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World longest span with ACSR Conductor – Design challenges

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SUMMARY

This paper describes a project for development of a new fjord crossing conductor with a higher ampacity and breaking load compared to currently used conductor, as well as development of associated conductor fittings for two crossing 4600 m and 4900 m long. The focus of the paper is the description of the design process and challenges met, and the paper focuses on the conductor, clearance, and vibration damping issues. Some aspects on the tower design are mentioned as well.

On long spans, due to bundle stability issues, a simplex configuration is used. The simplex conductor needs to match the current carrying capacity of two or more conductors used on the rest of the line, in this case a duplex ACSR/TW Athabaska conductor is used. Both the required breaking load and ampacity are high, which results in a large and heavy conductor.

Statnett does not allow for mid-span joints on long crossings, which means that the phase conductors need to be in one length. The conductor maximum operating temperatures and breaking loads are well above our usual values. As a result, not all the limiting values for material properties or test methods are defined in international standards. Test methods, acceptance criteria and laboratories needed to be agreed upon with manufacturers.

Stringing operations need to be planned and the required equipment modified or ordered.

The start of the design process was before 2016 with the preparations for the LIDAR wind speed measurements. The development and testing of conductors and dead-end clamps are expected to be finished by the end of Q1 2022 at the latest. The stringing of the first crossing is planned for 2024, and the second one for 2025. The entire design process, including commercial negotiations, technical discussions, qualification, and type testing of new products, took several years in total.

KEYWORDS

Long crossings - Design - Damping - Conductor - Development - Ampacity - Type testing

1 Background

Due to specific topography and a lot of fjords, the transmission line network in Norway has many long spans. In the Statnett operated network, there is between 40 and 50 spans longer than 1500 meters and 13 spans that are longer than 3000 meters. One of the ongoing projects is the rebuilding of the Aurland-Sogndal line. The project includes two very long crossings of the Sognefjorden. First is the crossing of 420 kV line Aurland-Sogndal, the second is the crossing of 420 kV line Hove-Sogndal.

The first mentioned Aurland-Sogndal line is being upgraded from 300 kV to 420 kV due to an increase in required transmission capacity. In practice a new 49 km long 420 kV Aurland-Sogndal II line is constructed in parallel to the existing 300 kV Aurland-Sogndal I line, the existing line will be demolished after the completion of the new line. The new line has two fjord crossings, the mentioned 4900 m long crossing of Sognefjorden, marked with 1 on Figure 1, and the shorter 2500 m crossing over Sogndalsfjorden, marked with 3 on Figure 1. As a part of the project, it is considered to renew a part of the existing 300 kV Hove-Sogndal line from Sogndal to across the Sognefjorden. That part of the Hove-Sogndal line includes the 2500 m crossing over Sogndalsfjorden, and a 4600 m long Sognefjorden crossing, marked with 2 on Figure 1.

