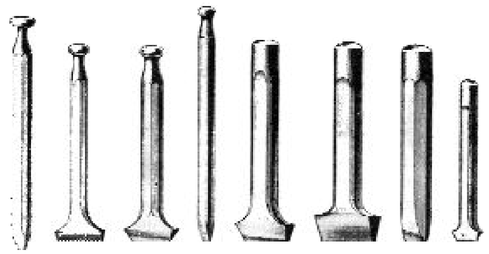

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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

MASONRY

CARPENTRY

JOINERY

STONE ARCHES.

87. Stone arches are generally used in both stone and brick structures, over door and window openings, for porches, etc. They are also erected over streams and roads for highway and railway bridges and aqueducts. Stone arches of long span are not as frequently built now as formerly, iron and steel having been very largely substituted for stone. In some ways, a stone arch is not as satisfactory as a brick one. Being composed of a few large pieces, instead of many small ones—as is a brick arch—the bond is not so perfect; and consequently, of the two, the stone arch is somewhat more liable to settle and crack.

The amount of masonry in heavy piers, etc., can, without injuring the stability of the structure, often be considerably diminished by the use of arches, provided the stone and the footings are capable of carrying the increased load. The pressure on the soil may, if necessary, be decreased by using inverted arches. (See Arts. **91 95,** *Masonry*, § 7.)

88. The principal parts of an arch are as follows: The *abutments* are the piers from which the arch springs, as at

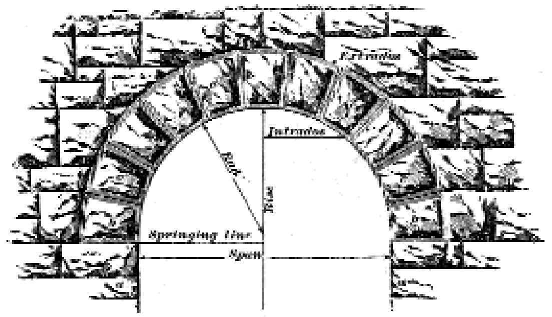

FIG. 48.

a, Fig. 48. The inner edge of the top of the abutment is called the *springing line;* the stones resting on the abutments, shown at *b*, are called *skewbacks.* The arch itself consists of wedge-shaped stones, called *voussoirs,* or *ring stones.* These are sometimes of varying sizes, but for the same arch are generally made as nearly uniform as possible; the depth (back into the wall), however, may vary as much as may be necessary for proper bonding. The voussoirs are shown at *c*. The ring stones between the keystone and the skewbacks are collectively known as the *haunches* of the arch. The masonry resting on the arch ring, from the piers to a horizontal line touching the highest point of the upper curve, form the *spandrels.* The under surface of the arch is called the *soffit*, and a line representing the curve of the soffit is the *intrados ;* the one parallel to it at the outer end of the voussoirs is called the *extrados.* The *span* of an arch is the distance between the abutments; and the *rise* is the extreme vertical height from the springing line to the intrados.

89. In building construction, it is not customary to determine the proportions of arches of small span by calculation. The appearance is often the controlling factor in designing such arches. But when the arches are of considerable span, the position of the *line of resistance* should be determined. As that is somewhat beyond the scope of this section, merely the conditions necessary for stability will be here mentioned.

In relation to arches for engineering purposes, the well known authority, Professor Rankine, says: "The best course in practice is to assume a depth for the keystone based on the dimensions of good existing examples." This statement holds good in connection with the construction of the arches which an architect ordinarily has to design.

90. Having fixed the depth of the keystone, the voussoirs are all made the same height, in arches of small span, while in longer ones the ring stones vary in depth, increasing gradually from the crown to the skewbacks, so as to preserve a uniform pressure on the stones as the load becomes greater. The resistance to crushing of any kind of stone may be readily determined, and a large margin of safety must be allowed over the greatest pressure to which it will be subjected in the arch.

91. To insure the stability of an arch, there are two conditions, besides the one just mentioned, which must be satisfied. One is that the pressure shall not cause the opening of the joints; the other, that the direction of the pressure shall not be such as to cause one ring stone to slide on another.

In order to prevent rotation on the edge of any stone, the line of pressure through which the load is assumed to act—must not be above or below the arch ring at any point, but must cut the abutting surfaces of the stones as near as possible to the center of the joint, and always within the middle third of the arch, so as to prevent the opening of the joints. To obviate the liability of sliding at any joint, the pressure tending to move one stone on another must not be sufficient, nor in such direction as to overcome the friction between the surfaces.

