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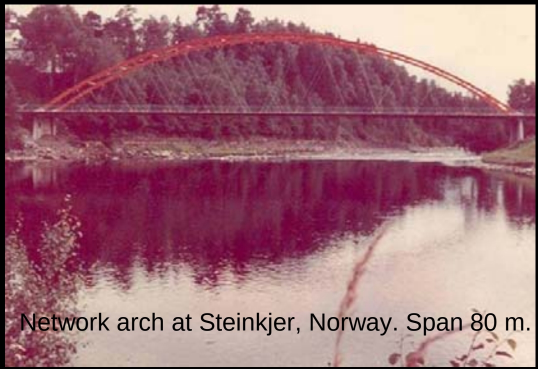

Network arch at Steinkjer, Norway. Span 80 m.

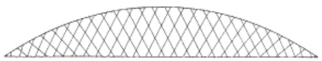
ABOUT THE NETWORK ARCH

Per Tveit, dr. ing, Docent Emeritus

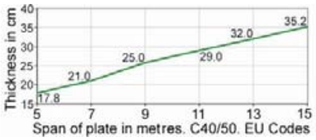
Bolstadstraumen Bridge span 84 m.


Traffic on bridge

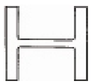

Optimal arch for evenly distributed load

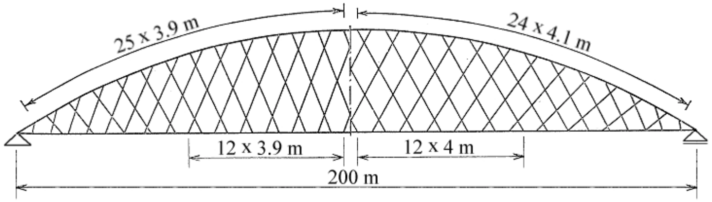

Skeleton lines for network arch spanning 200 m


Shape of lower chord with prestressing cables



Thickness of concrete slab between arches


Universal column for arch gives simple details

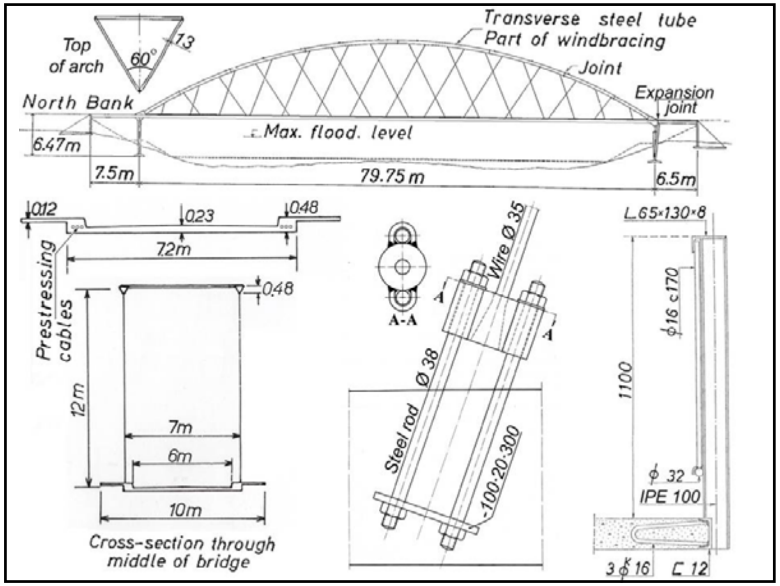


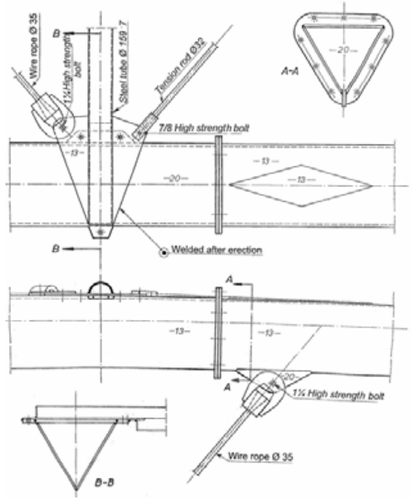
Arrangement of hangers for two bridges spanning 200 m

- Some hanger cross each other at least twice
- There is little bending in the chords
- Tension is predominant in the tie and hangers
- Compression is predominant in the arch
- The arch is well supported in the plane of the arch
- High strength steel is well utilized
- There are longitudinal prestressing cables in the tie

Characteristics of optimal network arches

Network arch at Steinkjer, Norway in 1963. Span 80 m

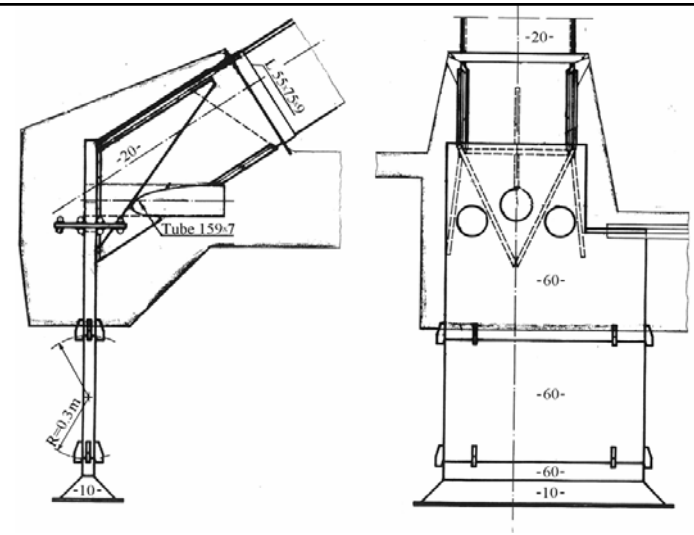




Details of network arch at Steinkjer

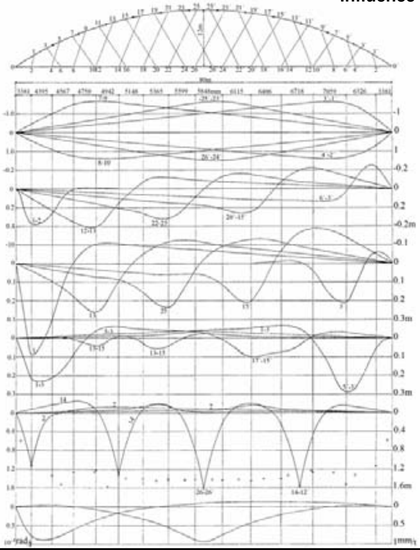
Hanger

End of arch filled with concrete



Moveable bearing in the network arch at Steinkjer

Influence lines for the network arch at Steinkjer



The slope of the steepest hanger is 74.4°. The difference in the slope between two adjoining hangers is 1.8°.

