Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 79 (1998)

Artikel: Great Belt East Bridge: aerial spinning of the main cables

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DOI: https://doi.org/10.5169/seals-59912

Great Belt East Bridge: Aerial Spinning of the Main Cables

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Summary

The East Bridge forms a major part of the Great Belt link which connects Denmark's two largest islands, Sjælland (Zealand) and Fyn (Funen). The total length of the link is 17.5 km and it is separated in the middle of the Belt by a small island, Sprogø. The East Bridge comprises a suspension bridge and two approach bridges with a length of 2592 m and 1567 m, respectively. The total length of the suspension bridge is 2694 m with a main span of 1624 m, the second largest span in the world. This paper represents the designer's point of views concerning activities related to the erection of the main cables and experiences gained from this work, especially as regards unbalanced spinning and down-time due to adverse weather conditions.

1. Method Statement for Cable Spinning

The spinning of the main cables is normally on the critical path of the working schedule when constructing suspension bridges. The start of many other activities depends on the completion of the spinning works (compacting of cables, erection of clamps, erection of hangers followed by erection of the main girder). Two options for constructing the main cables were given in the tender documents: Traditional aerial spinning or prefabricated parallel wire strands (PPWS). Due to higher construction costs for the PPWS option a traditional aerial spinning method was chosen, but modified by adopting "The Low Tension Control" principle. This modification gave several advantages being less time consuming and less sensible for adverse wind conditions compared to the traditional free hanging wire method. The cables were spun alternating the north and south cable. At the same time 2 strands were spun on the same cable. Two independent tramway systems were erected, one on each cable and each with 2 spinning wheels able to transfer 4 loops of wires at each trip. All installations were located on one anchorblock only. The use of "The Low

Tension Control" principle (80% of the free hanging tension) required installation of sag control cables to correct the lowering of the catwalk caused by the partial (20%) weight of the strand.

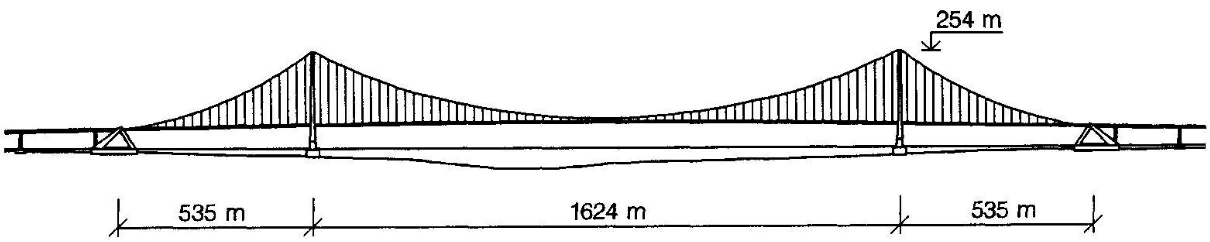

Fig. 1: Elevation of the suspension bridge

2. Pre-spinning Activities.

In order to have balanced horizontal forces on the top of the pylons during spinning of the cables the saddles at the pylons shall be placed offset to their final position. The design value for this offset was 1.24 m at each pylon top. Two possibilities for performing the offset were stated in the tender document: One possibility was by translation of the main saddles on the top of the pylon. Due to the configuration of the top of the concrete pylons, this solution would have required construction of solid platforms to extend the bearing area for the saddles. The other possibility was to directly pull back the top of the pylons towards the anchor blocks and this option was selected by the contractor. This solution was possible due to the slenderness of the pylons, but limitation of the bending stress and risk of cracks in the concrete give some limits in the general use of this the method.

The horizontal force needed to pull back the top of the pylons 1.24 m was calculated to approx. 8,000 KN, based on an E modulus of the concrete of 28,000 MPa corresponding to the figure given in Danish standard. This value includes the effect of creep. Experience on site showed that the short term E modulus of the concrete corresponded to 35,000 MPa.

The pull back cables were fixed at the top of the pylon and the hydraulic tensioning devices were placed on the concrete deck at level +10 m on the anchor block. The first tensioning was performed in April 1996, but due to damages on the pull back cables they were slacked again and retensioned late may 1996, approx. 1.5 month before start of spinning. When the calculated forces were reached, the actual horizontal displacement of the top of the pylons was only approx. 1.0 m compared to the design value of 1.24 m. Increasing of the displacement could be expected due to creep in the concrete, but due to the short time between pull back and spinning, the effect of creep was not fully present, when spinning started. As the pull back cables were damaged by hammering caused by vibrations of the cables, an additional tensioning of the cables, in order to get the design value, was not suitable. This unforeseen situation implied modifications of the initial geometry of the strands taking into consideration the actual displacements of the pylons at start of spinning work. The consequences of these modifications are further described in Section 4.

