Visit to the Steinkjer network arch 44 years later

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ABSTRACT. Network arches have inclined hangers that cross each other at least twice. In narrow bridges they can normally save over ⅔ of the steel needed for other steel bridges. Fig. 1 shows the author's first network arch. It was built because it was less costly than a concrete arch bridge with vertical hangers. This contribution sums up the experience from the first 44 years of the bridge's life. Damage due to a flood with winter ice has been overcome. Some lower ends of hangers have been bent because there were no railings to protect then. Otherwise the main span is in good shape. The southern side span has moved so the expansion joint is closed on hot summer days. Possible effects of this have been examined.

1. OVERVIEW OF THE NETWORK ARCH AT STEINKJER

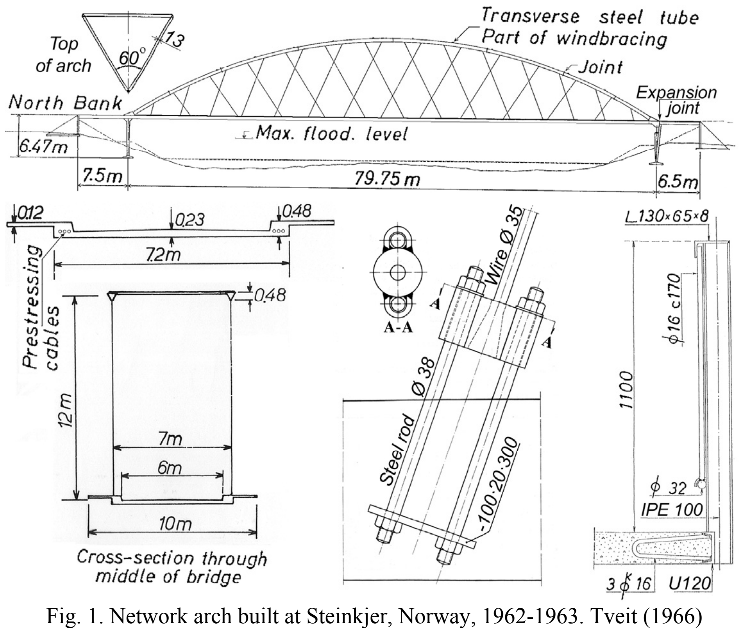

Fig. 1. Network arch built at Steinkjer, Norway, 1962-1963. Tveit (1966)

The network arch at Steinkjer, Norway was built about one km from the sea in a location with moderate wind speeds. The tie was cast on a scaffold on piles in the river bed. See fig. 4. It rained for three weeks after the tie had been cast. The cube strength of the concrete was well over the prescribed 35 MPa. The content of cement was 450 kg/m^3.

2. PREAMBLE

Forgive the author for devoting this page to telling about an efficient form of network arches. The content on this page has been presented at ARCH'04 and many other congresses and meetings. Those who have heard it before should proceed to the next page.

The network arch described in this page is a steel arch bridge with a partial prestressed concrete tie. See fig. 2. Some hangers cross each other at least twice. The chords have little bending. The arch has high buckling strength. Thus the network arch makes good use of high strength steel.

In recent years there has been an increased tendency to spend a lot of extra money on the pleasing appearance of bridges. The network arch can often be used to make a slender, attractive and economical bridge. A network arch has been the world's most slender arch bridge for more than 40 years. Tveit (2007) p. 7.

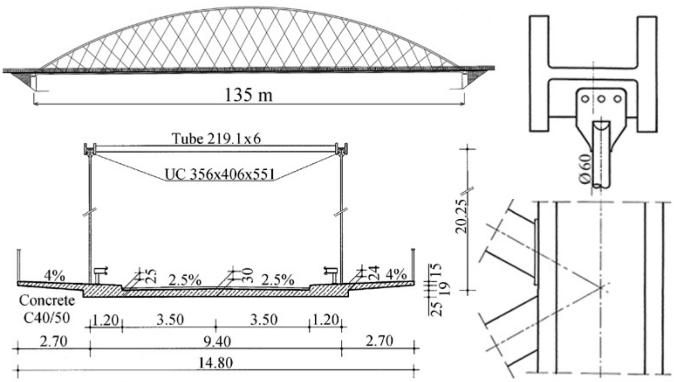

Fig 2. The Åkvik Sound Bridge in Norway. Teich and Wendelin (2001)