Compression in arch

Tension in tie

Force in hangers

Bending moments at nodal points in arch

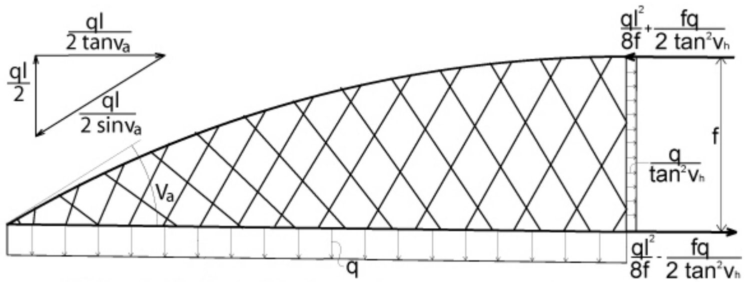
Bending points in the middle of members in arch

Bending moments in tie

Rotation at the end of the tie

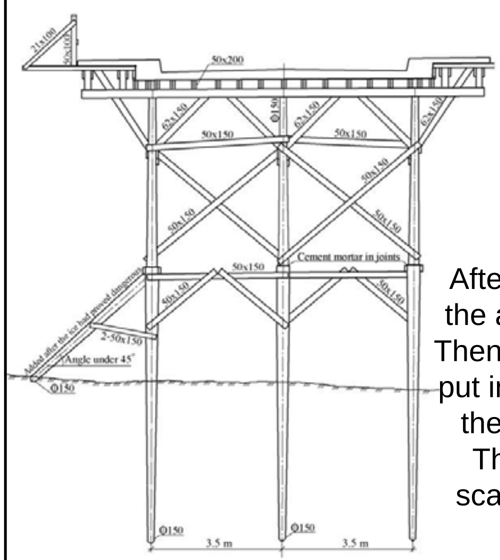
Deflection of tie at the middle of span

Axial forces in the middle of and at the end of a network arch. Bending has been disregarded.



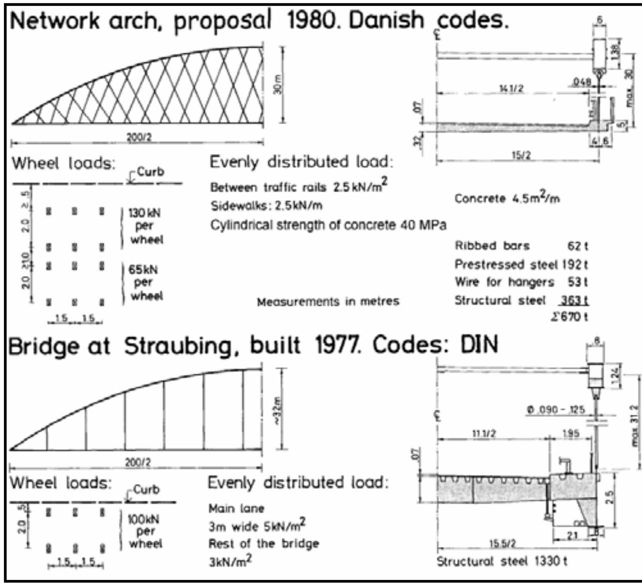
q = Uniformly distributed load
l = Length of span
f = Rise of arch

V_h = Angle of hanger
V_a = Angle of end of arch

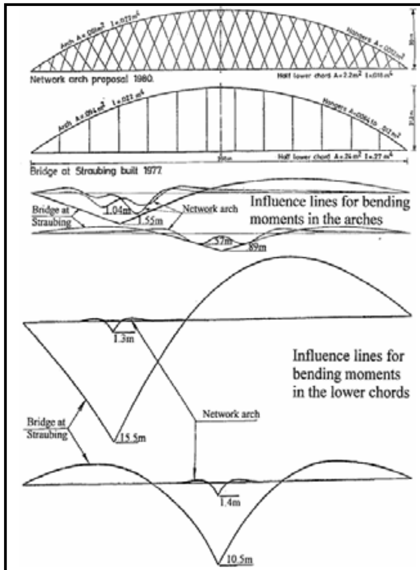


Scaffolding for the network arch in Steinkjer

After the tie was cast the arch was erected. Then the hangers were put in and tightened till they carried the tie. Then the wooden scaffolding could be removed.

