THE TAMAR BRIDGE

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Abstract: This article provides a critical case study of the Tamar Bridge, a suspension bridge located in the South West of England spanning the River Tamar. This article analyses the bridge in terms of aesthetics, loading including temperature and wind effects, construction, and widening and strengthening.

Keywords:
Steel Orthotropic Deck
Suspension Bridge
Truss Deck
Cantilever Lanes

1 General Introduction

The Tamar Bridge is a major road bridge in the south west of England, as its name suggests it spans across the River Tamar between the city of Plymouth and the town of Saltash. These conurbations are located in the counties of Devon and Cornwall respectively. It is a suspension bridge completed in 1961 which at the time was the longest suspension bridge in the United Kingdom. Recently the bridge has been the subject of a multimillion pound strengthening and widening project, that has won world renown for its innovation.

2 Location

The bridge carries the A38 over the Tamar River between the city of Plymouth and the town of Saltash. The bridge runs parallel to the famous Royal Albert Bridge, which was built by Isambard Kingdon Brunel in the 1850’s and regarded as one of his greatest railway bridges. It is worth noticing that the Tamar valley and estuary makes up part of the Tamar, Lynher, and Tavy Valley Area of Outstanding Natural Beauty, one of the country’s thirty seven locations.

The Tamar Bridge spans the border between the counties of Cornwall and Devon in the extreme south west of England. Cornwall is large county covering some 3563 km², but one that has a low population density of only 144 people/ km². The county is recognised for its wild moor land landscapes, varied and extensive coastline and beaches along it, and its mild climate. Also notable is the world heritage status for the counties mining heritage. Recent decades has seen a decline in many of the industries that have supported the county such as mining, fishing and agriculture leaving Cornwall one of the poorest areas in the country. Tourism now forms the major sector of the economy, with the majority of visitors coming from...
within the UK itself. This means that the road links are very important in sustaining the county, and there are only two major links the A30, subject of major improvement works, to the North, and the A38 which runs across the Tamar Bridge. It is clear then the importance of bridge to the county of Cornwall and its economy. Devon is also a very large county, ranked 4th largest in the country with a population of 1 109 900 again this county has a low population density and is mainly rural. The county has two major cities Exeter and the port city of Plymouth. As with Cornwall tourism forms a large part of the economy with the county having such assets as the Dartmoor and Exmoor national parks, the Jurassic coast and many historic towns including Plymouth.

Plymouth is a city with approximately 246 100 (2005 estimate) inhabitants. The city itself is located at the mouths of the rivers Plym and the Tamar, which form one of the world’s best natural harbours, Plymouth Sound. Because of this the city has a long and distinguished maritime history, most notably for the location from which Sir Francis Drake finished playing bowls before sailing to defeat the Spanish Armada in 1588, also it is the location from which the first pilgrims left England for the Americas in 1620 on board the famous ship the Mayflower. More recently the city was used as one of the staging posts for the Normandy Landings in 1944; indeed a site located directly below the Tamar Bridge was used as an embarkation point for US troops prior to the invasion. The city centre is currently undergoing a multi million pound regeneration scheme which was launched by distinguished architect David Mackay. This scheme requires demolition of many eye sores in the city centre, such as the old Drake Circus shopping centre and the Charles Cross car park and completely replacing them by 2020. Plymouth is a massive economic centre especially in an area which relies heavily on the tourist trade, and would also contain the vast majority of the industries that would have and still employ large amounts of people. The Navy are probably the best example in the area since they maintain a large dock complex at Devonport (located in the estuary on the Devon side of the river).

The town of Saltash has a population of approximately 16 000 people and is known as “the gateway to Cornwall”. The town is located literally at the end of the Tamar Bridge and the Royal Albert Bridge as shown by the map in Fig. 1.

3 Why it was built

Before the construction of the Tamar Bridge in 1961 there was no southerly crossing of the River Tamar for drivers. If people wanted to get to the city of Plymouth from the town of Saltash on the western bank, a journey which is made by a great many people who are employed in Plymouth, they had to either travel north on a long detour to the village of Gunnislake or travel even further north to the land link between the two counties. The main problem with the Gunnislake link is not only the distance people are required to travel to the north but also that the Gunnislake New Bridge is a seven arched granite bridge built around 1520, unfortunately it can accommodate only one lane of traffic so has very limited capacity (see Fig. 2).

