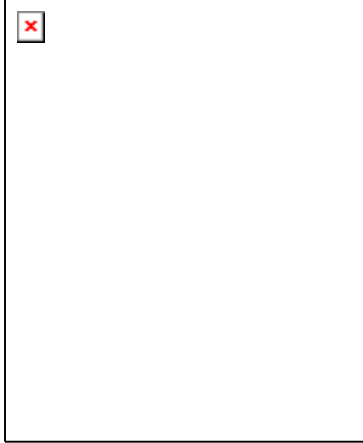


GENESIS AND DEVELOPMENT OF THE NETWORK ARCH CONCEPT



BIOGRAPHY

Per Tveit is Docent Emeritus at Agder University, Grimstad, Norway. He graduated from The Technical University of Norway in Trondheim in 1955. He was awarded his dr. ing. from the same institution in 1964.

He has worked in private firms for 5 years. The rest of his professional life he has been in institutions of higher learning in Norway, Denmark and the USA. This gave some time for research.

When working on his master's thesis he came up with the idea of the network arch. By the author's definition it is an arch bridge where some hangers cross each other at least twice. It has been the main theme of his research ever since.

In the early sixties he was allowed to build network arches in Steinkjer and Bolstadstraumen in Norway. They have lived up to his predictions and expectations. <http://pchome.grm.hia.no/~ptveit/>

The idea has spread. Recently network arches have been built or are being planned in the Czech Republic, Belgium, Spain, Norway, Germany, New Zealand, Hungary, Romania, Peru, Australia, Taiwan, India, Japan, Abu Dhabi and the USA.

Twelve years of retirement has given much time for research and lecture tours. Per Tveit has travelled around the globe 4 times and has given lectures on network arches in 50 countries.

SUMMARY

Working on his master's thesis in 1955 the author got to know the work of O. F. Nielsen. Around 60 of his bridges were built in Sweden between the two World Wars. (Nielsen 1929, 1932, 1936). Sloping hangers reduced the bending moments in arch and tie.

Today we have bigger live loads and stronger materials. Thus it is often advantageous to use arches where hangers cross each other at least twice like in the network arch.

The network arch is very competitive with a steel arch and a concrete tie with prestressing cables taking the longitudinal force in the tie.

Compared to usual tied arch steel bridges with vertical hangers, the bending moments in the chords are reduced by 80 % to 90 %. Savings in structural steel can be more than 75 % without substantial increase in the amount of reinforcement in the concrete tie.

Efficient methods of erection are available. The most straightforward is to cast the concrete tie on a scaffold. The tie makes a good platform for erecting the arch and hangers. Then the hangers can be tightened till they carry the tie.

Other methods of erection utilise the fact that the arch and hangers of a network arch supplemented by a temporary tie can carry the casting of the concrete tie. The steel skeleton can be erected on moderately thick ice and be lifted to the pillars.

Some of the facts presented in this contribution might seem like exaggerations. They are not. It would be silly to exaggerate when the bare facts seem like an exaggeration.

GENESIS AND DEVELOPMENT OF THE NETWORK ARCH

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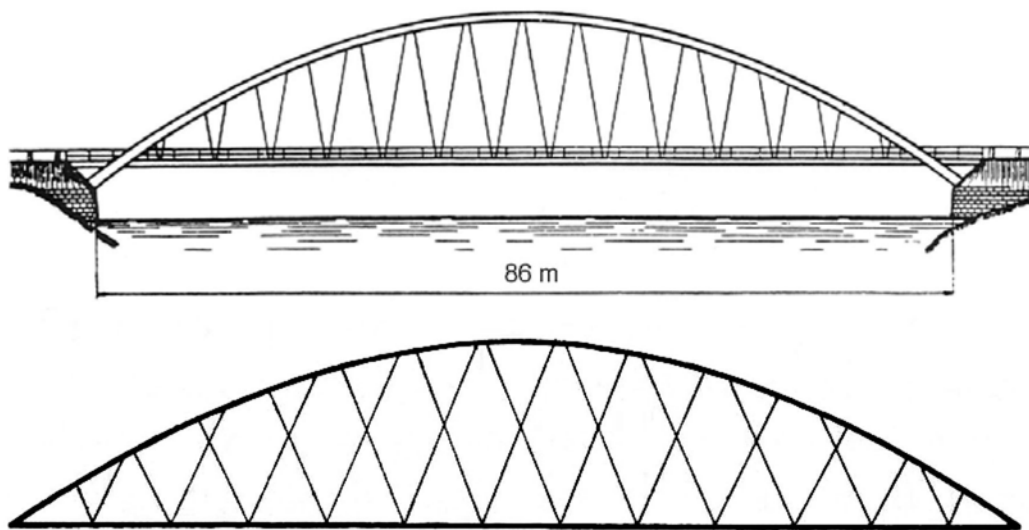
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Summary: The network arch is an arch bridge where some hangers cross each other at least twice. This contribution tells about the roots of network arches and how their design has developed. It will give examples of network arches and argue for their optimal form. The bending moments in the chords are very small. The chords can be very slim and pleasing to the eye. If slenderness of a tied arch is defined as the span divided by the sum of the chords, then a network arch is likely to remain the world's most slender arch bridge.

For two-lane network arches the tie would often be a concrete slab with prestressing cables in small edge beams. A tie cast on a scaffold would be a good platform for erecting the arch and hangers. Tightened hangers would carry the tie when the scaffold is removed. A temporary lower chord combined with arches and hangers can make a steel skeleton which can carry the casting of the concrete tie. This skeleton can be moved by various cranes. Other methods of erection will be mentioned. The network arch is equally well suited for road and railway bridges. - All units in this contribution are in metric.

The start of network arches

The author was working on his master's thesis in 1955 at the technical university in Trondheim. Starting point was the Nielsen arch bridges built between the two World Wars. See fig. 1. (Nielsen 1929). Higher concrete strengths make the chord slimmer and the tie lighter. To avoid big bending moments in the chords, the author suggested that some hangers should cross each other many times. These network arches have been the main theme of the author's research ever since.



After his master's thesis the author was awarded a scholarship to study at TH-Aachen in Germany. Nobody there was interested in arch bridges with inclined hangers, but Professor Dr. Phillip Stein helped the author to build a model of a network arch and discussed the idea with him.

Fig. 1. A Nielsen bridge and skeleton lines from Nielsen's patent application in 1926.

After a year in Aachen the author returned to his alma mater in Trondheim and worked on his thesis that much later gave the title dr. ing. (Tveit 1959). Measurements on a 4 m long model with many strain gauges were an important part of the thesis. This gave much insight. More information on the author's early struggles can be found on the author's home page <http://pchome.grm.hia.no/~ptveit/> in chapter j in the unfinished "A Systematic Thesis on Network Arches" whenever that work is put on the Internet.