A good example of an optimal network arch is shown in fig. 2. Teich and Wendelin (2001) and Tveit (2007) p. 93. It was designed in accordance with the current Eurocodes. The arch is part of a circle. The hangers are placed equidistantly along the arch. Two ways of fastening the diagonals between the arches are shown. The tensile forces in the tie are taken by prestressing cables in the edge beams. This gives a beneficial compressive stress in the tie. The welds are short and the cost of fabrication is low. Thus the cost of steel per tonne will be moderate.

In fig. 3 the bridge in fig. 2 is compared to German arch bridges with vertical hangers. Tveit (2007) p. 93. N means that there is no windbracing. S means that the arches slope towards each other. The years when the bridges were built are indicated. Fig. 3 supports the author's claim that the network arch can save over ⅔ of the steel needed in other steel bridges. Please note that arch bridges with vertical hangers use roughly the same amount of steel as many other steel bridge types. Herzog (1975).

Steel weight is not the only thing that matters. Fig. 99, Tveit (2007), looks at other differences between arch bridges with vertical hangers and network arches of the type in fig 2. The reduction of cost is of great interest. The biggest savings are obtained when the arches are less than 15 m apart and steel beams in the tie can be avoided. Tveit (2007) p. 93b indicates that over 35 % of the cost can often be saved. This applies to both road and railway bridges.

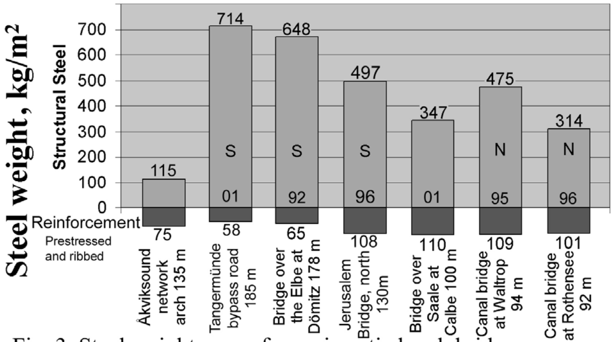

Fig. 3. Steel weight per m for various tied arch bridges

The method of erection has great influence on the cost. Sometimes the tie can be cast on a timber structure in the river bed. After the arch and hangers have been erected, the hangers can be tensioned till they carry the tie. Tveit (2007) p. 7a.

Sometimes a temporary tie can be used for erecting a network arch. Together with arches and hangers it makes a stiff skeleton that can be moved and can carry the casting of the tie. Tveit (2007) p. 20.

Finished spans of network arches over 200 m can be lifted to the pillars by big floating cranes. Tveit (07) p. 94.

3. THE BUILDING OF THE NETWORK ARCH AT STEINKJER

The steel arch and the hangers should have been carrying the tie before the winter set in, but the steel mill did not produce the steel as promised. A flood came after the ice was around 0.15 m thick and swept away over 17 m of the support under the tie. Due to this the tie was sagging 0.2 m and developed cracks over 2 mm wide.

The scaffolding was repaired and strengthened in a makeshift way. Tragically, a man lost his life in the process. Twelve piles in the river could not be replaced. When the steel had been erected, the tie was straightened by the tensioning of the hangers. Prestress closed the cracks. Now they are hard to find.

Allowable stresses without load factors were used in the calculation of the bridge. Comparison with modern loads and codes is complicated. The network arch at Steinkjer is 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.

The author has found that a load of 400 kN can be allowed to drive very slowly over the bridge when the two maximum axel loads are 140 kN and 2.5 metres apart. The next axel must be at least 6 metres away form a maximum axel load. There must be no other load on the bridge.

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.

