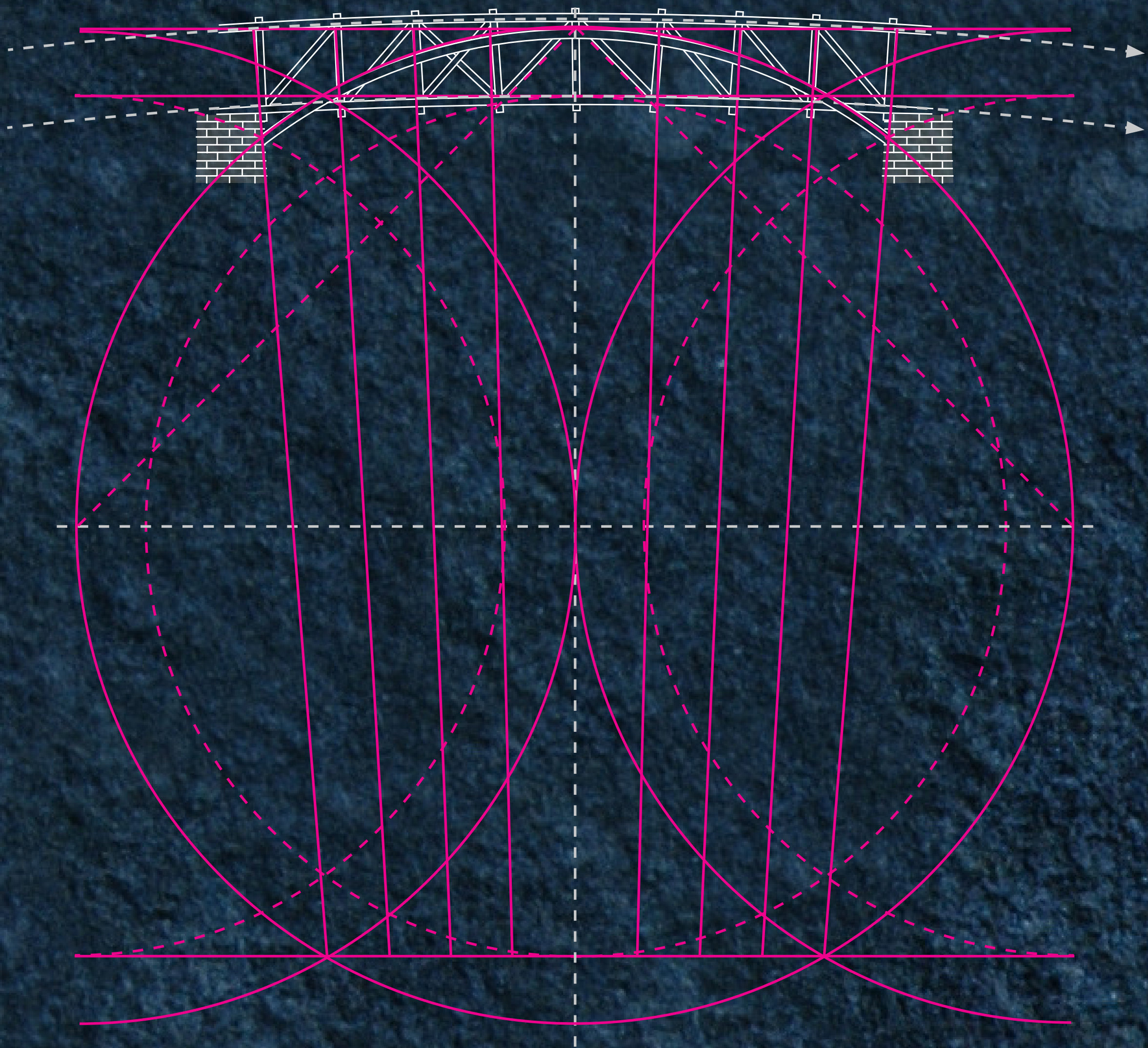
# The BURR ARCH Covered Bridge – A Geometrical Perspective



