CRITICAL ANALYSIS OF THE FIRST SEVERN BRIDGE

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Abstract: This paper provides a critical and informative analysis of The First Severn Crossing. Officially opened in 1966, this bridge was the first of a new era of suspension bridges. Not only does it commemorate a new form of bridge design but also a new economic era for the South of Wales as labelled by Queen Elizabeth II. This paper analyses the reason for a road crossing, the design, construction methods, loading conditions and post construction works. It will enable the reader to gain a deeper understanding into the bridge and appreciate its interesting features.

Keywords: Severn Crossing, M48, steel box girder, suspension bridge

1 Introduction

1.1 History

The concept of crossing the Severn Estuary had existed since the early 19th century. The problem was initially solved by a train-ferry-train transfer and later by the building of a tunnel. The bridge was then built in order to replace the ferry service that crossed from Aust Cliff to the Beachley Peninsula. When it opened on September 8th 1966 it was the longest, single-spanning suspension bridge in the world. It provided a direct, uninterrupted link to Wales and was promptly nicknamed the ‘Gateway to Wales’. When she opened it, Queen Elisabeth II hailed it the ‘start of a new economic era’ for South Wales.

1.2 Reasons for Crossing

The tides in the Severn Estuary are the second largest in the world and run at 9knots rising over 12m. This, combined with its rocks and treacherous shifting sandbanks meant the Severn estuary was a far more formidable barrier than its comparatively modest breadth might suggest. Thomas Telford was initially appointed to advise the Postmaster General on measures that would improve the main coach route between London and Milford Haven. It was Telford that first proposed a suspension bridge in 1824. However, it took another
140 years to realise that the bridge was the best option for the Beachley-Aust crossing.

The ferry crossing was unsatisfactory and dangerous. In 1839 the ferry boat, Dispatch was lost with over 20 passengers. A similar incident occurred in 1843, with members of the same family. In 1845, James Walker F.R.S – Telford’s successor stated ‘There is, as far as I know, no great communication in the country so bad, or therefore where an improvement is so much wanted.’

In 1845 the improvement and expansion of the railway demanded an improved Severn crossing but this time a rail crossing was required. Brunel’s initial proposal of a swing bridge was disregarded as it did not provide sufficient headway for shipping lanes. The Severn-Wye railway bridge was opened in October 1879 but was struck by an oil barge and in 1960 two of the spans were brought down.

1.3 Location

Figure 1 shows the proposed location of the bridge in 1960. At this time the M4/M5 motorways were still in the proposal stage.

1.4 Dimensions

The bridge stretches 1597m in length and the towers soar 136m above the river. It took two consulting firms, two contractors and three and a half years to construct at a cost of £8 million. The main span alone contains 18,500 tonnes of steel [1]. The height of the deck above the river provides beautiful views of the estuary as you drive across the bridge. The main dimensions are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Table 1: Bridge Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 - General Bridge Dimensions</strong></td>
</tr>
<tr>
<td>Main Span</td>
</tr>
<tr>
<td>Distance Apart, c. to c. of cables</td>
</tr>
<tr>
<td>Side Spans, each</td>
</tr>
<tr>
<td>Level of tops of Towers</td>
</tr>
<tr>
<td>Sag span ratio of cables</td>
</tr>
</tbody>
</table>

1.5 Crossing the Severn

The Severn Crossing consists of four component structures. Firstly, the Aust Viaduct constructed of a twin box girder with a concrete deck. Secondly, is the 1597m Severn Suspension Bridge. Thirdly comes the Beachley Viaduct which is also of box girder construction but is supported on steel trestles as it crosses the Beachley Peninsula. Finally, the Wye bridge is a single large cable-stayed section with two single-leg pylons supporting the bridge deck from the centre of the roadway.

1.6 Current Usage

Since it’s opening in 1966, 300 million vehicles have crossed it. Increasing traffic loads lead to a need for strengthening in the eighties, discussed in section 8.2 of this paper. The Severn Bridge was designed using state of the art technology to mitigate wind conditions however in extreme conditions it has to be closed (see section 4.4). With increasing traffic flows a bottleneck started to form at the bridge. This coupled with the burden of maintenance, closure due to the wind and accidents became unmanageable and the Second Severn Bridge was commissioned.