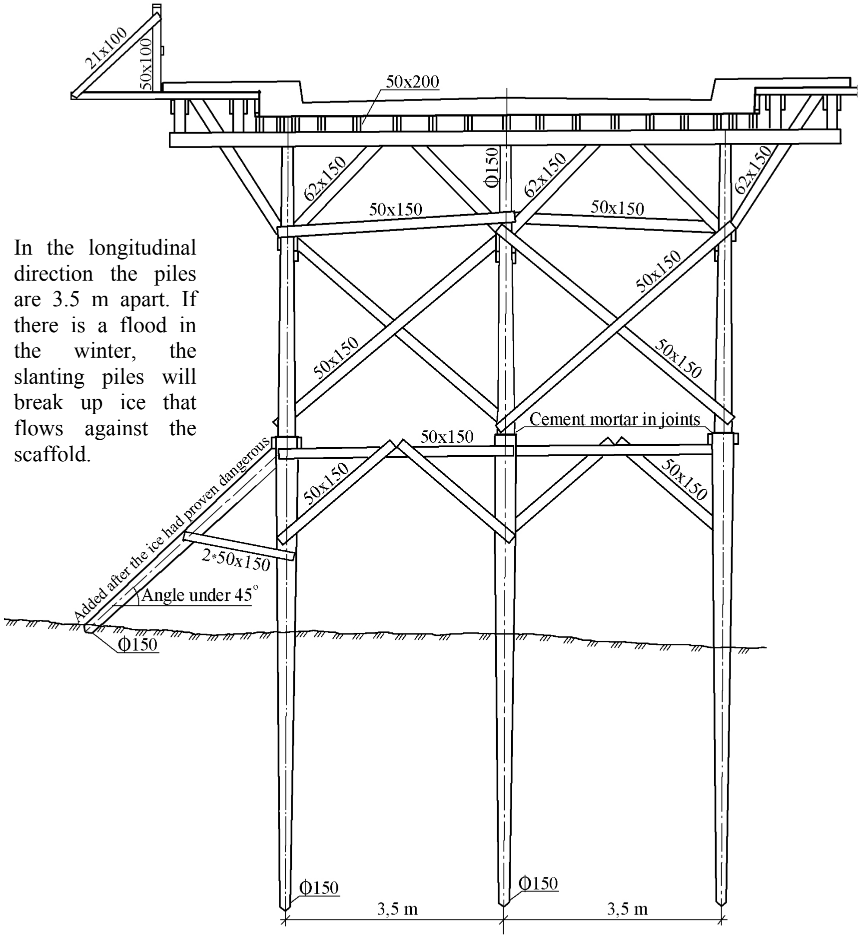

Fig. 4 shows the scaffold for the tie of the network arch at Steinkjer

4. EXPERIENCES WITH THE NETWORK ARCH AT STEINKJER

4.1 Lack of railings to protect the hangers

There are no railings between the traffic and the hangers. See fig. 5. That was a mistake. As a result four or five lower ends of hangers have been bent by vehicles bumping into them. The concrete around the hangers has not been damaged. The cross-section of the lower end of the hangers is ample where the hangers enter the concrete.

There is no point in bending the steel rods back because that might damage the concrete. Generally the concrete around the lower ends of the hangers seems to be in good shape. This might partly be due to the longitudinal prestress of the tie. Zoli and Woodward (2005) have found that the breaking of a hanger is not likely to make a network arch collapse. See also Tveit (2006) p. 22.

Photo: Alvestrand

Fig. 5. The network arch at Steinkjer

4.2 Railing outside the footpath

The posts, IPE 100, of the railings outside the footpath, see fig. 1, are welded to channels on the outer edge of the concrete. The welding was done slowly using little heat to avoid cracks between the channels and the concrete. To give the pedestrians a feeling of safety, the top of the railing is 130 mm wide. Outside the main span a vehicle has run into the vertical bars in the railing and has bent some of them. However, it was easy to straighten the bars by hand.

There is a rod, Ø32, at the bottom of the grid inside the railing. In order to reduce stresses in the railing due to creep, shrinkage and bending in the concrete tie, this rod is not fastened to the vertical posts. Tveit (2007) fig. 34. Since the IPE 100 s at the ends of the main span are still vertical, we can conclude that creep and shrinkage have not made the main span shorter than it was about half a year after the tie was cast.