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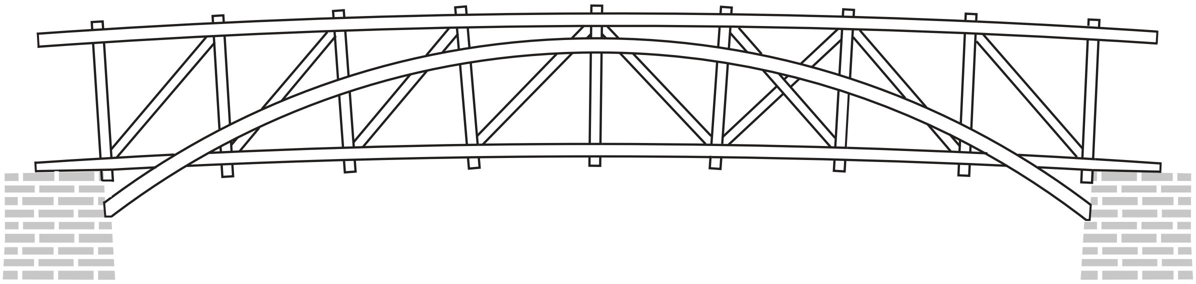


# The Burr Arch covered bridge

## *a Geometrical Perspective*

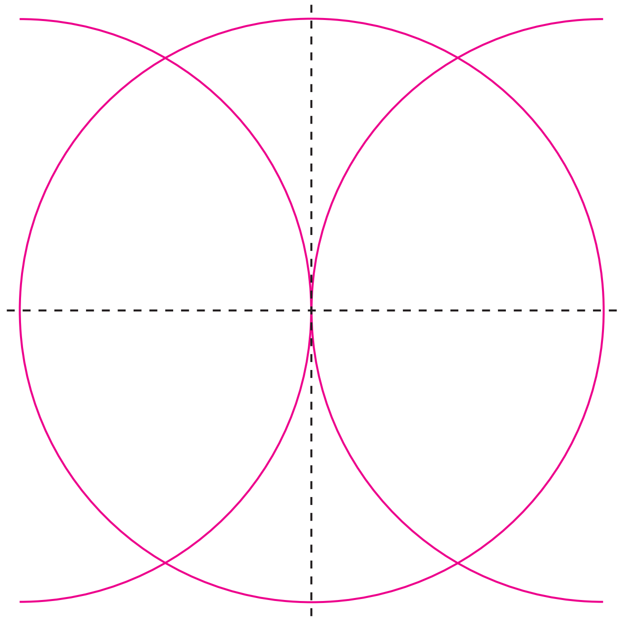
The electronic bridge across the Atlantic brings me welcome emails about TFG* conferences and other timber related events, which is how I came to be reading the TFEC* 2013 Symposium programme. Among many interesting topics Katie Hill's presentation on *Burr Arch covered bridges: how effective IS that arch?* and the drawing beneath it, a side elevation of the bridge structure from the 1817 Burr patent, caught my eye. The introduction commences, "*The Burr Arch is a timber truss configuration that superimposes one or more arches on a multiple kingpost truss. It was widely used for bridge construction. The combination of arch and truss – two structural systems that behave in fundamentally different ways – has led to endless theorizing by designers and builders on the respective roles of arch and truss and on how the load is distributed between them*" and concludes, "*. . . . . structural engineering remains – even with all our fancy analytical software – as much an art as a science*".

The introduction interested me for a number of reasons but primarily because when Theodore Burr took out patent 2769x in 1817 geometry was the state of the art design methodology of the time and fancy analytical software didn't exist. In the two hundred years between then and now the spatial language of geometry has been superceded by the numerical language of mathematics: the art superceded by the science. I had two thoughts: that numerical analysis of a geometrically designed timber structure might be barking up the wrong tree and that geometrical analysis might throw some light on the thinking that informed Burr's design.