In addition to these two road links between the two urban areas is the Torpoint Ferry located just downstream of the Tamar Bridge however this also has limited capacity. It is worth mentioning that the management of the ferry and the Tamar Bridge is joint, so that they are not in direct competition.

4 Description

4.1 General Description

The Tamar Bridge was the first major suspension bridge to be constructed in post Second World War Britain and was the longest bridge of its type in the country at the time. It carries the A38 road that runs from Bodmin in Cornwall to Mansfield in Nottingham. The bridge deck carries five lanes of traffic, three on the original deck and 2 additional lanes that have been added recently. The three original lanes are used for A38 traffic whilst the fourth takes eastbound traffic only with the fifth being reserved primarily for pedestrians and cyclists.

The following Figures give a series of views of the bridge. Fig. 3 shows the Tamar Bridge from the eastern bank also in this photograph the Royal Albert Bridge running parallel to the Tamar Bridge and the proximity of the two structures.
4.2 Construction

The idea for a bridge across the Tamar was first conceived in 1823 but it was dismissed at this time for being too expensive and impractical for the time. In 1924 the idea was raised again due to increasing traffic levels on the Torpoint and Saltash ferries, however although plans were apparently made nothing was done at this time. Then in 1950, Cornwall County Council had a conference with the Plymouth authorities about the construction of a road bridge. However the government of the time was not in support of the idea because they deemed it to be uneconomic, especially in post war Britain where large parts of the country had to rebuilt after German bombing. The two councils decided to pay for it themselves, the money has since then been earned back through the use of toll booths on the Devon bank. Invitations to tender went out on March 4th 1959, with a deadline of June 9th set for applications. Ten days after this deadline it was announced that the lowest tender had been accepted that of the Cleveland Bridge & Engineering Company, based in Darlington. Work started very quickly on the 7th of July 1959 with the Navy giving up land on the Plymouth bank and permission to construct piers in the channel, and Saltash Council giving over buildings to be demolished for the approach road and abutments on the Cornish side.

The Cleveland Bridge & Engineering Company were created in 1877 and are responsible for many of the countries most iconic bridges and structures including the Humber Bridge, Tyne Bridge, Forth Bridge, and the first Severn Bridge with its pioneering aerofoil deck.

The Tamar Bridge consists of two reinforced concrete towers both 67m high founded in the channel. There is one central span between these two towers that measures 335m and two side spans which both measure 114m in length, this brings the total span of the Tamar Bridge to 563m, and this layout is shown in Fig. 3. The deck itself was originally constructed from reinforced concrete with a steel truss approximately 5m deep forming the substructure, however due to extreme degradation this was replaced by orthographic steel plates. The deck now contains 82 of these plates each weighing 20 tonnes (20 x10^3 Kg) and measuring 6m by 15m. To support the deck there are two parallel cables with 44 steel hangers connecting to the deck, 10 connecting to each of the side spans and 24 to the central deck. The cables are not fixed at the top of each tower but are anchored at there ends, thus allowing the towers to be kept relatively slender, see Figs. 5, 6. As previously mentioned the widening and strengthening works (to be detailed in a following section) included the installation of 18 new diagonal cable stays connecting the newly widened deck top the towers clearly shown in Fig. 6 which effectively make the bridge into a hybrid between cable stayed and suspension.

4.2.1 Construction Method
The Tamar Bridge was most likely constructed by the method of suspended construction. This method involves the hanging of the deck elements from either temporary or permanent cables. Many large suspension bridges have been constructed using this method most notable include the Brooklyn Bridge, The Clifton Suspension bridge and the Severn Bridge. The latter was constructed by the same company that built the Tamar Bridge so it is reasonable to assume that this was the used method. The first step in suspended construction is to spin the cables up over the two reinforced concrete towers, then the hangers are attached to this cable and finally the deck sections are lifted most likely from a barge on the river. The first sections lifted into place are the central pieces, this creates a large dip in the cable but as more sections are added the deck assumes its final profile and requires only minor adjustments to its levels.

