A CRITICAL ANALYSIS OF THE FORTH RAIL BRIDGE, 1890 SCOTLAND

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Abstract: The following paper analyses the design and the construction of the Forth Rail Bridge in Scotland. The Forth Rail Bridge is one of the most iconic bridges in engineering history and great interest to engineers. Other considerations in this paper include the aesthetic quality of the bridge, the maintenance of the bridge today and the future improvements to the bridge.

Keywords: Forth rail, cantilever, steel, suspended span, Scotland

Figure 1: The forth rail bridge

1 Introduction

The Forth Rail Bridge is considered to be one of the most recognisable bridges in the world and greatest engineering feats of its time. It was the first bridge in Britain to be built entirely out of steel and also the longest single-span bridge at the time of completion. The bridge was built out of the necessity to enable trains access to Northern Scotland across the Firth. Various engineering challenges were associated with the crossing of the Firth and several proposals were presented such as tunnels, roads and railways and also methods to improve the ferry landings at the time. In 1873, Sir Thomas Bouch designed a double span steel suspension bridge. The bridge construction had already begun in 1879 when the Tay Bridge fell and the proposal was then abandoned. In 1881, Sir John Fowler and Benjamin Baker brought forward the proposal for a cantilever bridge. After the disaster of the Tay Bridge, the Board of Trade felt it was necessary to have a design that induced a feeling of safety and confidence in the public using it. Cantilever bridges had never been built in Britain before and although they had been built in the Far East, the spans

Figure 2: Location of forth rail bridge
involved were much smaller than the lengths proposed for the Forth. Thus this design was met with much speculation. Steel was a fairly ‘new’ material in Britain and its use was limited due to engineers’ hesitations about its brittleness in comparison to wrought iron. However, steel was an attractive material for use in long spans due to its ability to carry 50% increased working stresses. After much careful consideration, work begun on the Forth in 1883 and it was completed in 1890.\[1\]

Before the bridge was built, this area of Scotland was suffering from economic stagnation due to the inefficient transport between the two shores of the Firth. Today the bridge allows the crossing of trains directly from the South into the North of Scotland connecting the two shores and promoting economic growth.\[2\] Even 120 years after its completion the bridge stands tall as a proud monument to civil engineering and serves as a thoroughfare for nearly 200 trains a day.

2 Aesthetics

The aesthetics of a bridge is a very subjective matter that varies from person to person. It is difficult to determine what makes a bridge beautiful. Despite this subjectivity, Fritz Leonhardt developed the 10 rules of aesthetics which are essential to the design of a bridge: fulfilment of function, proportions, order within the structure, refinement of design, integration into the environment, surface texture, colour of components, character, complexity in variety and incorporation of nature. It is not necessary for a bridge to fulfil all of these requirements to be an aesthetically pleasing bridge.\[3\]

The Forth Rail Bridge clearly fulfils its function of providing a link which trains may use to cross the Firth. The structure of the bridge is obvious in that the main cantilever towers support the suspended span in the middle.

The bridge is well proportioned due to the whole span of the bridge being equally divided by the towers and cantilevers. The bridge is completely symmetrical which adds to its visual attraction. Even though the depth of the bridge is quite small compared to the overall length it does not seem disproportionate and rather looks more stable. The elements of the truss frame that provide the lateral and vertical stability to the towers are in proportion to one another and the bracing behind the main elements does not detract from the visual appeal of the main frame.

Order is hard to accomplish in truss bridges due to the presence of many elements. However in this case the structural members and the bracing of the towers were designed while taking order into consideration. The elements of equal length running in one direction are ordered well and when looking at the bridge straight on a clear ordered structure can be seen. The bracing and smaller elements are not seen and what is achieved is a very clean elevation of the bridge.

This can be seen in Figure 3. However, this view is not something that can be seen from every angle. At oblique angles the smaller elements can be seen and they detract from the main elements of the bridge. Even though aesthetically speaking they may look rather messy, order can be seen in the arrangement of the elements (Figure 4).

