A CRITICAL ANALYSIS OF THE ØRESUND BRIDGE, CONNECTING COPENHAGEN TO MALMÖ

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Abstract: This paper aims to provide a critical analysis of The Øresund Bridge, connecting Copenhagen (Denmark) to Malmö (Sweden). The analysis will include a discussion on the aesthetic, structural design, foundations, construction sequence, sustainability aspects of the bridge and the structural checks calculated under different load combinations. Attention will be paid to the short fabrication and construction time of the bridge.

Keywords: Øresund Bridge, cable-stayed, double-deck, girder, Svanen.

1 Introduction

The Øresund Bridge is the longest cable-stayed bridge in the world which carries both rail and road traffic, and connects the Danish capital Copenhagen to Malmö in Sweden. The Øresund Link crosses the Baltic Sea and is made up of an artificial island stretching 4 km, a 3.5 km underwater tunnel and a bridge spanning 7.7 km. In 2003, the Øresund Bridge was awarded the IABSE (International Association for Bridge and Structural Engineering) Outstanding Structure Award for the innovative planning and construction management techniques, and environmental considerations.

Figure 1: Øresund Bridge

In 1991, the governments of Denmark and Sweden came together and agreed to connect the two cities of Copenhagen and Malmö. Companies from both countries formed the Øresund Bridge Consortium (Øresundsbro Konsortiet), a 50:50 venture between the two governments (Fig 2). The consortium’s aim was to plan, design build and finance the link. Arup were appointed as the designers and Sundlink Contractors were commissioned to construct the US$1.3 billion link between 1995 and 2000. The aim was to build a fast connection between the two countries, in order to form an ‘economic powerhouse’. Reducing the journey time to 35 minutes from Copenhagen Central Railways Station to Malmo Central Railway Station allowed the two cities to be brought closer together to share their resources. The opening of the Øresund Bridge has allowed 17,000 people to commute across the bridge every day, which has reduced the issue of labour shortages in Denmark and improved the housing market in Sweden. The bridge has also improved trade, tourism and relations between the two countries and has allowed Sweden to be connected to mainland Europe.

Figure 2: The ownership structure of the Øresund Consortium [1]
2 Aesthetics

Analyzing the aesthetics of the Øresund Bridge is purely subjective, however Leonhardt Fritz’s ten rules of aesthetics will be used to gain an objective view of the bridge.

2.1 Fulfillment of function

The cable-stayed bridge is simple structure, where the load paths can be seen clearly from the harp shape formation of cables. The symmetrical cables, all at an inclination of 30° result in the pylons looking balanced and in equilibrium. When drivers enter and leave the high bridge the function of the bridge is clear, without the cables interfering with the road line. The principal horizontal girder makes a clear statement of its structural purpose. The absence of a cross beam above the road deck keeps the bridge design looking free and ensures the cables are the most important visual aspect when driving across the bridge.

2.2 Proportions

The deck seems to be much deeper than expected for a cable-stayed bridge. In the initial design stages, a single-level more elegant solution was drawn up. The design would result in the rail and roadway being on the same level, causing the deck to be very wide. This proved to be a structural inefficient option and the two-level bridge deck was a more logical alternative, whilst providing the stiffness and rigidity needed for high speed freight trains. Due to the large cross section of the deck, the pylons are a lot more slender compared to other cable-stay bridge such as the Stonecutters Bridge in Hong Kong.

2.3 Order

The Øresund Bridge is well ordered when viewed in elevation. The pylons are evenly spaced at 160m apart from those nearest the pylons, which are 140m. The symmetry of the cables gives a clean appearance. The width of the pier is only slightly wider than the truss, and the deep girder lends itself to longer approach spans, which makes the design of the bridge minimal.

2.4 Refinement

The angles of the warren truss are at the same angle as the cable-stays, creating a visual refinement which can be seen when the bridge is viewed in elevation. The pylon legs are pentagonal shape in cross section, and taper towards the top. The pylons are still able to provide stability as the harp only delivers a small load to the top of the pylon, creating a slender pylon that does not look as visually imposing. The detailing of the top of the piers, where connections only occur at the edge of the truss, gives the piers a more slender look (Fig 4). To give train users a clear view of the Øresund Strait, a more open bracing system on the trusses has been used, which in turn makes the appearance of the bridge lighter.

