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The 1935 Little Belt Bridge, Denmark: Maintenance Experiments

Expériences de maintenance sur le pont de Little Belt au Danemark

Unterhaltsexperimente an der Kleinen-Belt-Brücke, Dänemark

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SUMMARY

The design and construction phases of the Little Belt Bridge are reviewed. Special attention is paid to the design features enabling easy supervision and maintenance during the lifetime of the bridge. The displacement of the bridge piers due to the conditions of the seabed is described. An analysis of the impact on the superstructure is made. An estimation of the lifespan for the bridge is made based on the actual conditions of the bridge and assumed development in the traffic.

RÉSUMÉ

Le dimensionnement et les phases de construction du pont de Little Belt (1935) sont passés en revue. Une attention spéciale est portée sur les points du dimensionnement permettant une maintenance et une supervision aisée du pont tout au long de sa durée de vie. Le déplacement des piles dû aux conditions du fond marin est décrit. Une analyse de l'impact de la structure est faite, ainsi qu'une estimation de sa durée de vie basée sur les conditions actuelles du pont et le développement prévisible du trafic.

ZUSAMMENFASSUNG

Die Entwurfs- und Bauphasen der Kleinen-Belt-Brücke von 1935 werden betrachtet. Dabei gilt die Aufmerksamkeit solchen Entwurfsmerkmalen, die die Ueberwachung und den Unterhalt der Brücke während ihrer Lebensdauer erleichtern. Einen Problempunkt stellt die Verschiebung der Brückenpfeiler aufgrund der Veränderung des Meeresbodens dar, wobei deren Auswirkung auf den Brückenoberbau analysiert wird. Die Lebensdauer der Brücke wird im Hinblick auf ihren derzeitigen Zustand und die prognostizierte Verkehrsentwicklung abgeschätzt.

THE BRIDGE ACROSS THE LITTLE BELT

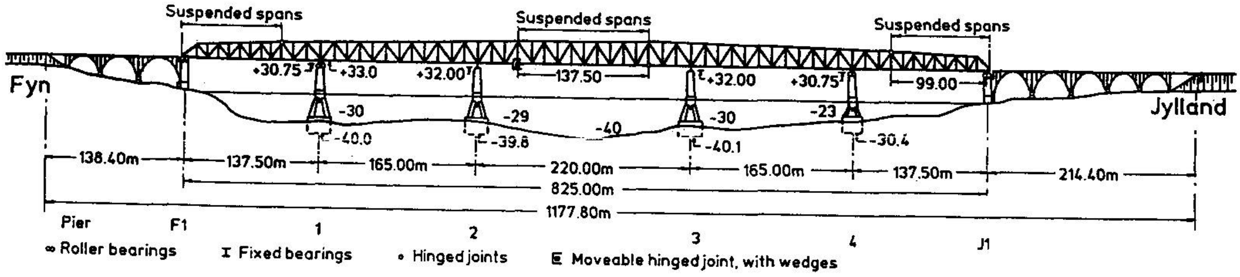

Fig. 1, Elevation

1 INTRODUCTION

The first thoughts, that were given on building a bridge across The Little Belt in Denmark, came up in 1880, when a new ferry connection was inaugurated.

Investigations were initiated to determine the optimal alignment for the railway, taking into account also the soil-conditions in the seabed of The Little Belt. Investigations on the quality of available steel and appropriate methods of construction were also made at this stage.

The seabed of the Little Belt consist of a special clay, that never had been discovered in Denmark before, and therefore was named "Littlebeltclay". It is a rich and dense clay, containing only a small number of stones (diameter 200 - 800 mm). Inspite it has been preloaded during the iceage it is still quite plastic. Several different outlines were made. In the final proposal the bridge was designed with 4 piers on direct founded caisons. To take into account the possibility of an uneven distribution of the settlement of the caisons, the superstructure was designed as a statically determinate structure.

The steel connections are very complex. Some include more than 30 parts. Every detail is worked out perfectly. The rivets were placed in such a short distance, that corrosion cannot part 2 plates.

Experience from shipbuilding was used to a great extent in the outline design and for choosing the methods of construction.

In May 1928 the design and the project for the Little Belt Bridge was put into an international competition with the request, that alternative offers would be of interest too. The evaluation committee, with participants from Germany, Sweden and Denmark, found, that the original tender design offered the best and cheapest solution.

In January 1929 contract was signed with Monberg & Thorsen Copenhagen and Grün & Bilfinger Mannheim in association with the large German steelsuppliers Friedrich Krupp Rheinhausen and Louis Eilers Hannover. The bridge was opened for traffic on the 14 of May 1935.