![Figure 3: View of the bridge head-on](image3)

The use of the colour red is effective as this leads to the perception of the bridge exuding strength and adds to the character. The colour also forms an effective contrast with the river below and the hills in the background thus highlighting it and its domination over the once unachievable task of crossing the Firth. This adds to the perception of the bridge being a symbol of strength and stability.

![Figure 4: View from the internal viaduct upwards](image4)

Due to its enormous size the bridge has plenty of character and the large structural members promote the feeling of safety in the bridge.

Refinements have been carried out in the approach spans of the bridge where the supporting columns have been tapered to prevent them from looking wider at the top. As the slope of the ground to the water’s edge is very small, the equal spacing of the columns does not diminish the aesthetics of the bridge.
The vertical columns of the tower are straight when viewed from the side but when seen from the front slope inwards at a rate of 1:7.5. This is due to the use of the effect of the Holbein straddle. A German artist Hans Holbein painted men’s feet with a straddle giving the impression of great stability. This same concept was used in the design of the towers giving the structure harmonious and simple lines and creates a perception of great stability and resistance to wind pressure.

![Figure 5: Forth rail bridge at night](image)

The Forth Rail Bridge is a beautiful landmark that depicts the advance in the engineering industry in the 19th century.

3 Key Aspects of the Bridge

3.1 Location and Geology

The location on which the bridge stands today was determined by the amount of headroom required by ships navigating the Firth and also by judgement of the levels of the ground on both shores. The Firth only contracts at this location in its whole length, the width being just over 1600m at this point and at least 3200m elsewhere.

The rocky headland projecting south from the Fife shore was a good source for building material and a perfect shelter for unloading vessels which is ideal during construction. South of the headland, at a distance of about 540m the Inchgarvie Island exists. This island is formed from whinstone rock which extends halfway through the south channel of the Firth and then disappears. A deep layer of hard boulder clay continues to cover the south channel and rises at the edge towards the shore at a gentle slope. Freestone ledges are formed as the clay disappears half way up the slope. Therefore, the rock provides perfect ground conditions for the foundations of the three cantilever towers.

The north and south towers are approximately equidistant from the central tower so that there are two equally long spans. The depth of both channels exceeds 60m. There were no problems encountered for the ground conditions for foundations of the approach spans. Overall, it was incredible that the geological conditions of the site were not troublesome. Given these considerations it made perfect to choose this location for the bridge. [4]

3.2 Material

During the period in which the Forth was being designed steel was a relatively rare material to be used for the construction of a bridge. Steel was more brittle compared to wrought iron which caused engineers to have reservations about its use. Given that steel was a considered a new material, knowing its chemical composition was insufficient and physical testing on the material would be needed to deduce its mechanical properties. Steel was an attractive material for the use in long span bridges due to its ability to withstand 50% increased working stresses compared to wrought iron. This increased strength is due to the presence of carbon in the steel which makes it harder than wrought iron. Baker and Fowler approached the Board of Trade to propose the allowable working stress in the steel to be 25% of the ultimate stress. The Board accepted this and did not apply any further regulations on the differentiation between tension and compression members, the effects of live load or dead load independently or applied together. Thus Baker and Fowler had to develop the design rules for working stresses using careful experiments and thought. [1]

3.3 Foundations

Each tower comprises four vertical columns each of which is supported by a circular granite masonry pier. Each pier is constructed to a height of 5.5m above the high water level. The foundations were placed at points on the riverbed where there was either hard whinstone rock or hard boulder clay. These geological conditions were suitable for the withstanding of heavy loads without settlement. Also, this prevented the need for high air pressure to be used to keep the water out of the caissons during construction. [4]