4.3 Aesthetics

There are many different methods used to analyse the aesthetic appeal of a bridge, mostly because it is a subjective process. The analysis that follows utilizes the ten rules of bridge aesthetics set down by world famous bridge designer Fitz Leonhardt and they are my interpretation of these rules. The areas identified were as follows:

1. Fulfilment of function
2. Proportions of the bridge
3. Order within the structure
4. Refinement of design
5. Integration with the environment
6. Surface texture
7. Colour of components
8. Character
9. Complexity in variety
10. Incorporation of nature

The first area is that of function, this means that a bridge should give the user clear understanding of how it works structurally, thus imparting the feeling of stability. The Tamar Bridge fulfils this to an extent by being a suspension bridge which are generally understood by the public (they know the cable supports the bridge). However the new cantilever sections that were added during the widening and strengthening works do not adhere to this, as Fig. 7 shows the new cantilever lanes seem incredibly thin and unsupported in comparison to the main deck which is the larger truss shown in the Fig. 7. It would appear that they were deliberately kept as light as possible to keep the extra load applied to the bridge to a minimum and equally important this can only really be identified if you are approaching or below the bridge.
deep. The cantilever lanes that were added have helped to reduce the visual impact of the truss by causing the truss structure to be shaded and the fascia beam to stand out.

Rule number three concerns order, in that there should be order in the edges and lines of the bridge. The Tamar Bridge has poor order for several reasons. Firstly the widening and strengthening work included eighteen new diagonal cables running from the tower to the deck. Which considering that all the original hangers are vertical, gives a cluttered appearance to the towers as shown by Fig. 8. Secondly as previously mentioned the deck is supported by a truss, which unfortunately never give the impression of being ordered. However these points aside it is clearly noticeable that along the length of the bridge there is a clearly defined fascia beam (see Fig. 3) which on the approach to the bridge does give a strong sense of order, this image however is broken when you get closer.

The fourth rule set down by Leonhardt is the refinement of the design; this is more concerned with little pieces of design that make the bridge aesthetically pleasing e.g. using tapered columns. In the case of the Tamar Bridge there is very little evidence of this sort of refinement this maybe due to the fact that it was the first major suspension bridge to be constructed in the UK and therefore more emphasis may have been put on ensure structural stability than on aesthetics.

Next on Leonhardt’s list is integration with the environment. This is usually taken to mean choosing an appropriate bridge type for the location. The Tamar Bridge is a suspension bridge which looks the right type in river valley terrain. The colours of the Tamar Bridge are also very similar to Brunel’s Royal Albert Bridge that runs parallel to it, namely grey steel with dark stone/concrete, see Fig. 4. This scheme of materials and colours may have been selected to integrate with the main industry in the area, which is the navy (Devonport Docks) and the grey of the ships. This also applies for Leonhardt’s sixth point which concerns the use of colour in creating appearances.

The last three of Fitz Leonhardt’s ten considerations for aesthetics in bridge are as follows; character, complexity, and finally nature. Character is one of those undefined qualities that make something special. As someone who lives in Cornwall I can say that the bridge does have a certain piece of character because it symbolises the crossing from the rest of the country into the county which still maintains a strong identity and enmity for Devon. However this is more to do with its location than the actual bridge design.

Complexity can be viewed in two contradictory ways firstly having a complex structure can be visually interesting or on the other hand keeping a bridge simple can also create visually pleasing structures. It can be said that the Tamar Bridge has a very complex truss structure that makes up the bridge deck which adds nothing to the elevation of the bridge. But the view of the underside...
along the banks of the River Tamar on both sides, is a lot more effective than just a plain surface, as shown by Fig. 9 below. The truss members create a series of ribs running the entire span of the bridge causing a sequence of light and dark areas between them.

The final of Leonhardt’s aesthetic considerations is the incorporation of nature into the design; it is difficult to find any evidence of this in the Tamar Bridge design.