1.7 The Bridge

Figure 1: The Severn Bridge

2 Design

2.1 Long Span Suspension Bridges

Suspension bridges are defined as bridges where the main load-bearing elements are hung from suspension cables, which are anchored into the ground at their ends [2]. The deck is usually slender and carries bending only whilst providing some stiffness to the system so that concentrated loads on the deck are spread to several hangers. In order to suspend the deck off of a cable, the shape the cable will choose to take must be observed. In 1974, Fuss developed the result shown in Eq. (1).
2.2 Design of the Severn Bridge

2.2.1 Site Conditions

At the site, the Severn is confined on the South-East side by a 42m high cliff and on the North-West side by the Beachley Peninsula. The distance between these at high tide is around one mile. The tidal range is 5.4m on neaps and 12.6m on spring tides. Up and downstream of the site, the river widens to approximately 2miles. The constriction of the flow at the site, coupled with the large tidal range, gives rise to currents of 8 knots. This was one of the main hazards for construction. The fast flow of the river had prevented any build up of alluvial deposits at the site and the sites for all the foundations therefore had a clear rock surface.

2.2.2 Superstructure

The design of the superstructure was still being completed as the substructure was being built. Calculations were being carried out around the time of the collapse of the First Tacoma Narrows Bridge. The same engineers had worked on the Forth Bridge and from this experience they agreed that the depth of the lattice stiffening trusses could be reduced. This would substantially reduce the deadweight of the cables and towers and the overall cost of the bridge.

A model was built for wind tunnel tests but due to errors in anchoring the model it was swept up in the tunnel. If it wasn’t for this accident the bridge may never have been built in its present form. The results were required but a duplicate model would take too long to produce. At this time the idea of a deck of streamlined box sections was conceived and pursued and a simple wooden mock-up was made. The results of the tests were very encouraging and so the design progressed in this way.

The design ‘fluttered’ a little bit at certain incidences of a low wind velocity. Sir Gilbert Roberts – the chief engineer, believed that this could be damped out completely by the hangers linking the deck to the main cables if they were inclined in inverted V formation instead of being vertical shown in Fig. 4. The theory goes if a piece of wire rope is stretched and then released, a proportion of the total energy imparted to it is absorbed by friction in the rope thus producing the damping effect as the oscillation of the deck varies the load on the hangers.

The longitudinal movement of the deck due to the live loads limits the included angle of the hangers at the main cable to 50 degrees. If this is not the case there is a danger that the stresses in a particular hanger might be reduced to zero. The critical angle varies along the span and increases to a maximum at the centre.

![Figure 4: Hanger Configuration](image)

This new design was compared to the old and a saving of £800,000 could be made. There was a constructional advantage also, the box sections of the deck would be buoyant and so could readily be floated out and lifted into the position whereas the lattice trusses of the Forth Bridge had to be built in situ. The plain surfaces of the box section were a far simpler proposition in terms of long term maintenance and painting than the intricacies of the open lattice girders.

3 Construction

3.1 Substructure

3.1.1 Piers

The piers are 40.2m long by 12.2m wide by 19.2m high and weigh 25,000 tonnes each. The Aust Pier is located on the Great Ulverstone Rock shown in Figure 5. The Beachley Pier rests on two 18.3m diameter concrete cylinders on bed rock 10.1m below the river bed.

The Beachley pier needed to be sited around 180m offshore where there was no convenient outcrop of rock. An excavation of 10m was required to reach 20m below mean water level before an inclined bed of hard mudstone was met which was suitable for the pier which can be seen in Figure 3 above. Two circular sheet-piled coffer dams were then built. Because the Keuper marl was too hard, the sheet piles could not be driven to bedrock. Therefore, prefabricated circular segments of cofferdam were bolted to a cast in situ concrete annular ring. The marl was then excavated from within and the interiors of the coffer dams were lined with precast
concrete segments to form two great cylinders, 20m in diameter. These were then filled with 20.2m$^3$ of mass concrete. The concrete base of the Beachley tower lies on top of these cylinders.