![Figure 6: Caisson at south main pier](image)
3.4 Cantilever Towers

There are three double cantilever towers in the structure which support two central connecting girders between them. A cantilever is projected from each side of the cantilever tower which is supported by four circular masonry piers. The north and south tower have additional support as their ends rest on the cantilever end piers. Since the central tower does not have this additional support the base of the tower is made nearly twice the width of the others. [4]

Almost identical, the only difference between the North and South towers is that their outer cantilevers are reversed. The six cantilevers are all completely identical in length, height and width except for the arrangement of the end-posts and the two outer fixed cantilevers which are heavier in construction. Each cantilever consists of a tension member at the top and a compression member at the bottom. Six pairs of cross-bracing on either side brace these members together. One end of the cantilever is closed by the vertical column and the other by the end-post. [4]

Each pair of cross-bracing consists of a strut and a tie i.e. a compression and tension member respectively. Their intersections are stiffened by strong gusset plates and other stiffening methods. From these intersections vertical ties which are lattice girders are attached to the bottom members. This is done to relieve the bottom compression members of deflection between the junctions. Twelve sets of horizontal diagonal cross-bracing connect the bottom members together. The internal viaduct is supported by trestles and cross-girders which also connect the bottom members. [4]

The bottom horizontal members, the vertical columns and the struts in the cantilevers had to be of a tubular section as weight for weight this section gave the maximum strength obtainable. This is due to the absence of sharp edges where fatigue and hence failure may occur due to local stress concentrations. Curved surfaces are less prone to buckling. The tension members at the top and the inclined tie members in the cantilevers throughout the bridge are open lattice girders. [4]

The bottom member of the cantilevers is not one continuous tube but of a polygonal form made of six straight tubes bolted together. This is not only because a straight tube has higher strength but also because by having this design the construction of the bottom member is simplified. The top member is one continuous lattice girder that decreases in cross-section in the direction of the end-post of the cantilever. [4]

In each of the towers horizontal bracing from the intersection of the struts is attached to the vertical columns. As the distance between the piers of the central tower is too great, deflection of the horizontal members is prevented by introduction of a vertical tie from the intersection to the bottom member and a vertical column from the intersection to the top member. [1]

The members and bracing of the tower give it immense strength and resistance to stresses induced by all types of load combinations. All these stresses must however be taken into the foundations via the

![Figure 7: Inchgarvie tower](image)

![Figure 8: Detail of a skewback](image)

![Figure 9: Arrangement of skewbacks](image)
connection between the tower and the foundation. Five tubular sections and five lattice girder sections join at this junction and terminate in a flat plate. This flat plate is called the upper bedplate. A lower bedplate is attached to the masonry pier on which the upper bedplate rests or can move or slide upon. The junction is called a skewback. Three of the four skewbacks are free to accommodate for movement due to temperature changes and the lateral pressure of the wind (Figure 9). [1]

3.5 Suspended Spans

The top member of the suspended span is polygonal in form similar to the bottom member of the cantilever. The bottom member is straight. There are eight sets of cross-bracing between these members comprising struts and ties. Similar to the cantilevers, the struts are provided with diagonal wind bracing. A vertical tie is provided from the intersection of the struts and ties to the bottom member. This tie supports the middle of the bottom member. The two top members are connected with sixteen sets of diagonal wind bracing. Solid plate girders run between the two bottom members to provide bracing. They carry the rail troughs. T-bracing and the solid floor of buckle plates further increase the stiffness of the girders. The top member and the struts of the suspended span are the exception to rule of having tubular sections for compression members. [4]

The suspended span acts as a simply supported truss with the top member in compression and the bottom in tension while under loading. The bracing consisting of struts and ties in compression and tension respectively provide the truss system.

3.6 Approach Viaducts

Although the approach viaducts are not one of the main features of the Forth Rail Bridge they are still substantial structures in themselves. The spans carry the two track railway line through to the cantilever towers at a uniform level and the same height above the water. The approach span from the South consists of four granite masonry arches that terminate at the abutment for the south approach span. From here ten girder spans begin in comparison to the five girder spans in the North approach viaduct. [2]

The last span of each side is supported by the respective cantilever end pier. The North approach viaduct has three similar granite masonry arches.