2 DESIGN AND CONSTRUCTION

The concrete caisons for the 4 piers were built on a slipway the same way as a ship. To be able to use the same slipway for all caisons, they were built upside down. This made it possible to shape the length of the skirt (made of pipes with a diameter of 800 mm) individually to fit the contours of the sea bottom.

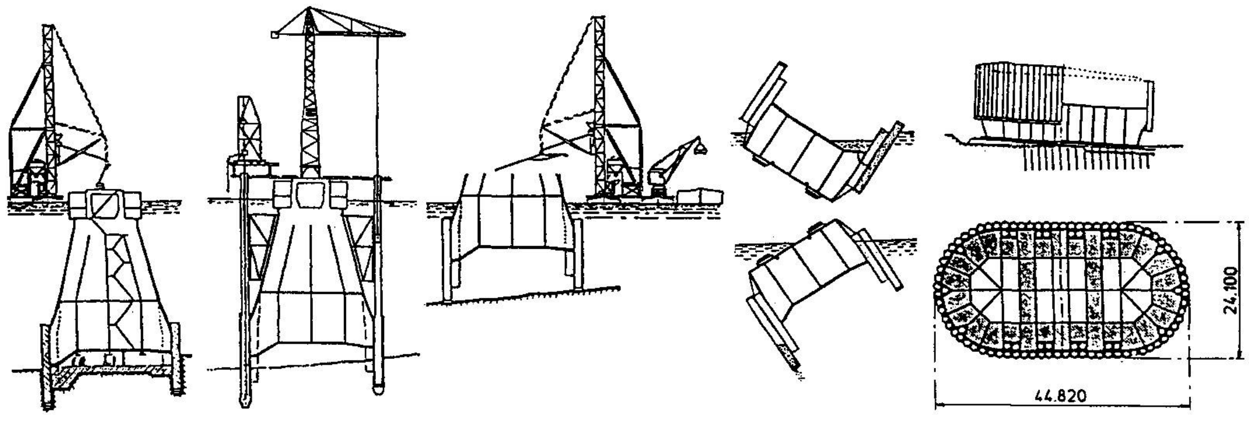

Fig. 2
The caisons were launched into the water (1), turned over by pumping in sand in the pipes and water in the working chamber (2) and increased in height (3) until the piers were tall enough to be placed in the final spot. The caisons were sunk into the seabed (4) by excavating from inside the hollow pipes, by means of a special drilling equipment, to a level beneath the pipes. There, special cutters were extended of the side of the drill, to make the diameter big enough. When holes were drilled in all the pipes around the caison, water was pumped into the outer cells in the pier, to make the caison sink to the wanted level. The Littlebeltclay was so impermeable, that soil could be excavated from inside the working chamber underneath the caison without having to create a pressurized chamber (5).

The riveted steel superstructure was assembled without use of falsework. On one side of each pier an erection bracket was placed and from there, the superstructure was cantilevered out to both sides.

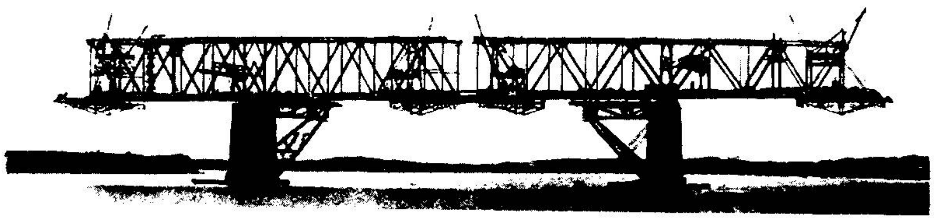

Fig. 3
The Situation from the construction where the cantilevered ends were just reaching each other between pier 3 and 4.

In the first and the last span there are fixed, hinged joints. In the middle span, there are 2 joints. One of the joints is moveable to equalize temperature expansions etc. There are - wedges for adjustments, so that jointconstruction for the railway and the roadway cannot be destroyed. See Fig. 1.
The bearings are placed on a steel plate and fixed horizontally by wedges. Plates are positioned below the superstructure, which enable lifting up the superstructure using hydraulic jacks. In this way it is possible to adjust the superstructure back into the right position if movements in the top of the pier requires it. The designer, Dr Anker Engelund has declared: The Little Belt Bridge can last for 300 years.

3 STRUCTURE STEEL

Steel was developed with strengths up to 540 MPa. New production methods and tests had proved, that it was possible to make a steel of uniform quality.

