Mathematical bridge

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Bridge History

designed in 1748 by William Etheridge

built in 1749 by James Essex the Younger in oak

repaired in 1866 due to timber decay, particularly in the cross-beams supporting the pedestrian deck, which suffered from poor water drainage

completely rebuilt in 1905 to the same design, by the local builder William Sindall, in teak instead of oak

Design Principles

- Timber voussoir arch bridge design uses gravity to maintain compression, requiring strong abutments at the arch's base.
- Wood, weak under bending, is strong in compression, a key factor in this bridge where timbers experience mainly compression, not bending.
- Triangulation inside trusses ensures stiffness and lightness, preventing hinging at arch joints.
- Open sides minimize wind impact, with cross-bracing only under the footway.
- Design theoretically allows individual timber replacement inside trusses without dismantling the whole bridge, though untested in practice.
- Various timbers in the bridge have lead capping, especially near joints: presumably to keep rainwater out of the joints.

Material analysis

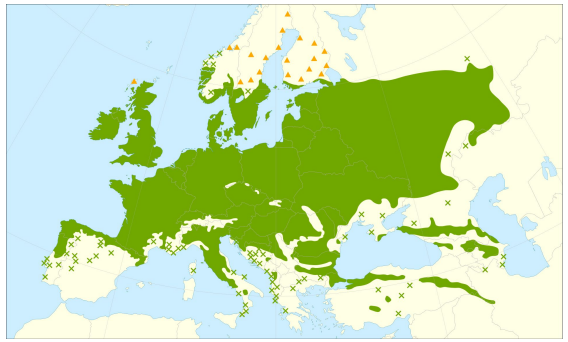
English Oak

Moderately inexpensive

Good decay resistance

Workable, but can get stained

IUCN: Least Concern



Teak

Expensive

Great decay resistance

Easy workability

Turns silver if left untreated

IUCN: Endangered, declining

Illegal logging

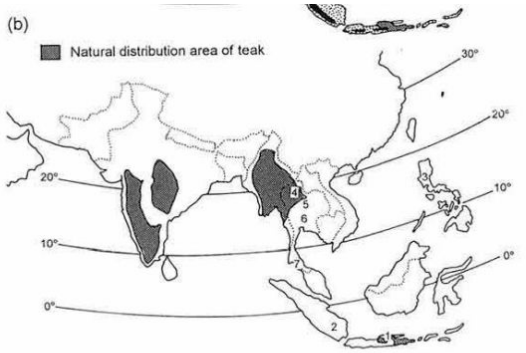
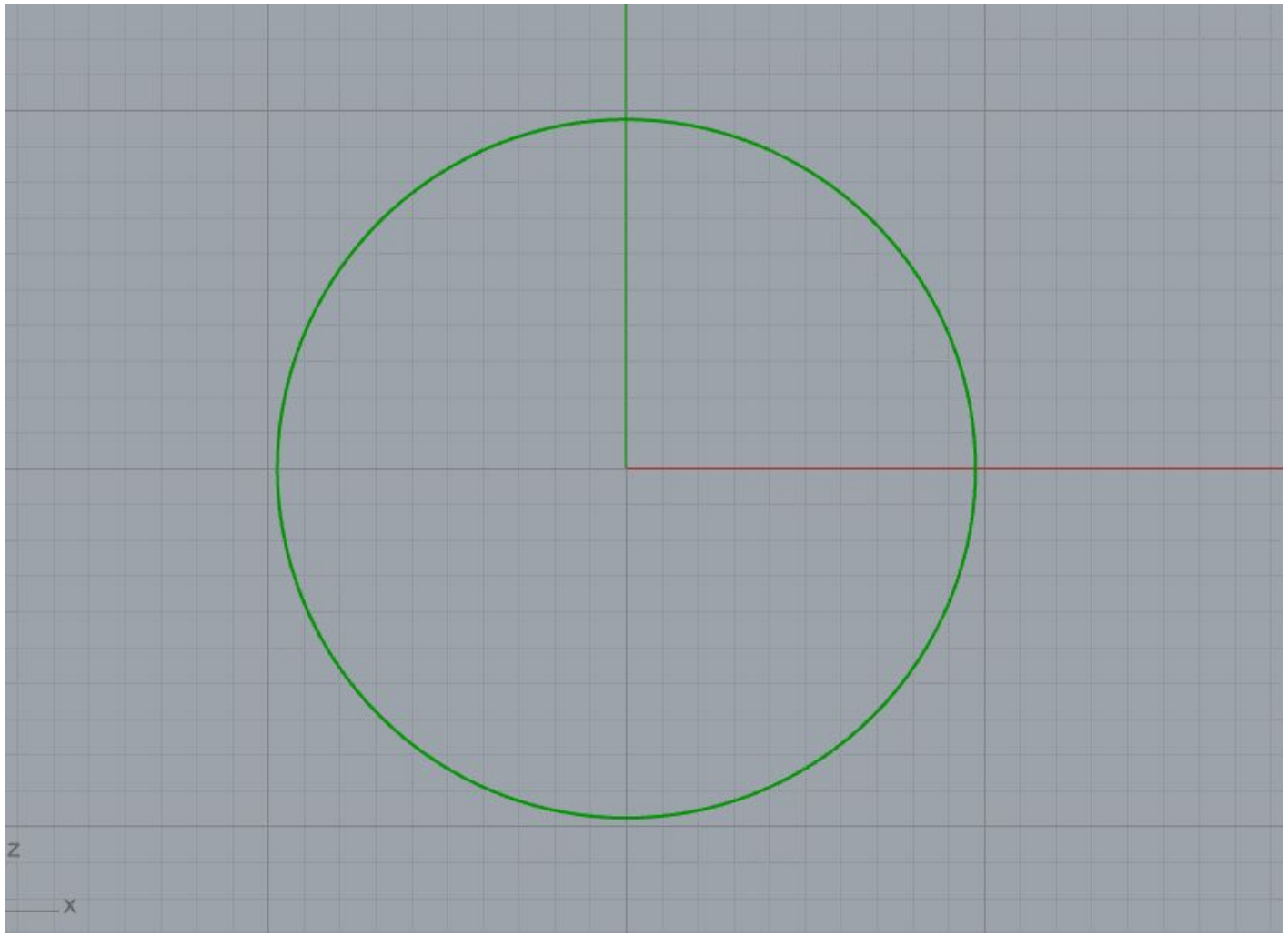


Fig. 1. Maps of (a) climate types[24] and (b) natural distribution of teak[8] The numbers in the map (b) indicate the locations of teak plantations described in the text as follows: 1; Cepu, 2; Benakat, 3; Carranglan, 4; Lampang, 5; Dong Larn, 6; Klang Dong, 7; Khao Chong.

