A CRITICAL ANALYSIS OF PONTE DELLA COSTITUZIONE, VENICE

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Abstract: Santiago Calatrava’s Ponte della Costituzione is a steel arched pedestrian bridge built in 2007, crossing over the Grand Canal in Venice. This paper aims to provide a critical analysis of this modern bridge built in such a historical City. It will look in detail into the design, aesthetics and construction as well as including simple calculations to assess how the structure behaves under different loading conditions. The geology and durability will also be analysed and possible future changes looked at.

Keywords: Ponte della Costituzione, Calatrava, Steel Arch, Pedestrian Bridge, Grand Canal

1 Introduction

In 1999 the Council of Venice opened submissions for a new pedestrian bridge to be built over the Grand Canal. The bridge was to be the fourth ever built across the canal and would provide access from the central train station Santa Lucia to the bus terminal Piazzale Roma, a span of roughly 79m. The challenge they faced was finding a design that was functional, beautiful and in keeping with the traditional Venetian architecture.

The person commissioned to create this design was Santiago Calatrava, who beat 70 other entries for the project. Calatrava was selected on his reputation for being an Architect and Engineer well known for creating sculptural, landmark bridges such as the Puente del Alamillo in Seville and the Puente del Campo Volantin in Bilbao. The Engineering was conducted by Enzo Siviero and the construction works were carried out by Cignoni. Works started in 2007 and the bridge opened in September 2008 at a total cost of around £10m.

There was some controversy about the bridge around the opening time as many locals didn’t think the City needed it, especially since the Scalzi bridge is not far away and because the design does not incorporate access for the disabled.

2 History and Location

Venice is a City steeped in history and is well known for its architecture, particularly for its arched bridges, of which it has over 400. What makes this bridge stand out so much is its location and modern design.

The Grand Canal is the main canal through Venice and travels through the center of the Island, splitting the City in two. Until 1853 when the Ponte dell’Accademia was built the only way to cross was over the Rialto bridge (or by boat). The third and most recent bridge in Venice is the Scalzi Bridge, which was originally built in 1859 and then replace in 1934.

Figure 1: The Scalzi and Rialto bridges

There are a lot of differing opinions on new builds in Venice, with the majority of the local population wanting to protect it from any change. Many applications from renowned Architects have
been rejected in the past including most famously designs from Le Corbusier and Frank Lloyd Wright. As it is a historical City some people feel it should be preserved as much as possible whereas others think it should embrace change and be brought into the present times. Modern architecture could add another dimension to the City although many people are attracted to it due to its ‘untouched’ state.

3 Design

The final design decided upon was of a slender, low rise, steel arched girder. Particular attention to detail was paid to the finishes to make the bridge as aesthetically pleasing as possible. The abutments are reinforced concrete clad in local Istrian stone, the deck is also paved in Istrian stone and interspersed with translucent glass panels. The parapets are solid glass with bronze handrails and the whole structure is lit up at night with LED’s under the deck and at the base of the parapets.

3.1 The Arch

The arch spans 80.8m over the Canal with a maximum height of 4.67m. This gives a span/rise ratio of around 16:1. Traditionally the bridges in Venice are built with much steeper arches at a ratio of around 7:1. This is partly as they are built over shorter spans and need a high rise to allow boats to pass but more importantly; because the poor soil conditions meant that any arch built with a higher span/rise ratio was likely to collapse. The methods of construction used meant the foundations would not be able to cope with the large horizontal forces generated. The Scalzi bridge has a span/rise ratio of around 4:1 and the Rialto around 4.5:1.

Calatrava’s design of such a low rise seems to be both for functionality and aesthetics. It allows pedestrians to walk over without it being too steep while still giving an uninterrupted pathway for boats to pass underneath. The problem of the large horizontal thrust is compensated for by a jacking system at the abutments, installed to cope with any horizontal displacements.

3.2 The Deck

The deck varies in width along its length with its greatest width of 9m at the mid-span and narrowest width of 6.5m at the abutments. This design detail may be to allow for some pedestrians to stop at the mid-span to look at the views, allowing others to pass uninterrupted along the central walkway to the other side.

The depth of the deck also varies along its length, being deepest at the center and shallower at the abutments. This is in contrast to the Rialto and Scalzi bridges which have deep sections at the abutments to help minimize the horizontal thrust.

