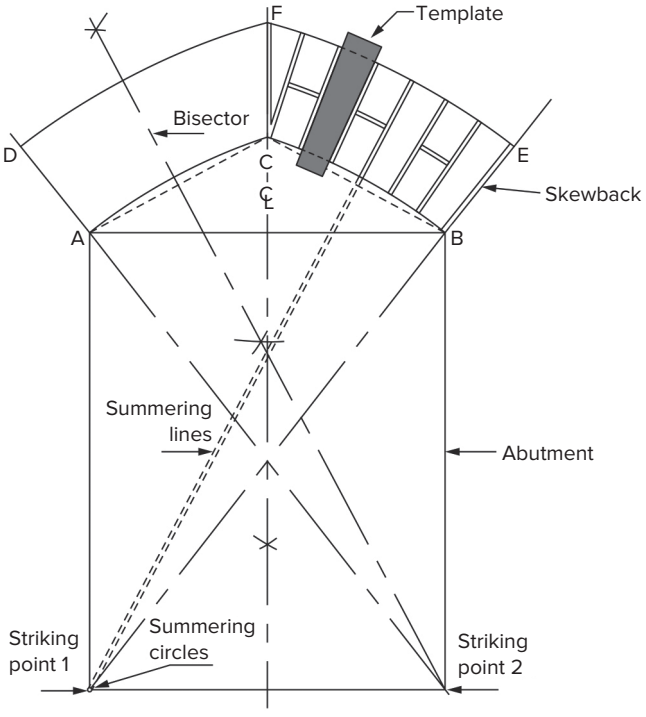
The three-centred arch is based on three circles that provide three striking points or centres. There are two common normals and the arch shape is similar to a semi-elliptical arch (Fig. 19).

This arch provides a comparatively low rise which is less than half the span, but the springing bricks do not require a skewback (Fig. 25). These arches are often used over wide openings such as a garage door.

Flat arches

There are a number of arches that may be referred to as a flat arch including a Camber arch, arches with a flat extrados and a curved intrados, and a Jack arch.

Fig. 23 Segmental Gothic arch



Striking points are located at the intersection of the bisectors of lines A-C and B-C with the abutment lines