Composition in the Krupp steel

	C	Si	Mn	P	S	Cu
Krupp	0,21	0,29	1,41	1,19	0,021	0,45
Corten	0,12	0,25-75	0,20-50	0,07-15	0,035	0,25-55
St 52-3	0,20	0,35	1,3	<0,040	<0,040	

The Krupp steel has a composition with a large amount of Cu, as for Corten steel. That may be a reason, why there has been very little corrosion in the steel.

Out of tests from building periods and test results after a fire in 1946, it has been found, that the Krupp steel is comparable with modern St 52-3. In this way calculations can be based on the Danish Standard (recommendation) "DS 412".
It will always be of DSB's interest, if someone has new test results for steel like Krupp steel concerning the durability (brittleness and fatigue characteristics).

4 MAINTENANCE AND INSPECTIONS

4.1 Surveying, temperature, movements

Until 1953 surveying of the piers (vertical and horizontal) were made 4 times a year. Since then only once a year. From uneven compression of the Littlebeltclay the 4 piers up till today have got vertical movements of 125, 270, 425, 365 mm. Horizontal 20 - 180 mm towards North (Jylland), and 10 - 80 mm towards East. The gap in the moveable hinged joints has been adjusted several times by use of the Wedges. First time in 1937. Then in 1942 and 1986. In 1992 alignment of the pier no 2 is initiated.

It is very difficult to find instruments with adequate accuracy for the measurements of the small displacements related to the large distances. The measurements are furthermore influenced by the spatial variation in temperature in the superstructure (delta T = 10 - 15 °C due to heating from the sun), and the difference in the friction in the roller bearings.

Surveying with the use of a theodolite has been found to have the smallest deviation. But it is rather expensive. It takes a long time, and in this way temperature can change and have an influence on the results. GPS cannot be used due to "shadow" of the superstructure. Electronic distance measuring has been found to have so big a deviation, that it is of no use. Therefor we take many simple measurements to all the distances in the joints, and afterwards we compensate for the influence caused by different temperatures. (ruler and electronics connected to a computer is used)
In this way so many results are collected, that satisfactory precision can be achieved.

4.2 Adjustment in superstructure.

The horizontal movements in the superstructure caused by settlement of pier no 2 present some problems. The superstructure between pier 2 and pier 3 is compressed during the summerseason, which reduce the capacity to carry vertical loads. A program has been introduced to bring the top of pier no 2 back to its original position. Hydraulic jacks have been mounted in moveable hinged joints to produce a constant compression force of 3,7 MN in the superstructure between the two piers. At the same time 2 tackles pulls via 4 bars in the top of pier 2 towards the abutment with a force of 1.4 MN. For 3,7 MN the superstructure should be 12 mm shorter due to contraction. The piers is bend 2 x 2 mm = 4 mm. The total opening in the moveable hinged joints should be 12 + 4 = 16 mm. But it is only 9 mm. It shows, that secondary structures as girders and concrete in the roadway, is working together with the superstructures.

As a temporary arrangement the hydraulic system works without problems, and it is a were economical way, considering the high forces.

4.3 Fire

Fig. 4
Microscope picture x1000

In the period 1944 - 1946 several fires took place on the railway track on the Bridge. In 1946 the fire was so heavy, that several secondary girders carrying sleepers and rails had to be replaced. Test-elements were cut out of the girders. Microscope-analysis showed, that the temperature had reached 650 °C. The microstructure had not changed.
Material tests showed the following values: tensile strength 350 MPa ultimate strength 540 MPa, fatigue with a gap of 170 MPa 1,8 E6 cycles, impact test before and after artificial aging with 250 °C in ½ an hour showed values of 150 J and 140 J. These results shows, that the steel has the same characteristics as, when it was new.
Aging tests showed furthermore, that the steel will not become brittle. In 1963 the wooden sleepers were replaced with steel sleepers to decrease the fire-risk.

4.4 Maintenance of paint

It is found, that complete cleaning by sandblasting combined with new painting is the cheapest. With the use of different paint-systems, that have been available during the years (the producers are continually changing chemicals), we have found, that the average lifetime of paintwork is 20 - 30 years.

Details, like correct drainage of salty water form the roadway, is of great importance. Salty water reduces the lifetime of the painting to 5 - 10 years. The drainage is now connected to a new system of tubes letting the water out so far below the superstructure, that heavy winds cannot carry the salty water back to painted steel.