Figure 4: Cross-section through deck at mid-span

Figure 5: Cross-section through deck at abutments

The main structure consists of a central triangular steel box girder, which changes in dimensions along the length of the arch. Below this main arch is a lower arch made up of two circular hollow sections. This lower arch follows a different radius and therefore has an even greater span/rise ratio than the main arch. A steel star-shaped section connects both arches. This section also supports the deck, which is cantilevered from the main arch.

It seems as though the lower arch may not be providing much support to the structure as its greatest depth is in the center where the greatest support is needed. If the section was deepest at the abutments and shallowest at the center this may result in a more efficient structure however the aesthetic appeal would be compromised. Another issue with the structure is that it doesn’t appear to have any diagonal bracing against torsional effects.

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4 Aesthetics

The majority of people who visit this bridge think it is a beautiful structure, however there are some who do not agree, which demonstrates that aesthetics are subjective. Fritz Leonhardt, a prominent bridge engineer, gives 10 concepts that should be considered during bridge design. This paper will look at some of these concepts in order to better analyse the aesthetics.

The arched form of the bridge demonstrates a clear structural function, sweeping in a single span from bank to bank, no part of the structure being hidden. Unlike in the Rialto and Scalzi bridges, the geometry of the long span and slenderness at supports may instill a slight feeling of instability. However the revealed steel framework below counteracts this, seen from underneath the deck and partly from above through the glass. The spine-like steel structure shows all the structural components and gives a great feeling of stability.

Calatrava has designed the proportions of the bridge so well that it almost looks as though it is floating. The glass parapets and dark red structure make the light Istrian stone of the deck really stand out from a distance, making the bridge appear to be an elegant strip of white stone. This gives the impression the deck is even more slender than it already is. The lighting effect at night also adds to this impression as a thin strip of LEDs run along the base of the glass parapet forming a line of light. The proportions of the bridge can also be appreciated when walking over it. The gradient of the slope means that pedestrians cannot see what is on the other side and the widening of the deck in the center opens out to allow people to stop and look at the surroundings.

There is order in the lines of the arch. On elevation there are three clear curves following the same path – the handrail, the deck and the steel work. These lines are uninterrupted and give the structure a sleek look. On closer inspection the lines of the steel work are clearly visible, if looked at from an angle they do cross over. This does not seem to complicate the structure nor does it stand out as the dark red of the steel work is overshadowed by the deck above.

One of the major aesthetic responsibilities for this bridge is to integrate itself into the environment. Although it is obviously a modern structure and cannot be mistaken for a traditional Venetian bridge there are aspects of the bridge that link it to its surroundings and help it to blend in. The Istrian stone used on the deck and abutments continues as paving on the embankments of the bridge and surrounding areas. This stone is a traditional local material that is found throughout the City. The ‘Venetian Red’ colour of the structure is reflected in the surrounding red brick buildings and adds a sense of richness to the bridge. It also separates the bridge from Calatrava’s other works where he has always used white for the steelwork. Perhaps the most extravagant part of the bridge aesthetically is the bronze handrails that run on top of the glass parapets. These chunky bronze rails give the feeling of expense and make the bridge seem more of a sculpture. At the ends of the rails where they meet the abutments there are engraved connection details. This seems to be Calatrava’s subtle stamp on the bridge as the detail is of the crest of the Knights of Calatrava.

A bridge with character will make it a memorable bridge. This is a bridge with lots of character and is certainly very memorable. From the low rising span to the changing geometry along its length it arches gracefully over the canal. It is an example of a combination of great architecture and engineering put into context, achieving a stunning end result.

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4 Loading

The bridge is designed for pedestrian loads only. The following section will provide a brief overview of possible loading conditions in order to better understand the structure. The assessment was carried out using DMRB Part 3 BD21/01 with methods of analysis taken from BS5400: Part 1. Since BD21/01 is for short span bridges, it ignores the effects of wind, temperature and secondary loadings, where these are looked at BS5400 has been followed.

4.1 Assessment Loads

The assessment load ($Q_A$) can be found from the following equation:

$$Q_A = \gamma_f Q_K$$

Where $Q_K$ is the nominal load and $\gamma_f$ is a partial safety factor. The table below gives the partial factors used.

<table>
<thead>
<tr>
<th>Loading</th>
<th>$\gamma_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>1.05</td>
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<tr>
<td>Superimposed Dead</td>
<td></td>
</tr>
<tr>
<td>-Surfacing</td>
<td>1.75</td>
</tr>
<tr>
<td>-Parapets</td>
<td>1.20</td>
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<tr>
<td>Live</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 1: Loading factors

For loading conditions it will be assumed that the bridge has a uniform width.