3.7 Dimensions of the Bridge

The total length of the cantilever bridge is 1624.6m. This consists of the cantilever towers, the central tower being 79.3m wide and the north and south being 44.2m. The length of each of the six cantilever arms is 207.3m and each suspended span is 106.7m long. The length of the North approach span is 295.1m to the end of the masonry arches and the South approach span is 602.9m. [2]

The height of the twin railway tracks above the high tide was 47.9m with a clearance of 46m above the water under no train loading. The masonry piers underneath the towers were built to clear the high water levels by about 5.5m and the difference between the top and bottom members of the tower is 100.5m. Therefore, the overall height of the cantilever towers is 110m. [2]

4 Construction of the Bridge

The contract for the construction of the bridge was awarded to Tancred, Arrol and Company on December 21, 1882. The construction work was divided into the following four classifications: site preparation, construction of the foundations and masonry piers, prefabrication of the steel and construction of the main and approach spans. These classifications weren’t necessarily focused on one after

Figure 10: Suspended span

Figure 11: Approach span
the other but also simultaneously. \[1\]

4.1 Foundations and Masonry Piers

To facilitate early construction of the masonry piers, their accurate positions were determined at once. Primarily, support piers were constructed. The construction of the piers of the southern approach span was accomplished with no complications. The construction was done in conditions of full tide or half tide using caissons. On the other hand, construction of the piers of the northern approach spans was more complicated due to the sloping rock below. Diamond drilling and blasting was used to level this rock to facilitate construction. \[1\]

There are four foundations per cantilever tower, each of which was constructed within an iron caisson of a diameter of 21.3m. Since the Queensferry tower was based on boulder clay, its four foundations were sunk under compressed air. The construction of the foundations of the Fife tower was carried out in open caissons due to the piers being founded on rock. Due to the variable geology under the central Inchgarvie pier, the two northern piers that were founded on rock were sunk under open air conditions while compressed air conditions were used to sink the two southern piers. \[1\]

4.2 Fabrication of the steel

Prefabrication of the steel elements of the bridge was done in specially built workshops and level yard areas next to the construction site at South Queensferry. Care was taken to ensure that the steel was cold-worked to increase its yield stress. The main columns that formed the main compressive members of the bridge had to be constructed with curved plates due to the limitation in the plate size available. The plates were joined together with stiffened longitudinal joints that were drilled and riveted. Similar drilling machines were used for the box lattice construction of the tension members and ties. \[1\]

4.3 Erection of the Bridge

The approach spans were first to be erected with the steel erected over low level piers. Using jacking operations, these were then raised to the appropriate level and the required masonry put into place (Figure 12). \[1\]

For the main cantilever towers, the first step of construction was the placing of the lower flat plates and then construction of the skewbacks. Platforms supported completely by the skewbacks were constructed 9-12m above the level of the deck. These platforms carried the steam derrick cranes used for the placement of the steel. Parts of the diagonal struts, vertical members and cantilever struts were used for the construction of these platforms to the greatest height possible. Constant care was taken in ensuring the correct positioning of the elements of the structure using theodolites. Due to the inclination of the members setting out was a difficult task. Once the construction had reached a height of approximately 15m above the deck, lifting platforms were built. These lifting platforms would facilitate the continuation of the construction of the towers to their full height. A system of movable support girders was used so that the construction platform could be raised up with the continuing construction of the tower. When the working platforms reached a significant height riveting cages were constructed on the undersides of the lifting platforms. By working in these cages the labourers were prevented from falling from height and their tools were also safe from dropping and injuring others below. The cages would rise with the lifting platform. Depending on the maximum height the crane on the platform could reach, the vertical columns were constructed above the platform. In 1887, the construction of the towers was completed. Removing the erection platforms was a tedious task that needed to be performed with the utmost caution as workers were present on the lower portion of the structure. Any falling piece of metal, however small, could prove fatal. \[1\]

Figure 12: Raising approach spans to required height

Figure 13: Schematic of main tower erection

Constructing the cantilever sections was the next step in the erection process. \[1\] This was initiated
briefly before the lifting platform for the tower erection reached the intersection of the diagonal vertical members. Construction on both sides of the towers was done simultaneously to maintain a balance (Figure 14).