As soon as the special support structures on the top of the pylons and at the splay saddles were installed, the erection of the catwalks was started. Prefabricated 40 m long rolls of mesh comprising wooden steps and side mesh, were transported to the top of the pylons and rolled down along the floor strands with assistance of the hauling rope. The floor strands and the mesh panels for both catwalks were erected in 33 working days. The transport of the wheel batteries of the tramway system and of the posts for the lighting system was performed by helicopter. This method was very time saving considering that the offshore work sites at anchor blocks and pylons were only accessible by boat at this time of the construction.

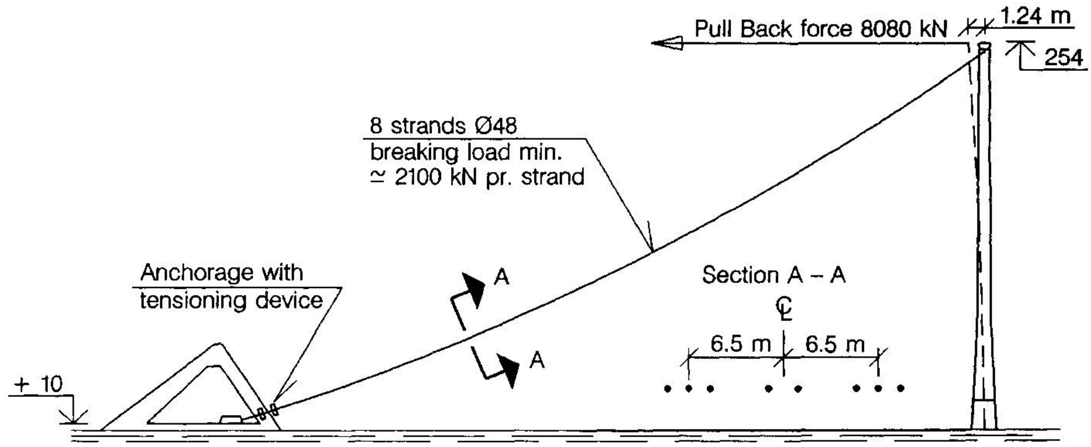

Fig. 2: The pull back system

3. Spinning Works

Each main cable consists of 37 strand of 504 no. of wires giving a total of 18648 no. of wires per cable, corresponding to a weight of 20,000 tonnes for the 2 cables. The spinning works implied the following successive operations: Supply of coils at the reeling unit, reeling and unreeling, spinning of the wires, strand compacting, serving and strand sag adjustment.

1. Supply of coils. All the reeling/unreeling units were located offshore on the eastern anchor block. The coils were transported by lorries on the eastern approach spans in level +57 m and lowered by lift to the anchor block at level +10 m. The average weight of the coils was 800 kg, corresponding to about 4,500 m wire or 1.5 times the length from anchor block to anchor block. The coils were supplied by two different suppliers.

2. Reeling and unreeling of coils. The coils were reeled on drums, each with a capacity of 10 coils. Each reeling/unreeling unit comprises 2 drums. When the wires were reeled on one of the drums from the coils with a tension of 90 kg, the wire on the second drum was unreeled to the spinning wheel. This operation was performed in parallel on all 8 units.

3. Aerial spinning. After a learning period for the personnel and testing of the equipment in full scale on the first strand which was spun with 2 loops only on the spinning wheel, the proper spinning work was performed in 18 set ups. The normal speed of the spinning wheel was 4 m/s with 4 loops of wires on the wheel. The average duration of a complete turn/return trip was 32 min. including time for anchoring the wires around the strand shoes. The global efficiency of the spinning works was 75%, and the 25% down-time was divided into 10 % due to weather conditions and 15 % due to unforeseen problems with the equipment or with handling of the wires. The spinning works began the 6th of July 1996 and were completed the19th of November 1996 giving a total duration of 137 days.