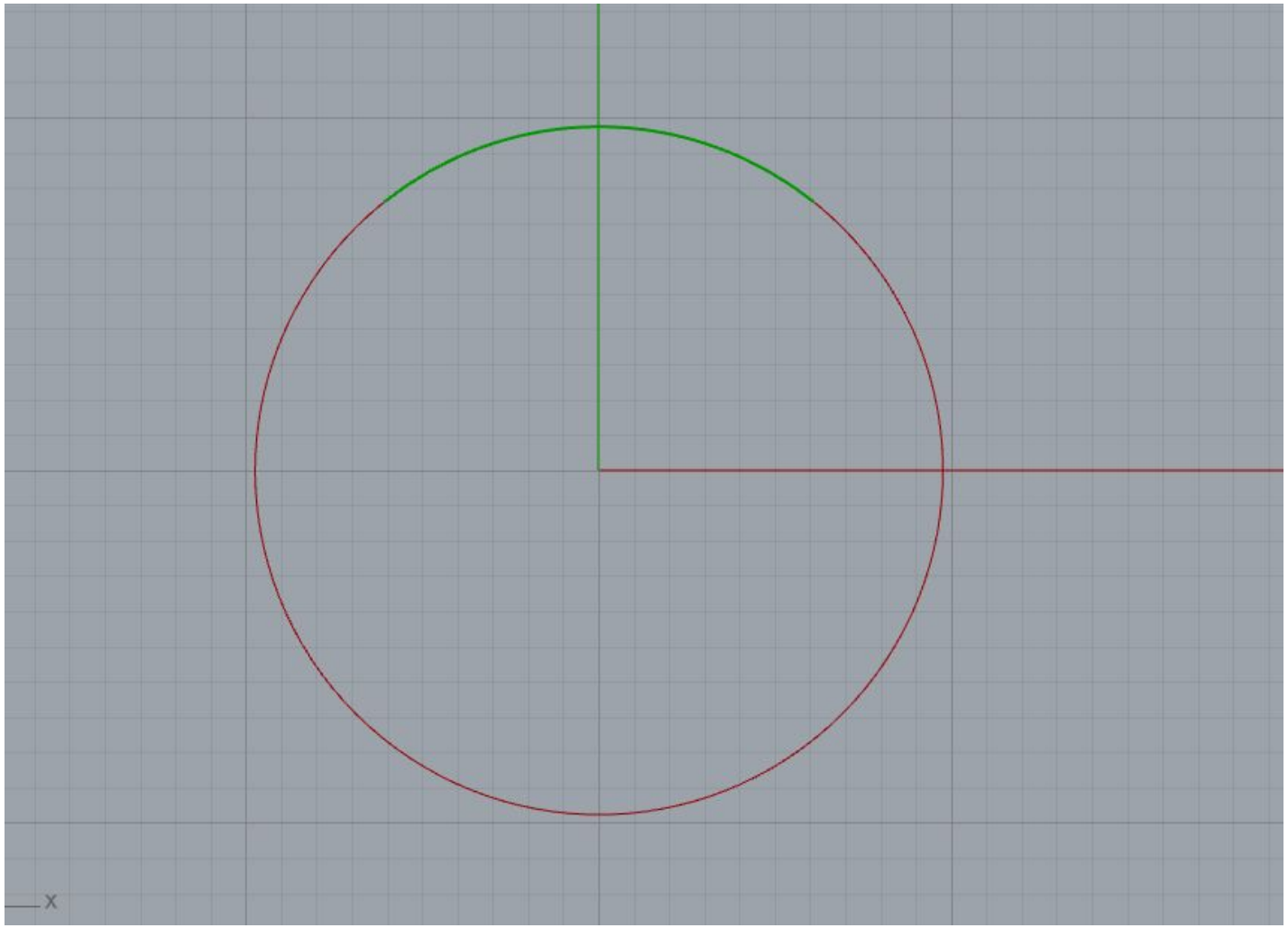
Mathematical analysis

circle of radius 32 ft



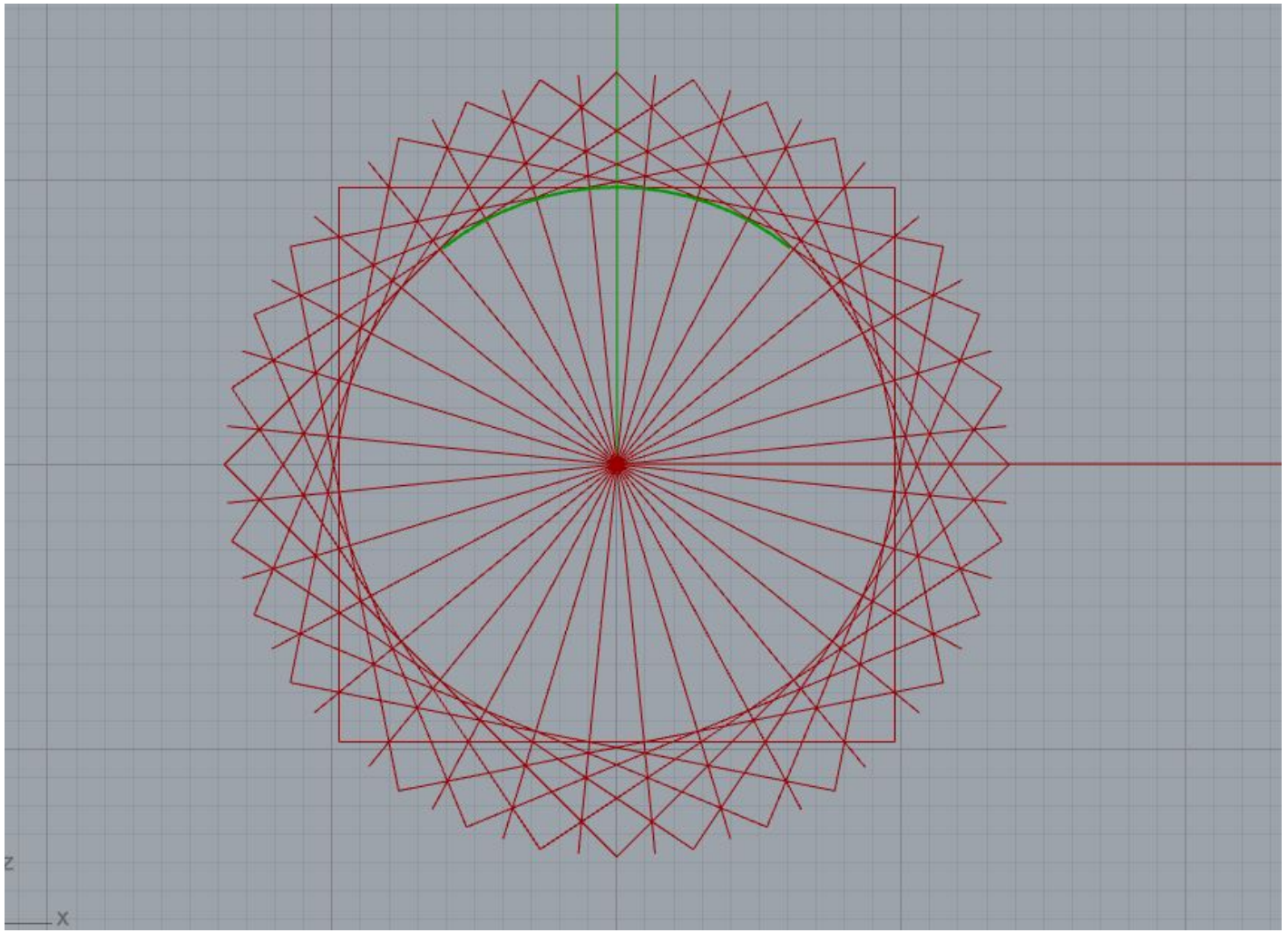
Mathematical analysis

bottom arch spans 40 ft



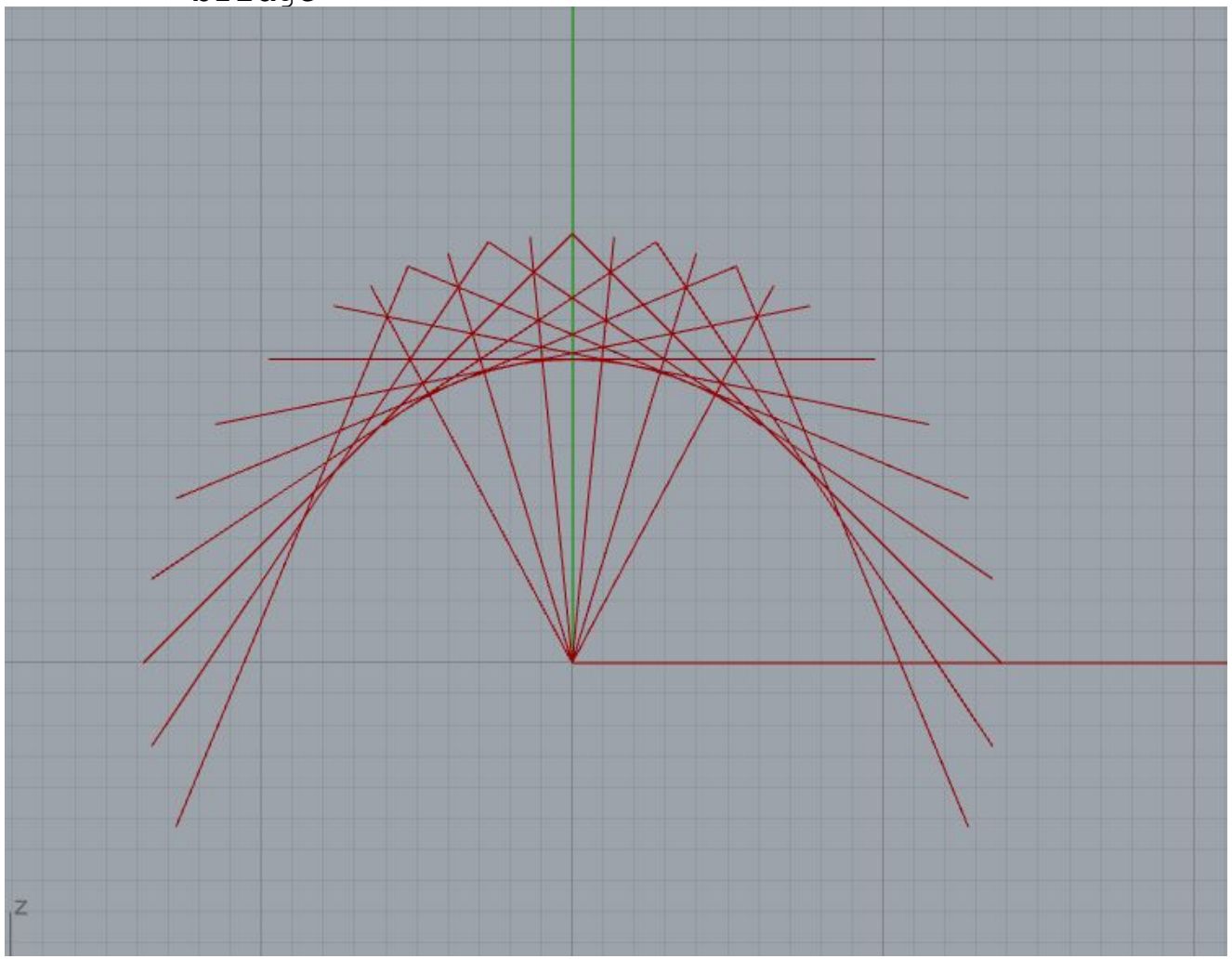