![Figure 14: Balanced construction](image)

The construction of the bottom member was initiated by placing a crane near a skewback. About 30m of the member was constructed and then a rectangular cage carrying the riveting machine was built at its end. A hydraulic crane used for lifting the next plates into place was positioned above this cage. This can be seen in Figure 15. As the construction of the bottom member continued, it was supported by a link tie. The top members of the cantilevers were also constructed at the same time. As the cantilevers were being constructed, the girders for the viaduct were also assembled by overhanging into the cantilevers.

![Figure 15: Erection of bottom member of cantilever](image)

At the end of each cantilever the end post was constructed, closed on three sides and open on the side facing the suspended spans. The bottom member was erected to the full extent of the end post while the top member only to the inner side. Before the suspended spans were constructed the distance between the cantilever arms was measured carefully. This measurement was taken on occasions of different temperature conditions. The length of the suspended spans was then ascertained and thermal expansion of the spans under full summer heat was accommodated for. Expansion of 0.6m is allowed for by fixing the ends of the suspended spans at the Queensferry and Fife ends and using rocking posts, slide blocks and expansion joints in the rails on the Inchgarvie ends. The loading of the suspended spans is supported entirely by the top members and bracings and is carried into the top of the end posts. The bottom member of the spans has no load bearing connection with the end posts of the cantilever. The method of construction of the suspended spans is similar to that for the cantilevers i.e. using overhanging. The ends of the spans were initially fixed to the cantilevers until they joined up and then were released.

The construction of the suspended spans was done by building out from the cantilevers (Figure 16). The suspended spans could have been pre-fabricated and transported by barges to the correct location and then lifted into place by cranes. However, this method was not adopted as it would have required heavy cranes to be placed on either ends of the cantilevers and could prove inherently dangerous if any cables snapped during the lifting of the suspended span. Snapping of a cable on one side of the span would cause the complete load of the span to be supported by one cantilever arm. This could lead to failure in the members of the cantilever which would have a detrimental consequence.

Construction of the suspended spans was completed in November 1889. The bridge was tested under train loads in January 1890 and the bridge was officially opened on the 4th March 1890.

![Figure 16: Outward construction of suspended spans](image)

5 Structural Analysis of the Bridge

5.1 The Human Cantilever

The following demonstration using three men was carried out in one of Sir Baker’s lectures to present the principle behind the cantilever bridge.
The two men sitting in chairs represent the double-armed cantilever towers. The chairs they sit on represent the circular granite piers. Their extended arms support the sticks that bear onto the chairs and also the suspended span between them. In this way the men mimic the diagram, shown above their heads, which illustrates two towers of the bridge. The cantilever towers are supported from overturning by the piles of bricks shown on either side of the men, which exemplify the piers at either end of the bridge. When the third man in the middle representing the train load sits on the suspended span the arms of the two men in chairs and the anchorage ropes go into tension while their bodies below the shoulders and the sticks go into compression. Imagining this same design on a much larger scale and in the form of steel girders for the arms and steel tubes in place of the sticks, a good understanding of the structure of the bridge can be obtained.