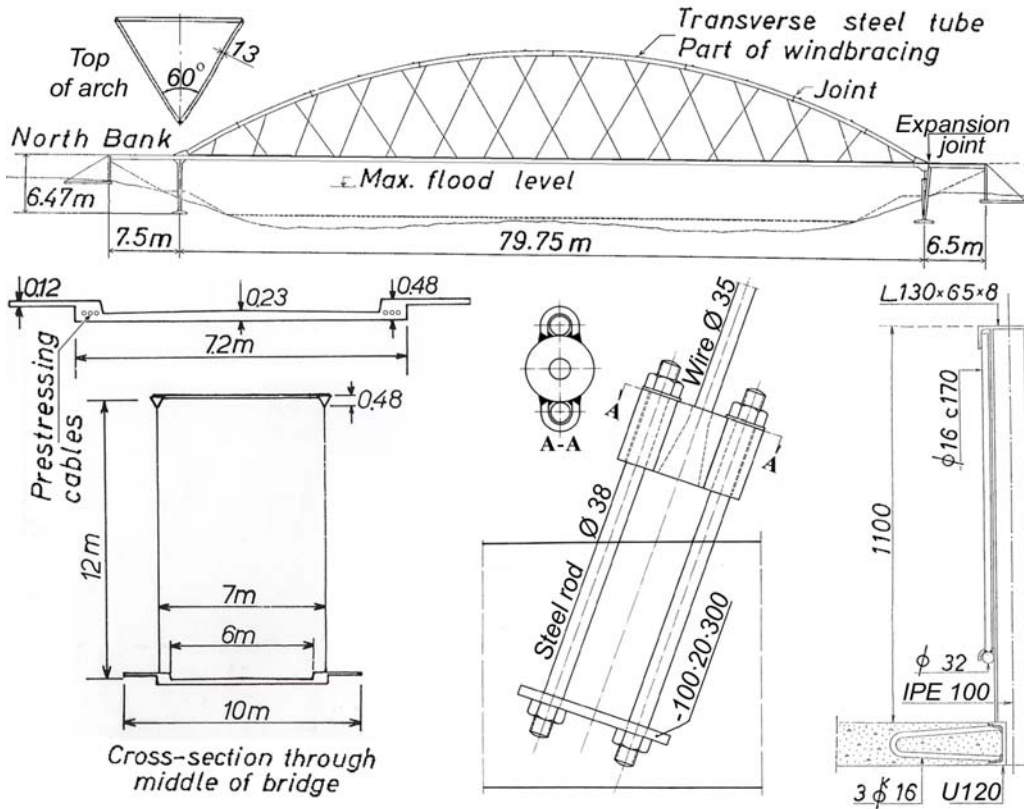
The Steinkjer network arch

In 1960 the author got a chance to design his first network arch for the town of Steinkjer in Norway. The town engineer Einar S. Balgaard thought that new and promising ideas should be tried. It was intended to verify the design with model tests. Luckily the development of computers made it possible to check the design with a general frame program.



Fig. 2. The finished network arch at Steinkjer, Norway. Photo: Alvestrand

The results were favourable. In the main span the materials needed per m^2 of area between the railings were: Concrete $0.22 m^3$, structural steel 60 kg, reinforcement 40 kg, prestressing steel 7 kg. (Tveit 1966)



Allowable stresses without load factors were used in the calculation of the bridge. Comparison with modern loads and codes is difficult.

The network arch at Steinkjer was built for a knife load of 177 kN in each of the two lanes plus an evenly distributed load that varies with the loaded length.

For a loaded length of 9 m this load is 41 kN/m in each lane. The simultaneous snow load is $0.918 kN/m^2$ over the whole bridge.

Fig. 3. An overview with structural details of the network arch at Steinkjer.

The building of the network arch at Steinkjer

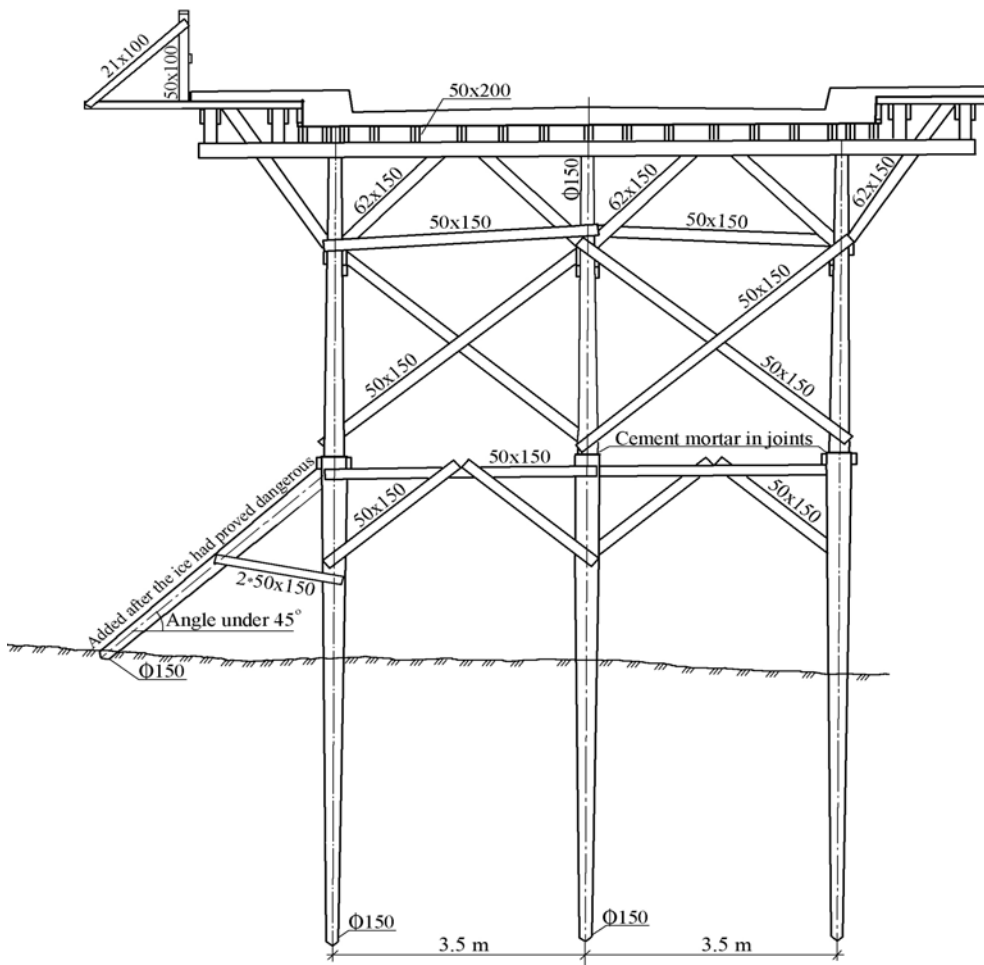


Fig. 4 shows the scaffold for the tie of the network arch at Steinkjer

The concrete tie of the network arch at Steinkjer was cast on the timber scaffold in fig. 4. In the longitudinal direction the piles are 3.5 m apart. If there is a flood in the winter, the slanting piles will break up ice that flows against the scaffold.

The scaffold gave a suitable platform for erecting the arch and putting in the hangers. Afterwards the hangers were tightened and the scaffold was removed.

There are some dirty cracks all over the concrete surface, but there is no decay around these cracks. In a few places there is rust on the surface.

The network arch at Steinkjer is in good shape after 46 years and is likely to last twice as long. There is more on this in (Tveit 2007).

The Fehmarn Sound network arch

When the author was building the network arch at Steinkjer, he heard about the Fehmarn Sound Bridge in northern Germany. (Stein & Wild 1965) See fig. 5. Span 248 m. It is an all steel network arch with arches that slop towards each other. It was built by Gutehoffnungshütte. Much later the author found that Professor Phillip Stein from Aachen had written the centenary history of Gutehoffnungshütte. The author wondered if his ideas of saving steel by using hangers with multiple intersections could have been passed on to Gutehoffnungshütte by Professor Phillip Stein. (Stein 1951).

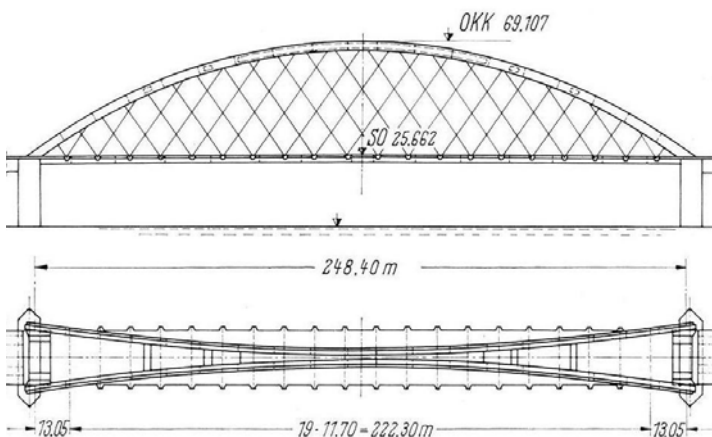


Fig. 5. The Fehmarn Sound Bridge. Finished 1963.