Mathematical analysis

tangentials and 32 radials of circle



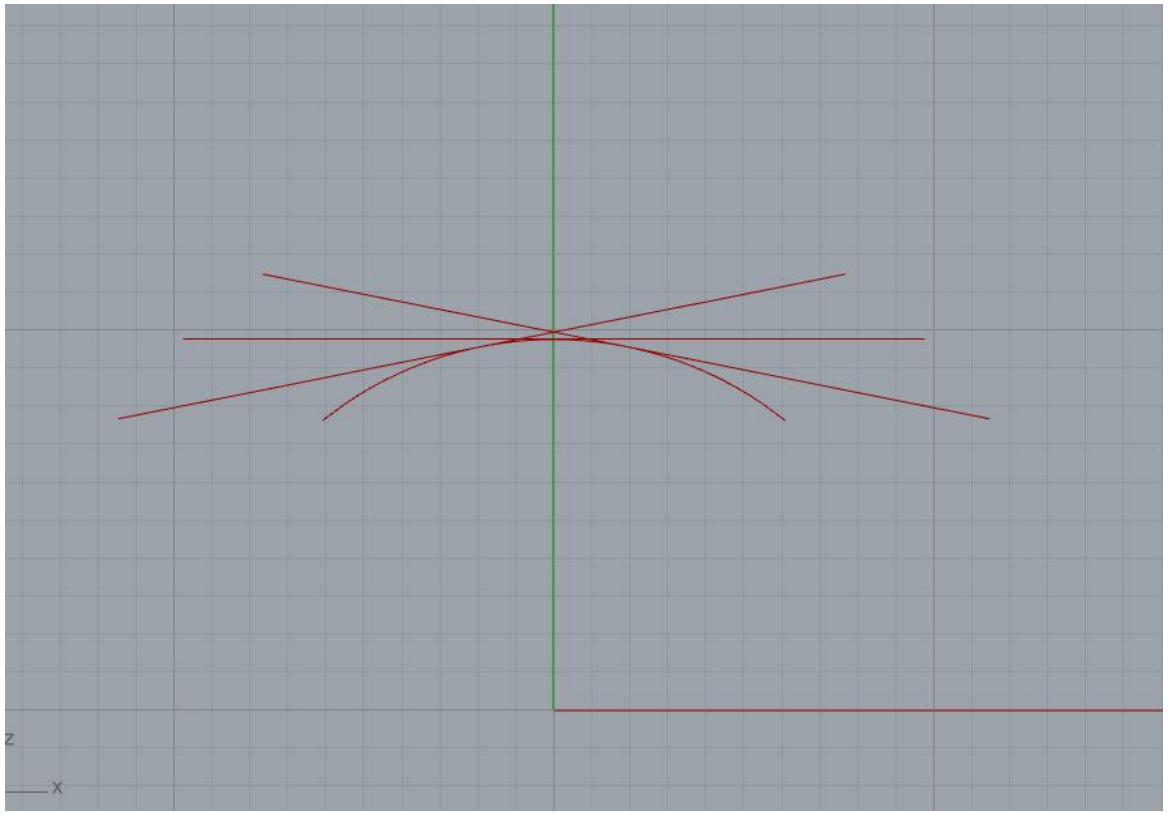
Mathematical analysis

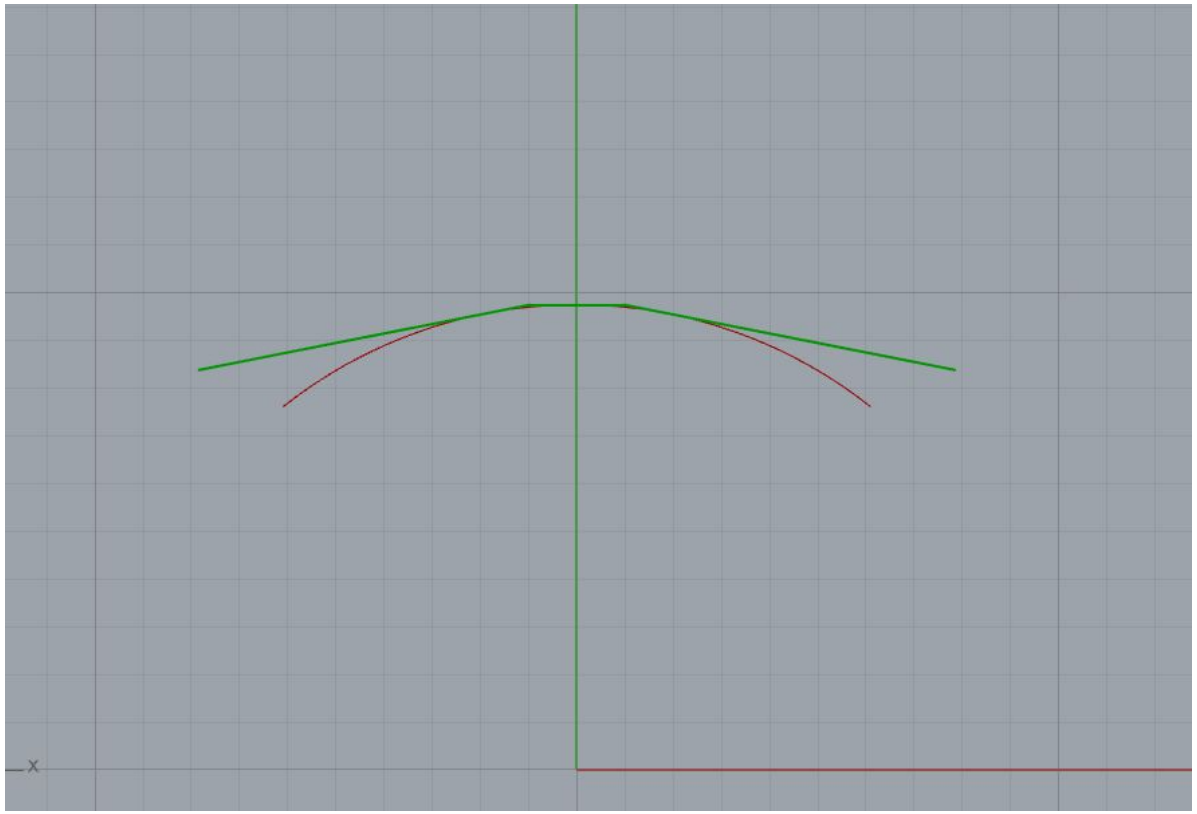
tangengentials and radials in the bridge