The works on the Beachley side prevented the Aust ferry boats from approaching the ferry pier on the downstream side therefore a breakwater had to be built on the Lyde rock to shelter the pier from the ebb tide. However this caused another problem – silting of the pier side.

![Aust Pier](image)

**Figure 5:** Aust Pier

3.1.2 Anchorages

The anchorages are 47.3m long by 33.6m wide by 42.7m high. They weigh 90,000 tonnes each. They are largely hollow and anchor the ends of the main cables and each anchorage resists a pull of 20,000 tonnes.

The contract for the main piers and foundations was awarded in March 1961. In order to build the substructure considerable temporary works had to be constructed which posed its own problems.

A cutting was driven through the Aust cliff to bridge deck level of 36m and a working stage was built and linked to the mainland in order for work on the Ulverstone Rock to begin. A mobile drilling platform was used to form the foundations of the working stage at the Rock and to drop the prefabricated steel sections of the staging into place. This temporary work had to be a large construction due to the fact that the first sections of the main towers were loaded from barges onto the platform.

The rock is only exposed for a brief period each day and is swept by fierce tides therefore founding a pier proved difficult. Any work done one day could easily be swept away the next. To combat this, steel rods were grouted into the rock to secure a ring of precast concrete blocks. In order to offer the least resistance to the tides the blocks were set alternately and the gaps were gradually closed until a permanent coffer dam of concrete rose above the high tide mark. The interior of the dam was then pumped out and filled with mass concrete.

![Beachley Anchorage](image)

**Figure 6:** Beachley Anchorage

Both anchorages are of gravity type i.e. they rely on sheer weight. The Aust anchorage is founded on limestone rock 500ft from the cliff. Blocks of concrete were formed in situ to above high water, each in a single tide. The anchorage appears to be a single block of concrete when in fact each cable anchorage is a separate block, joined by cross walls. 90,000 tonnes of concrete and 1,000 tonnes of steel were used in construction. The cable strands are anchored by strand shoes, threaded rods, distribution plates and prestressed steel bars running through the anchorage.

![Details of Cable Anchorage](image)

**Figure 7:** Details of Cable Anchorage

3.2 Superstructure

3.2.1 Towers

Each tower weighs 1300 tonnes and rises 122m high. Each is formed by two cellular legs constructed from welded high tensile steel plates, varying from 25mm to 14mm thick and capped by welded steel saddles which
take the load of 6,600 tonnes from each cable. Two sides of the leg have a constant width of 5.2m. The other two taper from 3.7m at the bottom to 2.9m at the top.

The contract for the superstructure was awarded in May 1962 to Associated Bridge Builders Ltd., the consortium that built the Forth Bridge superstructure. First the steel towers were erected on top of their piers. Each of the towers consists of two legs of square section tubes seen in Fig. 8. They are braced laterally by three horizontal portal beams instead of by the X bracing members used on the Forth Bridge. There were very precisely prefabricated steel sections used for the towers of the Forth Bridge which reduced site work and the weight of steel. This, combined with the new aerofoil deck, the steel in the towers can be reduced further on the Severn Bridge.

Figure 8: Tower Sections Craned into Place

The thickness of the plate used in the hollow box section legs is progressively reduced from 25mm above the base to a minimum of 15mm although the exterior dimensions are uniform. The first and heaviest of the 17m sections of each leg were swung into place by derricks mounted on the temporary staging and secured by means of prestressing strands embedded in the pier.

Each section is bolted to its fellow by interior flanges and 50mm diameter screwed rods. Finally, the cable saddles were mounted on the tops of the towers. They are the heaviest single units used in the construction of the towers weighing in at 23 tonnes and are designed to ensure that the 8000 tonne vertical load from the cable is distributed uniformly to the vertical plates of the tower legs.