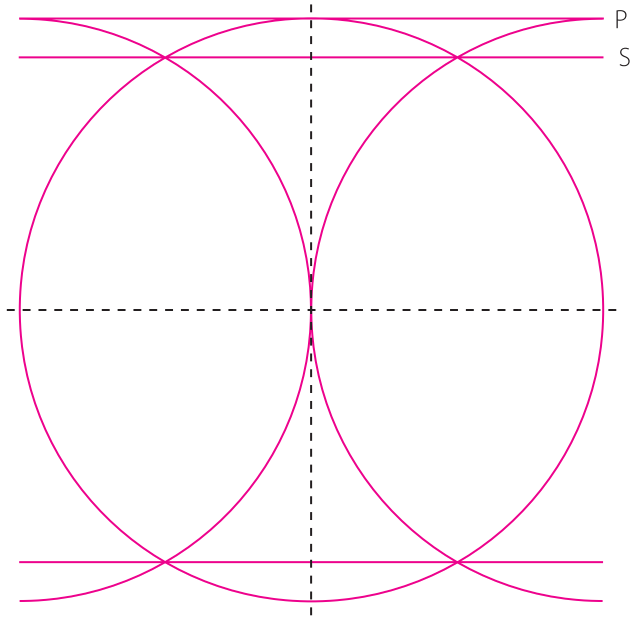
More recently, in Timber Framing 110, I read the letters from Joseph D Conwill, Jan Lewandoski and Katie Hill herself encouraging "*. . . . other engineeers to weigh in on their own approaches to evaluating historic structures*". So, although neither a carpenter nor an engineer, I'm weighing in with a geometrical rationale for the design of the bridge which I hope will be a useful contribution to the debate.

Looking at the drawing (mine is redrawn from the TFEC Symposium image) it was clear the multiple king posts were all radial to an undefined axis somewhere below the bridge. The axis of the arch, which is an arc of circle, was likewise somewhere unknown. Also unknown was whether these two axes were independent of each other or sharing a common point. I felt instinctively that the circle defining the arch was the element of the design to seek first and discovered, after some trial and error, that the design evolves incrementally from this initial circle using simple compass and straight edge geometry. The following drawings show the step by step development of the design with adjacent descriptions.

TFG Timber Framers Guild
TFEC Eastern conference

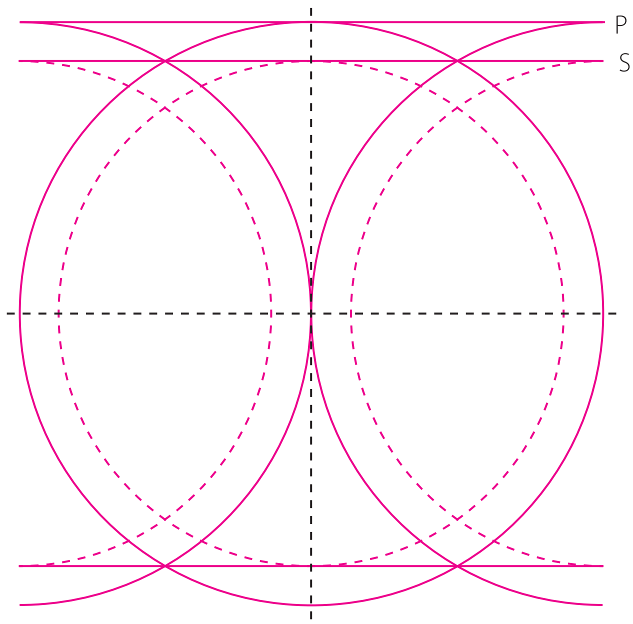


Drawing 1 shows the circle drawn from an axis formed by vertical and horizontal perpendiculars which simultaneously define the circle's North, South, East and West poles. Half circles drawn to the same radius from the W and E poles intersect the full circle in four places.