When asked about this in a letter Professor Stein answered: "Dass ist durchaus möglich". (That might very well have been the case). Professor Masao Naruoka saw model tests for the Fehmarn Sound Bridge in TH-Hanover in 1960. He took the idea to Japan where it has been flourishing. The Japanese network arches tend to have steel ties like the Fehmarn Sound Bridge. (Naruoka et al. 1977), (Yoshikava et al. 1993), (Nakai et al. 1995).

The Bolstadstraumen network arch



Fig. 6. The Bolstadstraumen network arch in western Norway was opened at the end of 1963. Span 84 m.

After the Steinkjer network arch the author designed the Bolstadstraumen Bridge for the Norwegian Public Roads Authority. There was a competition between a network arch and a tied arch bridge with vertical hangers. The bridge office of the public roads decided that the rise of their arch should be 21.5 % of the span while the rise of the network arch should be 18 % of the span. The network arch used 44 tonnes of structural steel and 7 tonnes of prestressing steel. The arch with vertical hangers needed 125 tonnes of structural steel. Both bridges had a concrete slab spanning between the edge beams. Such savings in structural steel is typical of well designed network arches. (Tveit 2007) (Tveit 2008)

It seems reasonable to define the slenderness of an arch bridge as the span divided by the sum of the depth of the chords. By this definition the slenderness of the Bolstadstraumen Bridge is 91. It was the world's most slender tied arch bridge until 2008. Then the Mangamahu Bridge in New Zealand was built. It is 4 % slimmer. The slenderness of the Brandanger Bridge to be built in western Norway in 2010 will probably be 198. It will probably be the world's most slender arch bridge for many years to come. (Tveit 2008)

The slenderness of the network arch is important from the aesthetic point of view. (Leonhardt 1991) said: "...we recognise the need to integrate a bridge into its environment, landscape or cityscape, particularly where the dimensional relationships and scale are concerned. Many mistakes have been made during the past decades by placing massive concrete blocks in the heart of older areas of a city.....Sometimes, long-span bridges with deep, heavy beams spoil lovely valley landscapes or towns."

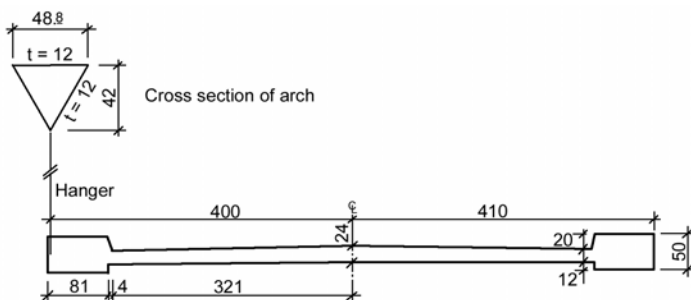


Fig. 7. Cross sections in the Bolstadstraumen Bridge

It is simple psychology of perception that when we look at a landscape with a network arch bridge, we automatically concentrate on seeing either the bridge or the countryside. That can not be done if a bridge has high beams that cover up part of the countryside.

Reasoning on optimal design of network arches

Most network arches that have been built have steel beams in the tie. The author is in favour of concrete ties in network arches that are less than 15 m wide. One can argue for this by comparing two arch bridges in fig. 8. They span 200m. The arch bridge with vertical hangers was built over the Danube in Bavaria in 1977. (Kahman 1979).

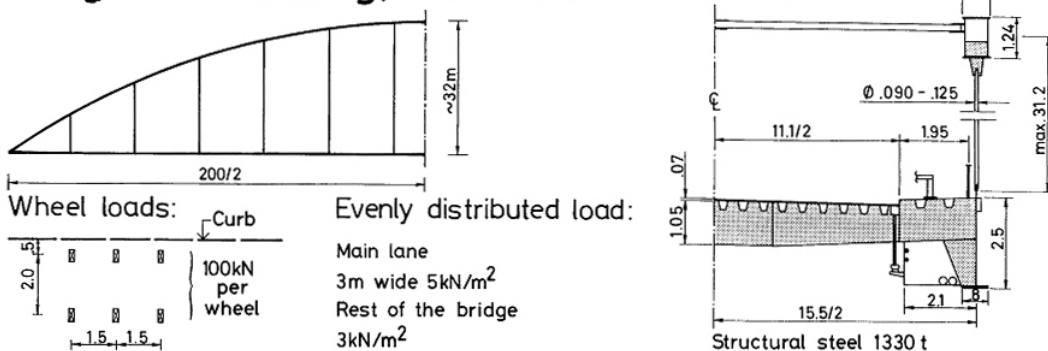
The author designed the network arch for the IABSE congress in Vienna in 1980. (Tveit 1980) and (Tveit 2008 pages 59 to 68). The two bridges are surprisingly similar. The rise of the bridge at Straubing is about 7% higher. For the network arch the concentrated loads are bigger, but the total payload for the two bridges is about the same.

The tie of the network arch should usually be made of concrete because the weight of the tie restrains the relaxation of hangers. The lower chord of the bridge at Straubing is an orthotropic plate with edge beams. The two arches have roughly the same cross-section and stiffness. The stiffness of the lower chord of the network arch is just under half the stiffness of the lower chord in the bridge with vertical hangers.

The upper part of fig. 9 on the next page shows a comparison between the influence lines for bending moments in the lower chord of the two spans. Please note that the maximum influence ordinate in the lower chord of the network arch is the same as for a simply supported beam spanning 5.6 m. The distance between the arches is 15 m. Thus it is obvious that the bending in the tie is much smaller than the maximum bending in the middle of the slab. Therefore a simple concrete slab with small edge beams would be a good tie.

The network arch usually saves more than half the steel compared with other steel bridges, but the steel weight for the bridge with vertical hangers is only twice the steel weight of the network arch. This impresses the author because the Straubing Bridge uses no concrete for the deck. Part of the reason for the moderate difference in steel weight is the importance of the deadweight in spans as long as 200 m.

Bridge at Straubing, built 1977. Codes: DIN



Network arch, proposal 1980. Danish codes.