4.4 Loading

When the bridge was designed and constructed in 1961 the average number of vehicles using it a day was only 4000. This had dramatically increased to an average of 38 200 each weekday with the hourly rate in the morning rush hour being around the 2500 mark Ref. [1]. In the summer months these figures increased with the weekday flow being in the region of 42 900 vehicles, this is because of the major pull of the region to tourists especially those seeking summer holidays. When designed the concrete deck had been capable of carrying vehicles up to 38 tonnes (38 x10^3 Kg), however when a review of the bridge was carried out in the late 1990’s it was found that the bridge would not be able to support the 40 tonnes required by a new European Union directive. Rather more worrying was the fact that the concrete deck had degraded so much that the capacity was at risk of being reduced to an impractical 17 tonnes.

4.1 Dead & Traffic Loading

The deck is made out of steel plates approx 20mm thick with stiffeners and a standard road pavement on top at a thickness of approximately 200mm thick. The truss that supports the deck is estimated at being 5m deep and having members of approximately 250mm thick. From these assumptions the dead load of the bridge deck can be estimated.

**Black top** – Depth ~ 200mm, Density = 2400 kg/m^3, Volume = 2.02 x10^3 m^3, Weight = 4.8 x10^6 Kg

**Deck** – Thickness ~ 20mm, Density = 7850kg/m^3, Volume = 1.126 x10^3 m^3, Weight = 8.839 x10^6 Kg

**Truss** – Depth ~ 5m, Density 7850 kg/m^3, Volume = 844 m^3, Weight = 6.625 x10^6 Kg

**Cantilevers (Deck and Black top only)** – Width ~ 4m, Black top weight = 2.24 x10^6 Kg, Steel weight = 7.071 x10^6 Kg

Therefore the total dead load will be in the region of 27.33 x10^6 Kg which can be equated to 273.3 x10^3 kN. This can then be converted to a Uniformly Distributed Load (UDL) by dividing by the area of the deck which is 10 x10^3 m^2. Therefore the UDL dead will be 27.33 kN/m^2. This load can be compared to the original deck which weighed 25 tonnes less than the modified bridge structure; this will give a minor reduction in the UDL to 27.30 kN/m^2, which considering that two extra lanes have been added is an achievement in itself.

In addition to the dead load there are many other load cases that are applied to bridges when they are designed. These loads are mainly to do with traffic and the various effects linked with moving vehicles. HA loading for the Tamar Bridge is 9kN/m and there are 5 notional lanes this means that there is a UDL of 2.5kN/m^2. In addition to this there has to be a HB loading applied to the bridge in the location that will give the worst loading effect. For the Tamar Bridge this location is most likely to be one of the cantilever lanes or more likely one of the outside lanes on the main deck, this is because Abnormal loads will not fit on these lanes or if failure did occur of one of these lanes the bridge would not collapse, rather the cantilever would probably separate from the main structure. There are many other load cases that need too be applied to the bridge to analyse it fully these include the placement of Knife Edge Loads (KEL) at worst case points, 120kN at the centre of the bridge, horizontal centrifugal loading (F_c = 200kN, with an associated vertical load of 300kN). Other loads include the braking of trucks, skidding loads, and collision loads.

4.4.2 Wind Loading

The United Kingdom is well known for being the windiest country in Europe, the reason behind this reputation comes from the maritime climate in which the country finds itself. For strong winds there must be a long clear distance for them to be able to blow, in other words no land mass to deflect the wind. This is certainly the case in the South West where winds can blow in off the Atlantic Ocean. In order to calculate the lateral wind load acting on the Tamar Bridge we must first calculate the maximum wind gust $V_c$ which strikes the bridge this is found using the equation Eq. (A),

$$V_c = v K_1 S_1 S_2.$$  

<table>
<thead>
<tr>
<th>Table 1: Max Wind Gust parameters</th>
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<tbody>
<tr>
<td>$v$</td>
</tr>
<tr>
<td>$K_1$</td>
</tr>
<tr>
<td>$S_1$</td>
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<tr>
<td>$S_2$</td>
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</tbody>
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Where $v$ is the mean hourly wind speed which for the location is 30m/s, $K_1$ is the wind coefficient quoted in British Standard (BS) 5400 as being 1.36 (for a length of approximately 600m and a height of 20m).
$S_1$ is the funnelling factor usually quoted as 1.0 unless the bridge is located in a deep valley or urban environment, for this case we will use 1.0, and $S_2$ is defined as the gust factor again given by BS 5400 as being 1.13. The maximum wind gust is therefore 46.104 m/s. This can then be used to calculate the horizontal wind load acting on the centroid of the part of bridge under consideration; this is given by Eq. (B),