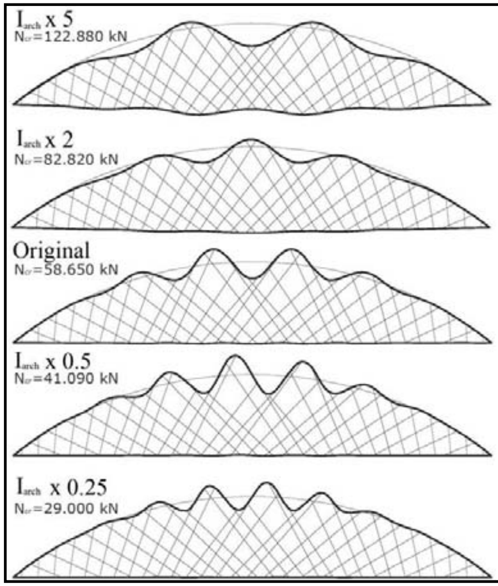


Data for two bridges



Influence lines for two bridges in the previous slide

One network arch and one arch bridge with vertical hangers

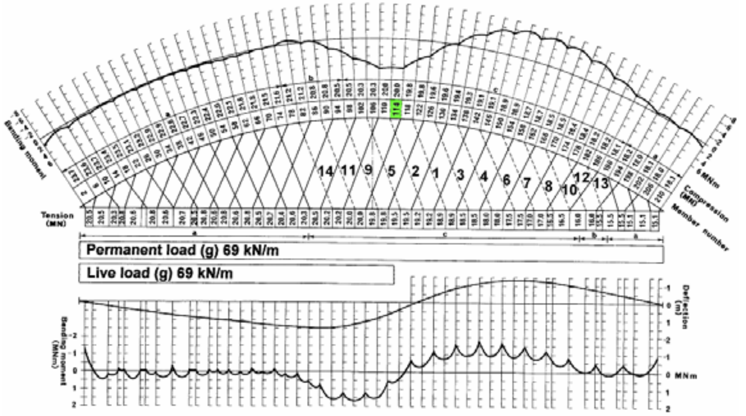


Stiffer arches

F. Schanak

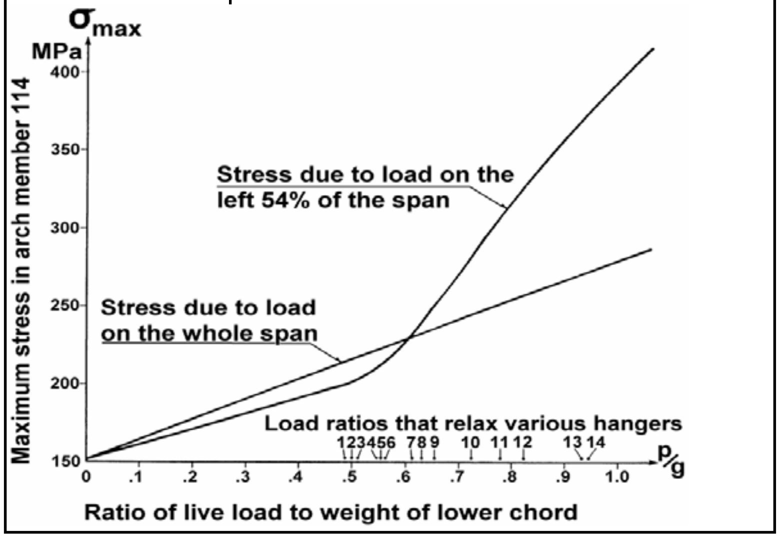
Examples of buckling

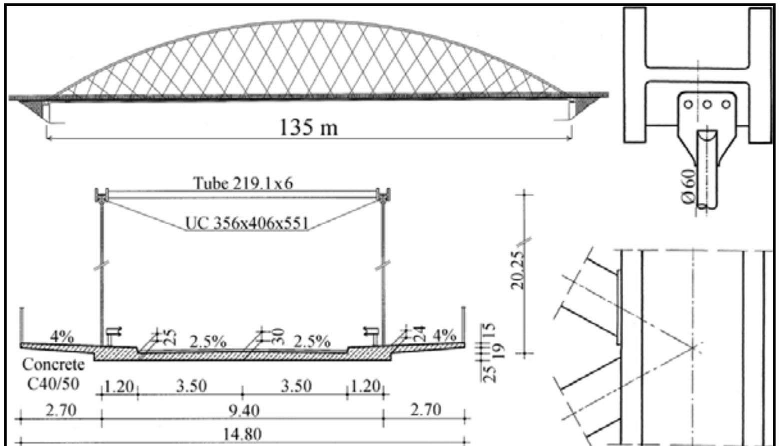
Less stiff arches



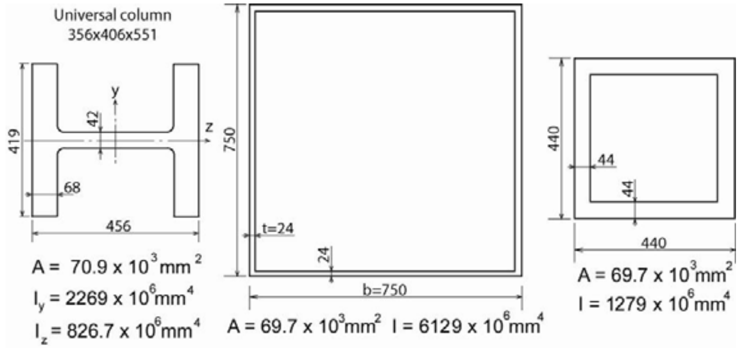
Forces and deflections due to
an extreme skew load on a bridge
spanning 200 m

Development of stress in member 114

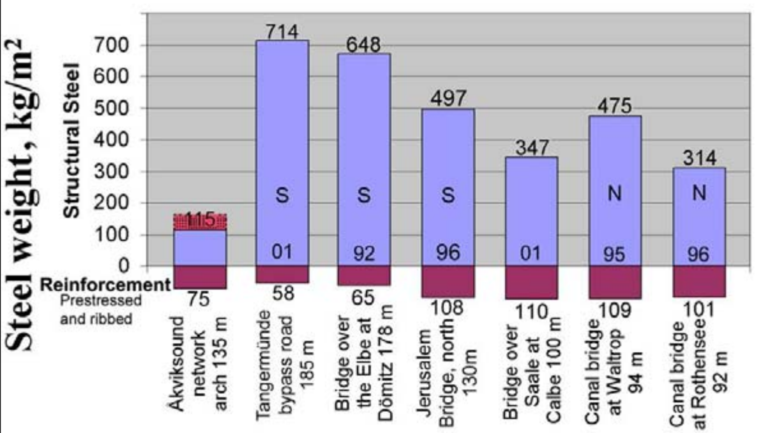




This Åkviksound Bridge network arch was the graduation thesis of Teich and Wendelin in 2001. It was designed according to EU Norms. Two ways of fastening the windbracing are shown. Calculations can be found at http://fag.grm.hia.no/fagstoff/ptveit/

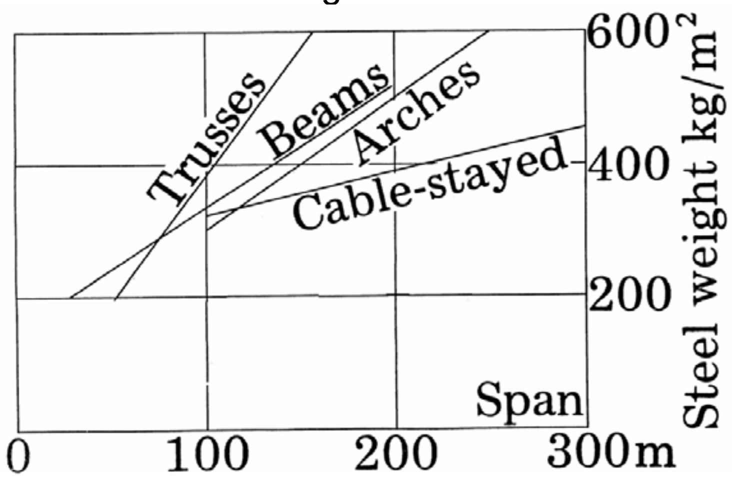


Three cross-sections that have the same area



Here the steel weight of the Åkviksound network arch is compared to German tied arches with vertical hangers. S means that the arches slope towards each other. N means that there is no wind-bracing. Steel in a temporary tie 51 kg/m². Prestressed reinforcement 12 kg/m². Calculations can be found at http://fag.grm.hia.no/fagstoff/ptveit/