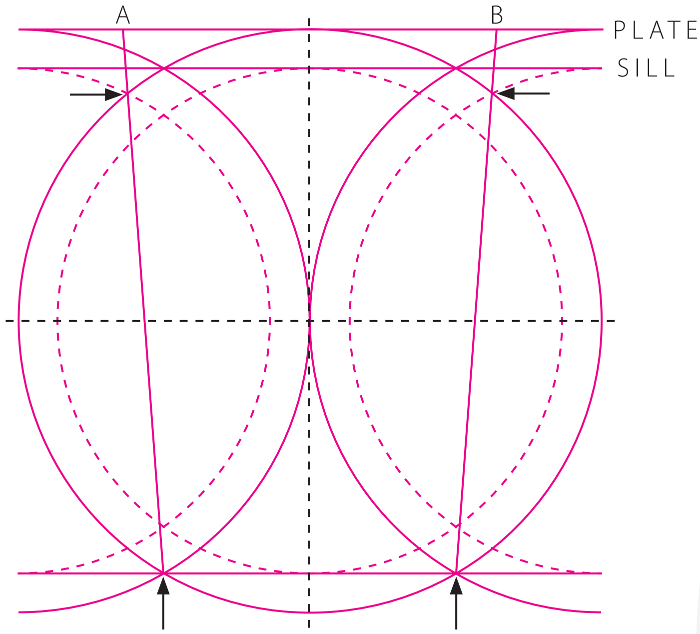



Drawing 2 shows two horizontals drawn through the four intersections of circle and half circles and a tangent drawn across the top of the circle and half circles.

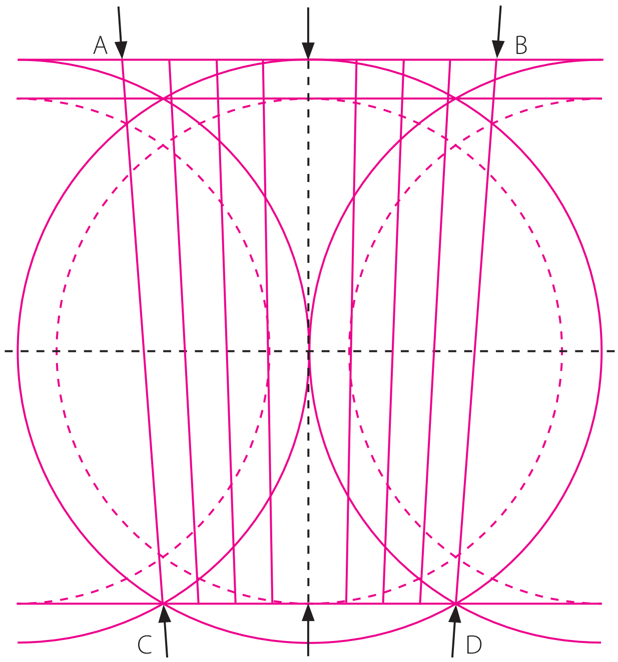
The tangent and top horizontal establish the alignments of the plate and sill respectively for the multiple kingpost sector of the bridge.




Drawing 3 shows an inner circle (in dashed line) drawn from the intersection of the perpendiculars so that it kisses the horizontals drawn in the previous drawing. Two dashed half circles are drawn to the same radius from the W and E poles. The dashed circles generate further points of intersection that are used in the next stage of the design.