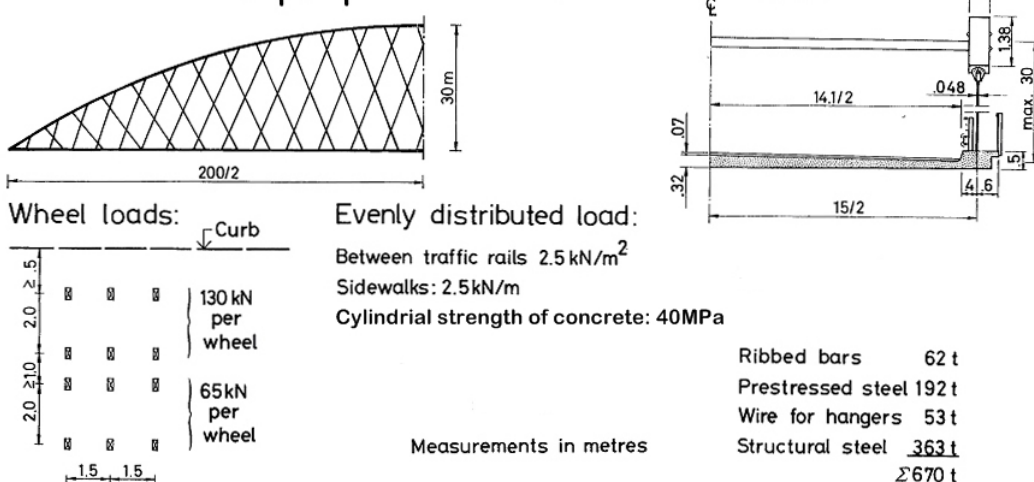


Fig. 8. Geometry, loads and quantities of the two tied arches

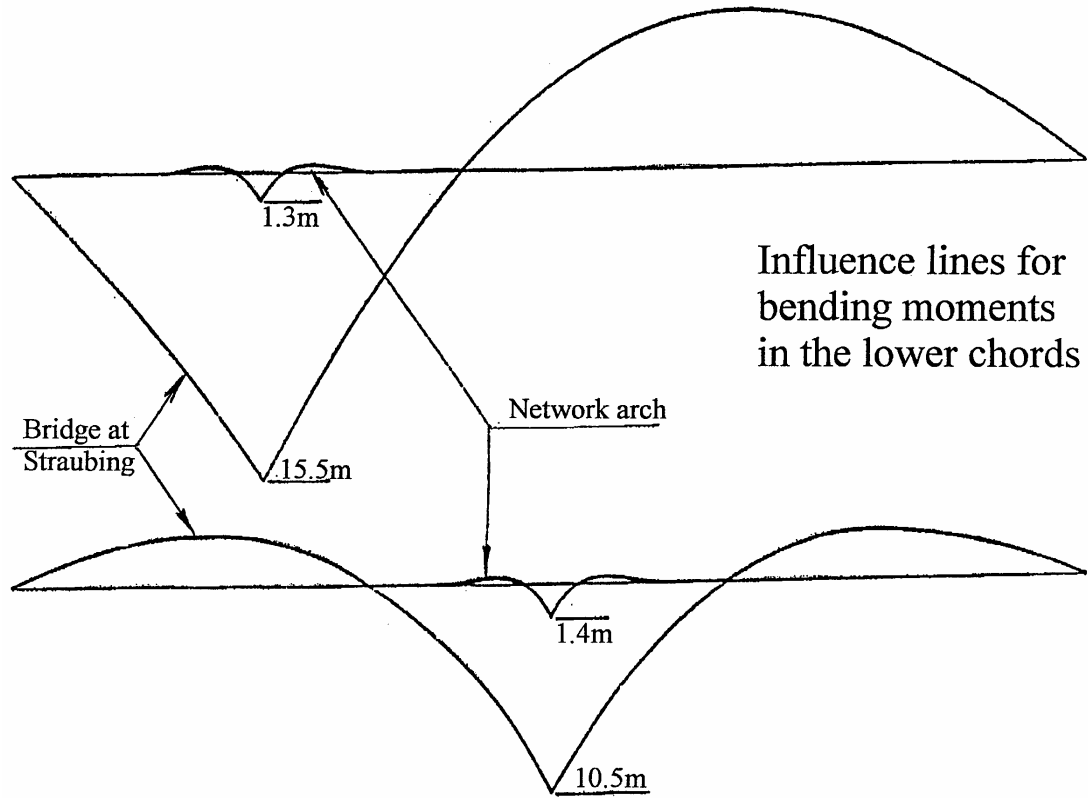
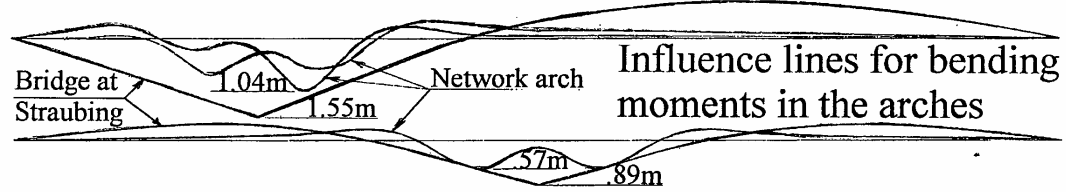
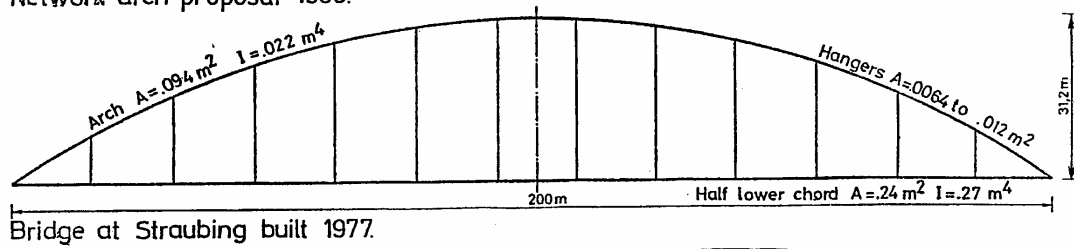
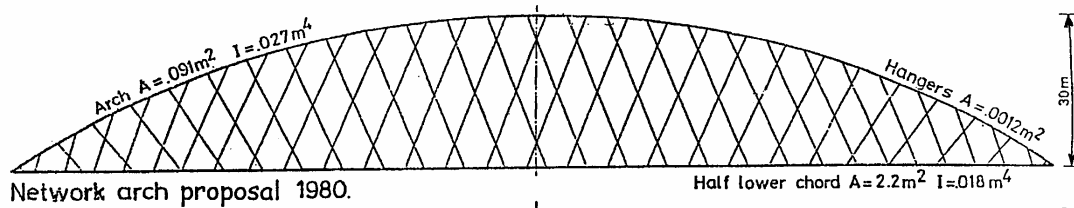
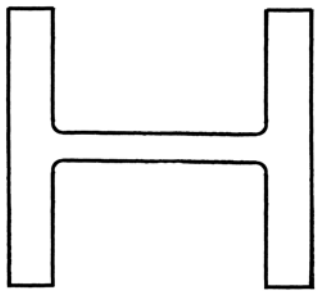


Fig. 9. Areas, stiffnesses and influence lines for the lower and upper chord of two tied arches



The author favours arches made from universal columns or American wide flange beams. See fig. 10. They give slender arches. (Schanack 2009) points out that the buckling in the arch is practically independent of the stiffness of the tie. Furthermore the arch is so well supported by the hangers that buckling in the plane of the arch is usually decisive. - The simple H-beam has a favourable distribution of materials for counteracting buckling out of the plane of the arch. Like in a bicycle wheel the sideways stiffness of the rim is bigger than the stiffness in the direction of the spikes. It is simple to attach hangers and windbracing to a universal column.

Fig. 10. Universal column

Network arches can be seen as simply supported beams. The arch is the compression zone and the tie is the tension zone. The hangers are a very light web. Most of the shear force is taken by the vertical component of the axial force in the arch, but some of the variation in the shear force is taken by variation in the hanger forces. The hangers distribute the loads in such a way that very small bending moments occur in the chords.

The axial forces in the tensile and the compressive flanges are inversely proportional to the distance between them. In tied arches, aesthetic reasons limit the distance between the arch and the tie. When the rise of the arch has been decided, savings in materials depend mainly on whether or not a design gives light chords and a light web. The arch would normally be part of a circle. This gives evenly distributed bending in the chords. A reduced radius of curvature near the ends of the arch can give less bending and axial force in the wind portal and a more constant axial force in a longer portion of the arch.

The upper nodes of the hangers should be placed equidistantly along the arch. The members between the last node and the end of the arch can be a little longer than other members in the arch. When universal columns are used in the arches, the lower half of the wind portal could have a steel plate on top. Then only one size of arch profile could be needed in the wind portal. The cavity under the steel plate could be filled with concrete.