3.2.2 Main Cables and Suspension

The primary cables are 500mm in diameter consisting of 19 strands made from a total 8,322 galvanised wires. These wires are bunched together with cast steel clamps 18.3m apart to which are attached the suspender ropes each 50mm in diameter. The tension in each cable is 11,400 tonnes and weighs 2,600 tonnes.

Each tower had to be strained back towards its anchorage to the extent of around 800mm before cable spinning could commence. This would make sure that when carrying the full weight of the suspended structure the towers would assume a vertical position.

The cables were carried across the river by barge to form the main supports for a wire mesh catwalk from which the cable spinning would occur. When spinning was complete the finished cables were wire bound by a special machine. Figure 7 shows the details of the cable anchors.

The deck hangers, each of pre-determined length, were then hung from the completed main cables. Their design and specification was aimed at securing the maximum damping effect. They consist of single spiral strands 50mm in diameter made up of 178 zinc coated wires and are attached to the cable clamps by clevis pins. Therefore they could be cut to length, prestressed and socketed off site. The hanger configuration of the Severn Bridge can be seen below in Fig.4 above.

3.2.3 Prefabricated Deck

The stiffened steel plates of the deck were prefabricated all over the UK with particular care taken to make sure they would all fit together, and were all brought to Chepstow for final assembly. Each section is an all-welded assembly 3m deep x 32m wide x 18m long, weighing 118tonnes. When completed each was covered in a protective coating and launched into the river to be towed round to the bridge site by tug. Then a special pusher barge manoeuvrable in any direction took charge, jockeying the deck section into a position where it could be grappled by slings operated by winches on the tower tops.

Once the deck section was at the correct height, the suspenders were attached and the section held to its fellow by temporary clamps until welding could be carried out. The bridge deck consists of 88 sections and the construction was carried out without a hitch but only due to the careful judgment and timing of wind, weather and tide. On average, only ten tides in each month were suitable [3].

3.2.4 Roadway

Two 7.3m carriageways and one 3.7m cycle track and 3.7m footpath are cantilevered out at the sides. The road surface was then laid on the steel deck. Common practice in America at the time was to use concrete here but that would have greatly added to the weight of the suspended structure. Therefore experiments were carried out using lighter forms of surfacing. These involved laying the sections out at bus stops and by-passes around the country. The results showed that a 38mm layer of hand-laid mastic asphalt would be satisfactory. Its characteristics were that it would neither disintegrate nor permit corrosion of the underlying steel.
3.3 Overall Construction

3.3.1 Materials
A summary of the volume of materials used in the bridge is given below in Table 2.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Towers</td>
<td>2450 Tonnes</td>
</tr>
<tr>
<td>Cables and Suspenders</td>
<td>4173 m³</td>
</tr>
<tr>
<td>Deck</td>
<td>10160 m³</td>
</tr>
<tr>
<td>Concrete Piers</td>
<td>21408 m³</td>
</tr>
<tr>
<td>Concrete Anchorages</td>
<td>74926 m³</td>
</tr>
</tbody>
</table>

3.3.2 Contractors and Cost
The contractors and cost of the project are given in Table 3 below. More than one main contractor and consultant was used due to specialities in differing areas.

<table>
<thead>
<tr>
<th>Contractors and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consulting Engineers</td>
</tr>
<tr>
<td>Messrs Mott, Hay &amp; Anderson</td>
</tr>
<tr>
<td>and Freeman Fox &amp; Partners</td>
</tr>
<tr>
<td>Substructure Contractors</td>
</tr>
<tr>
<td>John Howard and Co Ltd</td>
</tr>
<tr>
<td>Superstructure Contractors</td>
</tr>
<tr>
<td>Associated Bridge Builders Ltd</td>
</tr>
<tr>
<td>Total Cost</td>
</tr>
<tr>
<td>£8,000,000 (1966)</td>
</tr>
</tbody>
</table>

4 Loading

4.1 General Loading

4.2 Dead Load
The dead load of the structure in the main span is summarised below in Table 4.

<table>
<thead>
<tr>
<th>Section</th>
<th>Loading (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steelwork</td>
<td>64</td>
</tr>
</tbody>
</table>

4.3 Live Load
The live loading was designed to the specification in BS153 Part 3: 1954. In this analysis 45 units of HB load for the roadway decks have been included. The cycle track loading is equal to one half of that specified for footways. The layout of the HB vehicle is shown in Figure 10. The variation of the intensity of the HA lane load with loaded length is shown in Figure 11 below.