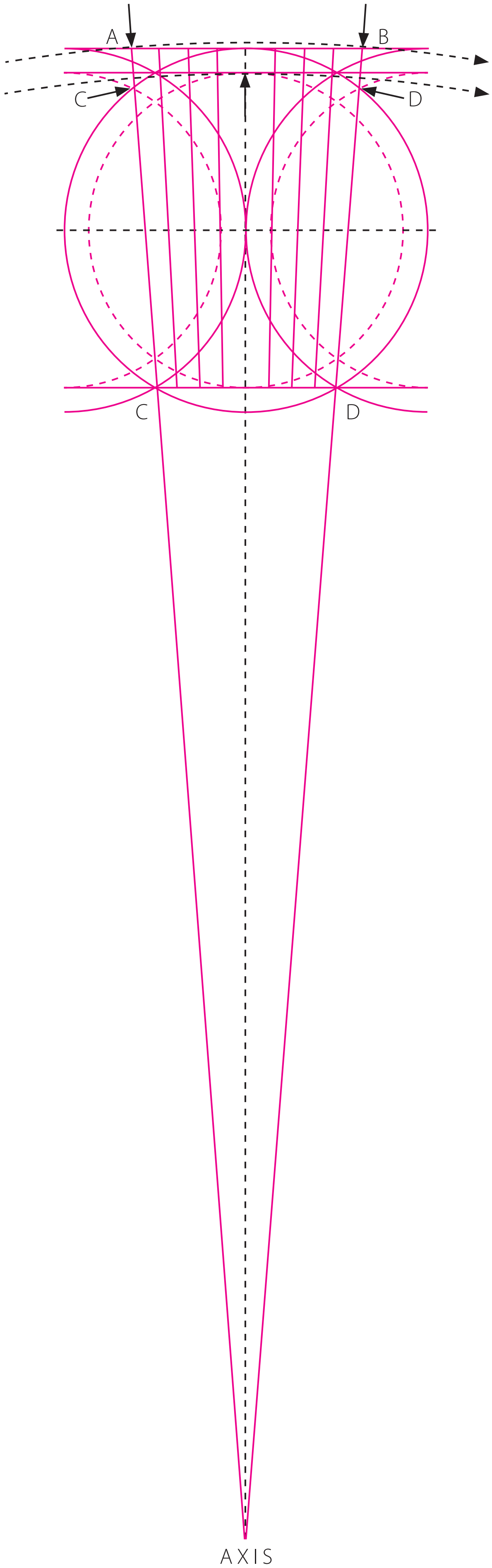



Drawing 4 shows two alignments drawn between the points of intersection marked by black arrows on the left and right of the drawing. These alignments start at the intersection of the solid line full circle and half circles at the foot of the drawing but pass through the intersections of the solid line full circle and dashed line half circles at the head of the drawing. This results in lines that diverge at the head of the drawing to give the outer king post angles between the plate and sill at A and B. The inner faces of the masonry buttresses beneath the sill (not shown) also follow this alignment.