Fig. 24 Tudor arch or four-centred arch

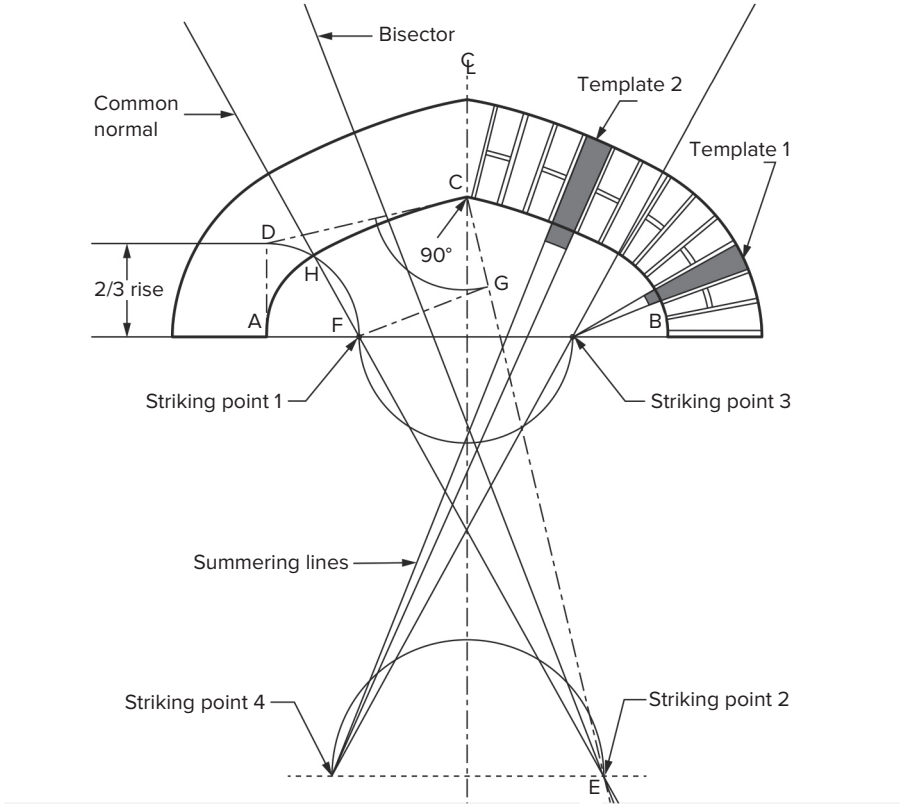
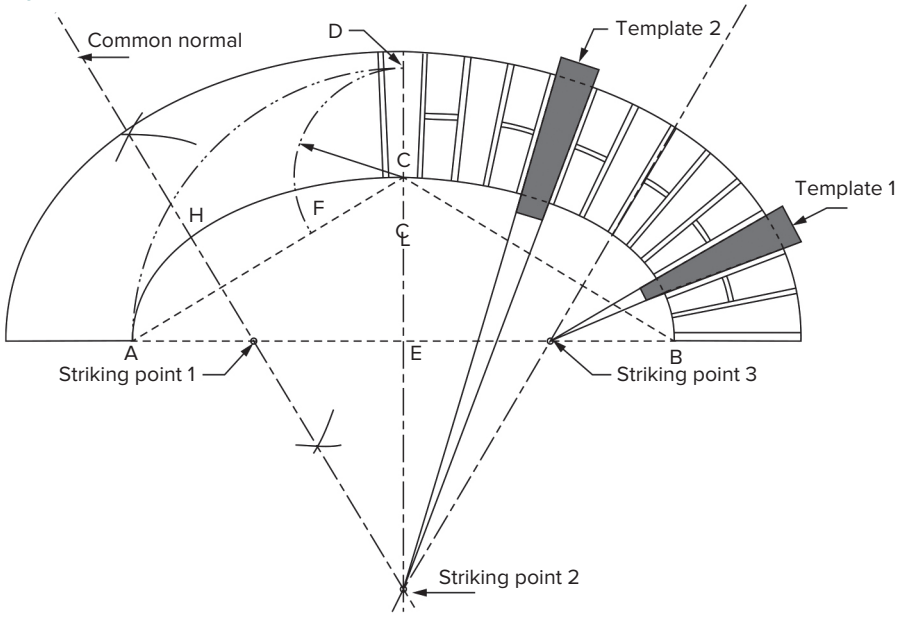


Fig. 25 Three-centred arch



Jack arches were an alternative to constructing a Camber arch, which requires detailed setting out prior to construction. They were not necessarily constructed as face brickwork, but often plastered. When constructed as face brickwork, a Jack arch provides an option to the Camber arch and can be constructed with a bonded face or constructed with concrete masonry blocks (Fig. 26).

Constructing a Jack arch over an opening

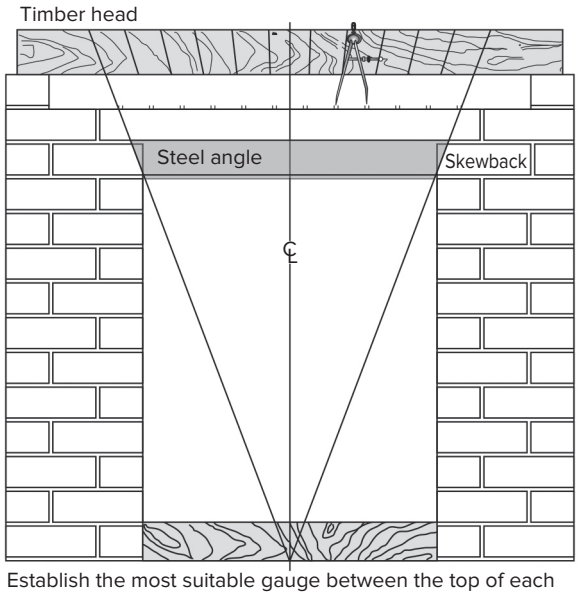
The arch is set out by fixing a piece of 90 × 45 timber at the bottom of an opening and driving a nail into the timber at the centre of the opening. This establishes the striking point or arch centre. A string line is then drawn from the nail through the springing point to provide the angle for the skewbacks. The distance between the top of the two skewbacks is then gauged to provide a key brick and an even number of arch bricks (Fig. 27). The joint between the bricks can be varied between 7–10 mm. Standard bricks 230 × 110 × 76 will only permit an arch face of around two courses unless the arch face is bonded.