The assessment load effects (SA) uses a further safety factor ($\gamma_f$) to take into account possible inaccurate assessment. In this particular case it could compensate for inaccuracies in dimensions and steel section properties, as many will be assumed.

$$S_A = \gamma_f Q_K$$

4.2 Dead and Superimposed Dead Loads

From [1] the total weight of the steel framework is given as 4073kN. For the bridge length of 80.8m this gives a factored dead load of 58.2kN/m.

The superimposed dead load includes the surfacing and parapets. The surfacing is known to be Istrian stone and tempered glass. It will be assumed that the total factored weight is 16kN/m. The parapets consist of tempered glass with a bronze handrail. Their factored load has been assumed at 1kN/m line load.

4.3 Live Loading

For pedestrian bridges over 36m a factor, $k$ can be used to estimate the live load.

$$k = \frac{\text{nominal HA UDL} \times 10^2}{L + 270}$$

Where,

$$HA = \left( \frac{36}{L} \right)^{2.5}$$

This gives a value of 0.375 for $k$ and a live load of 1.79kN/m$^2$. This is a very low load for such a crowded bridge and so a load of 4kN/m$^2$ will be assumed. This gives a total factored live load of 6kN/m$^2$.

An important loading case to consider for this bridge is parapet loading. It is often very crowded and the combination of many people leaning on the parapet on one side for a particular occasion could lead to a substantial moment being generated.

![Figure 11: Parapet Loading](image)

Due to the stepped nature of the bridge it is not accessible by cars and so no secondary live loads will be taken into account.

4.4 Wind Loading

The amount of wind experienced around a structure will be determined by several factors. Geographical location, the terrain of the area, local topography, the fetch of terrains upwind of the area, the height above ground and the dimensions all play a part in the overall pressure exerted on the structure due to wind. The following analysis is to BS5400-2 and will take into account horizontal and vertical loading only. It is not thought that longitudinal loading will have a great effect on the structure and so for the purposes of this paper it has been ignored.

According to BS5400-2, pedestrian bridges over 30m spans need to take into consideration the lateral, vertical and torsional effects due to turbulence. This paper however will provide only a simple analysis of the approximate pressure exerted on the bridge.

To calculate the maximum gust speed ($V_g$) it is necessary to find the gust factor ($S_g$) and the site hourly mean wind speed ($V_o$).

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\[ V_d = S_g V_s \]

The site hourly mean wind speed can be found from the equation:
\[ V_s = V_s S_p S_a S_d \]

The basic hourly mean wind speed \( (V_b) \) can be taken as 3.5 m/s [9] for Venice. The probability factor \( (S_p) \) can be taken as 1.0 as it is assumed a 1 in 50 year design period. The altitude factor \( (S_a) \) is 1.0 as it is 0m above sea level and the direction factor \( (S_d) \) is 0.91 as the bridge is facing the North West.
\[ V_s = 3.5 \times 1 \times 1 \times 0.91 = 3.19 \text{ m/s} \]

The gust factor can be found from the equation:
\[ S_g = S_b T_g S_h' \]

Where \( S_b \) can be found from multiplying the bridge and terrain factor \( (S_b') \) by the fetch correction factor \( (K_b) \). \( S_b' \) is taken as 1.59 for the bridge length of 80.8m, 8m above ground (water level). \( K_b \) is taken as 0.88 for its distance of >100km upwind from the sea. This gives a value of 1.4. \( T_g \) is a town reduction factor and is taken as 0.91 as the bridge is located less than 3km from the edge of town. \( S_h' \) is a topography factor and can be taken as 1.0 as there is not likely to be local funneling of wind.
\[ S_g = 1.4 \times 0.91 \times 1 = 1.27 \]

Therefore, \[ V_d = 1.27 \times 3.19 = 4.05 \text{ m/s} \]

The nominal transverse wind load \( (P_t) \) can be found using the equation:
\[ P_t = qA_1C_D \]

Where \( q \) is the dynamic pressure head:
\[ q = 0.613 V_d^2 = 10.05 \text{ N/m}^2 \]

\[ A_1 \] is the solid area exposed to the wind load which has been estimated at 150m². \( C_D \) is a coefficient of drag which has been assumed as 1.4.
\[ P_t = 10.05 \times 150 \times 1.4 = 2111 \text{ N} = 0.026 \text{ kN/m} \]

The nominal vertical wind load \( (P_v) \) can be found using the equation:
\[ P_v = qA_3C_D \]

Where \( A_3 \) is the plan area of the deck.
\[ P_v = 10.05 \times 626 \times 1.4 = 8008 \text{ N} = \pm 0.11 \text{ kN/m} \]

**5 Strength**

The shape of the steel structure was designed to give the highest strength possible but also to give the best aesthetic effect. The final shape was decided upon after extensive Finite Element modeling to understand better the effects of loading, temperature and seismic effects. The structure was also pre-assembled offsite and static loading tests were carried out.