5.2 Dead Load and Live Load

The construction of the Forth Bridge required 51,818.39 tonnes of steel. In the absence of live and wind load, the dead load of the cantilevers and towers are in complete equilibrium as the end piers are loaded with half the weight of the suspended spans to act as counterweights. This is because both the Queensferry and Fife towers have loading of the amount of half the weight of the suspended span on one side while the side is attached to the end piers. Therefore, to maintain stability the end piers need to be loaded. Since the bridge is subjected to both live and wind loads, the end piers are further loaded with the maximum loading that would pass over the opposite end of the tower. This counter load was taken as 2032.1 tonnes. Due to this extra loading, the ends of the free cantilevers of the north and south piers cannot deflect unless due to the elasticity of the steel. The fixed ends of the cantilevers at the end piers experience a range of downward loadings depending on the location of the live load. The maximum amount of loading would be the counterweight plus the weight of a train and the minimum being the counterweight minus the weight of a train.

The central pier is independently balanced when considering its dead load. However, when live load is taken into account, the structure is thrown off this balance. The live load causes the piers to act as a fulcrum causing the tower to topple. Consider Figure 18. The worst case loading scenario is two trains meeting on a suspended span. The maximum weight of train allowed on the bridge is 1422 tonnes. Assuming that the bridge is about to pivot about pier 1, Moments can be taken about this point to determine whether the bridge topples. Making the assumption that the bridge is about to topple, the reaction at pier 2 is equal to zero. If the anticlockwise moment is greater than the clockwise the bridge will overturn about pier 1 and fail.

Anticlockwise moment = Length of cantilever x (weight of half the suspended span + weight of 2 trains (acting as a point load))
= 207.3 x (4.1 + 27.9)
= 6633.6 MNm

Clockwise moment = (Weight of tower x 0.5 x width of tower) + ((length of cantilever + width of tower) x weight of half the suspended span)
= (186.31 x 0.5 x 79.3) + ((207.3 + 79.3) x 4.1)
= 8562.25 MNm

Since the anticlockwise moment is less than the clockwise moment, the bridge will not overturn due to the load of the two trains and is counteracted by the weight of the tower.

The ability of the dead load of the tower to counteract the load of the trains depends on the lever arm of the dead load and the dead load itself. As discussed before, the two outer towers are stable due to the counterweight acting at the end piers. Since the central tower doesn’t have this provision it has to counteract the live loading independently. Increasing the weight of the tower would be possibly unfeasible due to subsequent deflections. Therefore, increasing the width of the base of the tower allows increase in
the lever arm and thus increases the stability of the tower. The minimum width of the base can be calculated as follows:

For moment equilibrium about C:

\[
\text{Anticlockwise moment} = \text{clockwise moment}
\]

\[
207.3 \times (4.1 + 27.9) = (186.31 \times 0.5 \times w) + ((207.3 + w) \times 4.1)
\]

\[
6633.6 = 93.155w + 849.93 + 4.1w
\]

\[
w = 59.47\text{m}
\]

This calculated minimum width is higher than the width of the other towers and lower than the current width of the central tower. This allows for future changes in the weight of trains and also for other factors such as wind and temperature loading.

The bridge consists of a large number of compression members which could fail by buckling especially those of the cantilever. The bottom member of the cantilever is supported by diagonal cross bracing to prevent buckling. As the compression member nears the suspended span the cross section of the member decreases and so does its resistance to buckling. This is the reason that the bracing is closer towards the end of the cantilever.

5.1.2 Wind Load

Wind loading was very important in the design of the Forth Bridge as it was considered to be the reason for the collapse of the Tay Bridge. The site is one exposed to the prevailing wind from the south west with wind from the east being the next highest wind frequency. Occasional heavy gusts from the north-west or south-east are experienced but not frequently. For design purposes the Board of Trade Regulations certified a wind loading of 2.8 kN/m² be used. \(^{[1]}\)