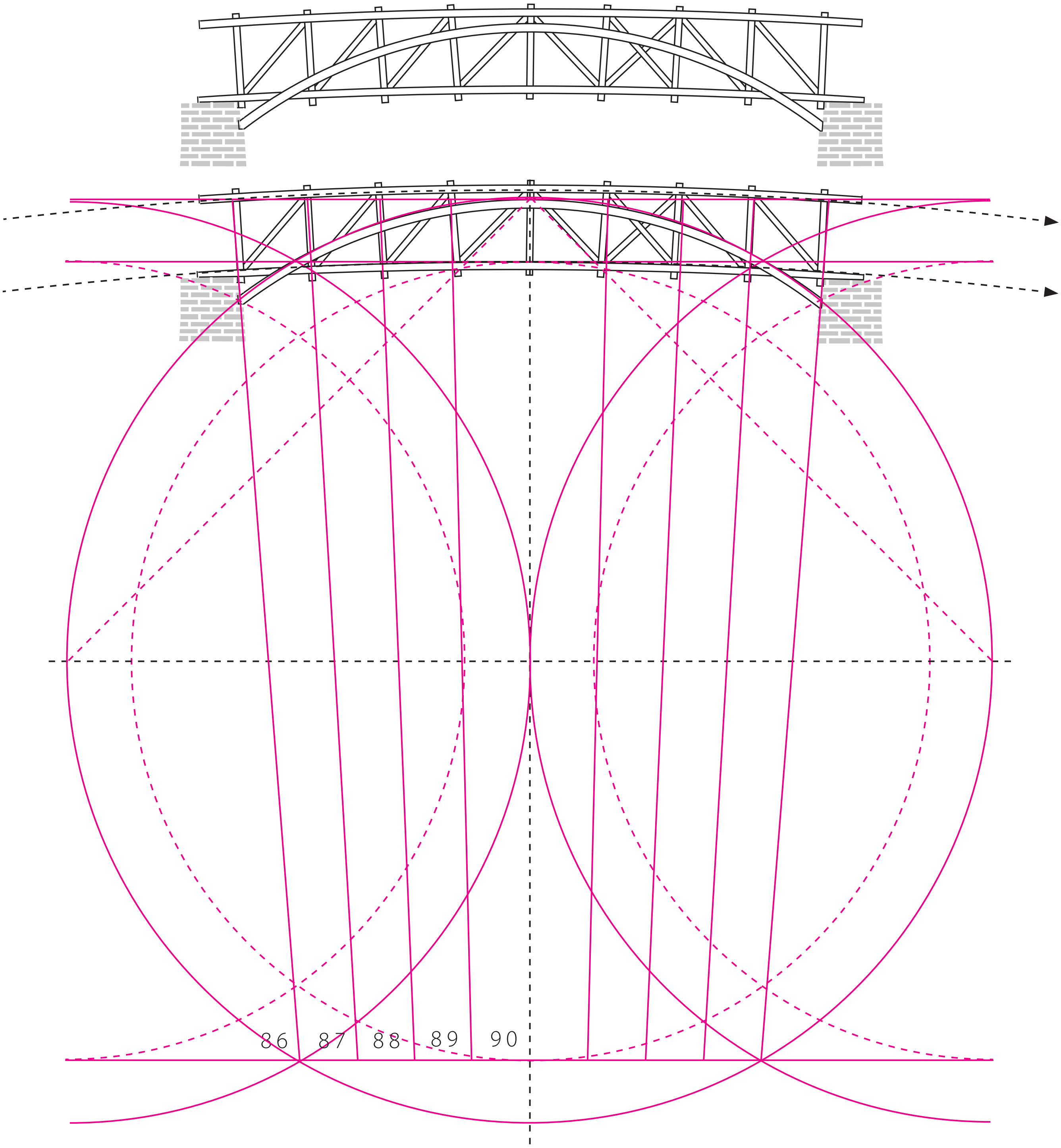

Drawing 5 shows the plate line AB and foot line CD each divided into eight equal sectors which are linked to form king post angles between the plate and sill.

Division into eight is attained by divider division of the full lines into halves (which is predetermined by the dashed black vertical perpendicular), divider division of the half lines into quarters and divider division of the quarters into eighths. Divider division eliminates the need for ruler measurement and is a simpler and more accurate method of setting out.




Drawing 6 shows the final stage of the design (the full circle is reduced by 25% so that the drawing's length fits the page). The outer lines AC and BD are extended downwards to meet at a common axis on the vertical perpendicular. Two arcs of circle are drawn from the axis, the first passing through the plate line at A and B, the second through the sill line at its centre point on the vertical perpendicular, the points marked by black arrows. The two arcs determine the parallel shallow curves of the bridge sill and plate.

As in the construction of a building, where scaffolding is an essential but temporary structure, much of the geometry shown acts as scaffolding that is superfluous after serving its purpose. The bridge occupies the upper sector of the construction from point A to point B between the parallel dashed arcs and follows the arc of the originating circle from point C to point D.




Drawing 7 is doubled in scale with the bridge superimposed on the geometrical construction so that the intimacy of the two is clear. The bridge is also shown separately for comparison. It can be seen that the masonry buttressing at either side of the bridge follows the angles of the outer king posts and that the bracing in the centre of the bridge connects the main circle's W and E poles to its N pole.