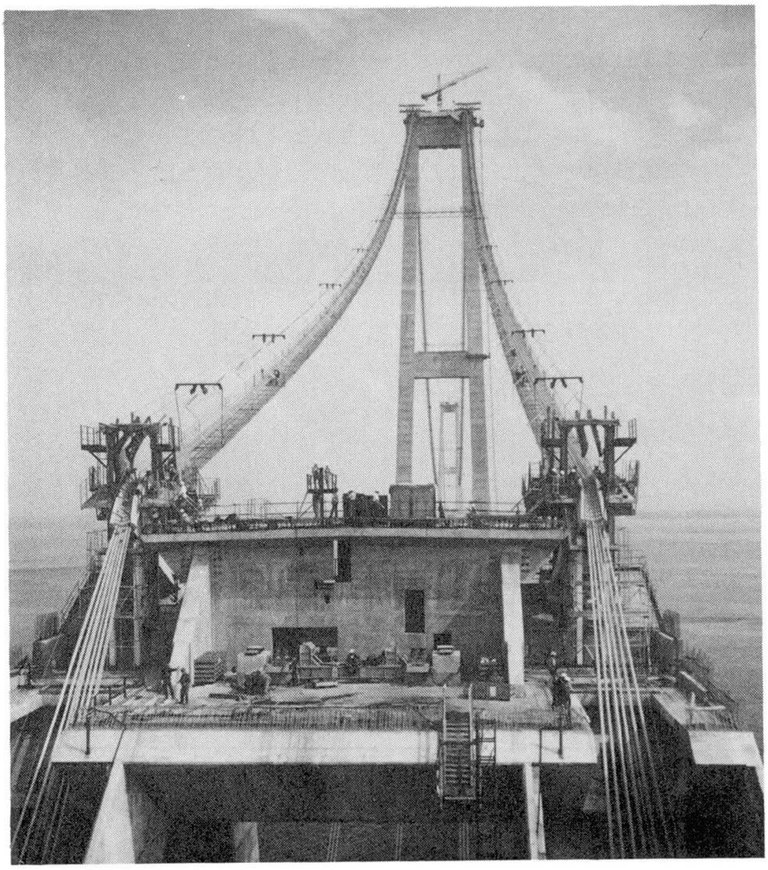

Fig. 3: Catwalk, tramway system and accessories

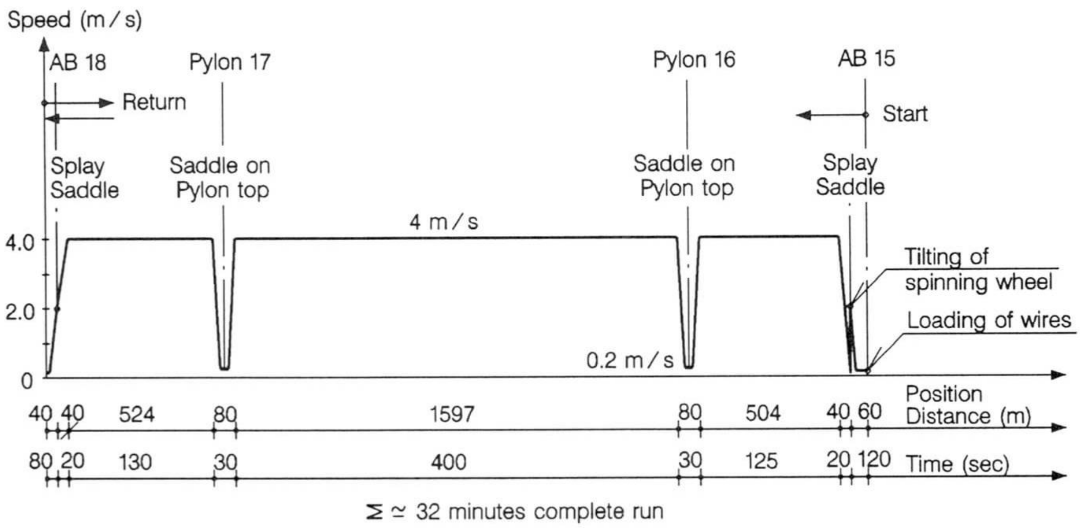

Fig. 4: Typical timechart for one trip of the spinning wheel

4. Sag adjustment. By using " The Low Tension Control" method the single wires are not adjusted during spinning. Adjustments are made on completed strands only. Immediately after the end of the spinning of a strand, the strands are compacted in circular shape and then served. The strands are pulled by jacks at the pylons top and at the anchorages until the strands are free of the cableformers and approx.100 mm above the strands already adjusted. At night time under constant temperature conditions, the strands are lowered into the design

position by slacking the jacks on the pylon top and at anchorages, taking in consideration the calculated cable length and sag, including the actual position of the pylons and the temperature of the strands.

4. Spinning with Reduced Pull Back

As mentioned earlier the full displacement of the pylons was not reached at the time of beginning of spinning. The consequence was an initial unbalance of cable forces at the top of the pylon, and the unbalanced cable forces therefore increased the displacement of the pylons top. A critical point was to be sure that this unbalanced state of forces did not introduce risks for sliding of the first strands in the saddles at pylons, and to demonstrate that the calculated displacement could be reached without additional tensioning of the pull back cables. A set of calculations was made to check this situation using the actual observed conditions as assumptions. The actual displacement of the top of the pylons was recorded periodically during the spinning. Fig. 5 shows that the actual displacement was larger than the assumed one, probably due to creep in the concrete and differential settlement in the foundation. These effects were not included in the calculations. The designed displacement corresponding to the balanced situation was actually reached at the end of spinning.