4.3 The state of the concrete

Little de-icing salt has been used on the bridge. Most of the concrete is in good shape. On the surface of the footpath porous pebbles have contracted water that has frozen in the winter. This has broken the concrete cover over the pebbles and has led to some cavities about one cm deep. To compensate for this, an epoxy membrane has been glued to the footpath.

There are some very small dirty cracks all over the concrete, but there is no decay around these cracks. In a few places there is rust at the surface. Probably some reinforcement bars have come too near the surface. So far the rust has not yet caused concrete to fall off.

4.4 Damage to the steel

A vehicle has bumped into a tube above the lane at one end of the bridge. There was extra bending capacity in the tube to take the resulting bending. Otherwise the steel structure is in good shape after 44 years. Good maintenance of the paintwork has contributed greatly to this.

The diagonals in the windbracing are tension rods, but the diagonals at each end of the span are the same as the hangers.

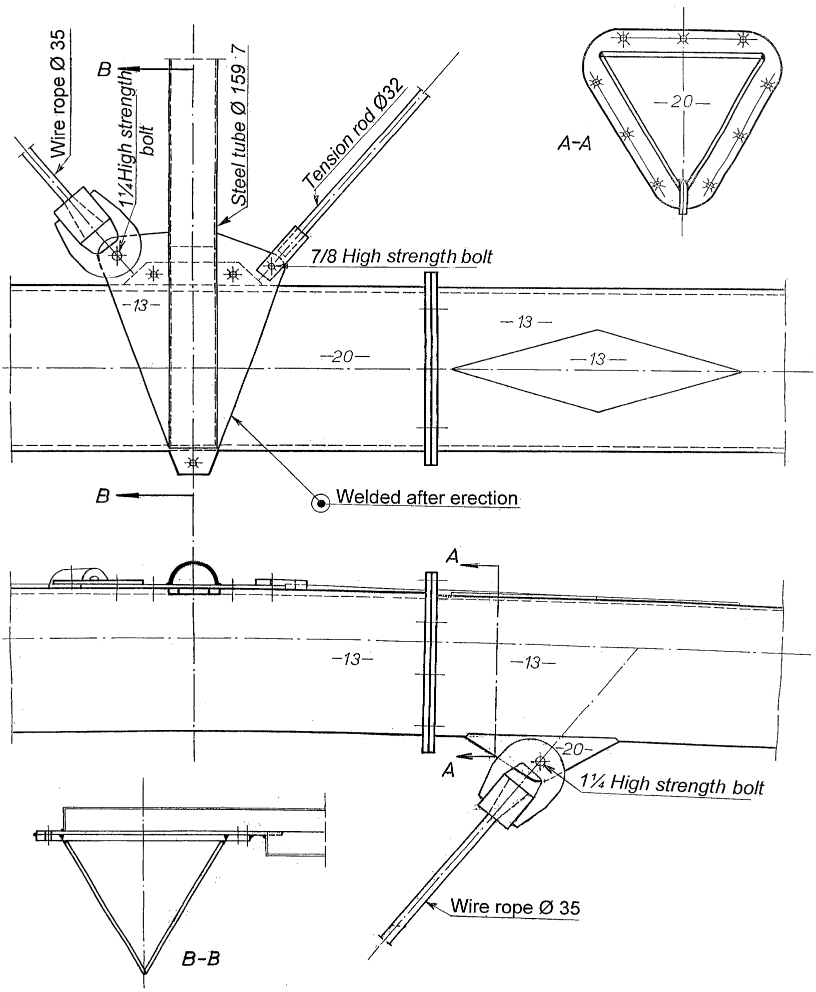

Fig. 6. Structural details around the second tube in the windbracing

4.5 The southern foundation

Under the southern end of the southern side span there is 2 m of clay and silt. The geotechnical consultant made some sketchy calculations of the settlements and was not alarmed. He liked the foundations because they were economical.