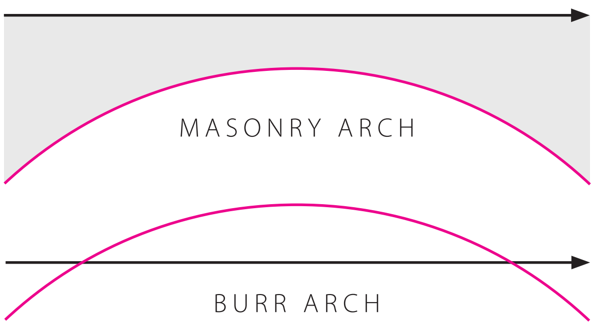
While we know intuitively that the vertical perpendicular is at 90 degrees to the drawing's base line, for those keen to know angles a protractor tells us that the adjacent radials are at 89, 88, 87, and 86 degrees on the perpendicular's left and the same angles in reverse order on the perpendicular's right.

# The Burr Arch covered bridge – *a third view*

There appear to be two major design opinions about the Burr Arch: that it is predominantly a king post truss supported by an arch or, conversely, that it is an arch strengthened by a king post truss. I hold a third view, that the bridge is a unified design where every component arises from the same geometrical matrix and is therefore in spatial harmony.

Where did the idea of the Burr Arch come from? In my view it is a linear timber frame evolution from solid masonry bridges, bearing in mind that the underside arch of a masonry bridge was built on carpentered centring and the road surface was supported on the necessary depth of masonry above the underside arch. So the precedent was already there but the innovative aspect of the Burr Arch was to consider the arch and road surface as two separate linear elements that could be formed from timber. More importantly, in the absence of masonry, the travelling surface and arch could be placed in a different relationship to each other. Drawing 8 shows the travelling surface of the Burr Arch as far below the apex of the arch as the masonry arch is below its travelling surface.

As drawing 7 shows, the linear elements of timber structures mesh perfectly with compass and straight edge geometrical design methods. The only issue is scale, translating a drawing to full scale structure. If the Burr Arch bridge in drawing 7 is 100 feet in length (some were longer) the initial circle would be 144 feet in diameter at full scale. At 1:12 scale this circle would be 12 feet in diameter, at 1:24 scale 6 feet in diameter and at 1:48 scale 3 feet in diameter, a scale that could be drawn comfortably on a 4 feet square table with a beam compass or trammel set to an 18 inch radius. With the radius established, the geometrical development is simple and straightforward. It would be interesting to know whether Theodore Burr, given some fancy analytical software, would define the design process as an art or a science.




Drawing 8 shows the road surfaces as black lines, the arches as magenta lines and their relationship in masonry and timber bridges.

Drawing 9, opposite, shows the Burr Arch bridge

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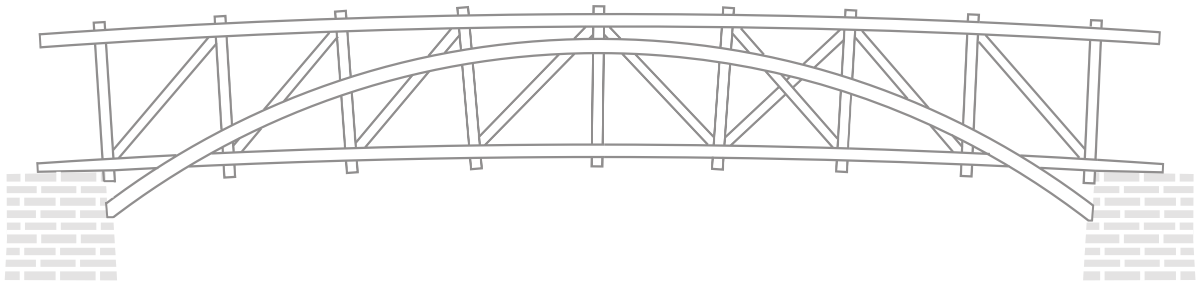

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