Mathematical analysis

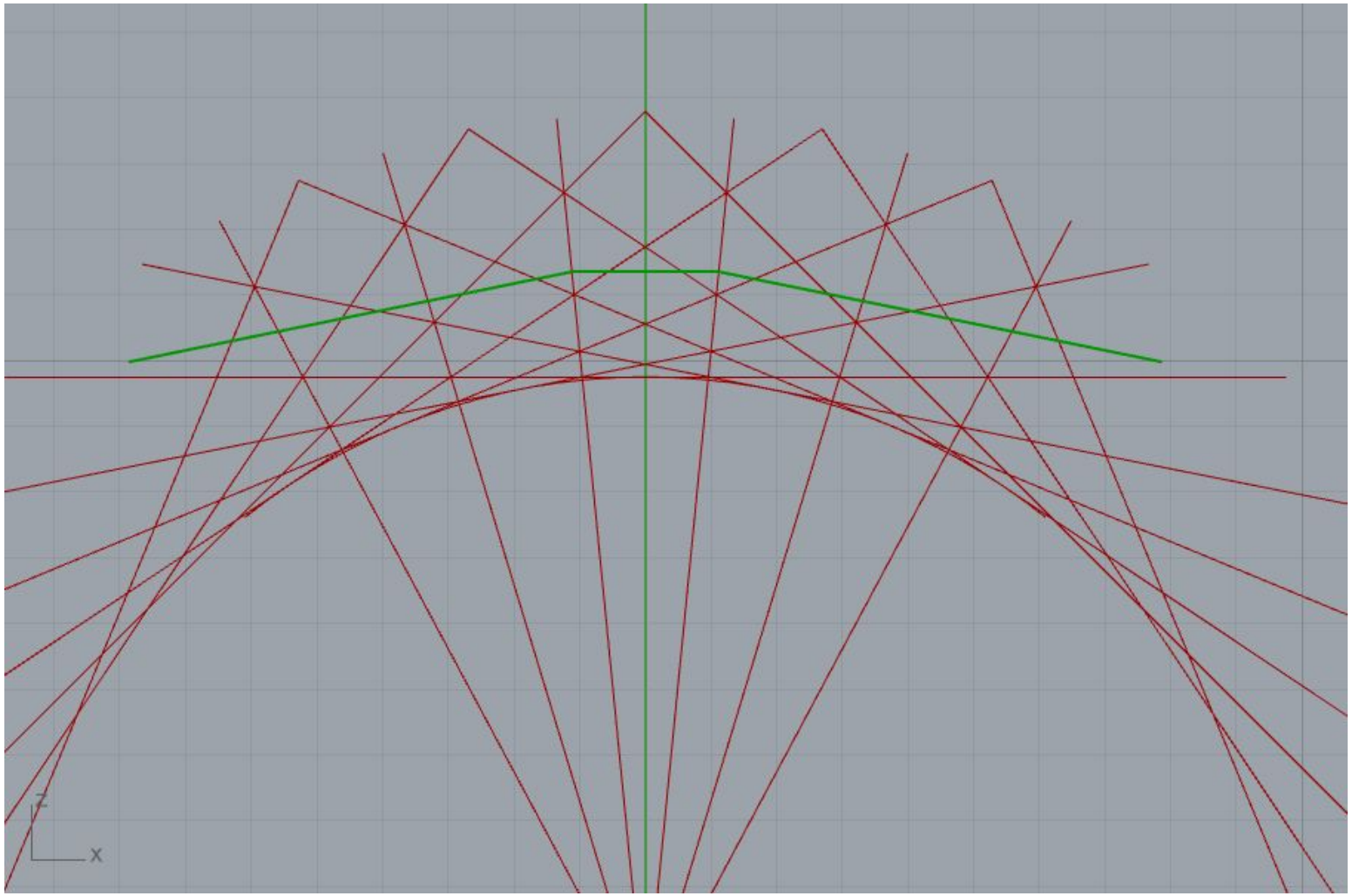
footpath made up of 3
tangentials
spans 50 ft 8 inches