$$P_t = q A_1 C_D$$

**Table 2: Horizontal Wind Load Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$q$</td>
<td>0.613 $V_c^2$</td>
</tr>
<tr>
<td>$A_1$</td>
<td>402 m$^2$</td>
</tr>
<tr>
<td>$C_D$</td>
<td>1.8</td>
</tr>
</tbody>
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In this equation the letters represent the following; $q$ is defined as the dynamic pressure head see Eq. (C),

$$q = 0.613 V_c^2$$

For this case study $q = 1.303 \times 10^5 \text{ N/m}^2$. $A_1$ is the solid projected area on which the wind load acts, to approximate this area is 20% of the total area of the truss which is 201,000m$^2$ in the central span, meaning that therefore the solid area is 402m$^2$. Finally $C_D$ is the drag coefficient calculated from the solidity ratio (20%) for trusses and using BS 5400, this is equal to 1.8. Therefore the horizontal wind load acting on the central span is Eq. (D);

$$P_t = 1.303 \times 10^5 \times 402 \times 1.8$$

$$P_t = 942.85 \times 10^3 \text{ N}$$

Using the same method the horizontal wind load on the two identical side spans is 320.85 $\times 10^3$ N.

When considering wind load conditions it is crucial to consider the uplift force generated by wind or similarly the opposite effect which is the downward force. This is calculated using the equation Eq. (E),

$$P_v = q A_3 C_L$$

**Table 3: Uplift Load Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q$</td>
<td>0.613 $V_c^2$</td>
</tr>
<tr>
<td>$A_3$</td>
<td>6030 m$^2$</td>
</tr>
<tr>
<td>$C_L$</td>
<td>0.4</td>
</tr>
</tbody>
</table>

These symbols represent the similar factors to those mentioned above except that $A_3$ is the plan area. For the central span of the Tamar Bridge $P_v = 3.143 \times 10^6$ N which as can be clearly seen is a lot bigger than the horizontal forces generated by wind.

### 4.4.2 Temperature Effects

The south west of England is well known for its high summer temperatures and it is also well documented the effects temperature changes can have on bridge structures. The first step in analysing these effects is to identify the maximum and minimum temperatures in the region, using isotherm maps of the British Isles the max temperature in the Tay valley region is 33°C and the minimum can be identified as -12°C. Secondly the cross section of the deck must be analysed in order to locate the centroidal axis and the materials identified. The deck is a steel deck on a steel truss. It seems reasonable to assume that this is at approximately 2/3 of the way up from the bottom face. Using this assumption values for the axial stress and bending stress can be calculated. Eqs. (F,G) are the equations for the max strain in the deck and the max stress respectively.

$$\varepsilon_{\text{max}} = T_1 \times \alpha$$

($T_1$ is max temp, $\alpha$ is thermal coef)

$$= 33 \times 12x10^{-6}$$

$$= 396x10^{-6}$$

$$\sigma_{\text{max}} = \varepsilon_{\text{max}} \times E_{\text{steel}}$$

$$= 396x10^{-6} \times 200x10^6$$

$$= 79.2x10^3 \text{ N/mm}^2$$

Therefore $\sigma_{\text{axial}} = 52.8x10^3 \text{ N/mm}^2$, $\sigma_{\text{bend}} = 26.4x10^3 \text{ N/mm}^2$, and $\sigma_{\text{bend}} = 52x10^3 \text{ N/mm}^2$.