4.4 Wind Loading
4.4.1 Site Aerodynamic Tests
At the time of the design of the 1597m long suspension bridge over the River Severn very little was known about the characteristics of wind acting on a front as long as a mile. Therefore, in 1945, tests were undertaken at the bridge site (Fig.12) to:

a) Ascertain the extent of the wind front and the variations in wind velocity over such a front
b) Find the maximum vertical inclinations of the wind
c) Investigate the relationship between high wind velocities and the direction and inclination of the wind.
Observations were carried out for 8 years.
4.4.2 Conclusions
After the various tests were carried out the following conclusions were made:

a) High and fairly consistent wind velocities were found to act simultaneously over the half mile front covered. For the bridge design the estimated critical wind pressure should be assumed to act over the whole span.

b) Due to the local topography, winds blowing in directions within 45° of normal to the bridge are unlikely to be critically inclined to the horizontal especially at high speeds.

4.4.3 Site Plan

![Site Plan of Severn Estuary](image)

4.4.4 Wind-Induced Oscillations of the Hangers
Soon after they were erected it was noticed that the longer hangers oscillated under the action of winds between 10 and 27 miles/hr. The frequency of the vibrations appeared to be proportional to the wind speed and it was apparent that the oscillation was vortex excited. As the hangers on the Severn Bridge are separate and different to those on previous suspension bridges a special type of damper was developed to fit the hangers over 30 m long.

4.4.5 Wind Loads
Arguably, one of the biggest aspects of designing a successful suspension bridge is to ensure that it can safely withstand the design wind loads. The UK is well known for being the windiest country in Europe due to the maritime temperate we face.

In order to calculate the lateral wind load we must first find the maximum wind gust, $v_c$, which strikes the bridge.

$$v_c = v \times K_1 \times S_1 \times S_2$$  \hspace{1cm} (2)

Table 5: Maximum Wind Gust Parameters

<table>
<thead>
<tr>
<th>5 - Max. Wind Gust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Hourly Wind Speed $v$</td>
</tr>
<tr>
<td>Wind Coefficient $K_1$</td>
</tr>
<tr>
<td>Funnelling Factor $S_1$</td>
</tr>
<tr>
<td>Gust Factor $S_2$</td>
</tr>
</tbody>
</table>

Therefore, the maximum wind gust = 50.3415 ms$^{-1}$. This can then be used to calculate the horizontal wind load, $P_t$, by:

$$P_t = q \times A_1 \times C_D$$  \hspace{1cm} (3)

Table 6: Horizontal Wind Load Parameters

<table>
<thead>
<tr>
<th>6 - Horizontal Wind Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Pressure Head $q$</td>
</tr>
<tr>
<td>Horizontal Projected Area $A_1$</td>
</tr>
<tr>
<td>Drag Coefficient $C_D$</td>
</tr>
</tbody>
</table>

Therefore $P_t = 15.2$ MN.

4.4.6 Design Wind Loads
The maximum wind speed designed for is 100 miles/hour, at deck level. The appropriate loadings were determined through the wind tunnel tests afore mentioned. The design wind forces are shown in Table 7 below. These are the forces acting laterally on the suspended structure and cables. All of the shown wind forces are those to 100 miles per hour at deck level.