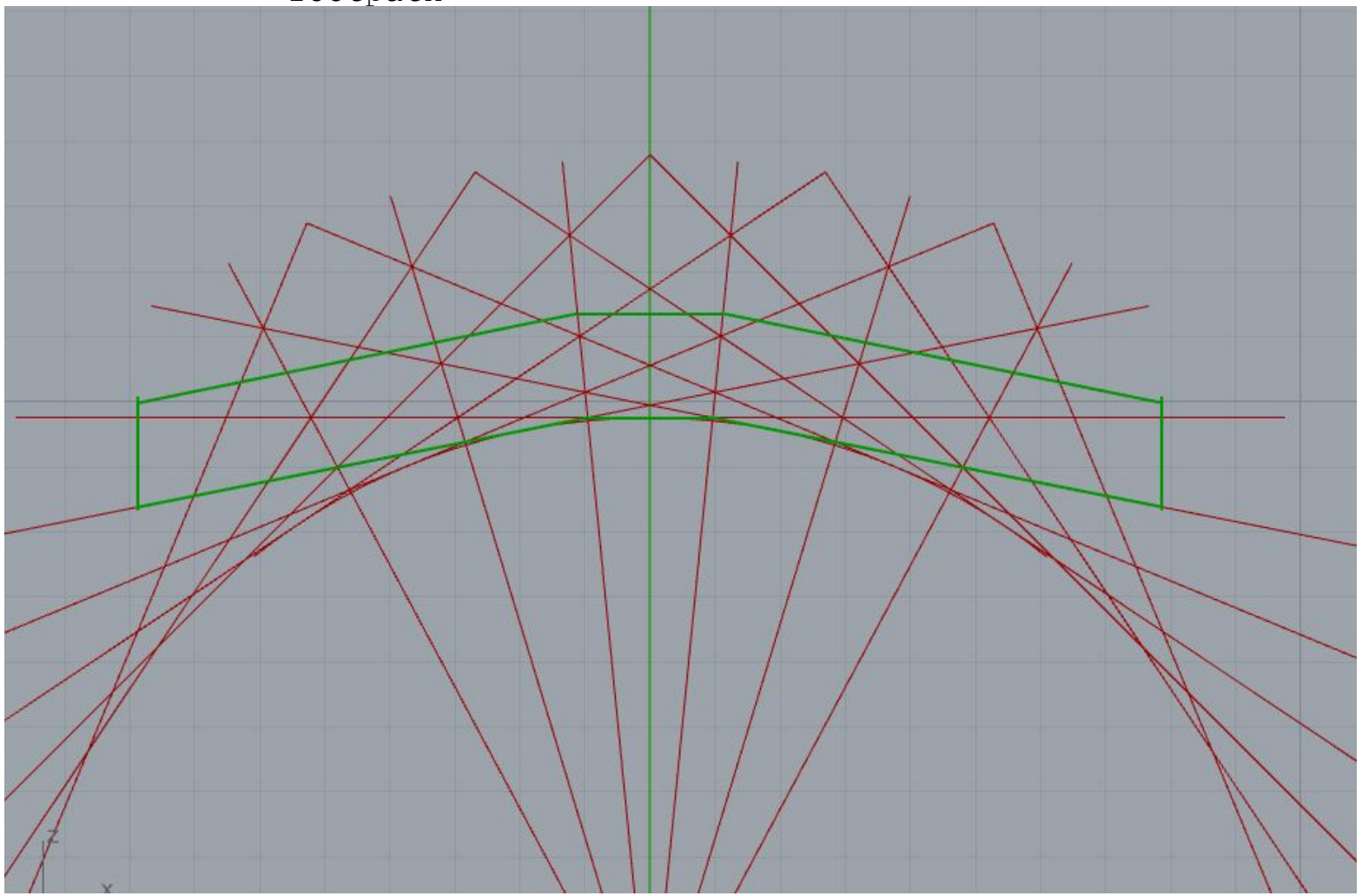
Mathematical analysis

railing at 1.6 meters from footpath



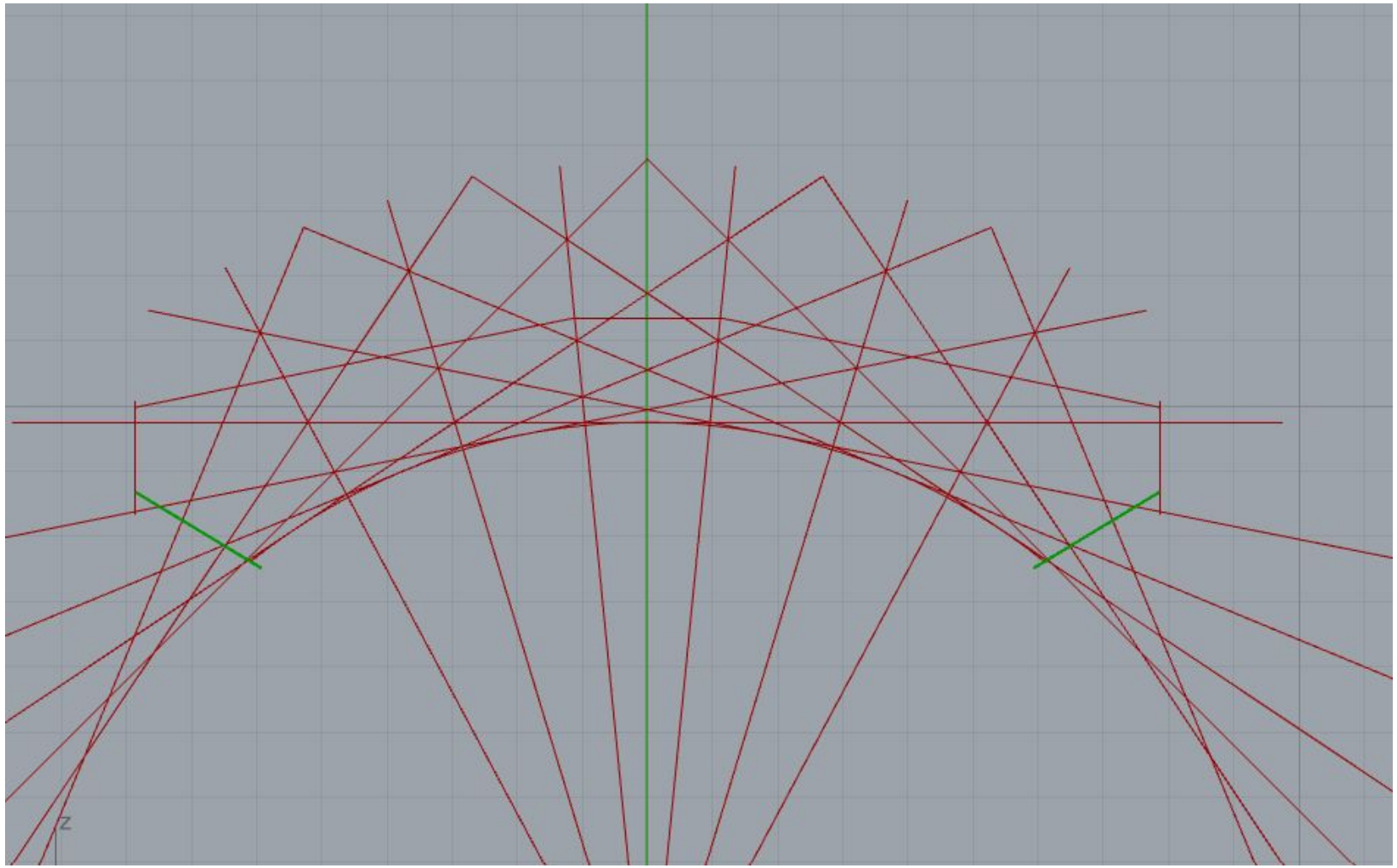
Mathematical analysis

verticals connecting railing to footpath



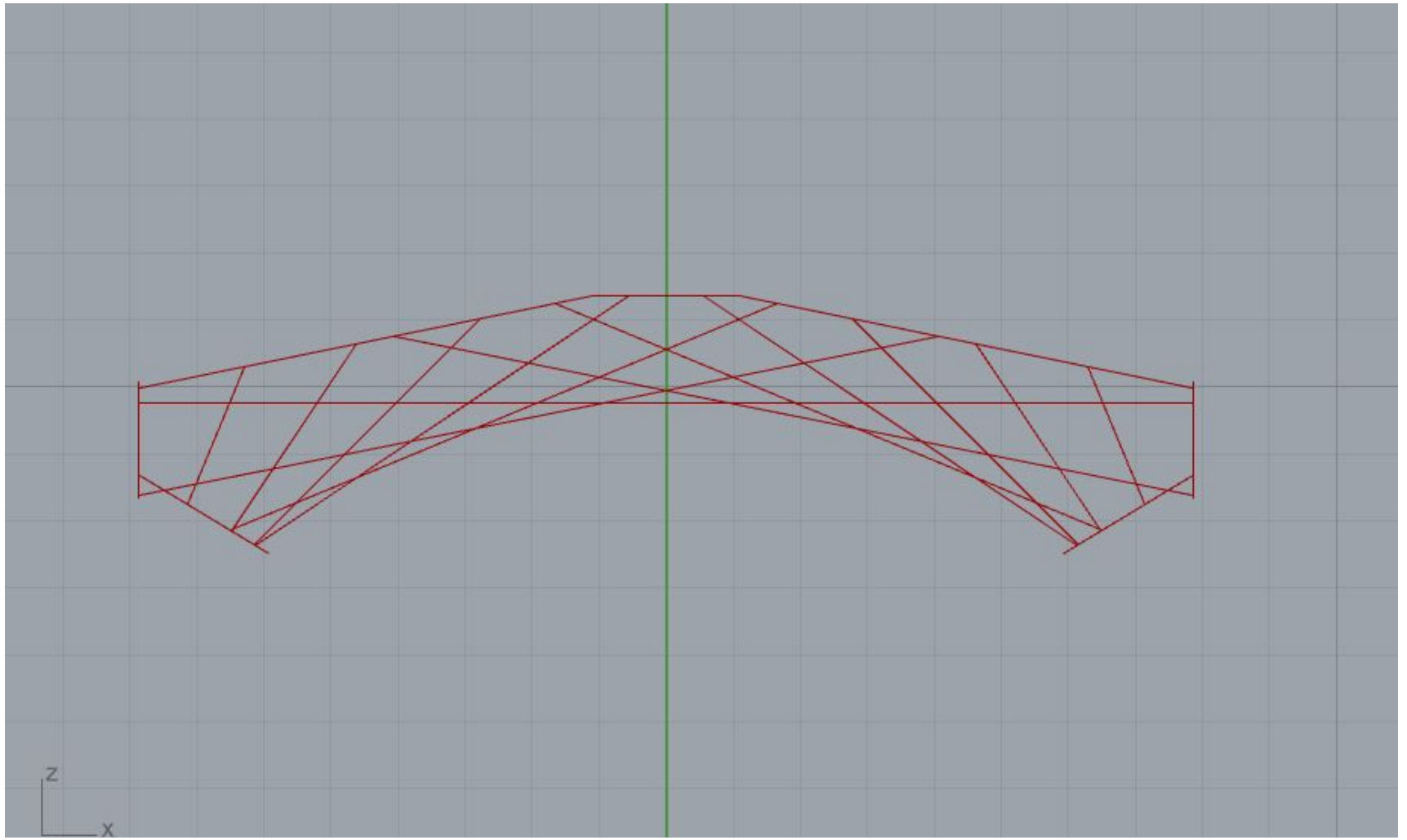
Mathematical analysis

abutments radials
not as same angle as other radials



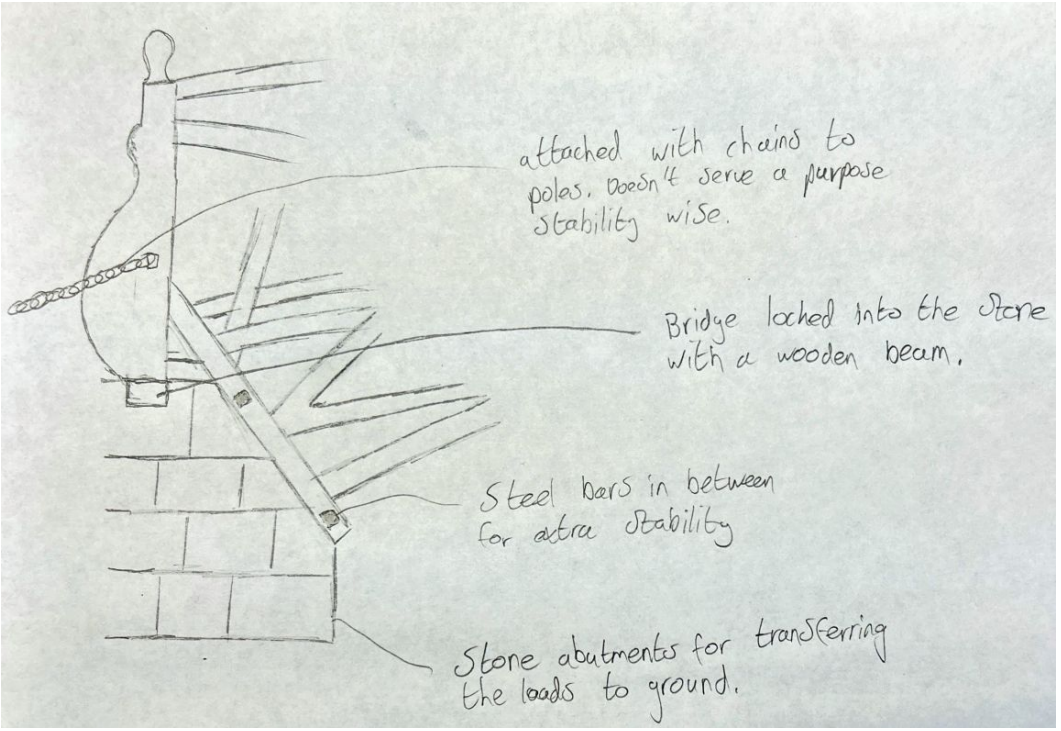
Mathematical analysis

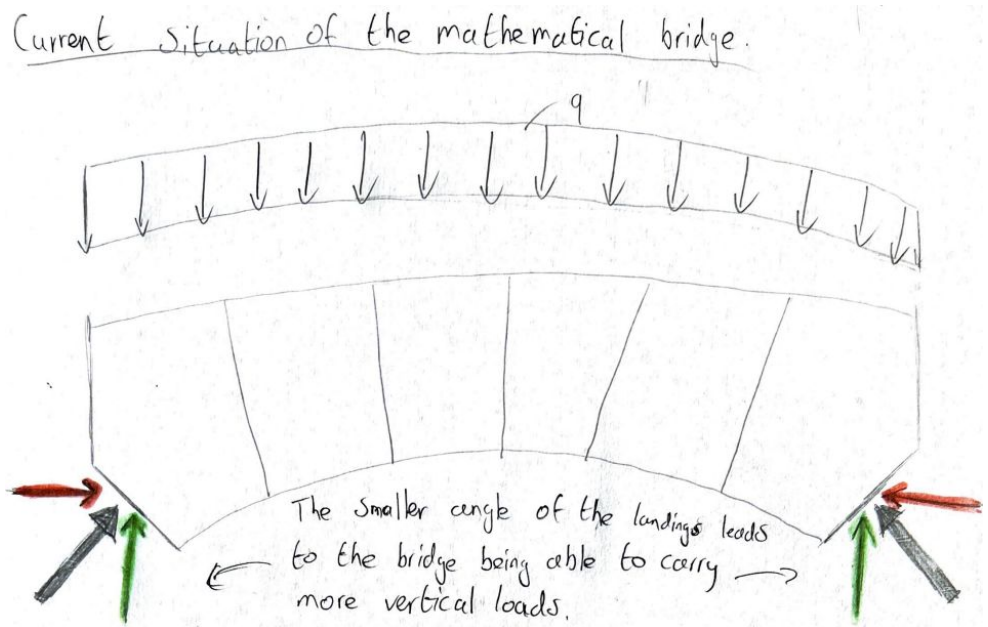
final bridge

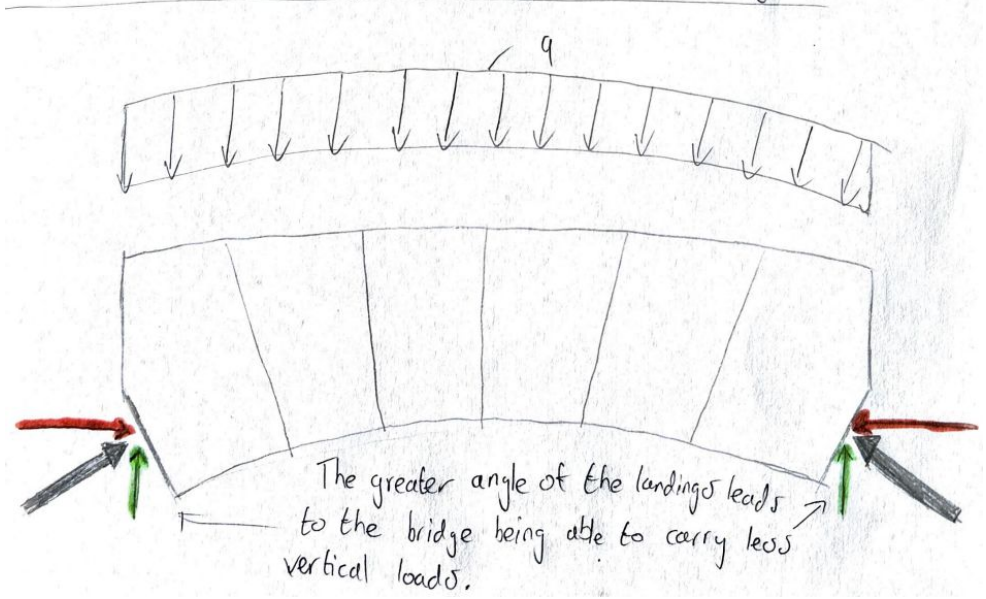


3D model

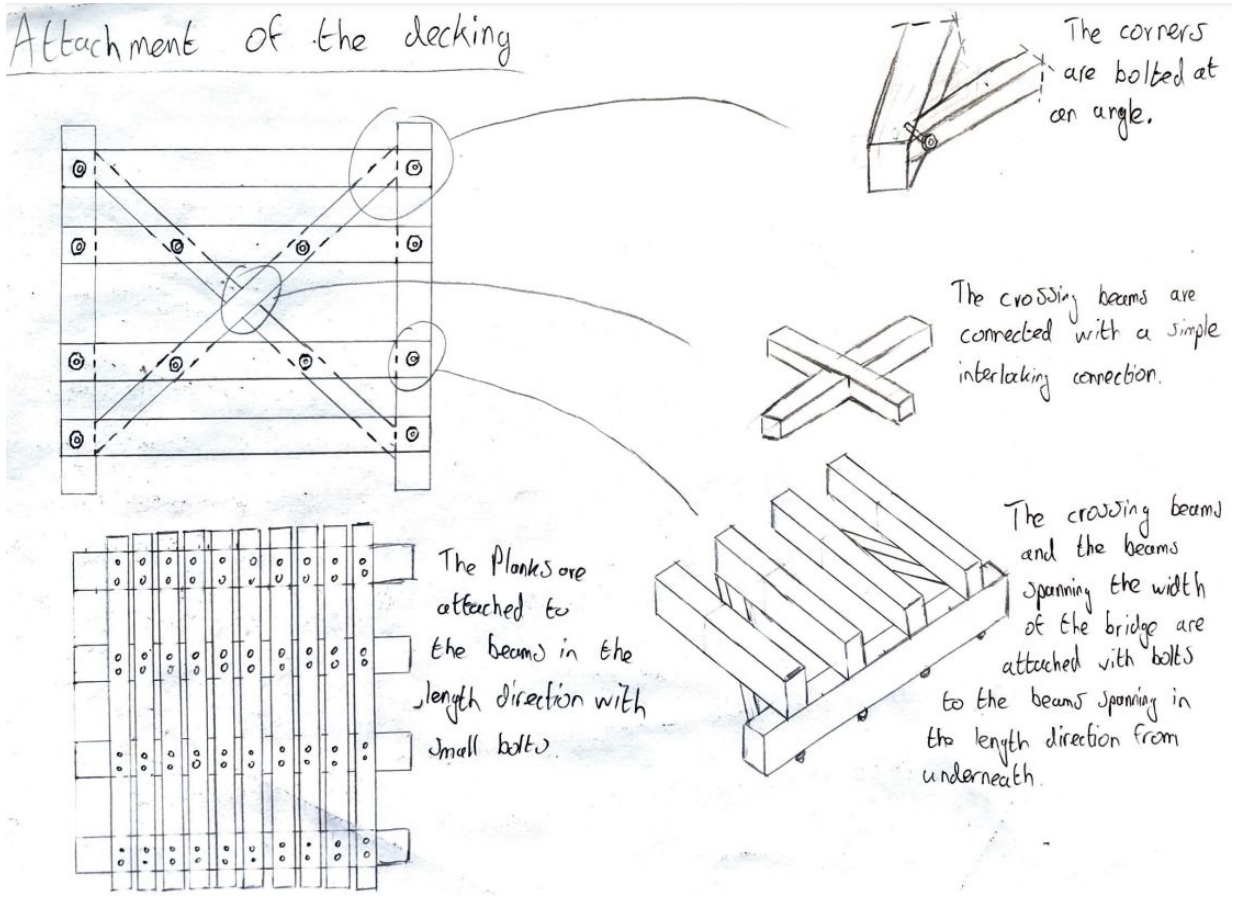
Landings


attached with chains to poles, doesn't serve a purpose stability wise.
Bridge locked into the stone with a wooden beam.
Steel bars in between for extra stability
Stone abutments for transferring the loads to ground.