2.5 Integration with environment

The alignment of the bridge is curved form the artificial island to Malmo, creating a subtle bridge line against the background of the Baltic Sea.

2.6 Character

The Øresund Bridge does seem to lack character, perhaps due to the simplistic design and the fact it stretches such a long distance over a huge body of water. However, the Øresund Bridge stands out as a major landmark and an important connection between Copenhagen and Sweden.

2.7 Surface Texture and Colour

The use of colour is understated in the Øresund Bridge. The warm grey concrete piers have not been painted, and will reduce maintenance costs of the life time of the bridge. The white pylons create a sleek backdrop against the sea and are floodlit during the night. This highlights the importance of the pylons.
and provides lighting to night time drivers, and makes the drive across the bridge less of a daunting task. The truss is painted black, giving the deck a sense of depth, however as the cross section is already deep it can be argued that painting the deck black results in the deck looking chunkier. The dark cables stand out against the blue sea and sky, and make them more visible during the day. Dark cables are a prominent feature of the bridge and give the impression that they are able to support a large load. Visitors to the bridge are able to see the cables from a distance, creating a definitive entrance and exit to the high bridge (Fig 5).

Figure 5: View of the bridge when driving across

2.8 Complexity

The Øresund Bridge is not a complex structure, and fulfills the structural requirements needed. No elements are unnecessary and the structural design is kept to a minimum.

2.9 Incorporation of nature

The curved plan of the bridge, coming from sea level and leading to Malmö incorporates the surroundings around it, harmonising the curvature of the land and sea. However, it can be argued that this was the most logical route the bridge could take.

3 Structural Design

3.1 Choice of Bridge Type

When deciding upon a design for the bridge, a number of considerations had to be taken into account. On the shoreline of Denmark was Copenhagen International airport. Building high towers would run the risk of a collision from airplanes. A bridge that was built too low may cause ships to collide, so an arch design was therefore ruled out. Designers decided against a suspension bridge, as the flexibility would result in the tracks bending, and trains would not operate on tracks that are subject to deflection. A cable-stayed bridge was the best option to achieve the rigidity needed at an economical cost.

3.2 Components of the Øresund Link

The Øresund Bridge is made up of a three main sections. A 3,014m Western approach bridge leading from the artificial island, a 3,739m Eastern approach bridge leading to the Swedish coastline and a 1,092m high bridge, with a main span of 490m. The central span of 490m is the longest cable stayed bridge in the world carrying both rail and road traffic. The main span is suspended off stay cables from four 204m high concrete pylons.

Figure 6: The Øresund Fixed Link [2]

3.2.1 The Deck

The double deck arrangement allows the separation of road and rail traffic. The upper deck is made up of a post-tensioned concrete deck, which supports four lanes of traffic. The deck is cantilevered 4.1m to both sides of the trusses, and results in an even distribution of positive and negative moments in the slab. The concrete road deck is connected to the steel truss by shear studs, which transfer longitudinal shear forces to the truss.

Figure 7: High Bridge girder cross section [3]

The lower part of the deck was designed as a steel warren truss section, made up of unilateral triangles and supports two railway tracks. The truss members are made as closed boxes with stiffeners inside, and are inclined about 30 degrees in order match the inclination of the cable-stay members.
In order for the main cable stay span to be able to deal with road and heavy freight trains, the cross section is slightly different to the approach spans. The railway deck is made up of a closed steel box deck instead of a concrete deck, in order to reduce the dead load where sagging moments are an issue.

3.2.2 Pylons

The pylons transfer the vertical loads carried by the cables to the ground. The H-shaped pylons of the Øresund Bridge, with the cross beam below the bridge deck result in 150 m of free standing concrete columns. The pylons legs therefore must be subjected to compression, from their dead load and vertical loads acting on the bridge deck. As a result the cable planes must be vertical.