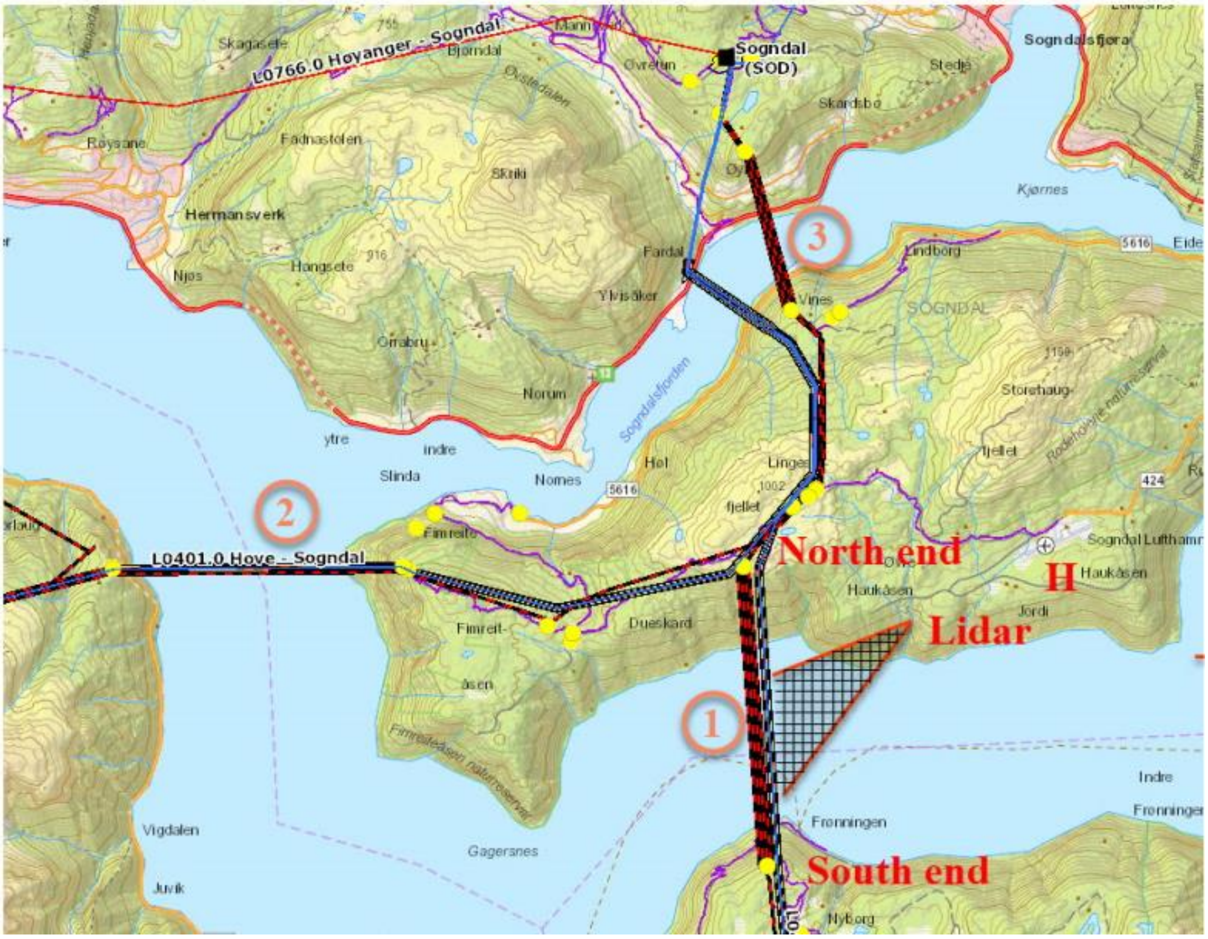


Figure 1 - Fjord crossings in the Aurland-Sogndal project

Such long spans have several challenges: very high values for Everyday Stress (EDS), high levels of induced vibrations, and availability of a conductor that has sufficient ampacity and has sufficient length. Sognefjorden is the largest and deepest fjord in Norway with a length of

205 km and maximum depth of 1308 m. Due to the steep terrain on fjord crossing sites, the required tower height is similar to a normal transmission line tension tower. Even though the challenges are present, because of the length and depth of the fjord, an overhead line crossing is the economically most viable solution.

The Norwegian and Scandinavian electricity market is divided into different electricity price zones. The two lines mentioned, connect two different price zones across the Sognefjorden, therefore the increased capacity will lead to lower price differences.

2 Exploring the possibility of utilising the existing AACSR Teist conductor

On long spans, because of conductor bundle stability issues, a simplex configuration is used. This can create a challenge or a bottle neck in a higher voltage transmission line because the simplex conductor should ideally have the same current carrying capacity of a duplex or triplex configuration used on both sides of the long crossing. If that is not the case, a bottle neck is created in the line. In the case of the two above mentioned crossings it is planned to have a 988-A1/69-EHST (ACSR/TW Athabaska) conductors in a duplex configuration on both sides of the crossing. The mentioned conductor has an ampacity of 1844 A at 20 °C ambient temperature and 90/100 °C conductor temperature, which would mean that the chosen conductor, if it was to match the duplex 988-A1/69-EHST, would need to have an ampacity of 3688 A. The Aluminium Alloy Conductor Steel Reinforced (AACSR) Teist conductors, which is used on the majority of 300 kV and 420 kV fjord crossings in Norway, has under same conditions an ampacity of 2816 A.

Table 1 - Conductor ampacities

Conductor	Diameter	Ampacity at 80/90 °C
988-A1/69-EHST (ACSR/TW Athabaska)	Ø38,3 mm	1844 A
1683-AL3/211-ST5E (AACSR Teist)	Ø56,7	2816 A
Requirement for new fjord crossing conductor types	None	≥ 3688 A

2.1 Minimum wind speeds and ampacity calculations

One of the first topics that was investigated was the frequency of winds with low speeds on the location where the Aurland-Sogndal line crossed Sognefjorden, marked with 1 on Figure 1. This work was presented in a CIGRE paper published in 2018 [1]. The measurements were performed in the period from summer 2016 to the end of 2017. To perform the wind speed analysis, observation from a scanning LIDAR and a meteorological mast, as well high-resolution atmospheric simulations were used. The motivation for the measurements was to find if it was possible to use wind speeds higher that 0,6 m/s [2] for conductor thermal rating calculations. Analysis and measurements showed that 15-minute winds weaker than 0,5 m/s occur for 2% to 10% of the time at certain locations along the span, and on the order of 5% when considering simultaneously winds over the whole span. Winds weaker than 1 m/s occur in the order of 10% of the time for the whole span [1].