These requirements are met by making the arch ring of proper depth, and generally do not need to be determined theoretically for small arches.

92. Flat arches those having but little rise—give way by breaking the four parts, opening at the crown of the intrados and at some joint on the extrados. When a flat arch breaks, the two upper parts fall inwards and press the lower parts outwards. In pointed arches, the reverse is the case, the lower portions tending to fall into the opening, and to force the upper parts outwards.

KINDS OF ARCHES.

93. Arches are frequently named from the curve of the intrados, as *semicircular, segmental, semielliptic, pointed,* etc. The *semicircular* arch is, as its name indicates, one whose intrados is a half circle. The *segmental* arch is one in which the intrados is generally an arc of large radius, less than a semicircle. Sometimes the curve is composed of arcs of two or three different radii, in which case it is termed a *three* or *five centered* arch. The upper part of such an arch has a long radius, while the portions near the springing line have short and equal radii. This arch is nearly elliptic in form, and is often so known. The true ellipse is also used, an example being given in Fig. 55. Examples of segmental and three centered arches are given under the heading "Brick Arches," *Masonry*, § 7. The *pointed* arch has its intrados formed of two arcs of equal radius, intersecting at the crown. The *equilateral* pointed arch is one in which the radii of the intrados are equal to the span, as shown in Fig. 51. There are numerous other forms of arches, but it is unnecessary to describe them all, on account of the general similarity between them and those already mentioned.

When the springing line of an arch is below the center, as shown in Fig. 48, the arch is said to be *stilted*, the distance from center to springing line being the *stilt.*

94. A stone arch frequently built is the one shown in Fig. 48. In this case the arch ring is of equal depth all around, and the voussoirs are all of the same size; the dressing is rock faced with pitched joints. Sometimes the voussoirs have a margin draft, as shown on *b* and *c*.

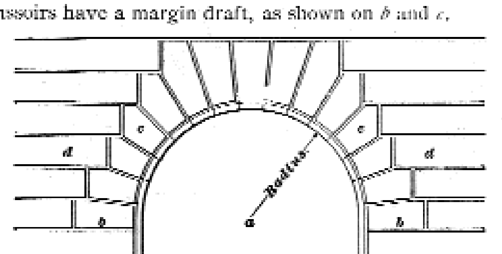

FIG. 49.

95. Arches that are used in coursed ashlar are often built as shown in Figs. 49 and 50. In each of these, *a* is

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the center of the arch; *b*, *b*, the springing line; *c*, *c*, the ring stones; and *d*, *d*, the coursed stonework. Arches of this description are more expensive to execute than those in

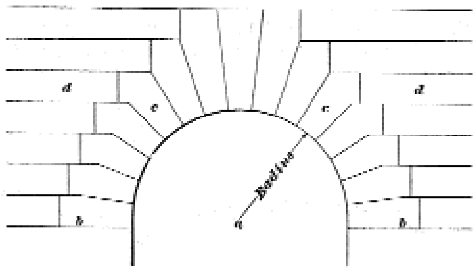

Fig. 50.

which the intrados and extrados are concentric, on account of the greater number of patterns required, the increased quantity of stone needed, and the work necessary to properly dress the voussoirs.

96. Fig. 51 gives an example of a *Gothic*, or pointed equilateral arch, with the intrados and extrados concentric.

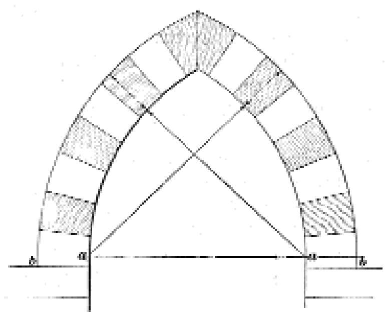

Fig. 51.

In this illustration, *a*, *a* are the centers from which the arch is struck, and *b*, *b* is the springing line.

97. Fig. 52 shows an arch having the intrados semicircular and the extrados pointed. Such arches are found in Venice, and are sometimes termed *Venetian Gothic* arches. At *a* is the center for the semicircular intrados; at *b*, *b* are the centers for the extrados, or pointed arch; and at *c*, *c* is the springing line.

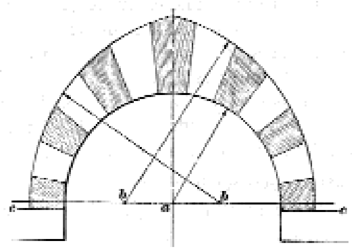

Fig. 52.