The stress profiles are shown in Fig. 10.
4.5 Susceptibility to Intentional damage

In today’s climate terrorism is a major world issue. A problem that can be identified with the Tamar Bridge is the ease at which access can be gained to the abutments, underside of the deck, and the anchors for some of the main cables; this could leave it vulnerable to intentional damage such as a terrorist attack. This area could be a potential target due to the large naval presence in the area; the east abutment sits on Admiralalty land consisting of a major ammunition store for warships. Access is very easy because a road runs under the bridge on both banks and the proximity of the bridge to the town of Saltash. Current security measures consist of fencing around the abutments and cameras on the Devon side where the maintenance machinery is located. There is however a daytime presence at the bridge again at the Plymouth end, due to the presence of the toll booths, and bridge office, which may help to reduce any intentional damage especially vandalism but would not be enough to stop determined individuals. Further issues may arise with the fact that one of the new cantilever lanes is reserved for pedestrian use and the fact that the barriers are open and fairly low there could a potential suicide issue along with vandalism to the structure of the bridge. The final issue that may arise is damage to the tower bases which are founded in the Tamar River. This most likely will be from boats, which frequent the channel, colliding with the bases. However these are liable to be only light vessels and the bases are protected to some extent by what looks like masonry cladding as shown in Fig. 11.

5. Strengthening & Widening

Between 1995 and 2000 the European Union brought out a new directive stating that all bridges must be capable of carrying of carrying lorries up to 40 tonnes (40 x10^3Kg). A review was carried out on the Tamar Bridge and it was discovered that the reinforced concrete deck had degraded so much that the capacity was in danger of being reduced to 17 tonnes (17 x10^3Kg). It was thought that a reduction of this magnitude would severely affect the economy of the local area, for example commercial traffic would have to travel the long journey north to the land link between Cornwall and Devon. The cost of building a new crossing was estimated at a minimum of £300 million pounds, and once a viable scheme to strengthen the bridge was proposed this idea was dropped. The major problem with any scheme proposed for the Tamar Bridge was the fact that
closing it for the duration of works was not a viable option. This was because the bridge was used by in excess of 40,000 vehicles a day and with no real diversion option it is clear why closing the crossing could not be considered. The solution that arose was to add two cantilever lanes to the bridge, on each side to carry the traffic whilst the deck was completely replaced. On completion of the strengthening work in 2001 it was decided to make these two lanes permanent additions to the bridge. The traffic flow on the bridge did not increase as a result of this extra capacity because of the regulatory effect of the Saltash tunnel, which is located approximately a mile west of the bridge.

Hyder Consulting Ltd. were the main designers of the widening and strengthening works with the main contractor being the Cleveland Bridge UK Ltd., who were the original company who built the bridge in 1959-61. The cost of the works came to £34 million; a fraction of the £300 million predicted for the cost of a new crossing, this money was generated from the toll that exists on motorists wishing to cross the bridge. The project began in 1999 and was completed one month behind schedule in December 2001. This delay was caused mainly because of the Total Solar Eclipse in August 1999, which saw Cornwall as one of the very few places in the path of the totality, consequently thousands of tourists travelled to the county. Also exceptionally bad weather in the winter of 1999/2000 did not help.

5.1 How it was Strengthened & Widened

The original concrete deck was completely removed and replaced with an orthotropic steel deck. An orthotropic is a deck formed from steel plates supported by transverse or longitudinal stiffeners. These stiffeners allow the deck to both contribute to the bridge’s overall structural behaviour as well as bearing directly vehicle loads. A steel deck is much lighter than a reinforced concrete deck, up to 25% in some cases, which allows this reduction to be passed throughout the bridge to the cables, piers and anchorages. The stiffeners serve several simultaneous functions. Firstly the increase the bending resistance of the plate thus allowing it to carry local wheel loads to the main structure. They also increase the overall cross-sectional area of the plate which in turn adds to the overall capacity of the deck and finally the stiffeners increase the plate’s resistance to buckling. Very large suspension bridges would not be possible without steel orthotropic decks, for this reasons thousands of this type of deck are in existence around the world, however the United States has only sixty of these, the majority in California including the San Mateo-Hayward Bridge. This unpopularity especially in the US is mainly due to their fabrication costs, a process which involves a large amount of welding. Furthermore they must be prefabricated and transported to site, which means they are less flexible in their use than reinforced concrete. The plates for the Tamar Bridge were prefabricated at the Cleveland Bridge UK in Darlington and transported nearly 400 miles to the site. The other problem that can exist with steel orthotropic decks is fatigue and to delamination of the wearing surface which, like the deck is often slim to reduce weight.