The structure has plenty of cross-bracing for resistance against wind loading. The large compression members of the bridge have an aerodynamic design in that they are curved and therefore have low drag coefficients. This leads to less force being exerted on the members due to the wind. The tension members are open lattice beams and provide little resistance to the wind and therefore require no bracing. This was also due to the fact that Baker wanted the force from the wind to be taken to the foundation via the shortest route. Hence, the large amount of bracing. \(^{[1]}\)

5.3 Temperature Effects

Majority of the structure is made of steel which when it is susceptible to varying temperatures throughout the bridge. The temperatures may possibly also vary according the position of the sun. Allowances have been made for expansion and contraction in the skewbacks of the towers and also in the connections between the towers and the suspended spans. If a temperature range of 45° is taken into account and the coefficient of thermal expansion of steel is \(12 \times 10^{-6} /°C\), then the amount of expansion can be calculated as follows:

\[
\Delta L = aL\Delta T
\]

\[
= 12 \times 10^{-6} \times 1624.6 \times 30
\]

\[
= 0.59\text{m}
\]

As mentioned previously provisions for 0.6m expansion at each end of the suspended span are made which is greater than the calculated amount of thermal expansion. If this allowance was not provided then the members of the structure would experience compressive stresses which would ultimately lead to failure due to buckling.

6 Maintenance of the Bridge

With the right maintenance this bridge has served its purpose for over 120 years. If this maintenance is continued this structure could remain standing for many years to come. The maintenance of the bridge is the responsibility of Network Rail Scotland.

Figure 19: Maintenance works

The maximum speed of trains allowed on the bridge is 50mph depending on the type of train. Inspections of the underwater parts of the piers of the bridge are done by specialists. The area of the piers above the water requires little attention. The steel of the bridge needs to be regularly maintained to avoid failure. The paint that covers the bridge needs to be renewed to ensure that the steel is protected from the corrosive marine environment. The surface area of the bridge is equal to 45 acres or 182108.5m² and this area needs to be coated with three protective layers of paint. The budget for the maintenance of the bridge is £18.5 million. The process for painting the bridge involves removing the existing paint, repairing the steel if need be and then applying the new paint. The new paint should last for at least 20 years. \(^{[5]}\)
7 Serviceability

Trains can only run on straight tracks and have a very minute tolerance for deflections. For that reason the bridge is designed with a high stiffness which can be seen with all the bracing of the members and therefore, the deflections are minimal. It is also necessary that the deflections remain small for the sake of large vessels passing below the bridge at high water levels.

8 Durability

The bridge is designed completely out of steel in a corrosive marine environment. The durability of the bridge is as good as the paint that protects it from corrosion. Painting the Forth Bridge was considered to be an endless task. Today with advances in technology this is not the case. However, continuous painting of the bridge leads to high maintenance costs. Due to the immense scale of the bridge and the way in which it has been constructed, it is difficult to access some areas of the bridge while adhering to health and safety regulations. This causes issues with maintaining the bridge and may affect the durability of the bridge.

8 Future Improvements

The rail industry has advanced much in technology since the conception of this bridge and will continue to advance. Obviously the designers could have only anticipated the future to a certain extent and this bridge has survived through 120 years of development, probably farther into the future than the designers had expected. There is very limited space for expansion of the internal viaduct to accommodate increased sizes of trains. The bracing above reduces the amount of headroom available to the trains therefore the viaduct cannot be raised. Over-head power cables could not be accommodated for either. This limits the type of trains that can travel across the bridge.

In the future it is possible that the bridge is used purely as a tourist attraction and another bridge be built alongside it to provide a thoroughfare for the main rail traffic. Although the location on which the bridge stands is the optimal location for a railway bridge, it is doubtful that the bridge will be replaced due to its heritage and value.

9 Summary

The Forth Rail Bridge stands as a prime example of good design and capable engineering. Although there aren’t many provisions for the expansion of the bridge for use in the future rail industry, with the correct maintenance and care the Forth Rail Bridge will continue to serve as inspiration to engineers worldwide and hold its recognition as one of the most celebrated and famous bridges in the world.

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