3.2.3 Cables

Cable-stay bridges work when the forces either side of the pylon are in equilibrium. This has the effect of reducing the moments in the pylon, and therefore the need of moment bearing foundations. The harp shape formation, with relatively steep cables and immediate supports on the side spans, provide the rigidity needed for passenger and freight trains. This symmetrical harp shape formation has been used in the Øresund Bridge (Fig, 10). The 30° inclined cables cause a compressive force in the bridge, the tensile forces in the cables are translated into a compressive force in the pylon. There are 40 cables in total (20 supporting off each pylon), each consisting of seven 5mm threads gathered in bundles of 63-73, with a cross sectional area of 108 cm². To reduce the vibrations caused by rain and wind, the cables are covered with polyethylene double helical spiral 2mm thick. However, this did not reduce the issue of oscillations of the longest cables. Dampers were therefore installed at the stay anchors at deck level. There are also dampers to limit horizontal movement from brake forces from trains.

4 Loading

To analyse the bridge the loads acting on the bridge need to be identified, these include dead, dead loads, live as well as loads caused by temperature and the wind. The Serviceability Limit State (SLS) and Ultimate Limit State (ULS) conditions will be used in accordance to BS 5400 [5]. ULS conditions determine the load conditions which would cause the structure to fail, and SLS to ensure the bridge is serviceable. In this case for the steel girder and concrete γf is taken as 1.00 for the SLS and 1.10 for the ULS. γv varies for different load cases and is given the 490m long high bridge will be analysed with different load cases to establish the worst case scenario.

4.1 Dead Loads

The dead load is made up of the weight of the steel girders, the closed box section inside the girder, the concrete trough which the trains run on and the concrete roadway deck. A conservative approach has been used by modelling the high bridge railway deck the same as the approach bridge.
4.2 Superimposed Dead Loads

Superimposed dead loads are made up of the loads on the bridge which are non-structural. These include, the asphalt surface, lighting and services and crash barriers. As the Øresund Bridge also carries railway traffic, there are additional superimposed loads such as the ballast, sleepers and track.

The road surface is 700 mm of asphalt (Ref x), spread evenly across the 23.5m road. 1 kN/m² has been assumed for all lighting, services and road furniture over the whole deck area, giving approximately 20 kN/m.

Asphalt Surfacing:
0.07 m x 23.5 m x 23 kN/m² = 37.8 kN/m

The ballast covering the surface of the railway deck will create an additional superimposed load. The density of the deck is assumed to be 16 kN/m³ and the depth has been taken as 0.5m (Fig 7). Any additional loads from the railway track and sleepers have been including in the loading for the ballast, giving an unfactored load of 40 kN/m. The loads are then multiplied by the partial load factors γfl for superimposed dead loads, 1.75 for ULS conditions.

Table 1: Factored Dead Loads

<table>
<thead>
<tr>
<th>Component</th>
<th>Unfactored Load (kN)</th>
<th>Factor (γfl)</th>
<th>Factored Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Girder</td>
<td>152,450</td>
<td>1.05</td>
<td>176,080</td>
</tr>
<tr>
<td>Steel Box Section</td>
<td>5,320</td>
<td>0.95</td>
<td>6,144</td>
</tr>
<tr>
<td>Concrete Railway</td>
<td>21,600</td>
<td>1.15</td>
<td>27,324</td>
</tr>
<tr>
<td>Concrete Roadway</td>
<td>27,000</td>
<td>1.15</td>
<td>34,155</td>
</tr>
<tr>
<td>Total (per m)</td>
<td>421 kN/m</td>
<td>1.05</td>
<td>498 kN/m</td>
</tr>
</tbody>
</table>

4.3 Live Loading

To work out the traffic loading on the bridge, the number of notional lanes must be calculated. The lane LANES are then loaded with HA and HB loads to determine the worst possible case. The Øresund Bridge has a 23.5 m wide carriageway which is modelled as 6 notional lanes, 3.9 m wide. The dual carriageway carried by the bridge is separated by a central reservation and has barriers on outside lanes.