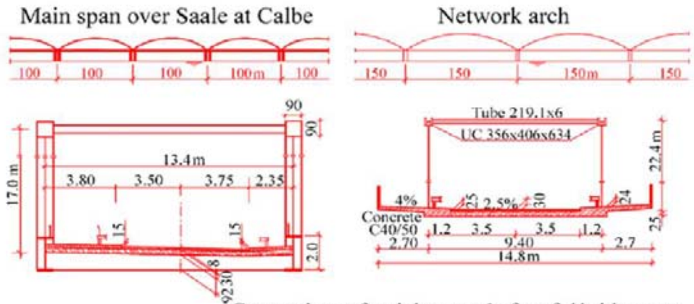
Diagrams showing the steel weight of various bridges before 1975.



Differences between arch bridges with vertical hangers and network arches

Aesthetics	Bulkier bridges
Adaptability	2 to 8 times deeper lower chords
Fabrication	15 to 30 times longer welds More complicated details
Corrosion protection	3 to 7 times more surface to protect
Maintenance	Other concrete parts need much more maintenance than concrete slabs with a slight prestress.
Erection •On sidespans •Floating into place •Erection on ice	Erection is more expensive with 2 to 4 times more steel

Material and cost of the Calbe Bridge compared to that of a network arch



Comparison of weight per m² of useful bridge area

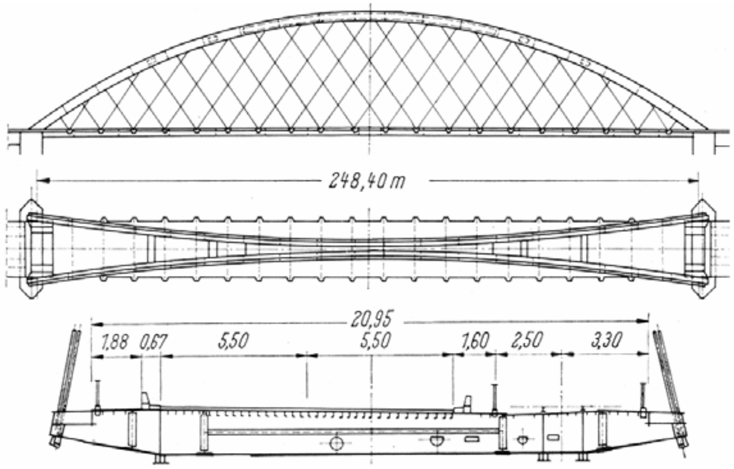
Structural steel incl. prestressing steel	Saving	58%
Reinforcement	"	34%
Concrete	"	24%
Weight to be moved during erection	"	46%
Pillars are the same for both bridges	"	33%

Savings in cost are probably 35 - 45% per m² of useful bridge area.

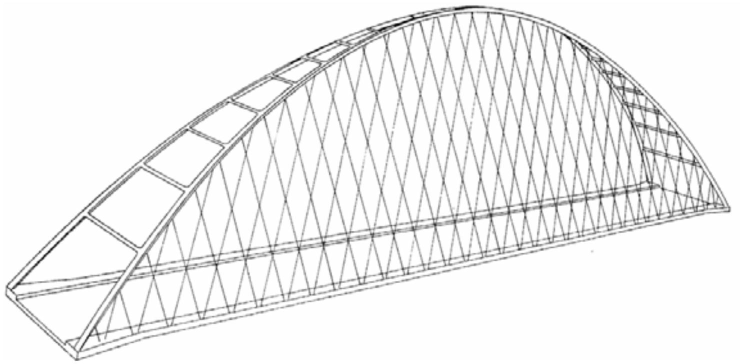
Comparison between the western part of the Great Belt Bridge in Denmark and an alternative using network arches.

• Max. weight of element:	5800 t to <4000 t
• Weight of concrete per m:	45 to 55 % reduction
• Weight of reinforcement per m:	25 to 50 % reduction
• Bridges piers per. m:	50 % reduction
• Forces on bridge pillars per m:	45 to 55 % reduction
• Cylinder strength:	55MPa to 55-65MPa
• Cylinder strength in arches:	140MPa
• Price of substructure:	25 to 50 % reduction
• Price of superstructure:	20 to 40 % reduction

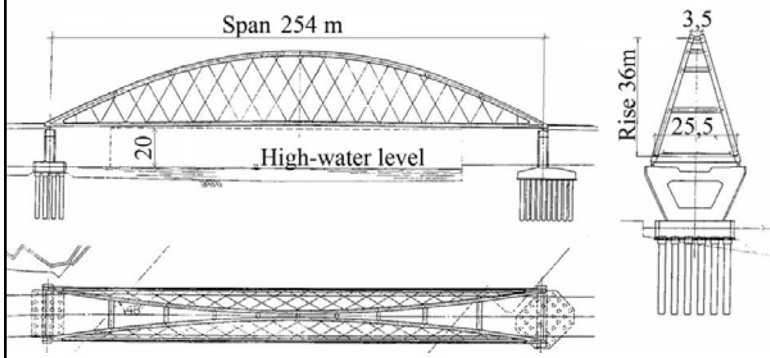
Savings in price: 25 to 35 %



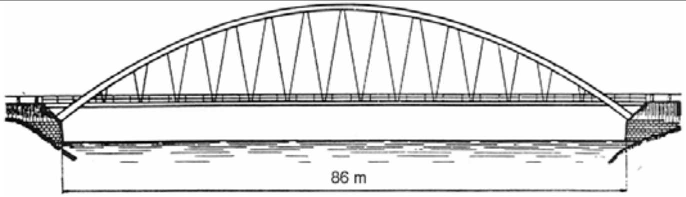
The Fehmarn Sound Bridge, Germany. 1963



Suggested bridge from the author’s Ph.D. thesis, 1959

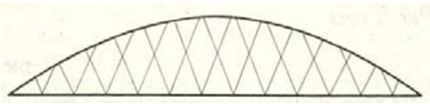


The Shinhamadera Bridge.
Built in Japan 1991. Span 254 m.