If there are transverse beams in the tie, the hangers would normally be fastened to the ends of these beams. Then the hangers would have many different diameters. In that case there are no strong reasons to avoid a constant slope of the hangers. This arrangement has been used in the Fehmarn Sound Bridge and many Japanese network arches.

With a careful choice of the slope of the hangers, the force in the hangers can become surprisingly even. In the first two Norwegian network arches there was a constant change of slope between adjoining hangers. The maximum force in the hangers in these network arches was less than 10% bigger than the average hanger force.

When some hangers relax, the bending moments in the chords increase and the buckling strength of the arch is reduced because the support of the arch is less stiff. This is normally compensated for by the inevitable reduction of the axial force in the arch. To avoid extensive relaxation of hangers, the hangers should not be inclined too steeply. Less steep hangers will normally increase the bending moments due to concentrated loads. A compromise must be found.

All members in an optimal network arch efficiently carry forces that can not be avoided in any simply supported beam. Therefore it is a most efficient structure. The network arch uses any kind of steel efficiently, but it will be even more competitive in combination with future high strength steels. (Tveit 1987).

Prior to calculation by a general frame program, the axial forces in network arches can be found by the formulae indicated by fig. 11. (Tveit 2006). For calculation of the axial forces due to a concentrated load in the middle of a span, replace the concentrated load by an even load that is twice as big. This is because the maximum ordinate of the influence line is roughly twice as big as the average ordinate.

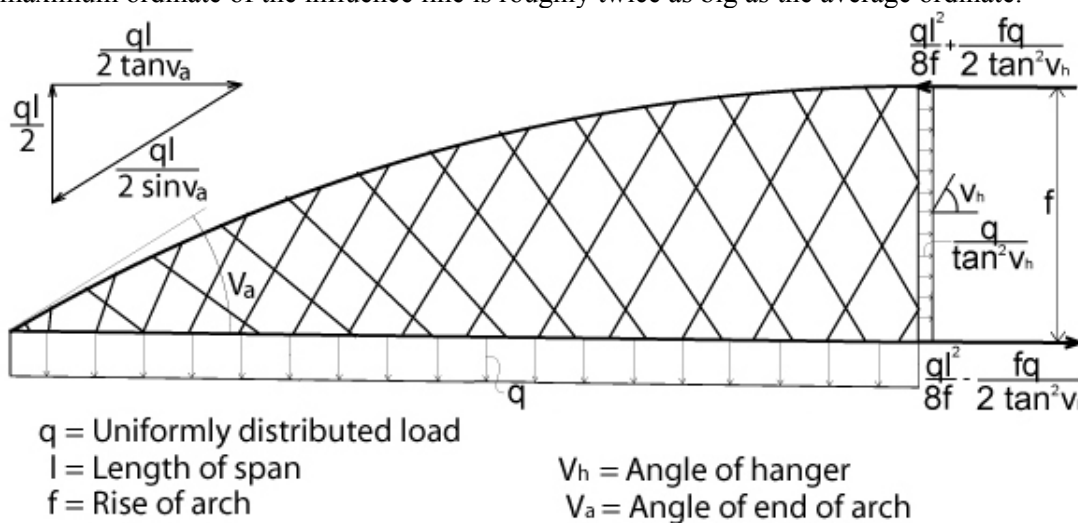


Fig. 11. Axial forces in the middle and the ends of the chords due to an evenly distributed load

An optimal network arch compared to other tied arch bridges

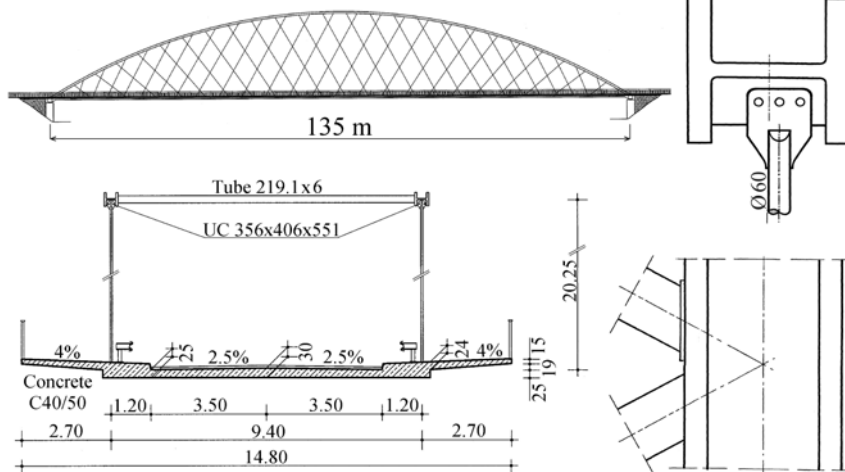


Fig. 12. The Åkviksound network arch according to EU codes

Two very able students of Professor W. Graße in TU-Dresden (Teich and Wendelin 2001) wrote their graduation thesis with the author. They calculated the optimal network arch in fig. 12.

The resulting steel weights per m^2 of useful bridge area are shown on the left in fig. 13. The loads and codes of the EU were used. Where there was doubt, solutions that gave the bigger steel weight were adopted. A revised version of the students' graduation thesis can be found at <http://fag.grm.hia.no/fagstoff/ptveit/>

Fig. 13 compares the steel weight of the network arch in fig. 12 to steel weights in recent German arch bridges with vertical hangers. The year the bridges were built is indicated. Bridges marked N have no wind bracing. In bridges marked S the arches slope towards each other.

It is surprising that the network arch tends to use less reinforcement in the tie than the bridges that have steel beams under the concrete slab. Part of the reason for this is the high amount of minimum reinforcement that is needed in the slab that lies on top of the elongating longitudinal steel beams in the tie. In the optimal network arch the moderate longitudinal prestress in the serviceable limit state reduces the need for minimum reinforcement. Furthermore it seems to the author that when the concrete slab can carry the concentrated load, not much extra reinforcement is needed to take the load to the edge beams.

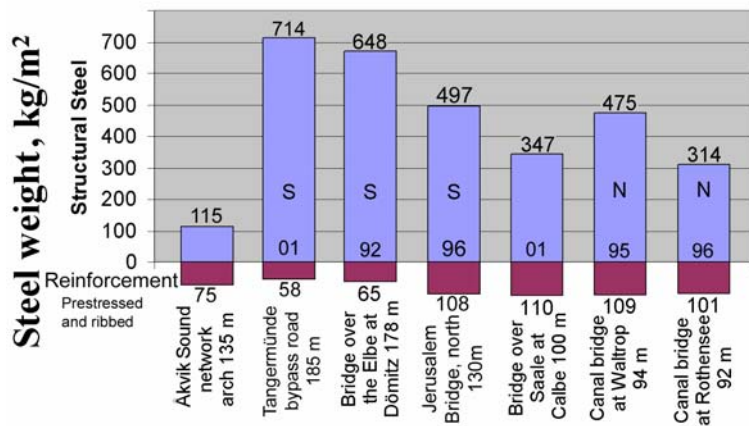


Fig. 13. Steel weight per m^2 for various arch bridges

The Jerusalem Bridge in Magdeburg uses more than 4 times as much structural steel per m^2 as the Åkvik Sound Bridge. The spans are nearly the same. The Åkvik Sound Bridge comes out better because the area under the arches is included in the surface that is used for calculating the steel weight in kg/m^2 . Different methods of erection contribute to the great variation in steel weight in fig. 13. A temporary tie for the Åkvik Sound network arch would need a steel weight of $\sim 45 kg/m^2$. The arches are pre-bent H-profiles made of S 460 assumed.