4.3.1 HA Loading

HA loading is made up on a uniformly-distributed load (UDL) acting over the notional lanes of the bridge plus a knife-edge load (KEL) acting at the most critical location. The UDL can be worked out using Eq. 1 below (Ref x).

\[
W = 36 \left( \frac{L}{l} \right)^{0.1} \tag{1}
\]

This gives UDL of 19.3 kN/m per notional lane. The knife edge load per notional lane is taken as 120 kN.

4.3.2 HB Loading

HB loading takes into account abnormal large loads on the bridge, due to trucks transporting long, wide and heavy objects. These might include xxx being transported to and from Malmo to Copenhagen, although it is likely that heavy freight will be transported by trains. Full HB loading will be used as 45 units, where each axle represents 10 kN. HB vehicles are made up of 16 wheels arranged on four axles, each wheel therefore carries 112.5 kN.

4.3.3 Train Loading

The lower deck accommodates two railways tracks and the loading of these trains has to be considered. Standard RU railway loading has been used and the loading arrangement is shown in Fig 11 (Ref x) and will be applied to both tracks.

Table 2: Superimposed Loads

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Surface</td>
<td>37.8</td>
</tr>
<tr>
<td>Lighting and Services</td>
<td>20</td>
</tr>
<tr>
<td>Ballast</td>
<td>40</td>
</tr>
<tr>
<td>Total (per m)</td>
<td>97.8 kN/m</td>
</tr>
<tr>
<td>Total factored load (per m)</td>
<td>188.3 kN/m</td>
</tr>
</tbody>
</table>

4.4 Wind Loading

Wind loading is a major factor affecting the Øresund Bridge. Horizontal and longitudinal wind loading will be considered. The wind gust can be calculated by using Eq. 2. The wind speed will be taken as 15 m/s (Ref x), the wind coefficient (K1) as 1.54 and the gust factor (S2) as 1.36.

\[
V_c = c K_1 S_1 S_2
V_c = 31.4 \text{ m/sec} \tag{2}
\]

The dynamic pressure head can then be calculated using Eq. 3 below.

\[
q = 0.613 V_c^2
q = 604 \text{ N/m}^2 \tag{3}
\]
4.4.1 Horizontal Wind Loading

The horizontal wind load (Pt) cannot be considered using Eq. 4 below. $A_1$ is the solid projected area which is resisting the wind. The main span of the Øresund Bridge is 490m and the depth of deck is taken as 11.7m. The solidity ratio is approximately 0.3 due to the open box nature of the truss, which gives a drag coefficient $C_D 1.7$.

\[ P_t = q A_1 C_D \]  
\[ P_t = 604 \times (245 \times 11.7 \times 0.3) \times 1.7 \]
\[ P_t = 883 \text{ kN} \]

4.4.2 Longitudinal wind loading

Longitudinal wind loads acting on all parapets and piers must also be considered. As the bridge deck is a girder structure, Eq. 5 will be used to calculate longitudinal wind load ($P_{LS}$) (is specified in BS-5400 5.3.4.2- charis cos). $A_3$ is the plan area and the coefficient of uplift, $C_L$ can be taken as 0.4.

\[ P_{LS} = 0.5 q A_3 C_L \]  
\[ P_{LS} = 0.5 \times 604 \times (245 \times 23.5) \times 0.4 \]
\[ P_{LS} = 696 \text{ kN} \]

4.5 Temperature

Temperature effects are important in bridges, as fluctuations in temperature can cause cracking of the concrete bridge deck, which can result in the bridge experiencing significant stresses. There are two temperature effects in bridges, overall temperature increases and temperature difference between the top and bottom deck.