Current situation of the mathematical bridge.
q
The smaller angle of the landings leads to the bridge being able to carry more vertical loads.


Situation where landings would follow the radian angles.
q
The greater angle of the landings leads to the bridge being able to carry less vertical loads.

Walkway


Attachment of the decking
The corners are bolted at an angle.
The crossing beams are connected with a simple interlocking connection.
The Planks are attached to the beams in the length direction with small bolts.
The crossing beams and the beams spanning the width of the bridge are attached with bolts to the beams spanning in the length direction from underneath.

Joints

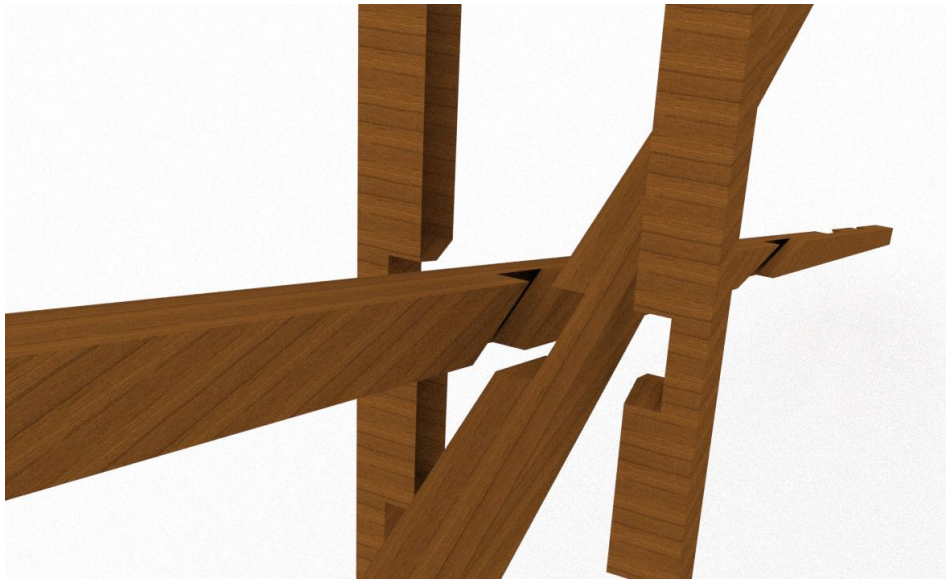
lap splice joints at tangential members crossings