Table 7: Wind Loading

<table>
<thead>
<tr>
<th>7 - Wind Loading</th>
<th>kN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 miles/hr Wind at Deck Level</td>
<td></td>
</tr>
<tr>
<td>Wind on Cables</td>
<td>2.17</td>
</tr>
<tr>
<td>Wind on Unloaded Suspended structure</td>
<td>2.38</td>
</tr>
<tr>
<td>70 miles/hr Wind at Deck Level</td>
<td></td>
</tr>
<tr>
<td>Wind on Cables</td>
<td>1.07</td>
</tr>
<tr>
<td>Wind on Suspended Structure carrying live loads</td>
<td>2.49</td>
</tr>
</tbody>
</table>

4.5 Load Combinations
Four combinations are used and considered and the allowable stress factors are shown in Table 8 below.

Table 8: Combination Loads and Stress Factors

<table>
<thead>
<tr>
<th>8 - Loading Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comb.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>
4.6 Temperature

Changes in temperature can cause large stresses to build up in structures, especially in long bridges like the Severn Crossing. With cold winters and warm summers the temperatures in the area vary significantly from -13.33°C up to 36.67°C, i.e. a total effective temperature of 50°C.

4.6.1 Expansion of the Deck

The thermal expansion of steel is $12 \times 10^{-6}/°C$. Therefore for the 990m deck a change in temperature of $10°C$ will increase the length by:

$$\Delta L = L \times \Delta T \times \alpha$$  \hspace{1cm} (4)

$$\Delta L = 990 \times 10^3 \times 10 \times 12 \times 10^{-6}$$

$$\Delta L = 108\text{mm}$$

However, if there is insufficient room for the deck to expand, the expansion is converted into an additional compression force within the deck. In the case of a slender, aerodynamic deck like that of the Severn Bridge, failure in buckling could occur. In the case of a temperature change of 50°C the deck would have to expand by 594mm. This is a large expansion which would need to be catered for by the expansion joints.

4.6.2 Expansion Joints

The ends of the suspended structure are supported by links hinged to the lower cross member of the tower and to a box member which forms a short end section of the deck. The lateral forces on the deck are transferred to the tower at these points through sliding bearings.

The main span deck is free at both ends and virtually centred between the towers by the inclined hangers. Expansion joints in the deck are provided at each tower. Each joint is designed to take the whole temperature movement between the ends of the main and side spans as well as longitudinal sway under asymmetrical loading and movement due to the end rotation which accompanies lateral and vertical bending.

It must be assumed that any of the expansion joints could become blocked and therefore not be able to take the expansion. The additional compression force that builds up due to this is calculated by Eq. 5 and 6:

$$\sigma_{\text{max}} = \varepsilon \times E$$  \hspace{1cm} (5)

$$N = \sigma_{\text{axial}} \times A.$$  \hspace{1cm} (6)

The compressive strength the bridge would have to carry is:

$$\sigma = \alpha \Delta T E$$  \hspace{1cm} (7)

$$\sigma = 12 \times 10^{-6} \times 50 \times 200 \times 10^3$$

$$\sigma = 120\text{N/mm}^2.$$  

A variation in temperature change is felt through the depth of the deck and therefore the axial force is calculated from stresses at the neutral axis (NA). Assuming the neutral axis is at the centre, the maximum stress can be halved to find the stress at the NA.

4.7 Other Load Effects

There are many other ways in which a bridge may be loaded. Sometimes they have minimal effects, other times they dictate the design.

4.7.1 Stress Relaxation of Steel Cables

Over time steel cables in tension will lengthen and reduce the stress upon them. This can significantly affect the deflections in the deck under loading and could become a serviceability issue over time.

4.7.2 Settlement of Supports

The piers and anchorages are founded on the river bed. The foundations and substructure go deep into the ground to cope with the forces transferred to them. Consolidation of the soil post construction was inevitable. However, it is unlikely that differential settlement will occur due to the nature of the ground conditions and the depth to which the foundations go.

4.7.3 Natural Frequency

Aerodynamic excitation of the superstructure of any type of long-span bridge may cause unacceptable oscillations. There are five distinct forms of excitation – vortex excitation, galloping, classical flutter, stall flutter and gust response. Classical flutter is a serious aerodynamic phenomenon in which vertical and torsional oscillations are coupled and the lift moment on a moving cross-section reinforces the movement. The streamlined boxes of the Severn Bridge are nearly plate-like. Classical flutter is amenable to mathematical analysis for plate-like structures.