98. The *horseshoe*, or *Moorish*, arch is represented in Fig. 53. The Alhambra, at Granada, Spain, has some of

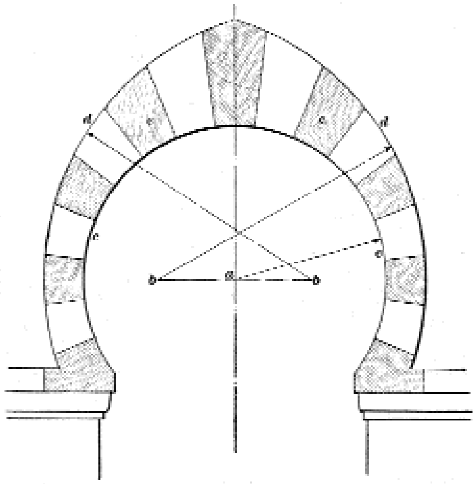

Fig. 53.

the best examples of this arch. Sometimes it is built with the intrados and extrados concentric, and also with the intrados having a horseshoe form, and the extrados a pointed form. The example given shows the latter method of construction. At *a* is shown the center for the horseshoe intrados; at *b*, *b* are the centers for the pointed extrados of the arch; *c* indicates the soffit of the horseshoe arch; *d*, the upper side of the arch ring; and *e*, the voussoirs. In all horseshoe arches the center is stilted far above the springing lines, to produce the required effect.

99. Arches having an elliptical or oval form, or pointed in the center and elliptical near the springing joints, are often used in architectural work. These may be formed either of true elliptic curves, or of 3 or 5 centered circular arcs. Very flat elliptical arches are not suitable for any considerable span, and, if built, should have large piers or abutments; or beams may be placed above the arch, to relieve it of some of the load.

The method of finding the direction of the joints in a false elliptical arch is shown in Fig. 54. The construction of the

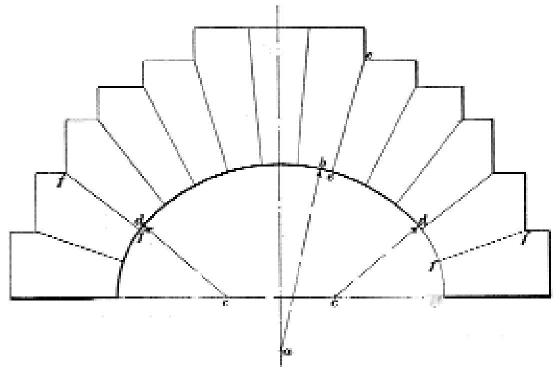

Fig. 54.

ellipse is similar to that given under the heading, "Inverted Arches," *Masonry*, § 7. The radius for the middle of the arch is *a b*; the radii for the two haunches are the lines *c d*.

The joints of the voussoirs in the central portion are drawn with *a* as a center, as at *e e*, etc.; and the joints for the haunches are drawn with *c*, *c* as centers, as at *f f*, etc.

100. A method of finding the voussoir joints in a true elliptical arch is given in Fig. 55. This shows d^1, d^2, d^3, d^4,

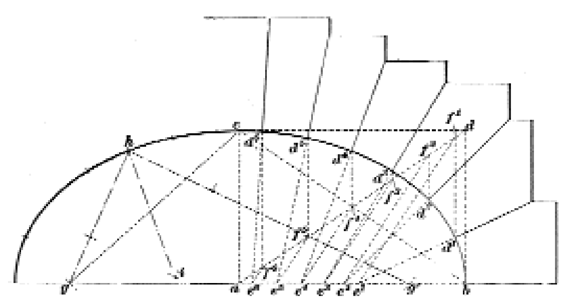

Fig. 55.

d^5, and d^6 as the points through which it is desired to draw the joints. Draw tangents to the ellipse at the points *b* and *c*, intersecting at *d*; also, the lines *a d* and *b c*; draw from d^1, d^2, d^3, etc., lines intersecting *a d* at f^1, f^2, f^3, etc. From these points, draw lines perpendicular to *b c* intersecting *a b* at e^1, e^2, e^3, etc.; then lines drawn through $e^1 d^1$, $e^2 d^2$, etc. will be normal to the curve and give the required joints.