![Figure 12: Load Testing](image)

For the purposes of this paper a basic strength analysis will be conducted on the bridge. Since the steel sections were all custom made, it is not known what exact section properties and dimensions are used and so they will be estimated where necessary.

**5.1 Arch**

The arch will be assessed under two loading conditions. The first will consider a uniform dead load along its length and the second will consider the worst case loading condition which is the effect of live load over one half of the bridge.

![Figure 13: Case 1- dead load only](image)

As an arch it is assumed that under uniform loading the section is in compression and no bending moments will be generated only axial force.
\[ R_T = \frac{wF}{2} = \frac{70.2 \times 80.8}{2} \]
\[ R_T = 30178 \text{ kN} \]
\[ \frac{wI^2}{2} = hR_T \]
\[ R_T = 13064 \text{ kN} \]

Resultant force = 10703kN

In order to calculate the Euler Buckling load, the second moment of area must be found. The primary structural element is a triangular steel box girder running along the center of the arch. The approximate
dimensions of the triangle are 1.4m breadth and 0.8m depth and the I-value is approximately $10.94 \times 10^{-3} \text{m}^4$.

![Figure 15: Triangular girder section](image)

$$P_E = \frac{\pi^2 EI}{L^3} = \frac{\pi^2 \times 205 \times 10^6 \times 1094 \times 10^{-2}}{80.8^3}$$

$$P_E = 3396 \text{ kN}$$

This is much smaller than the compressive force calculated in the arch and so it would theoretically buckle. However, it is likely that the secondary lower arch, which is not accounted for in these calculations, will provide substantial buckling resistance.

![Figure 16: Case 2 - worst loading case](image)

For a S355 section with yield strength of 355N/mm² this bending stress is acceptable.

5.2 Deck

The deck consists of the central triangular girder with ribs consisting of rectangular hollow sections cantilevered off either side. These ribs are spaced approximately every meter along the length of the deck and are welded onto the central section. As the exact dimensions are not known, a similar steel section taken from the Corus steel book will be analysed. The section used will be S355, 450mm deep by 250mm wide and 16mm thick with an I value of $5.57 \times 10^{-3} \text{m}^4$.

![Figure 17: Deck loading diagram](image)

The maximum moment will be as a result of the dead load, live load and parapet loading calculated in 4.3.

$$M = \left(\frac{46 + 76.2 \times 3.8}{2}\right) \times 2.18 + 11.34$$

$$M = 524\text{ kNm}$$

$$\sigma = \frac{My}{I} = \frac{524 \times 10^6 \times 225}{557 \times 10^4}$$

$$\sigma = 216 \text{ N/mm}^2$$

For the yield strength of 355N/mm² this is an acceptable bending stress.

5.4 Temperature

The effect of temperature needs to be considered as it may cause the steel structure to expand or contract, which will affect the internal stresses.

The difference in temperatures between the bridge deck and the steel structure should not cause any problems, as they are not structurally reliant on each other.

The temperature can range from $-25^\circ \text{C}$ to $+40^\circ \text{C}$ in Venice. As this is a pedestrian bridge and has an assumed design life of 1 in 50 years we can add $\pm 2^\circ \text{C}$ to these values. This gives a temperature difference of 61°C. Using a coefficient of expansion ($\alpha$) of 12x10⁻⁶ for steel the following equation can be used to find the possible change in length (e) for the central triangular girder:

$$e = \alpha L = 12 \times 10^{-6} \times 450 \text{ mm} = 0.0045 \text{ mm}$$

For the worst case loading this gives a possible overall stress of 397N/mm². This is more than the yield strength of a S355 section. This stress may actually be

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an overestimate as when considering the cross section of the deck the secondary arch was not taken into consideration. This secondary arch would reduce the overall bending stress and so the effects of temperature may not be problematic.

