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Introduction

The Great Belt Fixed Link (Storebæltforbindelsen) is the fixed link connecting the islands of Zealand and Funen across the strait of Great Belt. The link is composed of three mega structures: a road suspension bridge (known as the East Bridge), a railway between Zealand and Sprogø, and a box girder bridge (known as the West Bridge) between Sprogø and Funen (Railway-Technology, n. d.). The link was purposely designed to replace the primary means of crossing the Great Belt (Transportation Research Board, 1995). Combined purpose and aesthetic perfection, this majestic link exhibits eccentric engineering skills and craftsmanship, a true man-made wonder. Figure 1. The Great Belt East Bridge.

(Source: <http://driveeuropenews.files.wordpress.com/2013/08/the-bridge.jpg>)

The Great Belt East Bridge is one of the longest suspension bridges in the whole world, the longest in Europe (Femern, 2012). It has a total length of 6,790 meters, and the total length of suspension is 1,624 meters (Bridge Conference, 2006). It opened on June of 1998 to transportation, accommodating three lanes on either side. Since then, it proved to be a significant engineering feat of Denmark, increasing the rate of travelers across the Great Belt (Railway-Technology, n. d.).

The construction of the Great Belt East Bridge's was overwhelming with both engineering craftsmanship and aesthetic beauty. The design was done carefully with the consideration of strength and durability. The pylons alone rise to a height of 254 meters, among the highest points in Denmark. The Great Belt East Bridge had an annual average daily traffic of about 29,817 in

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2013. With the strength and durability of the Great Belt East Bridge, it could withstand several serious loads such as snow, ship impacts and gale winds (Femern, 2012).

Overall, the Great Belt East Bridge is the largest and the most important engineering feat Denmark has ever done.

History

The proposal of having a fixed link began being acknowledged since the 1850s. The Great Belt ferries initiated the construction of the railway lines in 1883 which connects the coastal town of Korsør and Nyborg. Then, in 1934, plans for building a bridge were proposed by the Danish State Railways, which were responsible for the ferry service. The Ministry of Public Works (now Ministry of Transport) issued a commission for the investigation of having a fixed link in 1948 (Iacobone, 2013).

Figure 2. The Great Belt East Bridge Location Map.

(Source: <http://www.railway-technology.com/projects/denmark/denmark1.html>)

In 1973, a law was enacted pursuing the development of a fixed link, but, a political issue delayed the approval of the project. The Venstre (Liberal) party demanded the postponement of various public spending, and so, the project was put on hold in 1978. The project proceeded in 1986, and the political agreement was enacted to have the project restarted. Then, in 1987, a construction law was passed, and the project was eventually designed by Dissing+Weitling, in partnership with the engineering firm COWI. Finally, the construction of the fixed link commenced in 1988 (Iacobone, 2013).

However, in 1991, Finland sought an injunction before the International Court

of Justice at Hague concerning the vertical clearance design of the Great Belt East Bridge. A redesign was requested by Finland because the 65 meter vertical clearance is not enough for their oil drilling rigs to pass through the Great Belt. By September of 1992, the vertical clearance 65 meter was kept after solving the problem, but the Denmark was obliged to pay \$15 million to Finland as compensation. The construction proceeded, and five years later; the erection of the Great Belt East Bridge was finally complete (Max Planck Institute for Comparative Public Law and International Law, n. d.).

Design

Figure 3. The main view of the Great Belt East Bridge

(Source: [http://3. bp. blogspot.](http://3.bp.blogspot.com/-7e7AQyKnc70/UdOhKBbQ3zI/AAAAAAAAAFic/sDZpxQ5V8qQ/s1200/20130702Odense-7319fblogo.jpg)

[com/-7e7AQyKnc70/UdOhKBbQ3zI/AAAAAAAAAFic/sDZpxQ5V8qQ/s1200/20130702Odense-7319fblogo. jpg\)](http://3.bp.blogspot.com/-7e7AQyKnc70/UdOhKBbQ3zI/AAAAAAAAAFic/sDZpxQ5V8qQ/s1200/20130702Odense-7319fblogo.jpg)

First, it should be noted that the Great Belt is considered an international shipping route. Thus, many vessels cross this region annually. Simulations were done to signify the optimum design suitable in the region, and it lead to the determination of the minimum length of the main span which is 1. 5 kilometers. Therefore, a realistic solution was to build a suspension bridge meeting the requirements. And after careful selection, a 1624-meter main span with 535-meter side span suspension bridge was selected for having optimum design for a suspension bridge (Weight, 2009).