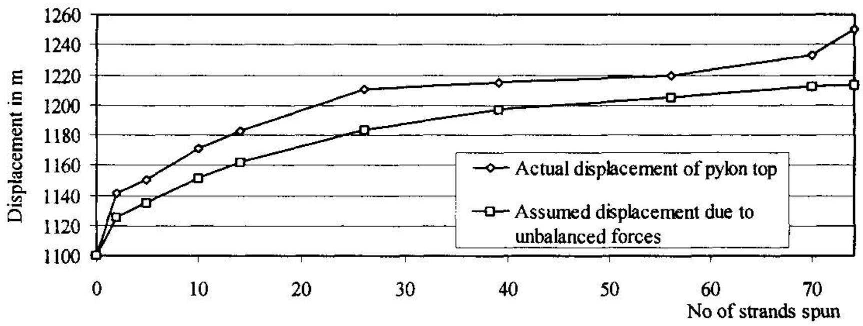

Fig.5: Displacement of pylons during main cable spinning

5. Down-Time due to Adverse Weather Conditions

An assessment of the expected down-time due to adverse weather conditions was carried early in connection with planning of the cable erection. Average down-time was estimated as time where one of the standard criteria in Table 1 from the special conditions was exceeded.

	Wind Speed m/s at +70 m							Precipitation per day	Temperature	Wind and temperature	Wave height	Ice Baltic Ice Code
Criteria	s<11	11<s<12	12<s<13	13<s<14	14<s<15	15<s<16	16<s	Above 10 mm	Below 5 deg C	Above 15 m/s	Above 1.5 m	Above 4
Standard Efficiency	100%	95%	90%	75%	55%	30%	0%	0%	0%	0%	0%	0%

Table 1: Standard criteria for down-time and standard efficiencies

The result is shown in Fig 6. Simulation on basis of 25 years registered weather data was selected instead of statistical modelling, because it was necessary to use several types of non-independent weather criteria with unknown correlations.

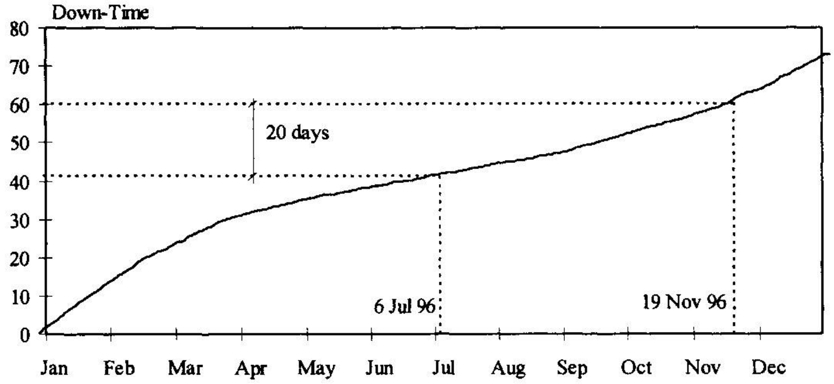

Fig.6: Average accumulated down-time over a year on basis of 25 years weather data

The contractor had foreseen a spinning duration of 147 days, incl. a loss of 16 days due to adverse weather. The spinning was completed after 137 days, incl. a loss of 9 working days due to adverse weather. Completion was 10 days ahead of schedule, 7 of which were won against the weather, in-spite that the weather conditions were worse than average for the 25 years period measured on basis of the standard criteria in Table 1. The contractor has actually recorded 14 calendar days with some weather loss corresponding to a loss of 9 working days. The weather loss was almost entirely due to adverse wind conditions. Other weather conditions did not directly cause delay, but rain can have been an accompanying cause of delay on few days. Temperature and ice conditions are not a problem during this time of the year. The spinning operation was mainly carried out for 21 hours a day and the 3 hours were used for repair and maintenance of equipment.

The estimated down-time was 20 working days, on average, ref. Fig. 6. The standard deviation was 5 days. For the actual spinning period in 1996 the model estimates 27 working days, 19 of which are due to exceeding of the wind criteria, whereas 8 days are due to heavy rains. Reducing the average of 20 days with also 8 days of heavy rain the estimate become 12 working days due to adverse wind conditions.

6. Conclusion

The aerial spinning of the main cables for the Great Belt East Bridge was successfully performed in only137 days in 1996 using " The Low Tension Control" method. When spinning started only a partial offset of the pylon saddles were present. Experience showed that using the unbalanced forces from the strands the full offset value was reached at the end of spinning. This method could be further developed and used in a larger scale in future spinning works for suspension bridges. Adverse wind conditions were the main weather problem. Modelling of down-time was reasonably good, but the model gave a slightly conservative estimate as the spinning contractor was able to work better than the assumed standard efficiencies.