Once the arch exceeds a span of 900 there is a need to build it with a slight camber at the intrados to prevent the illusion of the arch soffit sagging.

Fig. 26 Jack arch

Fig. 27 Jack arch construction: (a) setting out and establishing the gauge; (b) marking, cutting and laying the arch bricks; and (c) the completed arch

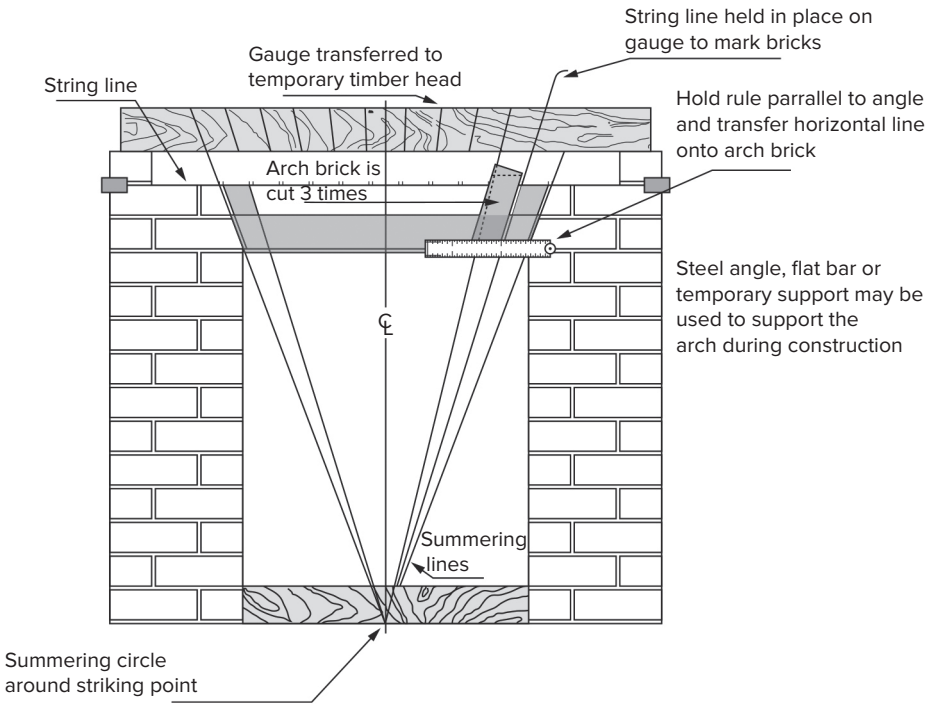
(a)



Establish the most suitable gauge between the top of each skewback by calculation or with dividers. Eleven arch bricks required

Transfer the skewback lines onto a temporary timber head and divide this distance by 11 bricks to extend the gauge onto the head

(b)



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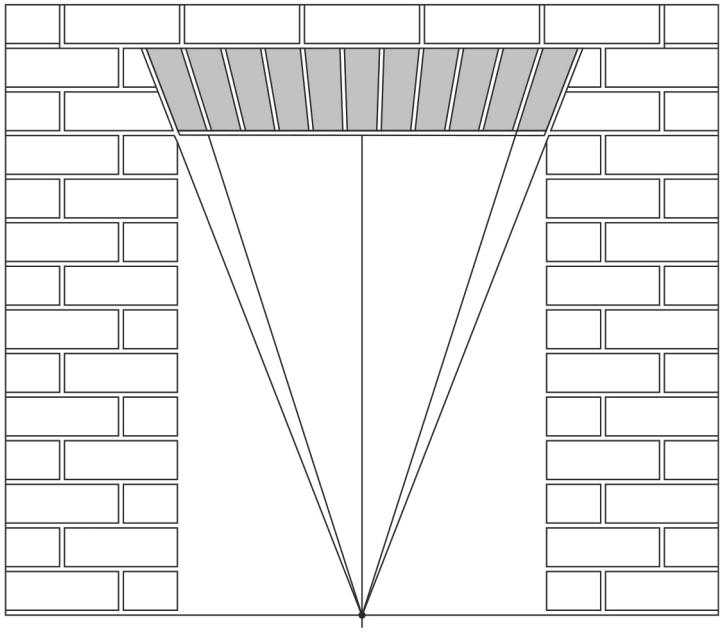