Superstructure and Girders

Over the whole length of 2, 694 meters between the anchor blocks, a continuous closed box girder was placed (COWI, n. d.). Because of such

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design, expansion joints at tower positions are then avoided. In order to remove issues concerning longitudinal short-term movements, the strategy was to place hydraulic buffers between the anchor blocks and the girder. Moreover, to eliminate the need for bearings at the tower, hangers provide vertical elastic support. The overall design of the girder, hydraulic buffers and superstructure enhances the stability, as well as the stiffness of the bridge, and maintains a lower cost value compared to traditional systems with joints at the pylons. Each box girder was aerodynamically shaped and fully welded. The interior surfaces are being protected by dehumidification of the volume of air inside (Weight, 2009).

Cables

Figure 4. The spinning of the main cable of the Great Belt East Bridge

(Source: <http://www.railway-technology.com/projects/denmark/images/dtr5.jpg>)

Pylons

The pylons were designed to rise to 254 meters, making them one of the highest points in the Denmark. This height was the result of a high sag ratio. Each pylon has legs that are slightly tapered. Also, the pylons have a rectangular, hollow cross-section. The legs of each tower were connected at mid-height and top cross beams. Inside one of the legs is an elevator for maintenance, while the other leg contains stairs. The construction of a monolithic structure is done at the lower part of the pylons. This monolithic structure was heavily reinforced with 1.2 meter thick walls. This thickness was designed to overcome the impact loads of 670 MN from a 250,000 DWT

tanker. Large foundation caissons were built to support the pylons. The positioning of the caissons was through the gravel bed at approximately 20 meter water depth. The towers built are from concrete material (COWI, n. d.).

Anchor Blocks

Foundations

Before the construction of the bridge began, an environmental issue was of concern by the Danish parliament. The construction and the bridge itself should not greatly affect the flow of water through to the Baltic Sea. Hence, an act was passed signifying that the water flow will be left unaffected by the construction of the bridge. Because of this, a “ Zero Solution” was adopted (Weight, 2009).

The land layers beneath the waters in the Great Belt was found to be weak, making it unsuitable for supporting colossal structures such as the pylons and anchor blocks. The layers consist of layered strata of tills followed by Paleocene marl on top of limestone layer. The tills are found to be stiff to hard clays with some boulders from mineral deposits while the marl layer is made up of weak to moderate, weak marl stone (Weight, 2009).

Supposedly, a layer of very dense glacial tills were found 2 to 3 meters beneath the sea bed. However, it was eventually revealed that at 8 meters below sea level, weak strata probably made up of relics from glacial lenses were found. Therefore, in order to construct the pylons and anchor blocks, it was necessary to dredge the weak materials and replace with compacted stone (Weight, 2009).

The construction of the pylons leveled at 20 meters which is the water level. A 10-meter layer full of soft tills was dredged out before filling with 5 meter bed of crushed stones. The caissons of each pylon are built with steel that are 0.5 meters in length penetrating into the stone bed by 0.3 meters (Juhani Virola Eur Ing, 1997).

As for the anchor blocks, a layer 22 meter below sea level was dredged out to build the wedge-shaped gravel foundation base. Two wedge-shaped stone beds with inclination of 16 degrees were built to lessen the shear stress at the interface, and to avoid sliding at the zone of boulder clay surface (Juhani Virola Eur Ing, 1997).

Construction

After the preparation of the foundations, the caissons could be placed. The pylon caissons are 78 by 35 meters with a height of 20 meters and weigh about 30,000 tonnes while the anchor block caissons have an area of about 6,100 m², and weigh about 36,000 tonnes. All the caissons were cast on a dry dock located 55 kilometers away from the site. So that the caissons could be towed to the site, the dock was flooded and breached (Weight, 2009).

Once the caissons were towed to the site, they were maneuvered to their positions using large winches. They were sunk to their corresponding depth. The caissons of the pylons were filled entirely with heavy sand (olivine). On the other hand, the anchor block caissons were ballasted with sand at the front and ballasted with olivine at the back (Weight, 2009).

After the completion of concrete structures, the main cables were hung. A

modified type of aerial spinning was used instead of the traditional parallel wire strands. The type used was called the controlled tension wire adjustment method, and was purposely used to save time and for protection from weather conditions such as harsh winds. The spinning began on July 6, 1996, and was finished four months later (Weight, 2009).

In 1997, the hangers were installed, and the positioning of the girders began. Originally, the assembling of girders happened in Portugal and Italy. The girders were transported to the site using barge. The girders were hoisted into position using two cranes above the main cables. After positioning of the girder, it was temporarily clamped to its adjacent girder, before welding the sections together. After this, the deck was sand blasted, and application of adhesive followed. Then, a damp proof course was laid over before two layers of mastic asphalt were applied (Weight, 2009).

Figure 5. Positioning of the final spans of the Øresund fixed link.