POINTS OF IMPORTANCE

Aesthetics
Adaptability
Materials
Fabrication
Corrosion protection
Maintenance

Erection

- Floating into place
- Erection on side-spans
- Erection on ice

OTHER TIED ARCH ROAD BRIDGES COMPARED TO OPTIMAL NETWORK ARCHES

Bulkier bridges
2 to 8 times deeper lower chords
2 to 4 times the steel weight
15 to 30 times longer welds. More complicated details
3 to 7 times more surface to protect
Other concrete parts need much more maintenance than concrete slabs with a slight prestress
Erection is more expensive with 2 to 4 times more steel.

Steel weight is not the only thing that matters. Fig. 14 indicates other factors that might be important. It gives reasons why the steel in network arches might cost less per ton than the steel in arch bridges with vertical hangers. The references that gives the steel weights in fig. 13 can be found in (Tveit 2002). (Herzog 1975) says that arch bridges use about the same amount of steel as other steel bridges.

Fig. 14. Comparison of various arch bridges

Casting the concrete tie on a temporary lower chord

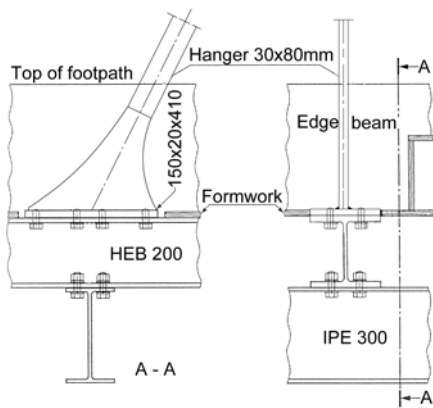


Fig. 15. Node in temporary tie.

The most versatile methods of erection of network arches utilise the fact that the structural steel, supplemented by a temporary lower chord, can form a steel skeleton so strong and stiff that it can support the casting of the concrete tie. Fig. 15 and 16 show an example of a temporary lower chord for a network arch.

When the steel skeleton and the reinforcement are in place, the lower chord can be cast. First the transverse beams at the ends of the arches are cast. Then the edge beams are cast from both ends to prevent big bending moments due to hangers relaxing. When the edge beams have been cast, they will take most of the bending in the tie. The prestressing cables will take most of the axial force in the tie. Finally the deck is cast. (Tveit 2008) P.29k to 30.

This temporary lower chord needs no corrosion protection. Any beams with sufficient length and strength can be used for transversal beams in a temporary lower chord. With slight alterations a temporary lower chord can be used in many different network arches. Part of the form for casting the concrete tie can be moved down and be used in a wagon for removing the formwork and the lower chord. The wagon will roll on the edge of the finished concrete tie. (Tveit 2008). P.52 to 53a.

The author would like to present an idea for the design and erection of a network arch. It is illustrated in fig. 17. It shows the first stage of erection and transport of a skewed bridge across a canal. The angle between the bridge and the canal is 45 degrees. The span is 100 metres. The width of the canal is nearly 70 metres. In order to reduce the thickness of the concrete slab the bridge has three arches. (Tveit 2008). P. 20.

The structural steel, supplemented by a temporary lower chord, is erected on the side-spans at 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 at both sides of the canal and the tie is cast.

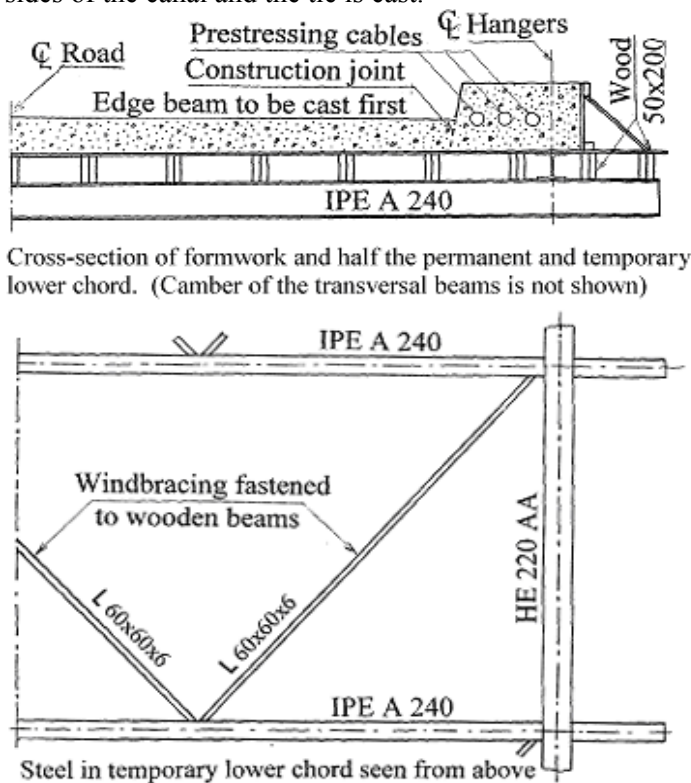


Fig. 16. Temporary lower chord

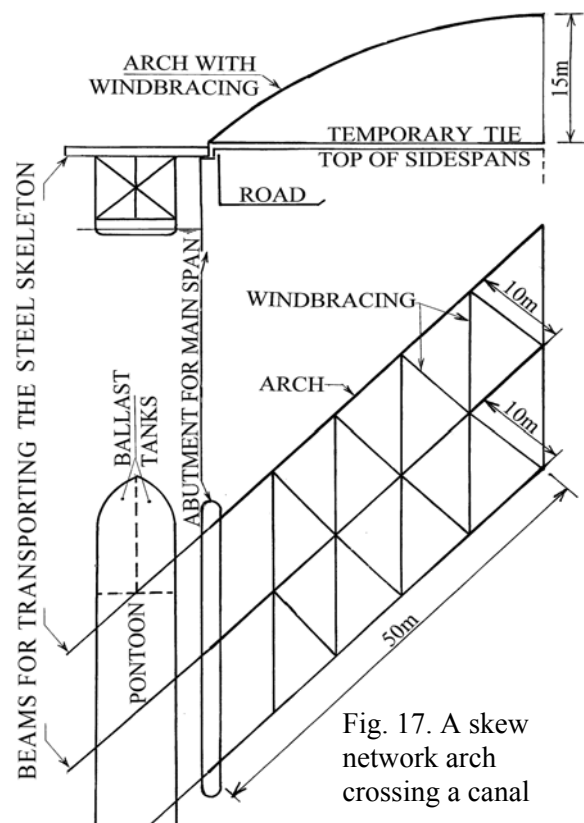


Fig. 17. A skew network arch crossing a canal

Erection of the Åkvik Sound network arch by a floating crane



Fig. 18. Lifting of the steel skeleton of the Åkvik Sound Bridge

A complete design of a network arch must also include a design of the method of erection. Fig. 18 shows the possible lifting in place of the steel skeleton of the Åkvik Sound Bridge by Norway's biggest floating crane. See fig. 12. (Tveit 2008 p. 29k).

A much lighter crane could have done the job. The lifting capacity of the crane is 600 t. The steel skeleton weighs 230 t. Local conditions will decide how much of the wooden form and the reinforcement should be put in before the steel skeleton is lifted to the pillars. Often it is better to use one crane at each end of the steel skeleton. Floating cranes that can lift over 3000 t are available.

Erection of the Blennerhassett Bridge over the Ohio river in USA

The bridge was designed by Michael Baker jr. (Wollman & al 2007). It was chosen because it was less costly than a previous design. The method of erection was influenced by the need to have room for passing ships. The rise of the arch is 53.3 m. There is 32.6 m between the planes of the arches. All hangers have an angle of 63.6° with the horizontal. Relaxation of hangers was not a problem.