4.7.4 Construction Loads

The construction loads were accounted for by the extensive temporary works that were built and discussed in section 3. The temporary works were capable of carrying a truck of 50 tonnes gross vehicle weight.
4.7.5 Stream-flow and Scour from the Severn

The foundations and piers will be subject to loads from the river. The stream-flow will induce a horizontal load on the piers. This has been accounted for by the streamline shape of the piers. The design of the piers is robust to ensure they are massive and immovable in case of impact from floating objects travelling at the speed of the rapid current. The pier top is set at a height above the water level to ensure that the steelwork of the tower is clear of splashing by sea water.

5 Strength

The bridge is constructed out of steel. During the mid-19th century the cost of the production of steel was significantly reduced by the invention of the Bessemer process. In 1865, Siemens and Martin invented the open-hearth process which became extensively used for the production of structural steel. However, it was not until 1879 that clean, high-quality steel was mass produced.

Structural steel gave the structural properties required to produce this innovative design that looks seemingly light and floats across the estuary.

The strength is derived from the parabolic form of the sagging high-strength cable. It is designed so that the shape closely follows that of the moment diagram thus creating a highly efficient structure. The sagging cable performs best under a uniform and symmetrical load. As it undergoes an asymmetrical load the cable deforms to adjust to the load case and thus shifts the rest of the structure. This adjustment causes secondary stresses in the horizontal surface and hence additional deformation.

It is expected that the real strength is higher than the calculated and designed value. Hidden reserves of strength are encompassed within:

1. Average and conservative strength of materials
2. Compressive membrane action
3. Work hardening of steel reinforcement
4. Compressive steel presence
5. Presence of surfacing

6 Aesthetics

When a bridge is observed by a passer-by, a potential user or even an engineer the first glimpse is the most important. Fritz Leonhardt, one of the greatest bridge engineer’s of all time, set out ten rules which he claimed would lead to an aesthetically pleasing bridge. The Severn Bridge will be analysed in accordance to these rules in this section.

The first of the rules states that the bridge should reveal its structure in a pure and clear form. Today, architects and designers have the resources and technology to create innovative and eccentric designs. If however, the bridge doesn’t look structurally stable, that it’s not supported in the correct places; people will be hesitant to use it. The Severn Crossing shows how the function of the bridge is fulfilled by the obvious strength of the main cable. The towers look substantial to be holding the cables and hence the deck. Despite its numerous components required to cross the Severn, the bridge displays beautiful simplicity which is often the key to success. Whether it works like it looks is irrelevant – as long as it looks like it works.

The bridge should also look and be in proportion. It should convey an impression of balance between masses and voids. The towers of the Severn Crossing look adequately spaced. Their thickness corresponds well to the depth of the deck and diameter of the primary and secondary cables. Suspension bridges allow the longest span bridges and looking at this bridge – the longest span of it’s time, the bridge looks beautifully proportioned.

The onlookers’ eye should float across the bridge without interruption. Order of lines and edges is necessary to avoid causing mental disquiet. Here, the eye floats nicely across the bridge. The fascia beams are placed on the outside of the towers and therefore a continuous line is achieved. The hangers down to the deck run parallel and from many angles are invisible providing good order over the whole bridge. The nature of the design almost dictated order as nothing could interrupt the smooth flow of the wind.

Refinement of design is the fourth of Leonhardt’s rules. There are many refinements that can be used to create an aesthetic bridge and each is specific to the structure. As previously discussed, the bridge was not originally designed as a box section but due to innovative engineering and risk this was possible. The towers of the bridge are tapered at the top to save on material and weight of the structure but also to emphasise the slender and sleek properties of the bridge as a whole. The tapered effect was first used by the Greeks to prevent optical illusions.