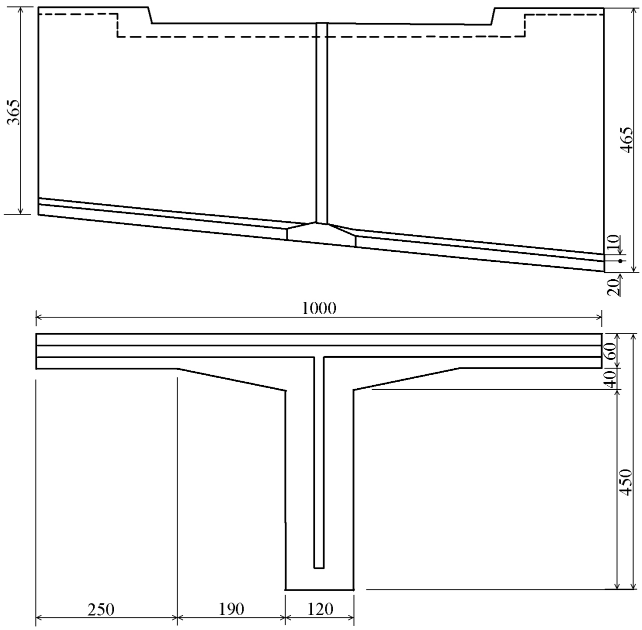

Fig. 7. The southern part of the southern foundation

5. POSSIBLE EFFECTS OF A CLOSING OF THE EXPANSION JOINT

The expansion joint between the main span and the southern side-span soon showed a tendency to close in warm weather. The fact that the concrete tie did not contract due to creep and shrinkage contributed to this. The southern tip of the southern foundation stabilises the southern side span. In hindsight the author wishes that he had made the southern tip one or two metres longer. This would have slowed down or stopped the closing of the expansion joint.

Six years after the bridge was built, a column of the type shown in fig. 8 was put in. Tveit (72). It did not work properly and was removed.

The Euler column in fig. 8 might be installed in the Steinkjer network arch. It works like a spring. It can be made of steel with a yield stress of 700 N/mm. It exerts a constant force of 230 kN. With a deflection of 0.39 m it utilizes 70 % of the yield stress and shortens the column by 64 mm. The low stress in the steel has been chosen with the hope of avoiding too much creep in the column. The northern tip of the Euler column is welded to the column during or after installation

The Euler column in fig. 8 can only be installed centrally in the bridge. At low temperatures the expansion joint might open so much that the column falls down onto the slanting plates below each end of the Euler column.

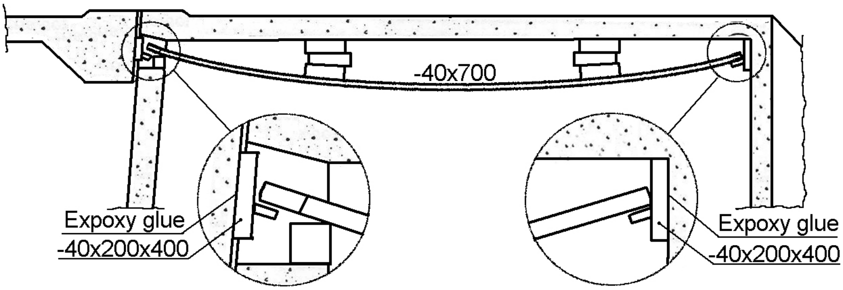

Fig. 8. Installing an Euler column at the southern end of the bridge at Steinkjer

The network arch at Steinkjer is 94 m long. It is usual to assume that in concrete 1°C increase of temperature gives 1 mm increase of length per 100 m. Since there is much cement in the concrete the increase in the length of the concrete might be more. Franz (1964) p. 53.

Last summer asphalt was laid down over the expansion joint. At what temperature of the air is not known. In sunshine the temperature under the black asphalt lane would have been much higher. In February 5th of this year the opening in the asphalt was 1 cm by the upstream arch and 3 cm by the downstream arch. The air temperature was about -5°C.

If we assume that the temperature was 25°C when the asphalt was laid, and there was no movement of the foundations after the joint opened, then the upstream expansion joint would have opened at around +5°C, and the downstream opening would have opened the night after the asphalt was laid.

Let us further assume that the abutment does not move, and the modulus of elasticity for the concrete is 25000 N/mm^2. The area of the tie is 2.15 m^2. The increase in temperature from +5°C to +25°C corresponds to 5.4 MN compression in one half of the area of the concrete tie. This force represents no danger to the capacity of the tie.