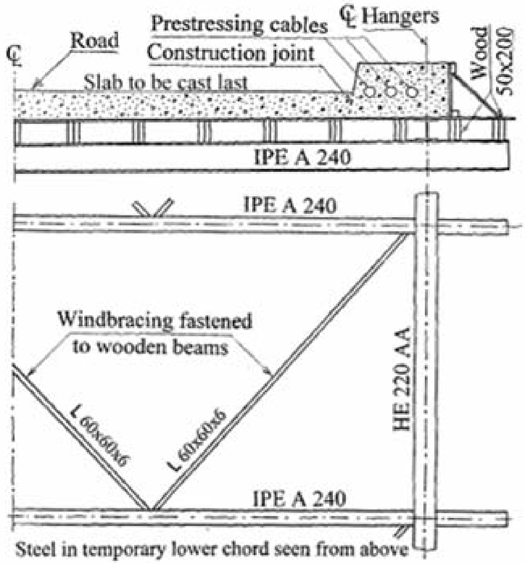


An early Nielsen bridge. Built in Sweden before1930.

The longest Nielsen bridge. Castelmoron 1933. Span 145 m.

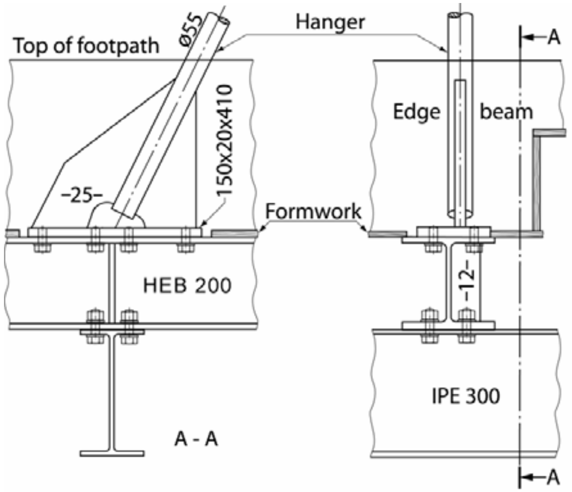


Nielsen never crossed the hangers of his bridges, but in 1926 in a patent document he showed crossing hangers.

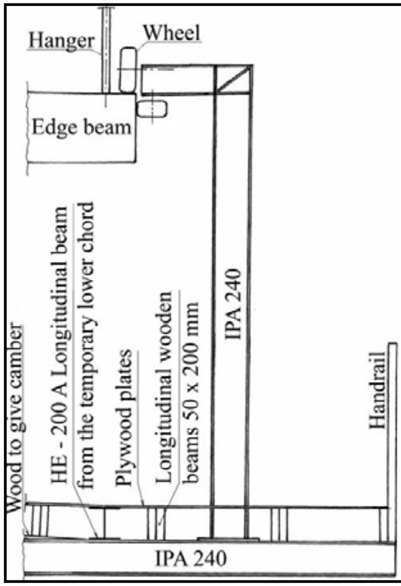


Temporary tie.

Combined with arches and hangers it makes a stiff skeleton that can be moved. It can carry the casting of the concrete tie.

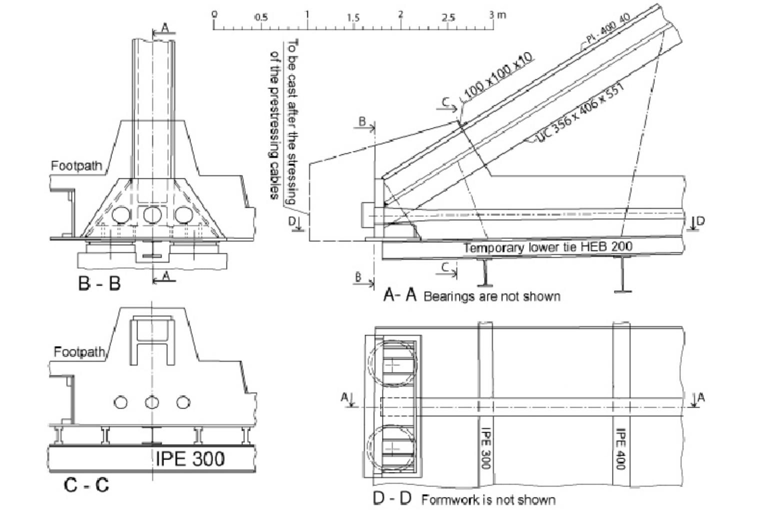


Joint in temporary lower chord



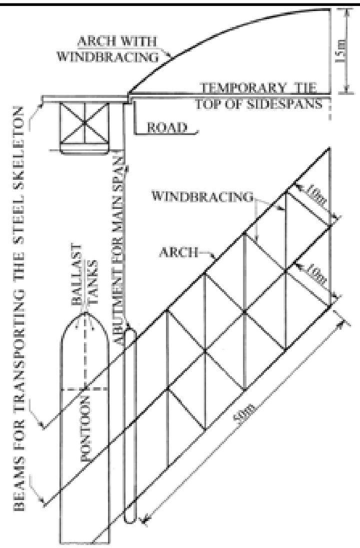
Wagon for removing the temporary lower chord

This deck has been used for casting the concrete tie



End of a span with a temporary lower chord

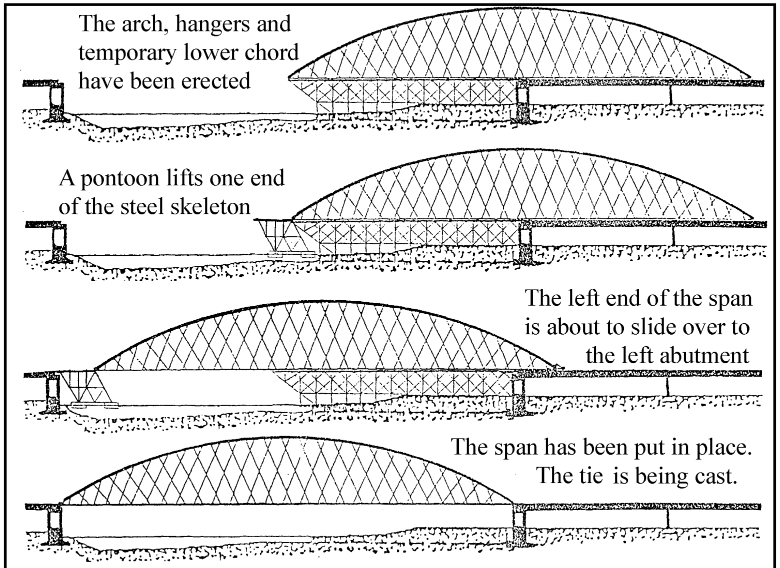
Lifting the steel skeleton for the Åkvik Sound Bridge. Capacity of crane 600 t. Weight to lift 410 t.