The first step to the widening and strengthening program was to fit the cantilever lanes to the sides of the deck as shown by Figs. 12, 13, 14 below. These were connected to both sides simultaneously time starting from the abutments and working towards the centre of the span in small segments approximately 10m in length, using cantilever gantries mounted on the main deck as shown in Fig. 13. To support these new lanes new diagonal cables were added to the bridge. These numbered 18 in total and they have unique anchorage systems which allow them to be tightened or if needs much loosened as shown by Fig. 14. Fig. 14 shows a diagonal cable anchorage on the western Saltash side span pier. The bridge remained open throughout the project and the flow of 40,000 vehicles a day over it was maintained although some tailbacks did occur. The final structure despite having two additional lanes only weighed 25 tonnes (25 x 10^3 Kg) more than the original.

Figure 14: Close up of Cantilever deck sections

Figure 15: Cable anchorage western side span pier
5.2 Worldwide Recognition

The Tamar Bridge was the world’s first suspension bridge to be widened using cantilevers, and additionally the world’s first to be done so whilst remaining open to traffic. For these reasons the project won many prestigious awards, including the British Construction Industry Award 2002, (Ref [1]) considered one of the highest honours in the industry, and the Historic Structures category (30 years or older) of the Institution of Civil Engineers Awards 2002. In addition to these awards the bridge was selected as one of the eight finalists for the Prime Ministers Better Public Building Award 2002. The Tamar Bridge strengthening scheme has also attracted the attention of New York engineers who are looking to improve their own suspension bridges. The city has thirty eight major bridges including the Brooklyn, Manhattan and George Washington bridges and the city’s chief engineer Moreau has been to visit the Tamar Bridge site with a view for using the same type of technology on their aging bridges Ref. [2].

6. Durability & Serviceability

The original deck could not have been very durable at all considering the extreme degradation of the reinforced concrete that occurred in the period 1961 to 1998, whether this problem occurred due to bad design or bad workmanship is unknown, it could even be down to the climatic conditions and that this would occur was known to an extent. The improvements made to the deck and the use of orthotropic steel plates should increase the bridge’s durability and they defiantly help increase the bending capacity of the bridge. In addition the stiffening members will help to stiffen the entire deck reducing vibrations and other unwanted effects thus keeping the bridge within serviceability limit.

7. Future Changes

There are several future changes that could change the Tamar Bridge. These changes are unlikely to be structural or involve widening the bridge, because the bridge has recently (2001) undergone an expensive widening and strengthening scheme. However if the volume of traffic dramatically increases from the current levels (~ 40 000 vehicles per day) then the use of the lanes may have to be altered, for example the pedestrian lane that exists at the moment may well become a traffic lane, even if it is at rush hour only. Other problems that could arise in the future could be related to the degradation of the reinforced concrete towers as with the degradation of the reinforced concrete deck, which had to be completely replaced. Although replacement will no be an option with the towers strengthening may be required, this may be achieved using fibre reinforced plastic wraps or other similar materials. Corrosion of the steel components, most notably the main cables and the truss which were not replaced in the strengthening works, of the structure will always be a problem especially in coastal areas where there is a high salinity, therefore these components will need constant maintenance and monitoring to insure they do not deteriorate to such an extent that the capacity of the bridge is reduced. Strengthening will only take place again if the weight of lorries rises significantly from 40 tonnes (40 x10^3 Kg), then most the most likely course of action will be to survey the bridge again and then carry out a cost benefit analysis on whether further strengthening is a viable option. The diagonal cables that were fitted to the bridge are able to compensate for minor changes in the loading or load distribution on the deck because of there anchorages, as previously mentioned see Fig. 15, so for the foreseeable future these should not need to be altered, or indeed should any of the structure.

8. Acknowledgements

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9. References

http://www.parliament.the-stationery-office.co.uk/pa/ld199798/ldselect/ldtamar/129/12903.htm

http://news.bbc.co.uk/1/hi/england/1742142.stm