(Source: <http://www.railway-technology.com/projects/denmark/denmark9.html>)

Finally, the Great Belt East Bridge was completed on 1998 and was opened to transportation on June 1998 (Hochtief, n. d.).

Traffic

The Great Belt East Bridge has a total length of 6,790 meters with a free span of 1,624 meters (Wangsadinata, n. d.). The Great Belt East Bridge has a total of three lanes on either side, for a total of 6 lanes. It accommodates two lanes of a motorway and an additional emergency lane on each side. Over the entire length of the bridge, it has no light traffic lanes. Each girder

has a total width of 31 meters, with a width between railings of about 23.6 meters. The deck section weighs about 530 tons. The total suspension span of the Great Belt East Bridge is 2,694 meters.

The annual average daily traffic (AADT) of the Great Belt East Bridge of 2013 was 29,817 (Bridge-Info, n. d.). Therefore, an average of more than 29,000 vehicles cross the Great Belt East Bridge daily. It was estimated that on busy summer days, the traffic may rise to 40,000 vehicles daily

(VisitWestZealand, n. d.). The bridge has no pedestrian access. The vertical clearance of the Great Belt East Bridge at the main span of the suspension bridge is 65 meters, allowing large ships to pass underneath the suspension bridge (Juhani Virola Eur Ing, 1997).

Figure 6. Great Belt Bridge rail and road routes.

(Source: <http://www.railway-technology.com/projects/denmark/denmark3.html>)

Accidents

First of all, it should be noted that Denmark is relatively a peaceful country.

In 2008, global peace index named Denmark as the second most peaceful country in the world. Thus, vandalism and crime rate is generally low.

Needless to say, experts believed that the Great Belt East Bridge would be subjected to intentional damage due to its location. The bridge is situated on a rural region, and it is only accessible via vehicles (Weight, 2009).

However, accidental damage is still a probability. For instance, ship impact is mostly feared concerning bridges on an active shipping grounds. Take for comparison the West Bridge; the West Bridge had two ship collisions since its

completion. On the other hand, the East Bridge has yet to experience a ship impact. But, even if the East Bridge experiences a ship collision, it may still be intact with minor or no deformations. Both the anchor blocks and the pylons were designed to withstand ship impacts with ships weighing 250,000 tons travelling at ten nautical miles per hour (Weight, 2009).

Another issue about suspension bridges is how natural phenomenon affects their serviceability and durability. One such natural phenomenon is the accumulation of snow on the bridge. During winter, the Great Belt East Bridge is expected to experience heavy snow falls. It is likely that the bridge is closed during road clearing. However, the effect of heavy snow load is believed to have detrimental effects on its aerodynamics (Weight, 2009).

One other issue is how temperature affects suspension bridges, especially those made up mostly by metals. Increasing temperatures may expand materials such as metals. However, the girders were designed so that it can have an allowable movement with a total of plus/minus 1 meter (Weight, 2009).

During the construction of the Great Belt East Bridge, a British World War II explosive containing 300 kilograms of dynamite was uncovered. It was safely detonated (Weight, 2009).

Conclusion

First, the bridge was completed late. It had many delays starting with the project proposals, and construction delays. With a total budget of \$1.1 billion, it is also considered over budget. However, with its purpose and aesthetic beauty, the outcome is generally worth the hard works and budget.

After all, the bridge links the country together, and its importance can be seen on the fact that travelling across the Great Belt has been cut by at least an hour.

Aside from the benefits of the Danish from the majestic Great Belt East Bridge, it has provided insights and ideas for the improvement of suspension bridges throughout the world. The engineering of the Great Belt East Bridge has supplied the world with better techniques for suspension bridges such as the modified type of aerial spinning used on cables, and continuous box girders.

The construction of the Great Belt East Bridge was full of care and elegance. The foundations of the pylons and anchor blocks were severely secured by dredging out soft tills and replacing with compact stones. The main cables used a revolutionary way of aerial spinning that emphasizes tensile strength while saving time. The placement of girders were in an organized manner, and the design itself emphasizes an engineering innovation about suspension bridges. Needless to say, the construction was done in a perfect manner, keeping both design and security intact, as well as conservation of time to compensate for the delays.

In summary, the Great Belt Fixed Link was an active debate that has ignited since the 1800s. The proposal of fixed link on 1970s paved way for several revolutionizing suggestions and ideas that led to the engineering feat that we see today. Although the construction had cutbacks and delays, still, the Great Belt Fixed Link is a colossal engineering feat which made the Danes truly proud. Their pride was displayed on the historic opening week of the

bridge, celebrated by 275, 000 people, not only by Danes but people who have recognized the importance of such feat.

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