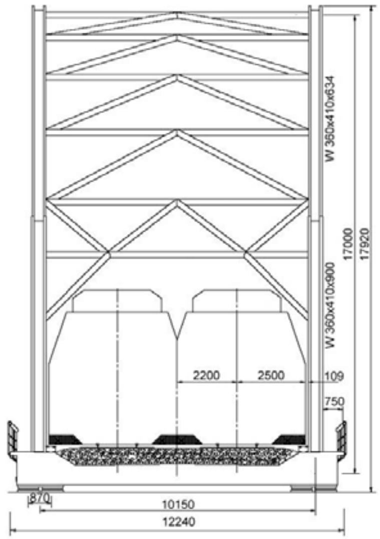
The first stage of the erection and transport of a skew bridge across a canal.

The structural steel, supplemented by a temporary lower chord, is erected on the side-spans on one side of the canal. If the shape of the steel skeleton is right, then no adjustment of hangers is needed later.

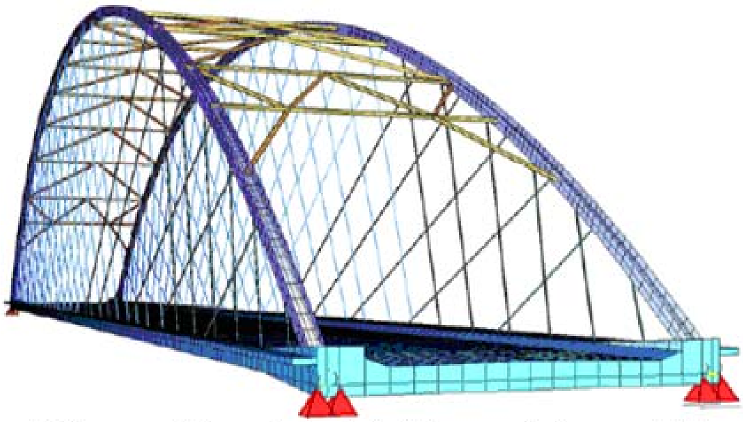
While the beams on top of the pontoon are tied to the abutment, the steel skeleton is rolled to the middle of a pontoon. Then the pontoon is pulled across the canal. Finally the steel skeleton is rolled on to the abutments on both sides of the canal and the tie is cast.



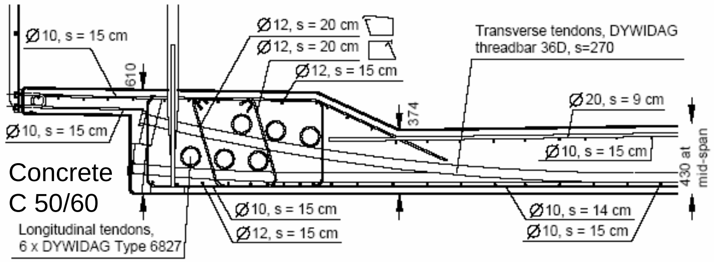
Double track network arch railway bridge spanning 100 m [Brunn and Schanack 2003]



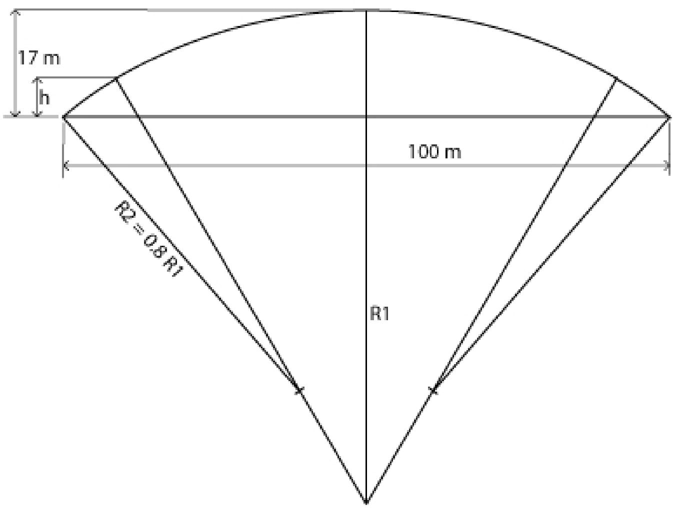
Bridge in the previous slide



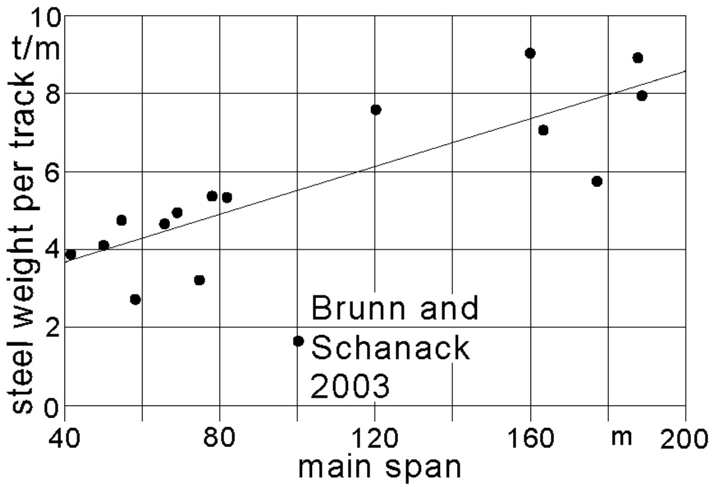
View of the 3-D FEM model used for calculations that can be found at http://fag.grm.hia.no/fagstoff/pert/