Another and simpler method to find the direction of the joints is as follows: Find the foci of the ellipse by striking arcs from *c* with *a b* as a radius, cutting the major axis at *g* and *g'*. Let *h* be the point where the direction of the joint is to be found. Draw *g h* and *g' h*, and bisect the angle *g h g'*, as at *h i*; then *h i* is the direction of the joint at *h*.

101. The flat arch is very common in architecture, but is not a strong construction. To be self-supporting it must

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be of such a size that a segmental arch of proper radius and sufficient depth can be drawn on its face, as shown in Fig. 56 by the dotted lines *a*, *a*. This arch should have a radius equal to the width of the opening—which in this case is 4 feet—while the limiting width for an arch of this description should not be over 5 feet. The keystone should

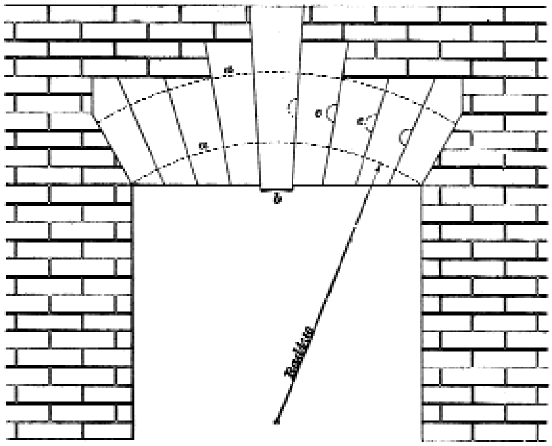

FIG. 56.

project about an inch below the soffit of the arch, as indicated at *b*, in order to more tightly wedge together the voussoirs. The strength of this arch may be increased by notching one stone into the next, as shown at *c*, *c*; or dowel-pins are sometimes used to bind the stone together.

102. When an arch is so flat as to have practically no rise, it should be cut out of one piece of stone, being really a solid lintel with false joints cut on its face, as shown at *a*, *a*, Fig. 57. The ends of this lintel should have a bearing on the wall of 4 or 5 inches, as indicated by the dotted lines at *b*, *b*. If the walls are of brick, about 2 inches of the front of the stone may be cut away and faced with brick.

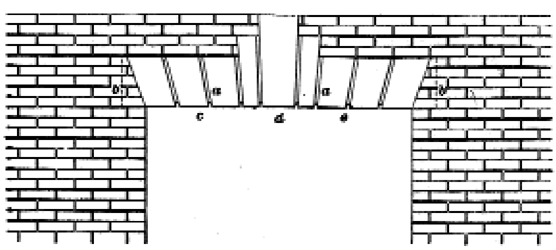

FIG. 57.

If this method is too costly, the lintel may be cut in 3 pieces, as shown at *c*, *d*, and *e*, and supported by a heavy angle bar, as described under "Lintels."

103. Rubble Arches.—For rough purposes, arches are sometimes built of rubble, as shown in Fig. 58, in which *b* represents the wall carried by the rubble arch, the ring stones of which, as *a*, should be narrow and roughly dressed

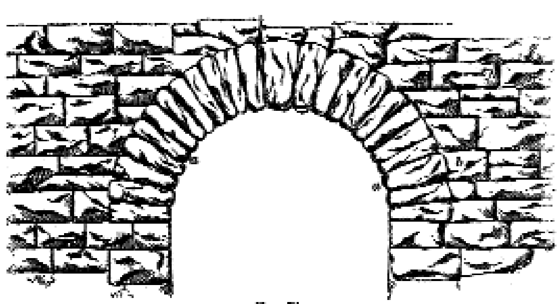

FIG. 58.

to a wedge shape. Such arches should always be laid in cement mortar, as they depend considerably upon the adhesive power of the mortar for their stability.

CONSTRUCTION OF ARCHES.

104. Voussoirs. The ring of the arch should be built of the very best kind of ashlar masonry, cut, so that the voussoirs bear evenly and closely against one another, with the thinnest possible joints, as it is desirable to have but little mortar between the stones. The width of the ring stones is seldom less than 1 foot, or more than 2 feet, and the thickness (back into the wall) varies from 1 to 3 feet. The joints of the stonework should be the same width throughout the arch, so that the bearing may be uniform over the entire surface. The thickness of the joints depends somewhat upon the character of the finish. If the work is finely dressed, $\frac{3}{16}$ inch is the usual thickness; while in rock-faced work it is seldom made less than $\frac{3}{8}$ inch; $\frac{1}{4}$ inch is all that is usually allowed for the best work.