Arch centres

Arch centres provide a temporary support for the construction of an arch. The design and construction of a centre depend on the span, the mass and the thickness of the arch and its shape. The centre must be able to support the mass of the arch without movement or deflection and must be fixed on its supports in such a way that it cannot be easily disturbed. At the same time, consideration must be given to its method of adjustment and removal.

Turning piece

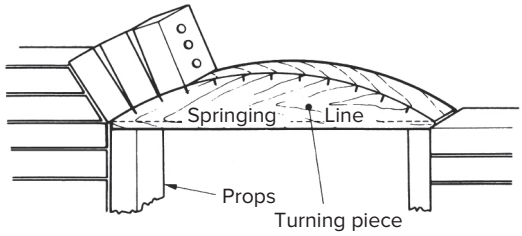
The simplest form of centre is a *turning piece* which can be used on 110 mm walls for segmental arches of shallow rise. The turning piece consists of a solid piece of timber, up to 75 mm thick.

When the brickwork reaches the level of the springing line, the centre is set up on props and braced securely. The spacing of the bricks forming the arch–*the gauge*–is set out on the turning piece by the bricklayer as shown in Figure 28.

Arch centres

A simple arch centre can be quickly constructed by using a sheet of 6–20 mm structural plywood as a smooth surface for setting out the arch and for the manufacture of the centre. This allows all geometry to be shown on the arch centre and facilitates gauging and alignment of the arch bricks to the striking point and summering circle or summering lines.

Fig. 28 Turning piece



As the arch bricks are laid it is possible to 'sight' down the bedding face of the arch brick (or use a string line or straight edge) and align it to the setting out on the arch centre.

- Using temporary nails or screws, fix a piece of ply behind the plywood used to set out the arch.
- Mark a parallel line 100 mm below the springing line and cut the two pieces of plywood simultaneously.
- Fix the two pieces together with 90–140 × 35 framing pine between them so that the extrados of each sheet is square to the other.

An alternative construction method is shown in Figure 29. Here the ribs are built up by laminating together solid material, approximately 25 mm thick. From the full-size set-out, templates are prepared to mark out and cut the various rib sections which overlap each other and are nailed together. The bottom tie is essential, as the centre will tend to spread at this point as the load is applied.

As the span and load increase, the ribs will have to be built up from a greater number of sections and some internal support may become necessary, particularly near the crown of the arch where the load is the greatest.