Therefore, it was concluded that wind speeds higher that 0,6 m/s cannot be used for conductor thermal rating calculations.

2.2 Mechanical utilization of AACSR Teist

Modelling showed that the shorter of the two long crossings, the 4600 m crossing marked with 2 in Figure 1, was the span with the highest conductor tension. This is due to the lower altitude of the end-towers, so the conductor needs to be tensioned more to achieve the minimum sailing height of 80 meters.

When it comes to maximum conductor utilization, recommendations given by IEC in [3] and [4] were followed, and conductors are utilized to a maximum of 80% of the rated tensile strength. Preliminary calculations showed that the AACSR Teist conductor would have been utilized to 89% at maximum ice load conditions, and that was unacceptably high.

3 Development of new conductors

Due to both ampacity and mechanical strength limitations, it was necessary to develop a new conductor type. Internal rules do not allow for long crossing to be designed with mid-span joints. As a result, the conductor needs to be in one length. With extra length needed for the stringing this gives drum lengths of 5,4 km. This is outside the normal lengths and weights of most conductor manufacturers and it creates a challenge with respect to drum size and weight.

3.1 Conductor development parameters

To secure the supply of an adequate conductor, a tender for development of the conductor and associated fittings was published in mid-2019. Besides for the Aurland-Sogndal project the developed conductors can be used on other projects where the AACSR Teist would be a bottle neck.

Conductor development parameters are given in the tables below. Ampacity calculations were performed according to CIGRE technical brochures 207 [5] and 601 [6]. Apart from the data in the tables tower coordinates were also provided.

Table 2 - Input parameters for ampacity calculations

Parameter	Value
Wind speed	0.6 m/s
Wind direction	90° to the cond.
Coefficient of emissivity	0.8
Coefficient of absorption	0.9
Latitude	65° N
Conductor orientation	East – West
Time of day	12:00 (noon)
Altitude	0 m
Atmospheric conditions	Clear, no pollution

Table 3 - Dates for temperature calculations

Temp.	Date
-30°	March 1st
-20°	March 1st
-10°	April 1st
0°	May 1st
10°	June 21st
20°	June 21st
30°	June 21st

Table 4 - Conductor requirements

Minimum production length without joints	5200 m
Minimum rated tensile strength (RTS)	Conductor is not to be utilised more than 80% RTS for the maximum utilisation load case
Minimum ampacity @ 20° C ambient temperature	3688 A

Table 5 - Other input parameters Sognefjorden

Parameter	Value	Unit
Minimum distance to sea at maximum temperature	80	m
Maximum ice load	3	kg/m
Maximum wind load perpendicular to the conductor	40	m/s
Phase distance	50	m

3.2 Tests required for conductors and fittings

Two potential suppliers were chosen as partners and they proceeded with conductor development. Both conductors are Thermal Resistant Aluminium Conductors Steel Reinforced (ZTACSR), use a Giga high strength steel (GHST) for the core, and AT3 thermal aluminium wires.

On all wire's, tests listed in NEK EN 50182 [7] were performed with following deviations:

- For steel wires tests as described in NEK EN 50189 [8], with the following discrepancies:
    - Limiting values for mechanical properties according to a previously agreed manufacturer specification.
    - Zinc uniformity test (dipping test) was performed with a 45 second immersion time instead of one minute, as specified for Zinc-Alu alloy coatings in ISO 7989-2 [9].
- For AT3 aluminium alloy wires tests as described in NEK IEC 62004.

