CRITICAL ANALYSIS OF YORK MILLENNIUM BRIDGE

Samuel Isaacs

Abstract: This paper explains the concept behind the design of York Millennium Bridge, this is followed by a critical analysis of the different aspects of bridge design and how they apply to the bridge, with the aim of considering improvements that could be made to its design and construction.

Keywords: York Millennium Bridge, Tied Arch Bridge, Inclined Arch, Iconic Bridge, Steel Box Section

1) Introduction

The York Millennium Bridge (YMB) was designed as an iconic millennium project to provide a much-needed pedestrian and cycle crossing across the River Ouse, joining two residential areas. It has been designed to form a meeting place, the characteristics of which reach out along the banks of the river into the city.

The bridge form is that of an inclined bicycle wheel, the remainder of which is projected onto the landscape to form an oval space focussed on the river and bridge. A seating area was designed into the main span to provide an area to sit and enjoy the space defined by the bridge and the unique views it provides over the city [1].

2) Bridge Aesthetics

This analysis is largely based on the work of Fritz Leonhardt. The ten rules he proposed encourage a bridge to be designed as to portray its function in an obvious manner. Its aesthetic appeal can be enhanced through the use of refinements to the design [2]. This element of the bridge analysis is particularly subjective as beauty is a personal taste.

- Fulfilment of function

The structure of the bridge is immediately apparent to the user with the main arch spanning the length of the river crossing and the lead up ramps supported upon piers. The simplicity of the bridge forms the basis of its beauty as there are few structural elements, which are all clearly displayed to the user.

The inclination of the arch however intrudes upon the feeling of stability as it hangs off from one side of the bridge removing any obvious contributions to the bridge's stability to the casual bystander.

- Proportions of the bridge

York Bridge has a good balance between the depth of the arch and the deck that is supports. The low profile of the arch guides the user’s eye across the bridge and it immediately looks "correct" and fit for purpose. The proportions of the bridge are also correct for the span it is crossing and also the deck height above the river Ouse, this is because the height of the arch above the deck is similar to the height of the deck above the waterline.

The thickness of the arch as viewed when crossing the bridge is in proportion with the depth of the bridge deck, showing that the bridge components are in proportion with one another to create a balance between the voids and areas of structural mass.

- Order within the structure

The lines the cables form from the arch to the bridge deck radiate in towards the centre of the circle that the arch would form. This alleviates the problem that would arise from having vertical cables, which would break the structure up at every cable connection but instead guides your eye towards the centre of the bridge.

The handrail supports have been attached to the soffit of the bridge but these are hidden behind the arch across the central span. If there had been no continuation of the handrail supports across the central span then it would have broken the bridge up into three
obvious sections, the two lead up spans and the main central span, which would have ruined its appeal. However the deck cable connections are at similar spacing and mirror the handrail detailing. This use of repetitive elements reduces the number of edges that are noticeable by the casual user.

The common problem with cable-stayed bridges is visual confusion caused by cable crossover when the bridge is viewed at angle other that side elevation. In this bridge the cables have been designed to crossover each other much like the spokes on a bicycle wheel. The result of this is that the cables look similar and crossover by the same amount from any viewing angle. Whilst it could be considered to reduce the cable clarity when the bridge is viewed in elevation it means there is limited contrast between different viewing angles, which is considered successful design.

2.4) Refinement of design

The parapets used on the bridge have tapered ends, creating a slim profile for the parapet protection. This aids the smooth visual transition across the bridge.

Whilst the abutments main function is to transfer loads from the structure to the ground it is important for them to maintain proper order to create a good experience. In this design the concrete abutments and steel piers springing from them are used to create one sculptural element. The height of this element above ground reflects the depth between the arch and the deck.

The pier leaves the concrete abutment at an angle tangential to the end of the arch and is tapered, giving the effect that the arch continues down into the ground. The concrete abutment has been designed to accentuate the interface between the pier and the abutments, however the stark angle that is made at the base of the pier does not reflect the curved nature of the rest of the bridges load bearing structure, creating a noticeable visual distraction.

The long Western approach span is supported on four piers, these have been tapered so the top edge is wider than the base. This attempt to make the appearance of the piers less stocky has not been fully realised and the increasing height of the bridge deck means the angle between the base and the top of the piers changes between each pier making the supports look unorganised.

2.5) Integration into the environment

A more standard cable stayed bridge would look out of place in this location but the use of the bowstring arch is more suitable.

The low profile of the bridge suits the surrounding countryside that is populated by low-rise buildings and the slender elements that make up the main span mean that when viewed in elevation the bridge does not overly obstruct the natural beauty that exists whilst providing a platform to appreciate it from. This lightness to the structure reflects the open spaces that surround the bridge.

In this case the environment around the bridge has been landscaped to further incorporate it and in plan view the oval space created by the surrounding topography can be seen; this is focused upon the bridge itself.

2.6) Surface texture

The texture of a bridge should relate to where it will be viewed from and the speed that those viewing it will be travelling.

For those travelling over the bridge the detailing of the cable deck connections has been carefully considered is strongly expressed as it divides the seat.
running along the main span. There is also a wire mesh that forms the back to the seat whose pattern can be seen because of the slow speed people will be crossing the bridge.