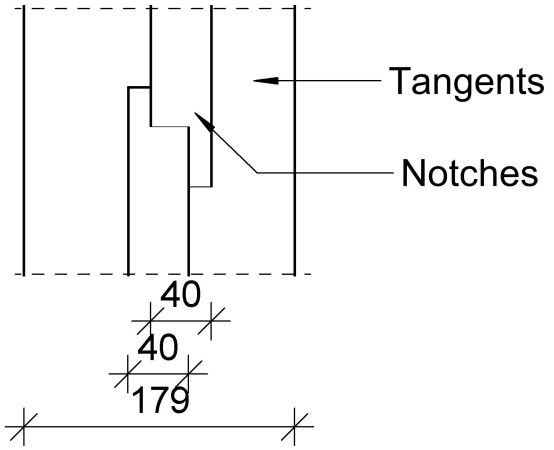
transmits the compressive stress from one tangent member to the next, with a bolt serving to hold the joint together laterally, rather than itself carrying any stress

notches in radial members to encapsulate the tangential members

lock all the overlapping tangents into a rigid truss, by creating triangles out of quadrilaterals

if timber availability doesn't permit full size tangential members, these can be constructed out of shorter beams, joined with tabled splice joints, concealed at intersection with other tangential or radial members

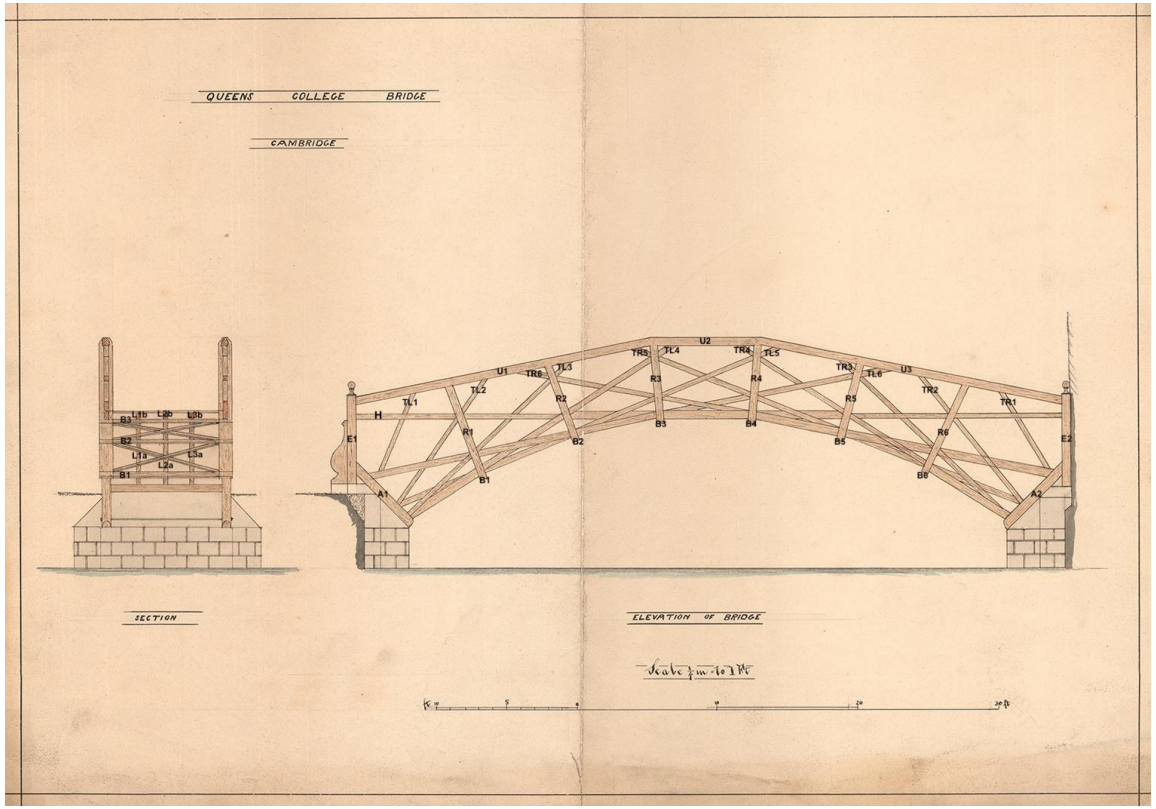




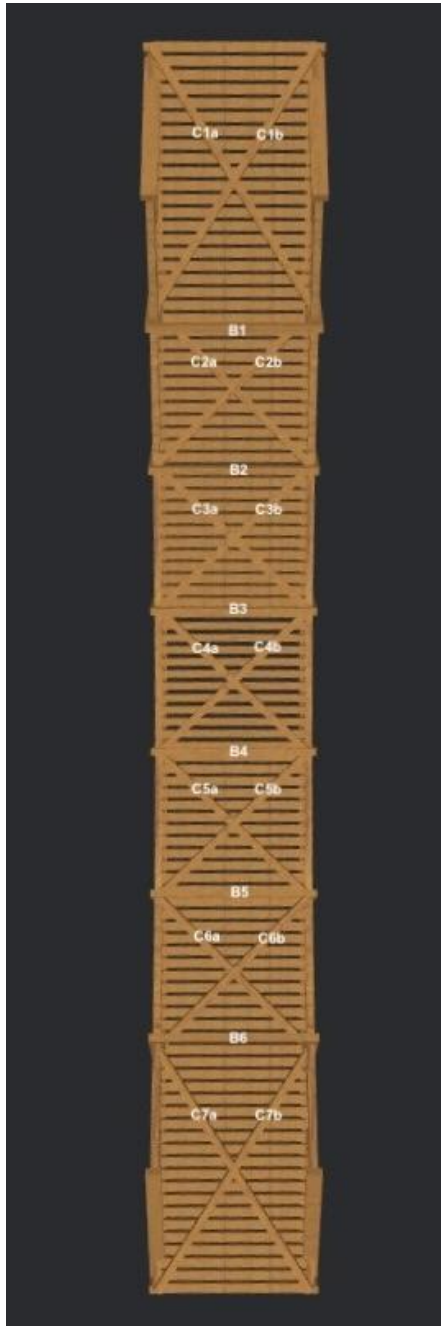
Building manual

3 parts:

1. Preparations
2. Side profiles
3. Walkway

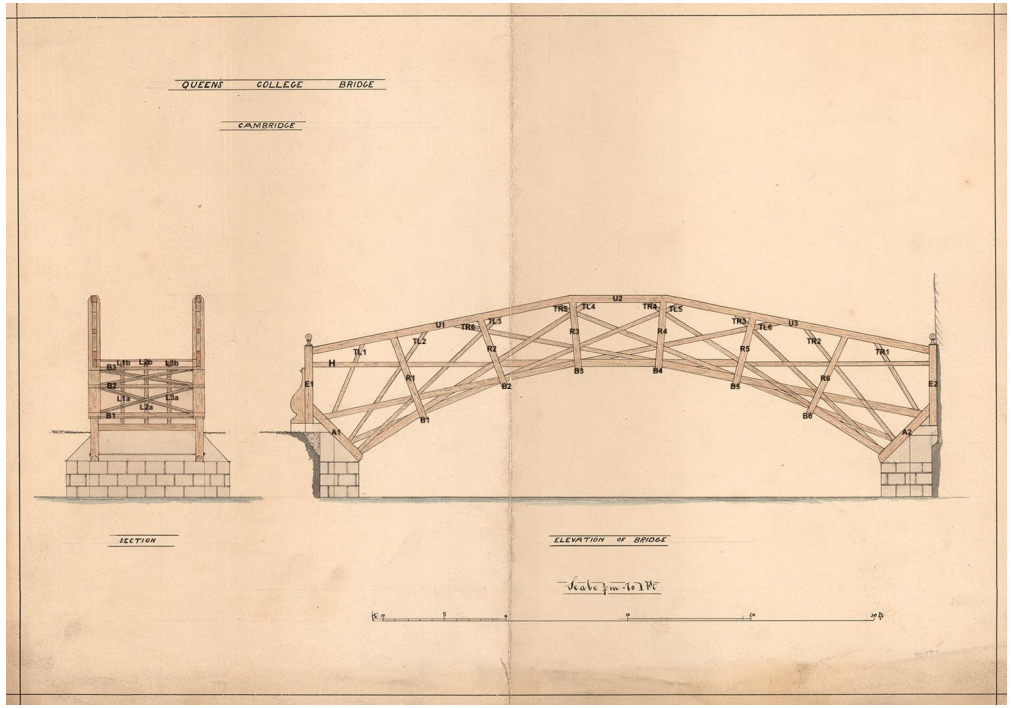


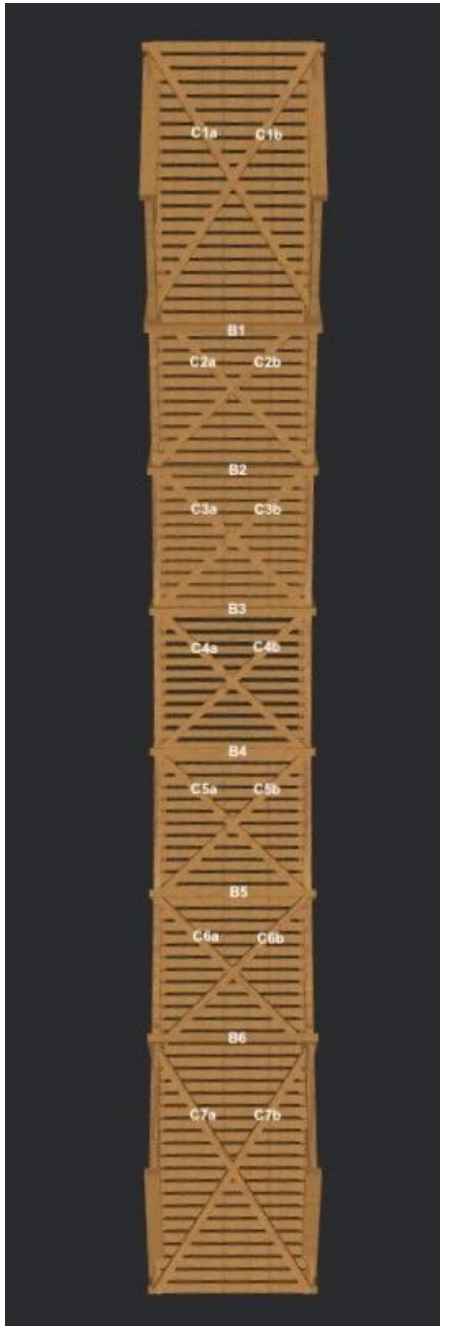
H = horizontal
TL = tangent left
TR = tangent right
U = upper
E = end (x2 sandwich)
R = radial (x2 sandwich)
A = abutment (x2 sandwich)
B = below radial
L = lengthwise (a, b, c and d)
C = cross (a and b)



Building manual - Preparations

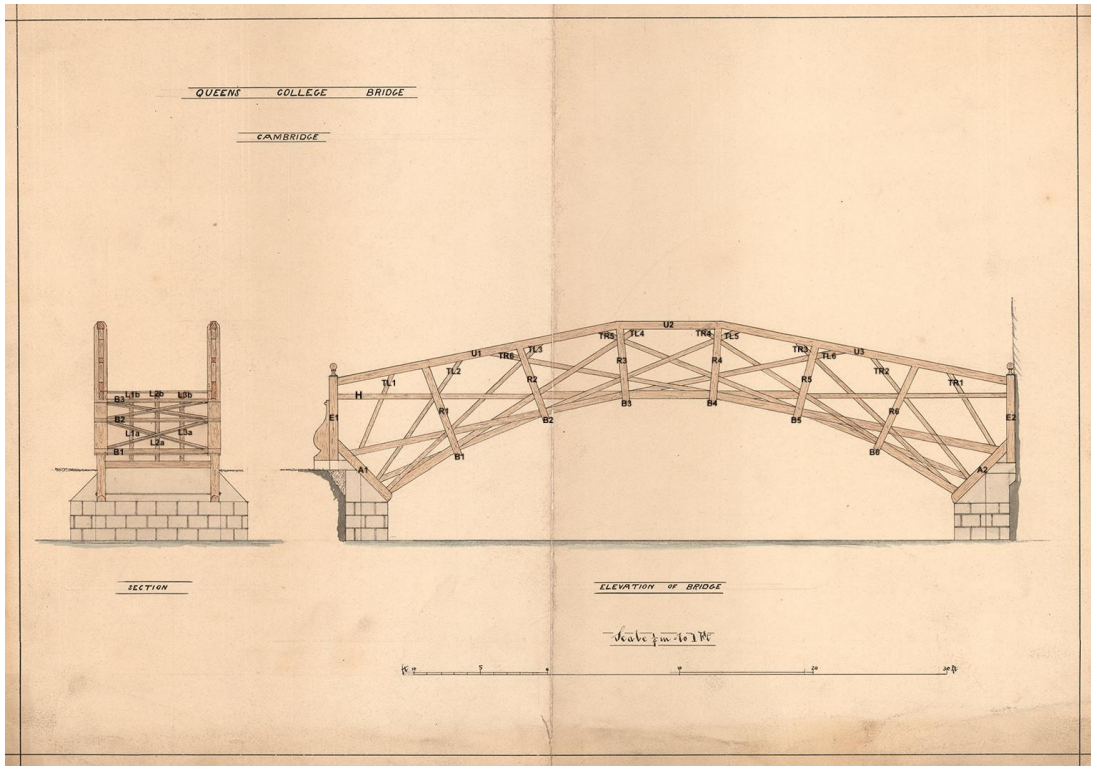
1. Make cuts and notches in all the wooden planks based on dimensions given by the algorithm. Note that B1 and B6 are planks that have 4 additional vertical “teeth”.
2. If timber pieces are not long enough, join two pieces together at radial intersections. Note that, going from up to down, once a tangent passes the final radial that it intersects, it transitions into a thicker plank.





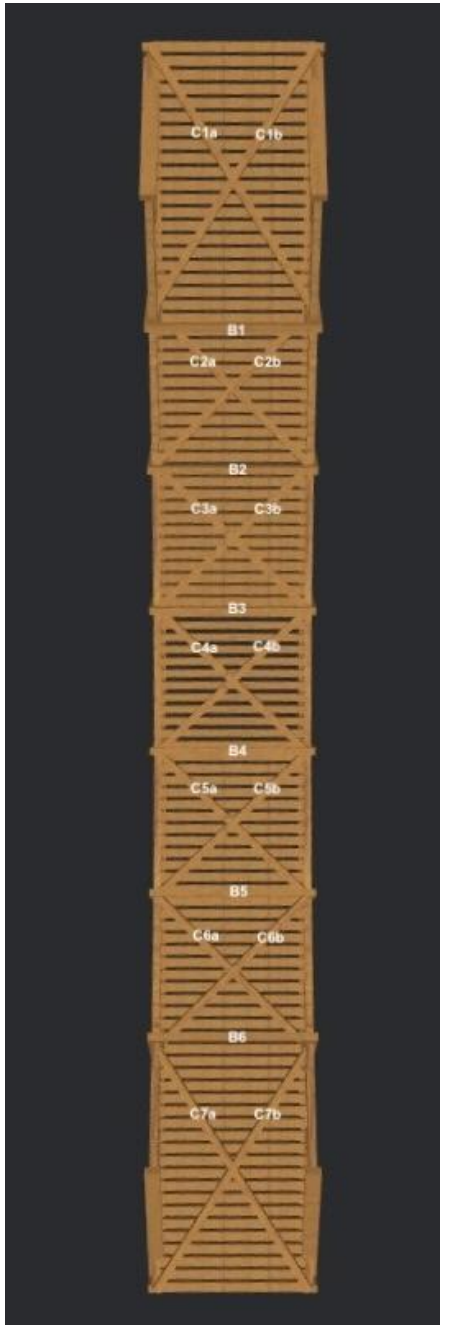
Building manual – Side profiles

1. Lay down H.
2. Connect TL2 and TR3 underneath H and TL3 and TR2 above H and bolt them at their intersections.
3. Connect TL5 on top of TR4 and then connect them both onto H, bolting their intersections.
4. Connect TL4 on top of TR5. Slot TR5 above TL5 and under H, ensuring TL4 ends up underneath H, and bolt the intersections.
5. Connect TL6 underneath H and TR6 above H and bolt the intersections.
6. Attach U1, U2 and U3 on top of the tangents by bolting them to the tangents' upper faces.
7. Attach the two E1 planks on either side of the tangents and U planks to "sandwich" them and bolt in place. Do the same for the two E2 planks.
8. Attach one plank of each of the following parts on top of the tangents one by one, and then flip the structure to do the same for their second planks: A1, R1, R2, R3, R4, R5, R6, A2. Bolt the sandwiches in place.
9. Repeat steps 3 to 10 to form the profile of the other side of the bridge.



Building manual - Walkway

1. Bolt B1, B2, B3, B4, B5 and B6 to the first side profile and attach the second side to the other ends of the B planks.
2. Bolt steel L brackets onto the outer and lower faces of the R and B planks respectively to strengthen their connection.
3. Separately, attach C1a on top of C1b and bolt their intersection. Repeat for all the C planks.
4. Place L1a, L2a, L3a and L4a on top of C1, C2 and C3 and bolt their intersections.
5. Place L1b, L2b, L3b and L4b on top of C4 and bolt their intersections.
6. Place L1c, L2c, L3c and L4c on top of C5, C6 and C7 and bolt their intersections.
7. Lower the groups of planks connected in steps 14, 15 and 16 onto the B planks and bolt the intersections. Additionally, bolt the C planks to the B planks that they touch through the C planks' diagonal end faces. Note that the "teeth" of B1 and B6 should align with the L planks.
8. Place the walkway planks on top of the bridge and bolt in place.
9. Attach the bridge to the abutments.



Railing assembly

Maquette

Sources

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