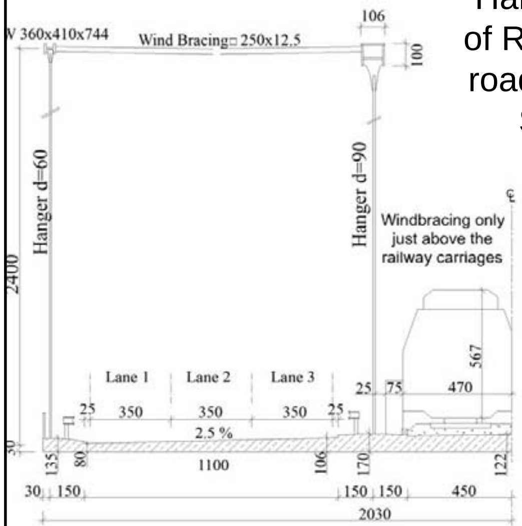
Reinforcement of the tie of a railway bridge spanning 100 m



Curvature of the arch

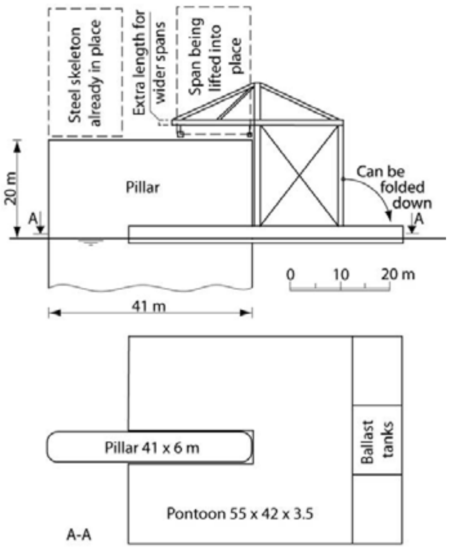


Steel weight in railway bridges

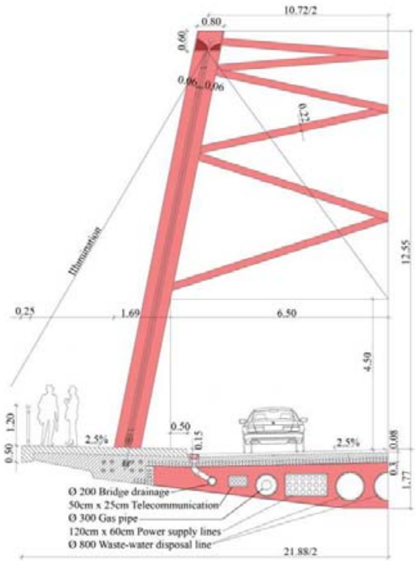


Half cross-section of Räck's bridge for road and rail, 2003. Span 160 m.

The bridge has one railway track and three lanes in each direction



Crane for moving steel skeletons from the shore to the pillars in wide rivers or in coastal areas



Bridge suggested for Schulenburg in Berlin

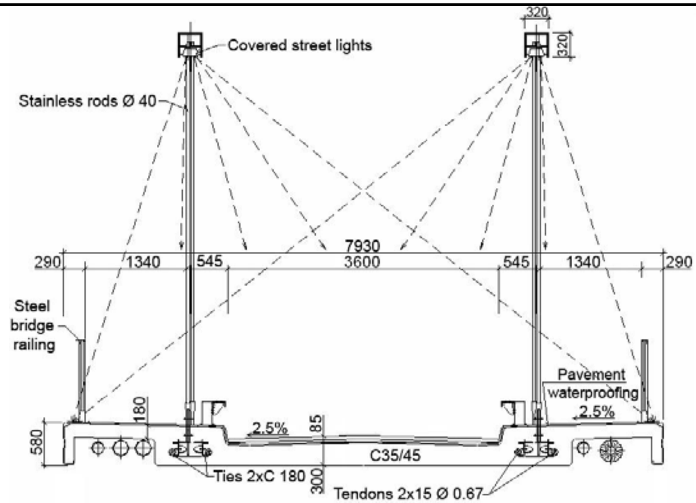
Span 90m

Graduation thesis of Wolfram Beyer 2005

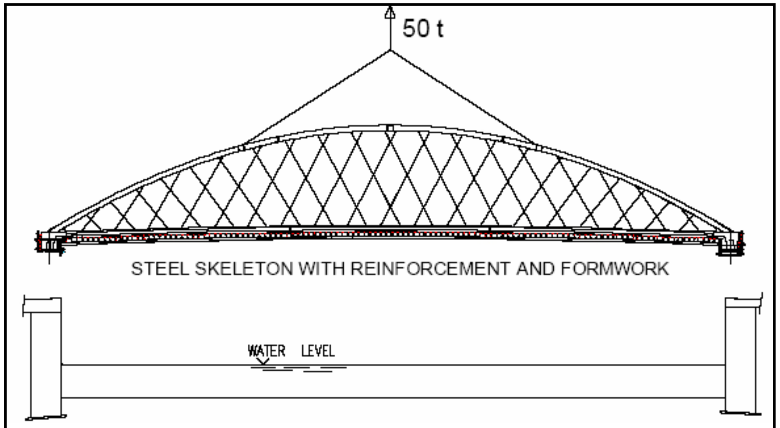
Adviser
Frank Schanack

Schulenburg Bridge

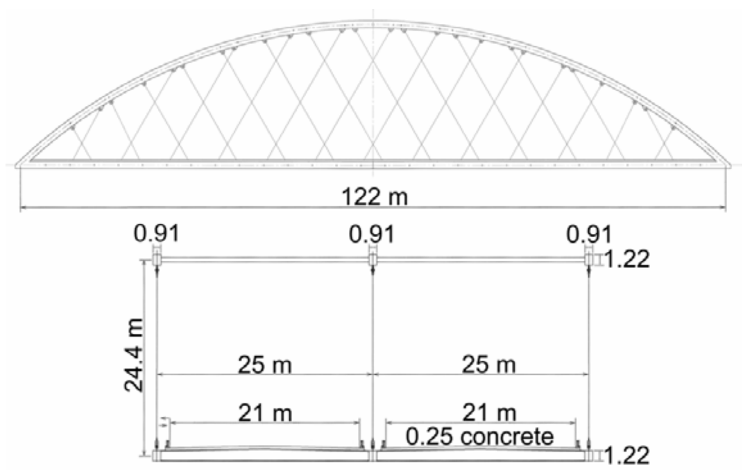
A network arch in Bechyne, Czech Republic.
Span 41m. Built 2004.