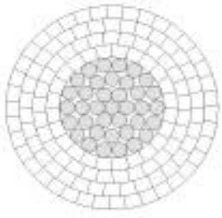
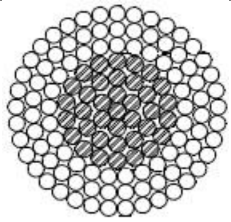
For the whole conductor, fittings, and conductor with installed fittings, type tests were as defined in NEK EN 50182 [7] and NEK IEC 61284 [10], with some additional tests and/or modifications as described below:

- Creep test was performed only 40% of the conductor rated tensile strength, as this is close to the everyday stress (EDS).
- Heat-cycle test was performed with 100 cycles and cycling from 40 °C below the conductor maximum operating temperature to 30 °C above the conductor maximum operating temperature. Since both conductors have a maximum operating temperature of 210 °C this was then from 170 °C to 240 °C. This was done to reduce the cooling time and the overall test time since natural cooling of a big conductor from 240 °C to a temperature 5 °C ambient temperature, as specified in NEK IEC 61284 [10], would take a long time.
- To ensure that the dead-end clamps hold the conductor at all temperatures the following was done:
    - For one of the conductors the heat-cycle test was performed with the conductors and dead-ends tensioned at everyday stress, which is close to 400 kN.
    - For the other conductor it was not possible to perform the heat-cycle test at EDS. Then an additional test was performed where the conductor with dead end clamps was held at the maximum operating temperature of 210 °C for 400 hours, the assembly was taken to breakage afterwards.

3.3 Developed conductors

Two different conductors and their dead-end clamps were developed, and type tested. In addition, repair fittings: a repair sleeve for one conductor and armour rods for another, were also developed and type tested. The conductors developed and type tested by the manufacturers, together with some of their properties, are shown in Table 6.

Table 6 - Some properties of developed conductors

Property	Conductor 1	Conductor 2
Overall diameter	Ø 50,30 mm	Ø 52,16 mm
Mass per unit length	6928 kg/km	6757 kg/m
Ampacity at maximum continuous operating temperature of 210 °C	4122 A	3705 A
Rated tensile strength	874,9 kN	1030,88 kN
Construction		

4 Vibration damping

Historically bretelle loop dampers (see Figure 2 and Figure 3) are the most used damper type in Norway. This is because Bretelle loop damper tolerate dynamic loads caused by ice sheading, which can be a problem in areas with heavy icing.

There is a practice to damp long span with bretelle loop type dampers at span ends, but experience has shown that it is difficult to damp long spans with just end-damping, so groups of Stockbridge type dampers have been used for additional in-span damping in the last decades.

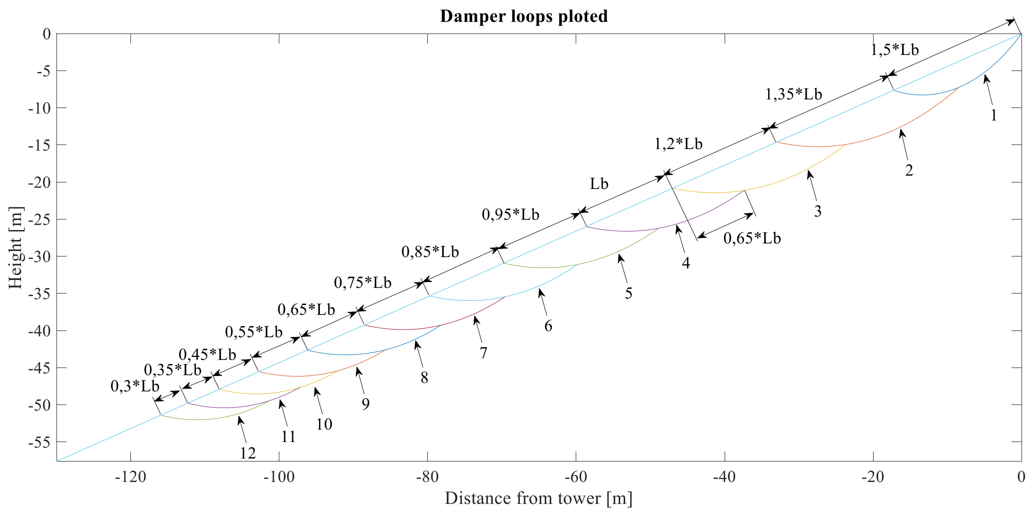


Figure 1 - Damper loop geometry

Figure 2 - Former Storfjorden crossing with an older tower type and a damper loop arrangement

On long spans the damper loop arrangements can exceed 100 meters in length. Damper loop geometry that is planned to be used is shown in Figure 2. The ratios of the damper loop lengths are based on an empirical rule. The loop base length is calculated by expression from [3]:

$$L_b = D\sqrt{a \cdot g} \qquad (1)$$

Where D is the conductor diameter in meters, a is the catenary constant of the span in meters, and g is the acceleration of gravity in meters per second squared.

The number of Stockbridge type dampers placed along the conductor has an impact on calculation of towers, and clearance between conductor and sea (sailing height). The span is dimensioned to allow for larger number of Stockbridge dampers than is deemed necessary, this is to ensure that in a later stage extra damping can be installed if necessary.