5.5 Natural frequency

Vibrations in footbridges are more common than in highway bridges. Due to being relatively lightweight structures they often experience a high live load in proportion to dead load so when loaded are more prone to oscillations. With such a heavily crowded bridge as this it is important that the natural frequency is checked. According to BS5400-2, if the natural frequency \( f_o \) is greater than 5Hz then the bridge design is adequate against vibrations. For the purposes of this paper it has been assumed that the bridge is a single spanning continuous beam that is straight in plan and elevation.

\[
f_o = \frac{C f^4}{2 \pi^2 m g}
\]

Where C is a configuration factor, for a single span continuous beam it has a value of PI. The acceleration due to gravity (g) will be taken as 9.81 and the weight per unit length (m) will be taken as 76.2kN/m. The I value of the cross section is estimated as 10.94x10^-3m^4.

\[
f_o = 4.08\text{Hz}
\]

If \( f_o \) is less than 5Hz the maximum vertical acceleration (a) must be less than 0.5sqrt \( f_o \), which is 1.01. Where,

\[
A = 4\pi^2 f_o^2 \sqrt{\frac{1}{K}}
\]

The value \( \gamma \) is the static deflection at the midpoint with a point load of 0.7kN. K is a configuration factor and for a single spanning beam has a value of 1. \( \psi \) is a dynamic response factor and will be assumed at 15

\[
\alpha = 4\pi^2 4.08^2 \times 0.002 \times 1 \times 15 = 19.7\text{m/s}^2
\]

This value is much bigger than 1.01 and so it seems the bridge is not capable of withstanding vibrations. However this method is based on a single spanning continuous beam with a constant cross section and does not take into account the secondary arch. It is not obvious whether any damping measures were used on the bridge although it is likely as such high live loads were anticipated.

6 Geology and Foundations

The Island of Venice is situated in an enclosed lagoon and as such has great difficulties with increasing water levels and settlements of structures.

Figure 18: Satellite view of Venice

The soil is normally consolidated and consists of alluvial deposits with layers of sand and silt nearer the surface and clay at greater depths. Traditionally the buildings and bridges in Venice were built using wooden piles that reached down to the clay layer.

Figure 19: Soil Profile

As shown in the structural analysis, the Ponte Della Costituzione has a very large horizontal thrust generated at the abutments due to the low rise and long span of the bridge. This force needs to be resisted by the foundations and as a result several piles over 20m deep were used. The ground was also strengthened prior to construction. The piles are laid on compacted bedrock beneath the alluvial layer and provide considerable strength however they are still subject to settlements.

Calatrava could have designed the bridge to deal with a known amount of settlement however it is likely to be subject to continuous settlements throughout its lifetime. A further problem is that due to the design of the bridge, too much horizontal settlement will have a massive effect on how the structure behaves.

As an arch the structure is designed to withstand high compressive axial forces and low bending stresses. Due to the low span/rise ratio of the bridge a small horizontal displacement at the foundations would result in the structure behaving as a girder rather than

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an arch. This would mean high bending stresses being generated which it is not designed to cope with.

The solution to this problem was to set up a permanent jacking system in the bridge and a permanent monitoring system, which continuously measures the displacements of the foundations. If a displacement of over 20mm is recorded on both sides of the canal then the hydraulic jacks will be used to bring the bridge back to its original shape. The jacks are installed permanently in the bridge between the abutment and steel structure, which is extended into the abutment. When needed it pushes the extended steel out so that the shape of the arch is restored.

![Figure 20: Horizontal displacement of foundations](image)

![Figure 21: Jacks return bridge to original shape](image)

Although this system will restore the arch to its original shape it is not preventing the movement of the foundations and this could possibly have an effect on the surrounding buildings. It seems like a fairly costly solution to a problem that could have been reduced by a change in design. A higher span/rise ratio or changing the proportions of the abutments to take more loading would have reduced the displacement. It seems as though the aesthetic design might have been more of a deciding factor over the final design than the structural implications.

### 6 Construction

One of the most important considerations in the erection of the bridge was the possible disruption caused on site. In such a busy area with lots of traffic on the Canal, any prolonged construction works could cause huge problems. In order to cause the least impact possible the steelwork was prefabricated offsite and the erection of the bridge took place over a few days with the Canal traffic being stopped for only two nights.

The first step in construction which took place in January 2007 was preparing the foundations. This included strengthening the ground due to poor soil conditions. The piles were then driven into the ground and substantial reinforcement assembled before pouring the concrete. Once the abutments were finally constructed the steel structure could be brought onto site.

The arch was prefabricated in three parts, these consisted of two side sections and a central span. All the steel was fabricated at a site on the edge of the lagoon so that it could be easily transported by barge.