Fig. 29 Archcentre

Courtesy of Alister Ford

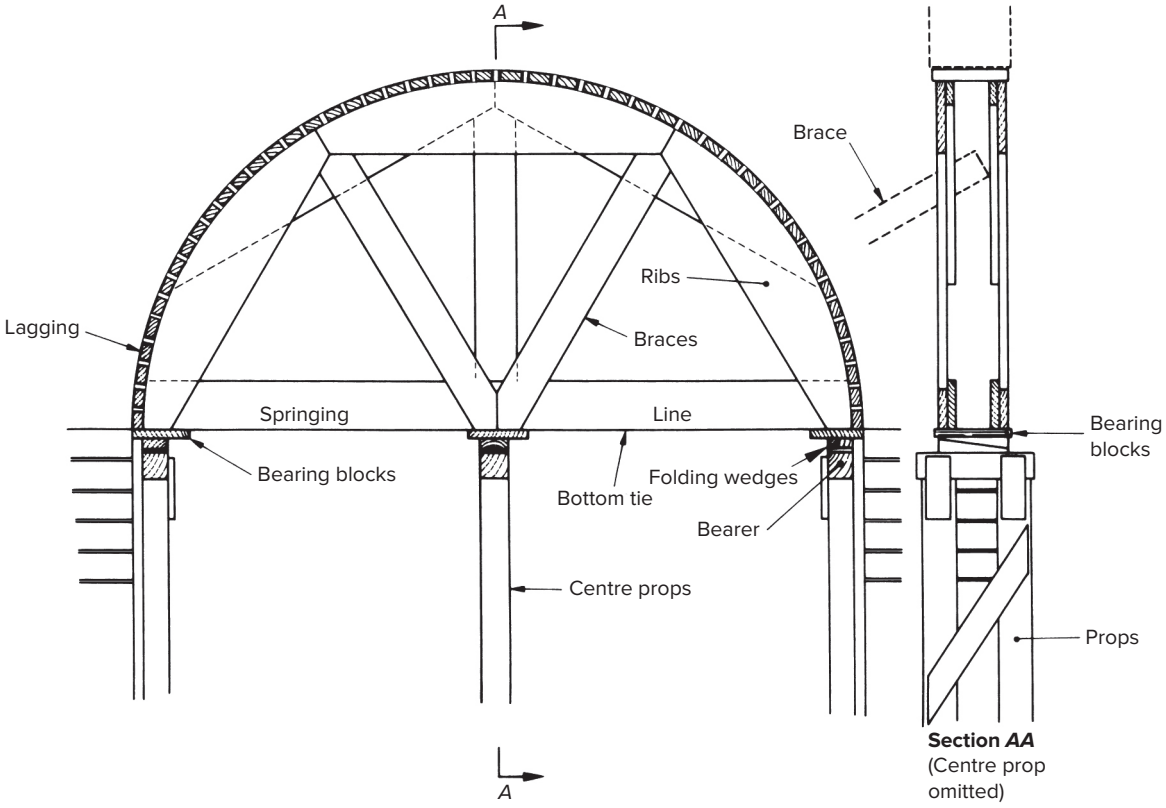
Supporting the centre

Centres are supported on props placed inside the jambs of the opening. These props must be sufficiently strong to support the loads, securely braced supported by sole plates (Fig. 30).

Folding wedges should be used to level the arch centre and locate it in the correct position to facilitate removal of the centre when the arch is completed.

If the arch has been constructed properly and all joints are full and have achieved initial set, it

Fig. 30 Centre for a greater load



is possible to carefully ease and then remove the centre. However, it is preferable to allow at least 24 hours. This will allow minor pointing and cleaning of the brickwork at the intrados as the mortar will not have fully hardened.

The Building Code of Australia

The Building Code of Australia (BCA) has the standing of building regulations throughout all states and territories through links in the various governments' legislation. The BCA ensures a high standard of consistency across Australia (some state governments, however, make variations to the BCA to accommodate local conditions).

The BCA contains technical requirements for the design and construction of buildings to achieve a minimum standard in particular areas like structure, fire safety and health. Different types of buildings are classified, for example, Class 1–single dwellings, meaning detached housing, townhouses, terrace houses, small guest houses, and Class 9–hospitals, theatres and schools.

The BCA comprises two volumes. Volume 1 covers commercial, industrial and public buildings and Volume 2 covers houses and other outbuildings. Volume 2 also includes structural design, energy efficiency, site preparation, footings and slabs, masonry, framing, roof and wall cladding, glazing, fire safety, health, safe movement and access.

The BCA is performance based. This means it defines the minimum levels of performance that must be met. The performance, however, allows flexibility in how the level of performance is achieved. This means that alternative solutions to design, materials and construction can be approved by the government authority, usually local or shire councils. Thus, it provides a dual approach–it defines a high degree of certainty along with a high degree of flexibility to take alternate approaches on the understanding that any different proposal must achieve the performance requirements of the BCA.

Student research

Taking into account the requirements of reinforced concrete masonry construction (see Solid Masonry additional reading) set out a gauged and bonded semi-circular arch using 200 series concrete blocks with a span of 2410.

- How would you core-fill and reinforce such a structure?
- Calculate the measurements of the arch blocks.

Refer to the Concrete Masonry Association of Australia for assistance (www.cmaa.com.au).