5 Tower design

Typical fjord crossing towers in Norway are relatively low due to the steep terrain along the fjords. A typical fjord crossing tower used today is shown on Figure 4.

Figure 3 - Typical fjord crossing tower design - Langfjorden crossing

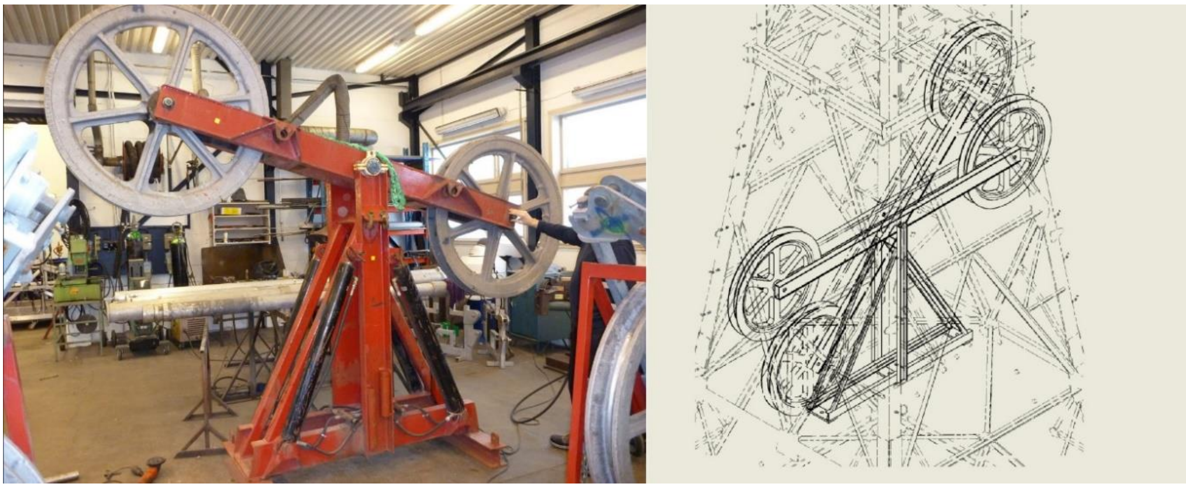


Figure 5 - Hydraulically actuated blocks used during stringing through the tower

Final tower calculations had to be done after the conductor mechanical properties were determined by testing. A hydraulically actuated tandem block, shown on Figure 5, is during stringing placed in the tower. When the dead-end clamp is passing the blocks, it is operated up and down to prevent contact of the dead-end clamp with the blocks and consequent dead-end bending or damage. Because of high stringing forces and fittings longer than the ones used so far, a new larger and stronger hydraulically operated tandem block will have to be ordered. Consequently, the tower geometry needed to be modified. A new strength class of fjord crossing towers was needed.

6 Future work and challenges ahead

6.1 Vibration damping and measurement

Parallel to the design of the crossing, an R&D project to develop a vibration measurement and monitoring system is started in cooperation with an external partner. The goal is to have a system that will be able to measure synchronously both triaxial acceleration and conductor bending amplitude on different locations along the span. Such a vibration measurement system is crucial to correct the damping arrangement if that proves to be necessary.

6.2 Conductor stringing

This is a new type of conductor for our contractor, they have never strung AT3 conductors which have a lower hardness of material in outer layers. It is possible that some procedures might need to be corrected to avoid conductor damages. A trial stringing or installation is considered. This might be done at a shorter crossing or at a training centre. It is expected that, at least when first phases are strung across the longer crossings, conductor manufacturers will be requested to be present.

6.3 Dead-end clamp installation

Fittings are newly developed, and they have never been installed by the contractor. For one conductor type the dead-end clamps are of a hydraulic pressed type, for the other conductor they are of the implosive type, meaning that the end fitting is compressed with the use of explosives. In any case the presence of manufacturer representatives will most likely be requested. The possibility to do on-site non-destructive testing after installation is also under consideration. This is just to confirm with X-ray examination that everything is installed properly, and that the steel core is in the appropriate position.

7 Conclusion

There is a limited number of conductor manufacturers in the world that can produce conductors in lengths that were required for this project. Development process for a new fjord crossing conductor and fittings requires a relatively long time for design, sample production, type testing, and qualification. There was a lot of other aspects that needed to be covered as well in the time planning, like a new tower design, purchase and design of some new stringing equipment, and development of other fittings. Such a development includes multiple parties in different countries, like conductor and fittings manufacturers, laboratories, stringing machine manufacturers, and TSO. The process will require several years.

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