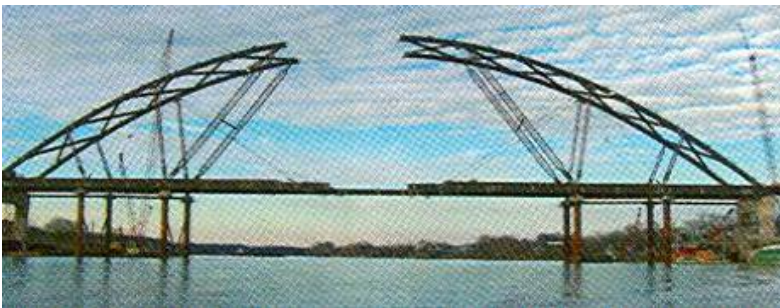


Fig. 19. Erection of Blennerhassett Bridge. The last beams in the tie is about to be put in.

Compared to a bridge with vertical hangers the crossing hangers reduce the live load deflections by a factor of 11. Arch rib and tie beam bending moments are reduced by a factor of 4 and 5 respectively. With the great width of the bridge and the correspondingly heavy concrete deck slab, live load stresses in the inclined hangers remain low and hanger unloading is not an issue.

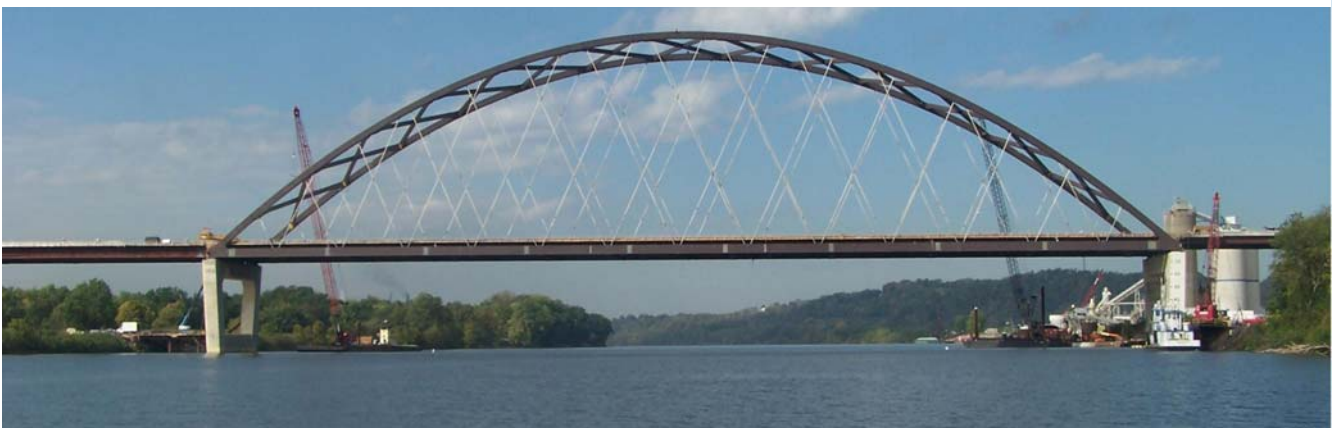


Fig. 20. Blennerhassett Bridge over Ohio River. Span 268 m. Built 2007.

Network arch in Providence, Rhode Island, USA

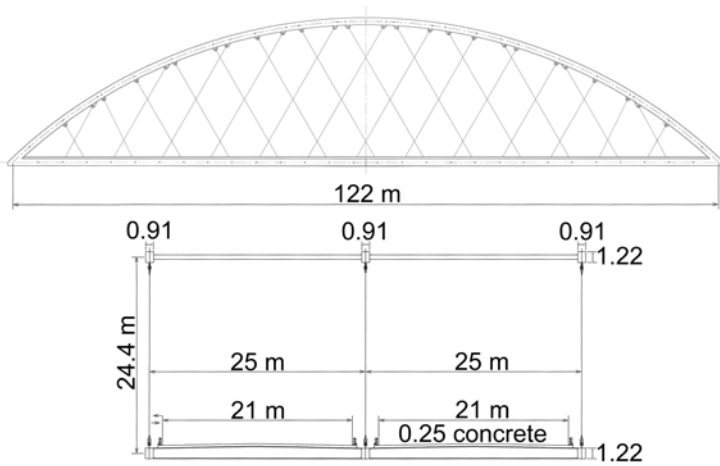


Fig. 21. Network arch in Providence. Opened 2007

The rise of the arch is 20% of the span. Three parallel arches are used because the distance between the two outer arches is 50 m. Because of the width, the lower chord could not be a concrete slab. Instead transverse beams under the deck have been used. The distance between most floorbeams were 4.2 m. (Steere and Wu 2008).

There is one hanger at the end of each transverse beam, which is half the number of hangers normally used. The slope of the hangers is 60° . The steel skeleton was assembled 20 km away from the bridge site, placed on barges, and floated into position.

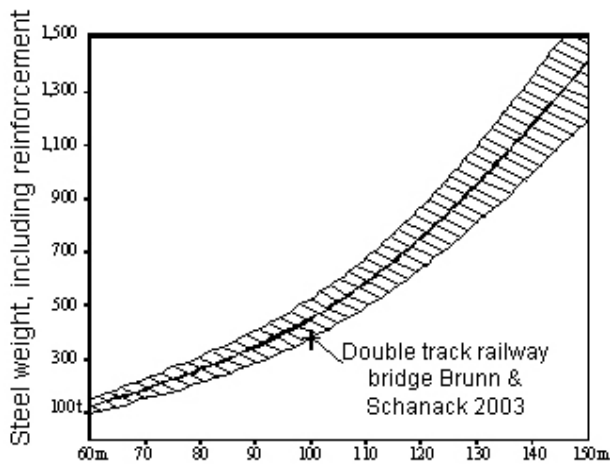


Fig. 22. Steel weight in two-track railway bridges. Courtesy of B. Brunn and F. Schanack.

The diagram in fig. 25 is strongly influenced by data found in (Brunn and Schanack 2003). The diagram applies to railway bridges with train speeds not exceeding 200 km/h.

The diagram in fig. 23 has been made starting out with the materials needed for the bridge in fig. 15. The dots in the diagram come from that bridge. Thus the diagram is more reliable near those dots.

In the bridge in fig. 22 a 50 N/mm^2 cube strength of concrete was used. Higher concrete strengths lead to lighter and more durable bridges, but the deflection in the middle of the concrete slab between the two arches must be calculated more carefully.

The weight of the temporary lower chord is bigger than necessary for the bridge in fig. 12. This is because the author thinks that the temporary lower chord should be designed to fit many bridges.

Steel weights in medium span network arch road and rail bridges

In the initial stage of bridge design several alternatives should be considered before choosing the final alternative. The diagrams in figs 22 and 23 (Tveit 2009) give a rough estimate of the steel needed for medium spans of rail and road bridges. The diagrams are made in accordance to EU codes, but give a hint of steel weights according to other codes.

Network arches might be especially advantageous for these spans. For longer spans the permanent loads are higher. They are not reduced by crossing hangers.