The arch is strengthened by the tension in the tie. See Tveit (2007) p. 46 to 49a. Fig. 9 indicates how the arch will buckle in the plane of the arch. Calculation by computer gives a slightly longer distance between the points of inflection. Fig. 92 in Tveit (2007) indicates the same type of buckling. For buckling like in Fig. 9 the buckling load in the arch is 39.8 MN. If the tension in the tie is reduced by 5.4 MN, then the buckling load in the main span is reduced, but that hardly influences the buckling load of the main span.

The measurements show that the biggest force due to temperature and movement comes in the upstream side of the southern side-span. To achieve a constant force in the upstream part of the expansion joint, a plastic bag filled with fluid can be put in between the main span and the southern side-span. This must be done on a cold winter day.

The fluid should have a freezing point below -35°C. If it freezes at a lower temperature, it might not matter much. The bag must be made of very strong materials and might have an area of 3x0.3 m^2. To keep the tension in the walls of the bag down the thickness of the bag, (opening in the expansion joint), should be limited to 30 mm. Then a pressure in the bag of 1 Mpa gives a 15 N/mm tension in the wall of the bag.

The bag could have a valve that opens when the pressure in the bag exceeds 1 MPa. A movement towards the bag would give a constant pressure of 900 kN in the expansion joint. The bag should have a second valve so that it could be refilled each winter.

If the expansion joint is closed at low winter temperatures, the effect of the compression in the concrete tie on hot summer days should be examined very closely.

The expansion joint could be widened by removing a little of the clay under the southern bit of the southern side span. At the same time a small opening must be cut in the asphalt on the road just south of the southern side span and some sand must be removed under the cut. This would be a complicated and potentially dangerous operation. It should not be done without consulting advanced geotechnical expertise.

The author regrets that this chapter on the possible effects of a closing of the expansion joint has a lower level of precision than the rest of this contribution. Consequently the results should be regarded with a healthy suspicion.

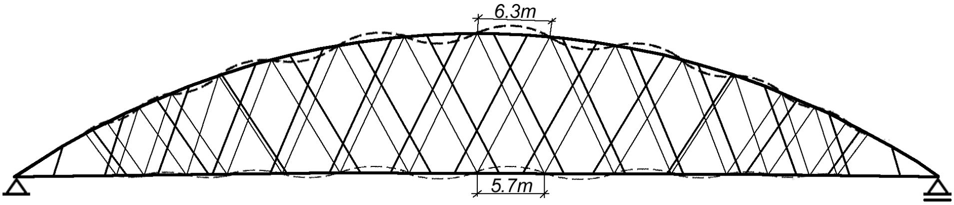

Fig. 9. Indication of buckling in the Steinkjer network arch

6. CONCLUSIONS

A network arch with a partially prestressed tie saves ⅔ of the steel compared to most bridges. In network arches with over 15 m between the arches there will normally be steel beams in the tie. Then the savings as a percentage of the steel weight are much smaller, but the savings in tonnes will be considerable.

The network arch at Steinkjer, Norway, was built in 1963 because it was less costly than competing alternatives. If the arches had been universal columns the bridge would have cost even less, because it would have been much simpler to produce.

The network arch at Steinkjer was built on a scaffold on piles in the river bed. Sometimes a steel skeleton with a temporary chord can be lifted in place before the tie is cast. Big floating cranes can lift finished spans over 200 m in place.

The expansion joint in the network arch at Steinkjer has a tendency to close on hot summer days. If the closing takes place only for temperatures over 10°C it represents no danger. The closing of the expansion joint can be counteracted by a centrally placed steel column that takes an Euler load for movement between 0 and 67 mm in the expansion joint. The constant Euler load as little influence on the load carrying capacity of the main span.

Since the upstream part of the expansion joint has the greater tendency to close, a bag filled with a fluid could be put into the upstream part of the expansion joint. A valve could keep the pressure in the bag at a tolerable level. The bag would have to be refilled every winter.

The network arch at Steinkjer is in good shape after over 40 years. Given good maintenance it is likely to last at least another 40 years.

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