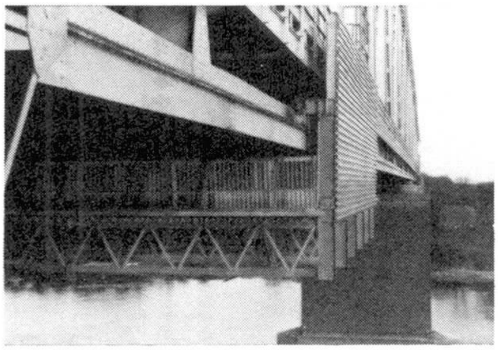

Fig. 5

During the lifetime of the Little Belt Bridge different simple uncovered scaffolds are used.
In 1990 a new big platform was mounted on rails underneath the superstructure. By use of frames and foam rubber it is possible to make a tight room, where the dust from sandblasting can be extracted and collected. By an artificial heating system the temperature can be regulated to a level so the paintwork during a day has been doubled.

The platform was primarily designed to collect the dust from sandblasting and the lead in the old paint, and in this way protect the environment from pollution. 90 % of the sandblasting sand is collected. By the use of the new platform we not only protect environment, but the paint work can be done in a more rational way, with lower costs and better quality. The price for a complete cleaning and new paintwork is 100 USD/m².

4.5 Stonecover

From ±3 m according to sea-level the piers are covered with a layer of 220 mm granite to protect impact from ice. In Denmark the temperature day - night in general fluctuates between - 5°C and +5°C in the wintertime. This causes solid surfaces like concrete to freeze in a depth of 50 mm. Therefore the cover-layer on the reinforcement is often demolished. Since the stonecover is more than 50 mm thick, the frost cannot reach the concrete, and the granite can stand millions of frost-thaw cycles.

4.6 Description of maintenance manual

In 1994 a new instruction manual for management, inspection maintenance work was made. All activities are listed, and every function of constructions, lights, lanterns, pumps, fog-detector, platforms, inspection waggon etc are made. By the help of a checklist we make sure, that all activities are carried out. Remarks are examined and repair- and maintenance work are performed.
Quality-management is at the same time described in the checklists. Information on executed works are registered so future generations can learn from past experiences. It is important, that the manual is updated every year.

4.7 Calculation of the lifetime of the Little Belt Bridge.

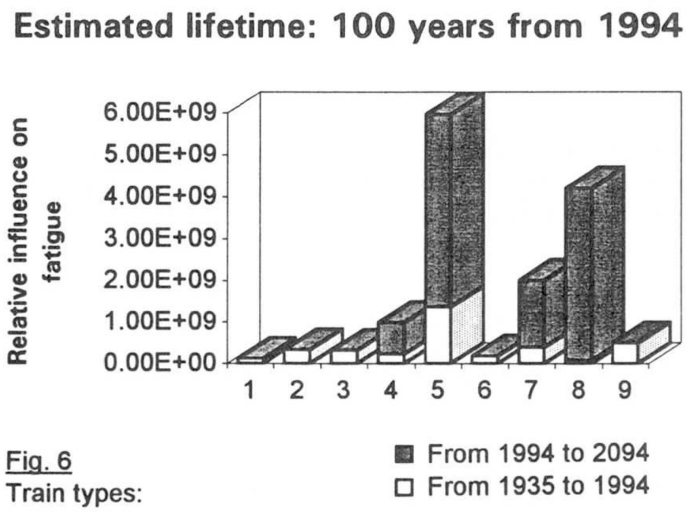

Fig. 6
Train types:
1-3: Steam trains, with 2 and 4 axled wagons
4-5: Diesel powered Freight trains
6-7,9: Light passenger trains
8: Fast passenger trains (IC3)

Heavier traffic loads can be foreseen when the construction of the Great Belt Bridge and Tunnel is completed. Taking into account the increase in number, weight and speed of future trains, new calculations of the lifetime for the Little Belt Bridge have been made.

From annual reports and old train timetables the total number and weights for the trains have been calculated. Preconditions for future heavier, faster or bigger trains are made.

9 standard trains for the past and for the future are set up.

In the Fig. 6 it is showed, how much each standard train already has used and in the future will use in fatigue calculations. (6.00E+09 is the same as 100%).

If the maintenance condition is kept like today, the remaining lifetime for the Little Belt Bridge will be at least 100 years.

5 Conclusive remarks

It has been a very interesting experience to participate in the maintenancework of the Little Belt Bridge, where the design includes so many features which enabling easy inspection and maintenance procedures.
It can be concluded, that it is very important to have a precise record of the history of a steel bridge (type, load and speed of the train and the road traffic, misfortune from cars and ships, fire etc, structures that corrode or are demolished and exchanged). Calculations are the most economical tools for making the decision: When do You have to replace an existing bridge.