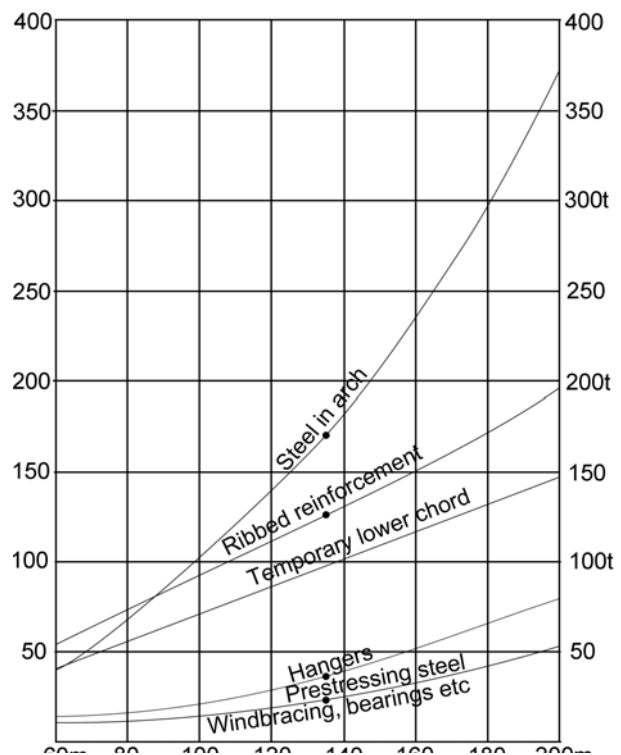


Fig. 23. Steel weight in two-lane network arches

A comparison between network arches and arch bridges with vertical hangers

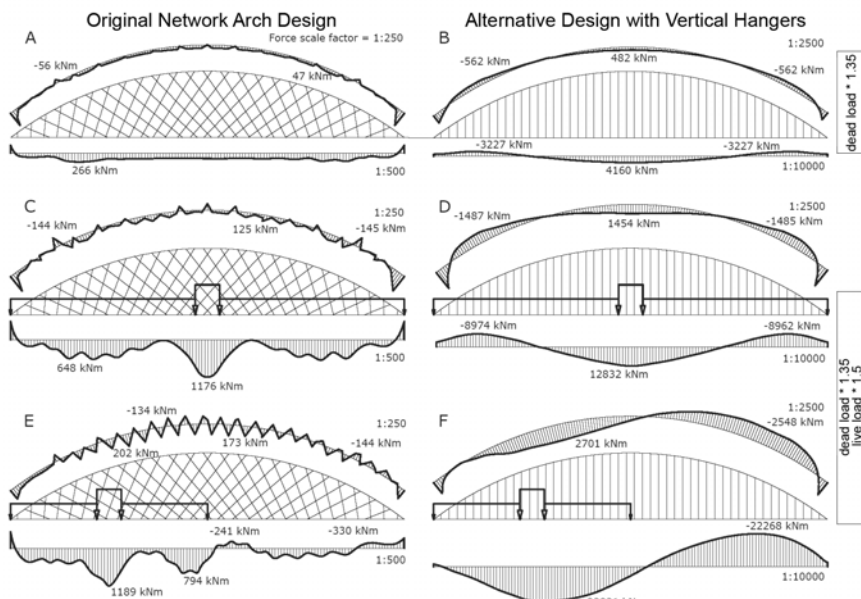


Fig. 24. A comparison between two 100 m railway bridges

This page is based work by (Schanack & Brunn 2009). Fig. 24 and 25 compares two kinds of arch railway bridges. Both span 100 m. It is a network arch and one with vertical hangers.

In fig. 25 Bending moments are compared. They start with a bridge with vertical hangers that has maximum load on half the span. Then the angle between the arch and the hangers is gradually decreased. The reduction of the maximum bending moment is 94 %

Network arches for railway bridges.

Bending moments in tied arches

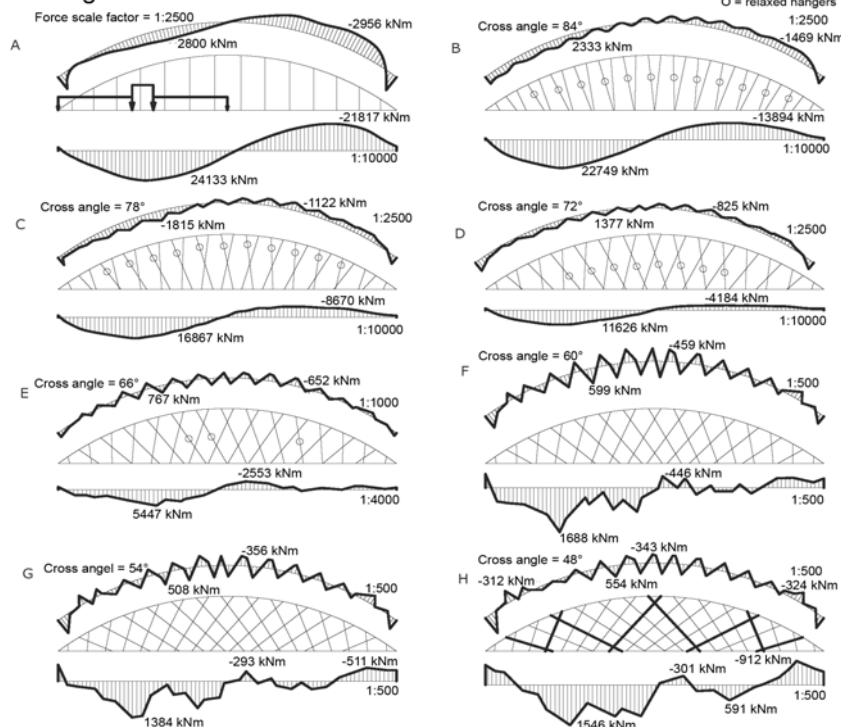


Fig. 25. Gradual transition between two kinds of arch bridges

The German railway authority advisory board for bridge design has published guidelines for the design of railway bridges (Schlaich et al. 2008). In these guidelines the network arch is proposed as an innovative alternative to the classic tied arch bridges.

The authors of that publication stress the financial advantages of network arch railway bridges compared to standard tied arch bridges with vertical hangers, especially for long spans. The guidelines point out the equality in structural and fatigue behaviour, despite the possibility of remarkably lighter structures for network arches.

Considerable advantages of the network arch over its classic competitor are also seen in the serviceability limit state due to greater stiffness and lower self-weight and therefore smaller

deflections. Wind-induced and rain-wind-induced vibrations are also less significant when sticking to the hanger arrangement of network arches. The members of the DB advisory board do not regard the possible high slenderness of network arches as a drawback in terms of robustness.

Frequently a matter of discussion, the costs for corrosion protection measures are also regarded as being equal to both network arches and tied arches with vertical hangers, whereas network arches become more advantageous because benefit of the possibility of using a pre-stressed concrete tie. In all aspects, the DB advisory board's comparison between railway network arches and railway tied arch bridges with vertical hangers turns out equal or in favour of network arches.

Conclusions after 54 years

A well designed network arch 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 or cityscape behind them.

The slim tie is an advantage when the traffic on the bridge is lifted up to let other traffic pass under it.

Lightness and vertical reactions give savings in the substructure.

If the bridge has 15 m between the planes of the arches, the tie can be a simple concrete slab.

Then the concrete ties should have small edge beams with room for the longitudinal prestressing cables.

If the span of this slab is more than 10 m, transversal prestressing should be considered.

Network arches have very small longitudinal bending moments in the chords.

All members efficiently carry forces that can not be avoided in any simply supported beam

Tie and hangers give the arch good support and high buckling strength in the plane of the arch.

H-beams with horizontal webs have a favourable distribution of stiffness and give simple details.

Tension is predominant in tie and hangers.

All hangers can have nearly the same cross-section.

Network arches are equally well suited for road and rail bridges. Efficient methods of erection are available.

Erection can be done using a temporary lower chord which combined with the structural steel has enough strength and stiffness to carry the casting of the concrete tie. Other efficient methods of erection are available.

Network arches are not sensitive to uneven settlements in the foundations.

High strength and low weight give the network arch good resistance to earthquakes.

Most concrete parts need more maintenance than a concrete slab with a slight prestress.

Network arches have small surfaces. Thus they need little corrosion protection.

Network arches uses very little steel.

High strength steels are well utilised.

If things go well, the network arch can save up to 40 % of the cost and 70 % of the structural steel.

Since network arches need little steel, a high percentage of the cost will be labour.

Since the advantages of the network arch are so great, there is no need to exaggerate.

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 and lack of time are important obstacles to the building of network arches.

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