![Figure 22: Cross section through abutment](image)

The first parts to be transported were the side sections, which were carried on separate barges along the canal. Each section was 15m long and had a weight of around 100tonnes. Once on site the sections were crane lifted into place. A temporary platform with piled foundations for stability was used to support the steel frame and a hydraulic jacking system was installed at the abutment to control the geometry of the section.

![Figure 23: Transportation by barge along the Canal](image)

The second part to be transported along the Canal was the central section. This was done in the middle of the night as to minimize the disruption to traffic and more importantly at low tide so that it could pass under the other bridges on the Canal. The central section was...
around 60m long and around 270 tonnes. Transporting it along the Canal took a long time, as it had to navigate its way carefully around the bends.

Figure 25: Rotation and lifting of central section

Once on site the barge had to perform a careful rotation so that the section was placed in the right direction. Due to the limited width of the Canal, it had to be transported the wrong way round to navigate the corners. Finally in the correct position, the hydraulic jacks lifted the structure until it was above the two side segments before lowering it into place. The sections were then quickly welded together. Once welded the temporary supports could be removed as the bridge was self-supporting.

Without end restraints the central section would be subject to very high bending stresses as it would behave as a beam rather than an arch. The section was not designed to cope with these high stresses and the solution to this problem was to use tensioning cables along the length of the arch.

Figure 26: Tensioning cables

Three cables were used in total and were tensioned all the way through construction until all the segments had been welded together, at which point they were de-tensioned. The assembly of the steel structure took two days in total, causing minimum disruption to the local canal traffic.

The next stage before adding the decking was to do load testing to confirm the strength of the arch. The arch was loaded with its worst case loading condition - asymmetrical loading to test for deflections.

Figure 27: Load testing on assembled structure

The last stage in construction included the paving of the deck and installation of the parapets, handrails and LED lighting. Finally, after almost a year since the first sections were installed, the bridge was opened to the public.

7 Durability and Vandalism

Durability is of great importance to this structure as it was built to be a landmark bridge which will hopefully remain standing for many years to come, as the Rialto, Accademia and Scalzi bridges have.

An area of concern for this bridge in particular is the corrosive properties of salt water on the steel structure. Although none of the steel is in constant contact with the water there will be some splashing and perhaps flooding throughout its lifetime. It is assumed that a suitable coating will have been used to protect against this happening and will be easily reapplied if needed.

As all the steel work is exposed and the deck is laid directly on top, it is not expected that there will be any problems with maintenance as all parts of the bridge seem to be easily accessible. If the bridge did have to be closed for a period of time it would not be catastrophic as the Scalzi bridge provides an alternative crossing point and is not far away.

Vandalism does not seem to have been an issue for the bridge so far. In an area which is almost always crowded it is unlikely that any vandalism would be carried out.

8 Future Changes

One of the great subjects of controversy surrounding this bridge when it was first built was its lack of disabled access. On the one hand, was the design and vision of the bridge more important than making it accessible for everyone? Or on the other hand, as Venice has over 400 stepped bridges that don’t provide for disabled users why should this one be any different? Calatrava says that he provided designs with access but the Council of Venice preferred this one and ultimately the final decision was up to them. However, due to the number of complaints received the
council decided they should incorporate a lift into the design. This was meant to be implemented soon after the opening of the bridge but does not seem to have been carried out yet. Figure [28] shows the final design, which should soon be in use. It consists of an egg-shaped capsule that rises from the banking onto the side of the bridge, attaching itself to a set of rails which will be incorporated into the framework.

Figure 28: Egg-shaped capsule

10 Conclusion

Throughout this paper the aesthetics, design and other important aspects of this bridge have been looked at and analysed. To arrive at the final design this bridge had to overcome several hurdles including weak ground conditions, delays in construction and escalating costs.

As shown in the analysis, there may be ways in which the design could have been made more efficient however it does provide a solution to the large horizontal thrusts generated which have caused problems in so many other Venetian bridge designs in the past. It has also proven through extensive testing that the structure works efficiently under the worst loading cases and so really there is no reason to change the design and compromise on aesthetics.

What ultimately defines this bridge are its surroundings and location in such a historical City, which seems to have dictated almost every design decision, from the arched shape to the paving on the deck.

In conclusion, this elegant structure described by Calatrava as a ‘carpet of light’ and the ‘most beautiful bridge he has ever created’ aims to provide a balance between the old and the new and does so very successfully. It is a shame that the controversy surrounding its implementation has overshadowed its overall design and that it has not received more recognition. Hopefully over time the locals will come to appreciate the design more and it will become globally recognized as a landmark feature of Venice.

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