4.5.1 Effective Temperature

The Øresund Bridge connects Sweden to Copenhagen, and these two countries have slightly different climates. The bridge may experience temperature variation during different times of the year or from one end of the bridge to the other. The temperature range has therefore been taken as 40 degrees acting over the length of the bridge. The coefficient of thermal expansion for steel is $\alpha = 12 \times 10^{-6}$

\[ \Delta L = \Delta T \times L \times \alpha \]  
\[ \Delta L = 40 \times 7,845 \times 12 \times 10^{-6} \]
\[ \Delta L = 2540 \text{ mm} \]

The stresses along the bridge can therefore be calculated (Eq. 7) using 210,000 N/mm² as the young’s modulus of steel.

\[ \sigma = \alpha \times \Delta T \times E \]
\[ \sigma = 12 \times 10^{-6} \times 27 \times 210,000 \]
\[ \sigma = 68 \text{ N/mm}^2 \]

Expansion joints installed were installed along the bridge deck to deal with the temperature variations.

4.5.3 Temperature differences between deck

Heat transfer across the deck can create temperature variations. These variations can cause stresses in the deck which in turn can lead to bending moments in the deck, affecting the strength of the deck. Fig 12. shows the possible heat transfer across the steel and concrete deck.

\[ \text{Figure 12: Variations in temperature through the bridge deck} \]

5.1 Deck

The analysis of the bridge deck will be simplified by modelling it as a continuous beam with rigid supports representing the cables. The bending moment will be calculated with a UDL of dead and superimposed loads applied across all lanes and a knife-edge load applied at midspan. The bending moment for the high bridge can be calculated using Eq. 8.

\[ M = Wl^2 + Pl \]  
\[ M = 498 \times 20^2 + \frac{120 \times 20}{10} \]  
\[ M = 20.5 \text{ MNm} \]

The worst possible case results in a bending moment of 20.5 MNm at the end supports. The bending moment diagram of the deck can be seen below (Fig 13).
The stresses in the deck caused by the bending moment can then be calculated, by using Eq. X. The bridge section is a steel box girder, and contains steel stiffeners, the I value is taken as 5.4 x 10^14.

\[ \sigma = \frac{M_y}{I} \]

(9)

\[ \sigma = \frac{20.5 \times 10^6 \times 5850}{5.4 \times 10^{14}} \]

\[ \sigma = 2.2 \times 10^{-4} \]

The small stress experienced by the deck shows the rigidity of the warren truss.

The deck can also be modelled as a simply supported beam with a fixed end at the pylon end and a pinned end, where the dead load of the deck is taken by the cables. The bending moment can then be calculated with a UDL of live loads (HA and train loads) and a point load acting 2/3 along the deck to produce the worst possible case. Producing a maximum moment of 767.2 MNm

\[ M = \frac{W(0.75l_{eff})^2 + P\frac{b}{2}(2l+b)}{8} + \frac{Pa^a(2l+b)}{2l^3} \]

(10)

The tension of the cable which supports 20m = 8,422/\sin 30° = 16.8 MN, and the tension of the cable which supports 22.5m = 9,475/\sin 30° = 18.9 MN.

5.2 Compression in the deck

As the cables are inclined, they cause a compressive force in the deck, this can be calculated by considering the horizontal component of the force worked out from the cables. The compression in the 20m sections = \cos 30° x 16.8 = 14.5 MN, and in the 22.5m sections = \cos 30° x 18.9 MN = 16.4 MN.

5.3 Torsion

The symmetrical evenly spaced cable stays along the pylons provide good resistance to torsion. Torsional moments are resisted by the steel box section which has torsional rigidity.

6 Construction

The Øresund Bridge was constructed on time and on budget, which is unusual for the size and complexity of the project. Prefabrication was used extensively to ensure quality and efficient construction, with elements being of a high standard. Construction of bridge sections on land, also reduced the amount of time spent at the bridge line and the risk that the marine environment would be polluted or disturbed.

Construction of the Øresund Bridge started with the 204m high towers, which were fabricated in Malmö harbour. The two towers were the only major elements to be constructed in-situ. The tower was constructed in 4m sections every 7-10 days, using climbing formwork. Ensuring one tower was always 12m taller

The dead load of 8,422 kN, but the shortest cable supports 22.5m length of deck amounting to a dead load of 9,474 kN. The cables are orientated at 30° to the horizontal.