105. Usually the arch is divided into an odd number of voussoirs, and the keystone is placed in position last. Except for the convenience of the masons in laying, and for the sake of appearance, there seems to be no special reason for an uneven number of voussoirs, and some authorities claim that an even number makes a better job. Narrow voussoirs, while more economical in the amount of material used, are more expensive in labor, as more cutting and fitting is required than with wider ones.

Sometimes two of the voussoirs are cut from one stone, with a false joint between. Although this is generally done for economy, there are cases when the stability of the arch is thereby increased; as, for example, when the skewbacks are made twice the size of the remaining voussoirs, the number of joints is decreased, thus tending to strengthen the arch. In the case of a pointed arch, as shown in Fig. 52, the keystone should be made in two pieces, as the danger of its cracking or slipping is very much lessened when this is done.

106. Backing.—As a rule the cut-stone arches in buildings are only from 6 to 8 inches thick, having a backing of a less costly kind of stonework. Large arches, especially when both sides are visible, as in some entrances, porches, etc., are often constructed as shown in Fig. 61. In this case, the stone ashlar is backed with brick, and tied together with clamps, as indicated at *f*.

107. Beams and Tie-Rods.—When an arch is to be built in a position where sufficient abutments to resist the arch thrust cannot be provided, one or more steel beams should be laid on the wall immediately over the arch, with the ends resting on the masonry forming the abutments. Anchor rods, securely embedded, should be used to tie together the beams and the stonework. Immediately below the middle of the beam, a small space, or joint, without mortar, should be left, so that if the beams deflect under the load they will not rest upon the arch. This method relieves the abutments of the arch thrust due to the load, which is, instead, transmitted vertically to the supports.

In building a segmental arch it is a good precaution, if conditions permit, to tie the arch together with steel rods, to take up the thrust until the mortar in the masonry has thoroughly set.

108. Bonding.—Whenever arches are carried on piers or columns, care must be taken in cutting the springing

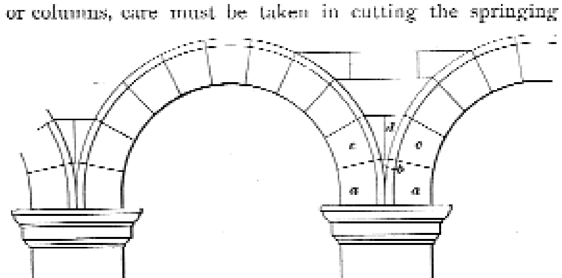

FIG. 59.

stones, so that they will bond properly into the spandrel masonry. In Fig. 59 are shown two arches springing from a pier; if the stones *a* are so cut that the wedge shaped piece

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b is necessary to fill up the space between them, there is danger that the weight of masonry over *b* will force it down, displacing the springing stones *a*; and similarly with the stones *c*. To prevent this, the stones *a* should be cut in one piece, while those marked *c* should be cut so as to make the joint come at *d*.

A somewhat similar case is represented in Fig. 60. Here the back of the arch extends almost to the corner of the wall, as shown at *b*. It is evident that, if the brick wall

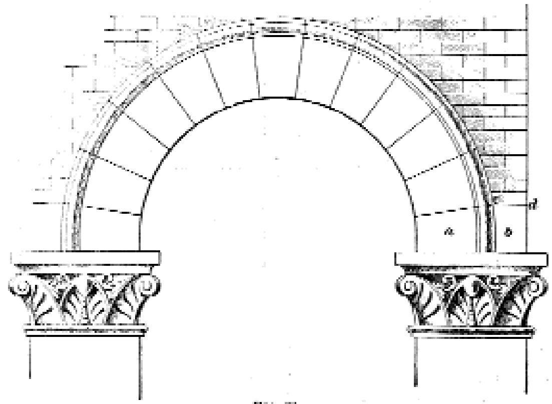

FIG. 60.

rests on such a small footing, it is liable to separate from the arch, thrusting out of place some of the lower bricks. In such a case, the lower voussoir *a* should be cut so as to extend to the corner of the wall, until the distance *c d* is at least 8 inches; more than this should be allowed if the wall is very heavy.

109. Molding.—Arches are often decorated with more or less elaborately dressed stone, known as *label* and *soffit* moldings. The former is sometimes cut in the ring stones, but oftener forms a separate course of thin stone. If such is the case, the stability of the arch should not depend on the strength of the stone in the molding.