Cross-section of Šašek's bridge in Bechyne.
Note how the pipes are placed under the footpaths.

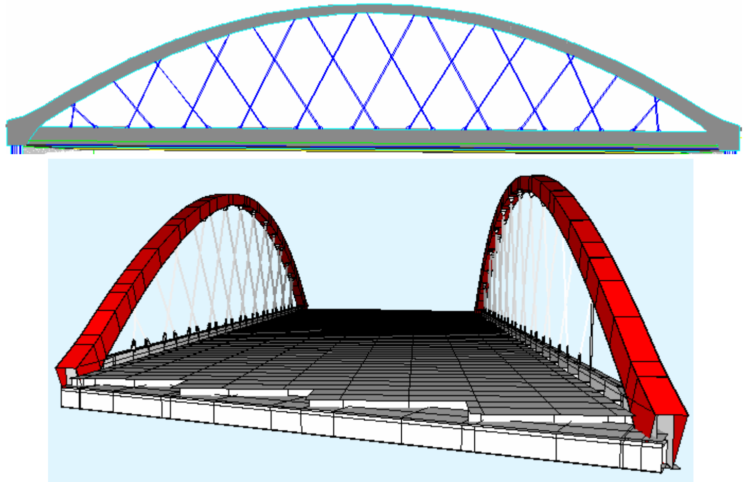


An advanced method of erection suggested for the Bechyne Bridge



Network arch with three arches in Rhode Island, USA

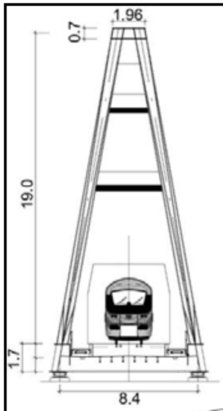
The steel skeleton for a network arch on Rhode Island, USA, before it is floated to the site



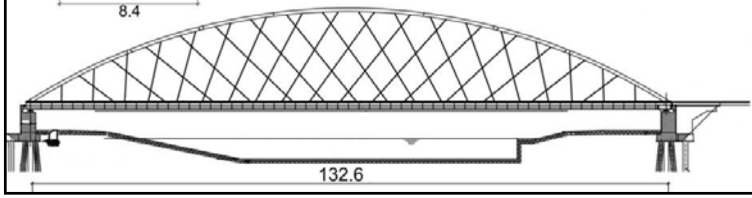
Network arch for a motorway in Saxony in Germany
Two parallel spans 27.4 m wide. Span 88 m.

The finished bridge. The four arches seem like three. It is an optical illusion that the ties seem to be sagging. The bridge was opened in 2006.

Flora Bridge

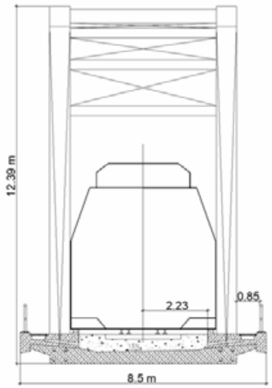


This railway bridge is going to be built in Germany. It is so light and stiff that it can be used for train speeds of up to160 km/h.



Blennerhasset network arch

268 m span over the Ohio river, USA

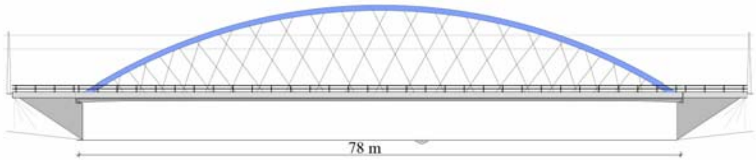


Network arch spanning 78 m

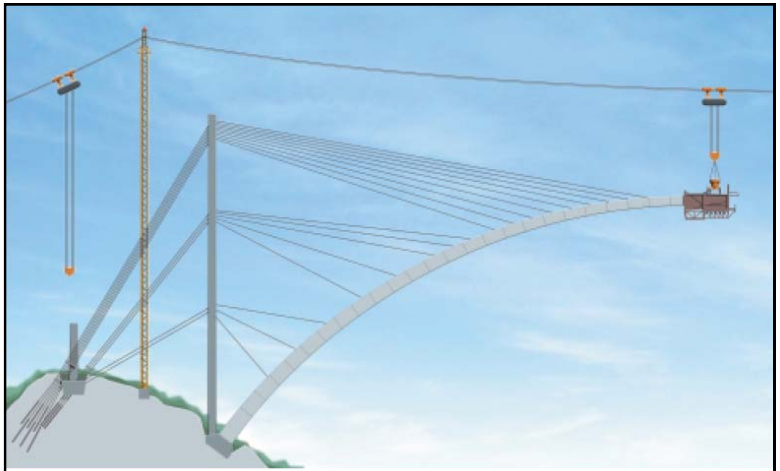
Suggested by Dr. Steffen Marx

The wind-bracing gives a high buckling strength in the horizontal direction

Note how the hangers are fastened to the vertical plates in the arch



Bridge over Svinesund between Norway and Sweden. Main span 247m. Opend in 2005. Structural steel 2800 t. A network arch would need 450 t. Reinforcement used was 970 t. (1200 t). Concrete 5300 m^3 (5500 m^3)



Casting of the arch of the Svinesund Bridge

Lifting of 1450 t of the steel tie of the Svinesund Bridge

A group of my students have designed a network arch further out in the fiord. The two main spans can be completely finished on a quay 20 km from the site. The main spans can be put into place by big floating cranes lifting 800 t each. The biggest lift of the bridge that was built was 1450 t. Preliminary numbers.

Summing up

Network arches are equally well suited for road and rail bridges. They use very little steel

An optimal network arch bridge is likely to remain the world's most slender tied arch bridge. The slim chords are pleasing to the eye and do not hide the landscape behind them.

If the bridge is not too wide, the tie should be a concrete slab. Concrete ties with small edge beams can be used for up to 15 m. between the arches.

Efficient methods of erection are available.

Since the network arch needs little materials, a high percentage of the cost will be employment.

The poverty in some parts of the world is one more reason for using network arch at suitable sites.

Depending on the site the network arch can save up to 40% of the cost and 70% of the steel.

If the network arch had been a well known type of bridge, it would have been hard to argue convincingly for arch bridges with vertical hangers and many other bridge types.

Conservatism is the main obstacle to the building of network arches

http://pchome.grm.hia.no/~ptveit/