Figure 15: Construction of the pylon towers
than the other reduced the risk of the cranes becoming tangled up with each other. As new sections of the tower are cast, the weight of these segments will cause compression forces in the cross section below. This will result in pre-stressing and will increase the pylons ability to transfer moments due to lateral loads (wind). When the towers reached 44m, the cross beam was installed.

Dredging to depth of 6-10m of the sea floor, took place to prepare it for the caissons, which support the piers and pylons. The pylon caissons for the high bridge were built in the dry dock. With each pylon weighing 18 mkg, there were no vessels which were cable of carrying the towers out to sea, so the engineers constructed a catamaran to lift and transport the caissons. Once the dry dock was flooded the catamaran could be floated out. At bridge line, the caissons were lowered into a pit, and GPS, divers and underwater camera were used to guide the pylons to 8 cm of their target. The pier and pylons were placed on three pre-positioned concrete pads. The underside of the caisson was grouted in place and then ballasted

![Figure 16: Caisson construction in the dry dock](image16)

The heavy lifting vessel ‘Svanen’, which has a lifting capacity of 8,700 tons, was used to collect the caisson and pier shafts to the bridge line. The first stages of constructuction were on the Eastern Approach Bridge and the High Bridge, in order to minimise the disturbance to sea traffic in the Øresund waters.

The steel truss and concrete road deck, were fabricated and painted in Cadiz in Spain. To reduce temperature variations in the workshop, large air condition plants were installed. The approach span girders were then transported on specially equipped barges and tugboats to a harbour in Malmo.

The prefabricated railway troughs were then installed. The ‘Svanen’ was also used to erect the steel truss in place. Lifting the trusses using ‘Svanen’ resulted in the girders being cantilevered 40m at either end. This caused large tension forces in the concrete road deck, a load that had not been accounted for. As the railway deck is likely to experience tension, the aim was to reduce these tension forces during construction. The steel girders were therefore constructed with only part of the railway deck in place, thus reducing the dead weight of the girder. The concrete trough and steel connections were then fitted once the girders were finally installed on the piers.

The cable-stayed deck, which is made up of eight sections, two of which are 120m and six of 140m in length, was constructed in Karlskrona in Sweden, about 200 km from site. These sections and the two approach bridge were shipped on a roll-off roll-on ship to the North Harbour. The bridge elements were then transported by the ‘Svanen’ crane to the work site.

As the Øresund is not very deep, three temporary towers were constructed in order to hold up the main span prior to the installation of cable. After the superstructure was constructed from the midspan to the end of the side spans, the cables were erected. Each cable consists of around 70 strands. And one single strand was pulled up 70 times. As a result the load was transferred from the temporary piers to the cables.

![Figure 17: Svanen lifting the girder into the bridge line](image17)

6.1 Bearings

The truss girders are supported on pot bearings, which consist of a rubber disk within a steel cylinder, which allow for rotation. The approach spans have longitudinal fixed bearings on two piers and the high bridge also have longitudinal fixed bearings as well as partially fixed bearings. Fixed bearings limit longitudinal movements due to temperature variations but are able to take longitudinal forces due to ship collisions or earthquakes. Hydraulic units are installed at the expansion joints between the approach spans and side spans of the cable-stayed bridge, which allow for movement from temperature variations and absorb and transfer braking forces which would otherwise be taken by the cable-stays and result in bending of the pylons.
7 Durability

The Øresund Bridge has a design life of 100 years, if maintained well. The smooth outer surfaces of members ensure moisture and dirt do not accumulate. It is likely that some structural elements will need replacing if they become damaged or worn out.

7.1 Corrosion

Arup design and research team were commissioned to develop the corrosion protection for the Øresund Bridge. The brief was to provide the maximum possible protection, by using a thick barrier coat over a primer. Table 1 below details the specification of the coatings used.