The soffit molding is frequently in the form of a bead and cone, or three-quarter round and cone, or some similar shape. Entrance arches are often decorated with various devices cut in the soffits, especially in entrances to cathedrals, public and office buildings, etc.

In Fig. 61, the label mold is shown at *a*; the arch rings, at *b* and *c*; the soffit mold, at *e*; the brick backing, or filling, at *d*; and the voussoir joints, at *g*. Every alternate pair of voussoirs should be tied together with galvanized-iron clamps doweled into the stones, as shown at *f*.

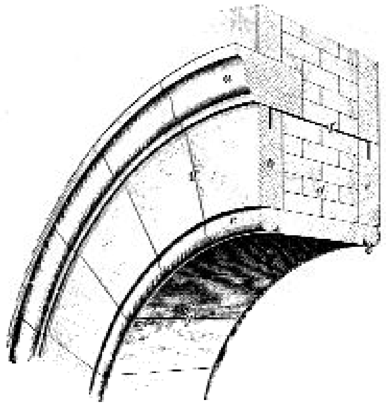

FIG. 61.

110. Centers.—In building an arch, it is carried up from both piers or abutments at the same time. During construction, the stones must be supported until the ring is completed. For this purpose, a framework, made of planks having one side cut to exactly fit the curve of the arch, is used. This framing, known as a *center*, is supported on posts; it is usual to insert wedges between the center framing and the posts supporting it, which, when the arch is completed and the mortar has set, are driven out gradually, so as to bring the load on the arch ring without shock. The center should be strong enough to support the weight of the arch and a share of the wall above, as no weight should be put on the arch until the mortar in the joints has become hard.

111. Fig. 62 represents a form of center suitable for arches of small span. At *a* are shown the *bearers*, which

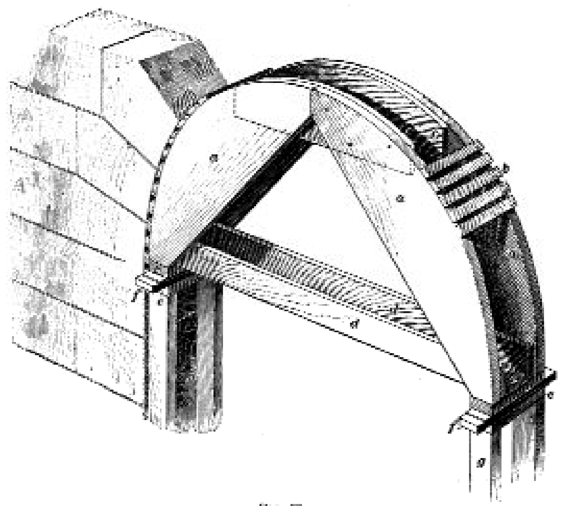

FIG. 62.

are cut out of 2-inch plank, to a radius about 1 inch less than that of the intrados of the arch. At *c* are indicated pieces of plank, nailed at the crown of the center to splice and stiffen it. Small bearing strips *b*, about 1 in. × 2 in. in section, are nailed to the curved pieces *a*. At *d* are the longitudinal braces; at *e* are the plates under the center and on top of the posts; at *f* are the wedges; and at *g*, the posts, which, if quite long, should be braced at the middle by struts.

112. For arches of considerable span, centers more strongly built are necessary. Fig. 63 shows a good form of construction. At *a* and *b* are represented the bearers, break-

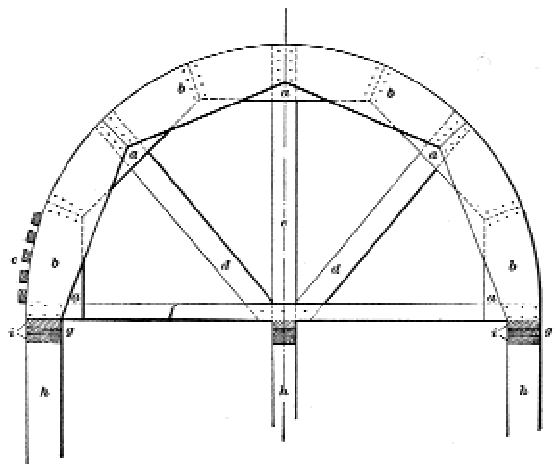

FIG. 63.

ing joint as shown; *c* indicates the bearing strips; *e*, the upright; *d*, the inclined braces; *f*, the tie piece; *i*, the bearing plates, with wedges *g* between; and *h*, the side and center posts.

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