The remaining of Leonhardt’s rules are integration into the environment, texture, colour, character, complexity and nature. These all integrate with one another and compliment each other on this bridge. For example, texture. The bridge is smooth where people may want to touch it but robust elsewhere. It is primarily used as a transport route and this is reflected in the aesthetics.

The bridge has been painted white and stands out in the estuary. It makes a statement saying ‘look, I’m here’ but at the same time doesn’t overpower the surroundings at all. A local writer at the time said, “In 1966, from the heights of Dean and Cotswold that overlook the Severn Sea a striking new landmark had appeared.”

Tall steel towers and the graceful converging curves of the cables and deck springing across the water were the panoramic views witnessed of the Severn Bridge.
“It so happens that the work which is likely to be our most durable monument, and to convey some knowledge of us to the most remote posterity, is a work of bare utility; not a shrine, not a fortress, not a palace but a bridge.” - Montgomery Schuyler, 1883

7 Intentional Damage

In light of recent terrorist attacks e.g. the World Trade Centre 2001 and the London 7/7 bombings civil engineering structures are drawn to the attention of terrorists. Although no attack has been made on bridges up to now, terrorist threats received by the country say that large bridges are considered as potential targets. Since the crossing has been ‘superseded’ by the Second Crossing its potential to be a target has been significantly reduced as the usage of it has reduced. However, if it were to fail as a result of a terrorist attack and impede the shipping lanes it could be catastrophic for the local and regional economy.

At the time of design ‘blast loads’ are unlikely to have been considered and therefore in the strengthening works still to occur these will be considered. A risk assessment of the probability of the bridge being attacked will determine the likelihood of the blast load test results being applied.

8 Durability and Maintenance

Since the bridge was completed many checks have been carried out to monitor its performance. Strengthening works have taken place since due to the increasing loading.

8.1 Serviceability

As previously mentioned, the bridge opened in 1966 and is still in use. The use of steel was becoming more and more normal and the cost was reducing due to innovative techniques. However, at the time of building the Severn Bridge construction methods, health and safety mandates and general care taken over construction were severely neglected.

Although the majority of post-construction works have been to strengthen the bridge, other changes were made due to the poor quality of work initially carried out on the bridge.

8.2 Post-Construction Strengthening Works

Soon after the Severn Bridge was designed (between 1962 and 1977) there were some major changes in the freight transport pattern. The amount of goods moved by road virtually doubled, the number of goods vehicles with a gross weight of 25 tonnes rose from an insignificant amount to 90,000 tonnes. Because of these increases in loading an investigation was launched into the bridge structure in the 70s and 80s. The strengthening was commissioned by the Department of Transport to carry out an appraisal of the bridge structures and was awarded to Flint & Neill Consultants.

A 120m high tubular column was installed at each corner of the four towers so that 25% of the loading initially in the tower shell was transferred to the foundations via the columns. The inclined hangers were replaced with larger ones to improve the design sockets and the load transfer from the roadway deck boxes to the two main suspension cables. Welds immediately below the wheel tracks had suffered fatigue damage. These were removed and replaced with an improved weld joint. A lower horizontal portal connects the ends of the deck boxes at the towers to the towers. One end of a vertical beam is attached to the end deck box and the other to the portal.

Modified bearings replaced the original bearings at each end of the beams. Movement of the roadway deck caused rotation about the longitudinal and transverse axis and the new bearings allow for this. The complete crossing was resurfaced with a waterproof membrane bonded to the steel deckplate and covered with mastic asphalt in order to act in composite action with the steel deck plate helping to distribute vehicle wheel generated stresses.

8.3 Future Changes

There are not any current plans for the Severn Crossing. However, it is constantly being monitored and general maintenance has been carried out as on all bridges.

The future of the bridge is uncertain. Since the construction and opening of the second crossing the Severn Bridge does not get used as much. However it will probably stay there and stay in use because there’s nothing else that can be done with it! Service stations in the area have already closed down, as have view points.

9 References

[1] 40th Anniversary of the Severn Bridge, Available at www.bbc.co.uk/news

10 Bibliography