<table>
<thead>
<tr>
<th>Coating</th>
<th>Material</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primer</td>
<td>Zinc rich epoxy</td>
<td>40</td>
</tr>
<tr>
<td>Barrier 1</td>
<td>Epoxy micaceous iron oxide</td>
<td>150</td>
</tr>
<tr>
<td>Barrier 2</td>
<td>Epoxy micaceous iron oxide</td>
<td>150</td>
</tr>
<tr>
<td>Finish</td>
<td>Polyurethane</td>
<td>50</td>
</tr>
</tbody>
</table>

Arup also reviewed the steelwork design and proposed changes to the design in order to increase water run off on the structure. The recommendations included, ensuring water run-off at node points and highlighting details that could cause an issue with water retention. The design team also visited the workshops in Sweden and Spain where parts of the bridge were being fabricated and continued to make visual inspections of the steel elements, which were essential in order to highlight areas which would need remedial work.

8 Foundations and Pier Design

The approach spans are supported on reinforced concrete piers with raft foundations. The lower part of the pier and the caissons (35m x 37m) are filled with concrete and sand to provide the dead weight needed to resist impact forces from ships and potential lover turning. The caissons have been designed to withstand a longitudinal collision force of 560 MN and a transverse collision force of 428 MN.

9 Sustainability

The Øresund Bridge was built to have minimal impact on the marine environment, during and after construction. High standards of environmental protection were ensured, by monitoring and protecting the flora and fauna. The road and high speed rail connection have brought the two countries closer together, and train passenger numbers increased by 25% in 2007 compared to 2006. Air pollution in the region subsequently has reduced by about 50%. A number of environmental and conservation organisations were consulted on the project and in 2001, the Danish and Swedish authorities concluded that environmental requirements had been met.

The Swedish Water Council also ensured the bridge would have minimal blocking of the Øresund strait. The design of the bridge ensured that pylons would have minimal effects on water flow. The bridge pylons have since become habitats for algae and mussels providing food for fish and birds in the Baltic Sea.

During construction 5,000 local workers were employed and involved in the project and materials such as steel and granite were sourced from Denmark [7]. An employment programme was set up to train workers in order to have the necessary skills for the project. The programme also helped train unemployed workers in carpentry and steel work and allowed skilled Civil Engineers to gain the special requirements needed for the project.

The shallow waters of the Øresund strait meant bridge lighting had to be carefully considered. Illumination of the bridge is therefore kept to a minimum so not to detract and fish migrating birds.

10 Serviceability

In 2000, shortly after the bridge had been opened the bolts on the guard rail were seen to be corroding. Preventing the bolts rusting through was an essential to reduce the risk of failure. This required removing the nuts from the 16,000 bolts, blasting the bolts clean and coating the bolts with gel to prevent moisture ingress.

The Øresund Bridge was built to contain a large number of dehumidifiers, which keep the air temperature to 60% relative humidity. The lack of
moisture reduces the risk of rusting of the steel elements.

11 Maintenance

The Øresund Bridge was built with a hanging gantry underneath the steel girder. The hydraulic arm can carry workers outside the truss and allows for easy access to the bridge without interrupting the flow of traffic, without interrupting the flow of traffic. Access to the concrete piers is achieved by lowering a maintenance box from the gantry to sea level. This allows workers to check the cement for cracks and change light bulbs which guide ships through the navigation channel.

12 Future Improvements

The use of the Øresund Bridge is set to increase as the region continues to prosper. From Figure 19, the number of journeys made by cars has continued to increase since the opening of the bridge. The two lanes of traffic in each direction may not be able to manage with this continued rise. Widening of the road is possible, however the construction work needed for improvement may result the flow of traffic being interrupted, which would in turn affect the journeys of thousands of commuters and bridge users.

Figure 19: Daily traffic across the Oresund Bridge

13 Conclusions

The Øresund Bridge has successfully connected and integrated the two cities of Malmo and Copenhagen, as well as improving the development and economic growth of the region. Around 17,000 people commute across the bridge on a daily basis, and the reduced journey time between Copenhagen and Malmo has alleviated the labour shortages in Denmark and has improved the housing market in Sweden. The programme trained unemployed workers in skills needed for the building of the bridge and sourced materials locally, demonstrating the sustainability aspects of the project. The construction of the bridge was completed on time and on budget for a project as complex as the Øresund Link, and demonstrates how two countries can come together to combine their resources and produce a momentous bridge.

15 Acknowledgments

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