Off of the bridge the piers and abutments have been given a strong textural interface, with the smooth piers springing from rough concrete abutments. The smooth finish for the pier is not usually recommended however it allows a sense of continuity between the pier and the arch that also has a smooth finish.

However the continuous smooth finish on the other main deck components have limited textual appeal as they do not identify specific structural or aesthetic components or replicate the natural textures found around the site. This may have been intentional since the bridge was designed as a millennium project with the bridge being designed as a modern minimalist sculpture identifiable due to this stark contrast.

2.7) Colour of components

Colour has been used well on the bridge to divide up the different elements. There are three main elements that have been identified, the arch, the piers and the deck. The arch is not coloured but is coated stainless steel, its glossy finish means it catches the light, thereby standing out. It is also these three features that are lit and highlighted at night.

2.8) Character

York Bridge’s more unusual design creates more public interaction as they question how it works since it initially appears to have an illogically inclined arch. It is only after appreciating how the bridge is balanced that it is justifiable.

2.9) Complexity

The inclined arch of the bridge adds a layer of complexity so as to enhance the experience of the bridge, forcing users to think more about how it might work and keeping them stimulated with the design.

2.10) Incorporation of nature

The bridge incorporates nature into its design through the economic use of materials. The design was analysed so that each elements was working to its full potential and this reflects the mantra in nature, survival of the fittest, and the adaptable.

However the bridge designers could have taken more inspiration from nature in copying naturally occurring structural forms, with the main arch being designed more as a spine with the body of the bridge hanging from it.

3) Bridge Design

3.1) Choice of bridge type

The bowstring arch bridge is particularly suited to crossing waterways in a single span from supports at equal height either side. It lends itself to being used in a sculptural structure although this is also true of asymmetric cable stayed bridges, which are beautiful due to their simple design. However the tower required for a cable-stayed bridge would have looked out of place within the local environment where the arch represents the flow that arises from connecting two previously separated communities on either side of the river.

The principle of the tensioned ties connecting the two arches means the deck can be very light and slender, enabling the navigational clearances of the river to be easily met whilst with careful landscaping the arch can be incorporated into the local topography.

To create a slender sculptural arch steel would need to be used, at the current time there is little price difference between the two materials. The skills required to design and construct in both materials are equally available within the UK.

A strong advantage of using a bowstring arch is its suitability for use in the soft soils of riverbanks that could not withstand the horizontal forces associated with arching action.

The inclined bowstring arch does not lend itself to future adaptation, therefore it must be designed for future increases in capacity, which will be wasted until it is fully utilised, and there is a chance that transport requirements will change meaning the extra capacity is never required. This problem has arisen due to the inclination of the arch and if the arch was at the vertical would not be as problematic. However since this is predominantly a pedestrian bridge further dramatic increases in capacity are unlikely to be required.

3.2) Structural Form

York Millennium Bridge is a tied or bowstring arch bridge, this is a self stressed structure. When a load is applied to an arch it thrust outwards at the ends of the arch. In a tied arch the arch is in compression due to load applied to it by the hangars, however the outwards thrust is contained within the deck which is used to “tie” the ends of the arch together. This puts the deck into tension, and the hangars that support the deck are also in tension [3]. The stresses within the bridge are shown in the following diagram.
The bridge has an overall length of 150m with the main span being 4m wide and 80m long. The deck consists of a trapezoidal steel box girder. The front section of which is cantilevered out onto outriggers. The deck is suspended using 19mm diameter cables from the arch that is inclined at 50 degrees to the horizontal. The cables are at approximately 1m centres and alternate joining the deck between the front and the back of the seat running along the main span of the bridge. This gives the bridge its characteristic bicycle spoke appearance.

The deck and the arch are mutually independent structural systems. The deck, whilst as a stiff box girder can carry a proportion of the vertical loading is dependant on the arch for support. The arch in turn uses the deck to tie it together, resisting the thrust from the arch, too offset and completely balance the loads created by the arch inclination and to provide restraint against buckling through the cable triangulation [1]. This restraint against buckling could have been provided by the use of rigid hangars such as the beam sections used on Merchants Bridge, Manchester [1] shown in fig 6. This would have lowered some of the visual complexity that arises from the use of crossing cables, usually strongly avoided, although they have been used to good architectural effect in this bridge.

In order to carry these restraint forces the deck must be a closed torsion box, but it also has to carry the torsion derived from eccentricities of vertical load.

The arch is hollow with a cross section of 600mm by 200mm, it is made from four plates of high strength stainless steel. At its maximum the deck is 900mm deep, this is because it can take advantage of the extra depth available under the seat. The long approach on the West side goes over four intermediate piers before joining the main span. The seat is not present on this section but the box girder has sufficient strength without the extra depth afforded by the seat to span the shorter spans without changing the walking surface or soffit profile.
This gives the bridge a much greater sense of continuity that it would have lacked had the deck had to change appearance to compensate for the missing seat; although the large piers that need to be relatively close together detract from the slim delicate profile of the rest of the bridge. Had the soffit profile changed gradually from that of the main central span into one that allowed the box section to support itself over greater spans on the Western approach then this would have created a better visual flow. It is important for the walkway surface to remain the same over the entire length.

The bridge piers project from the abutments and have been designed to follow the curve of the arch into the ground. Since they only support vertical reactions from the tied arch a moment will be set up due to the eccentricity of the top of the pier with respect to the base. This means the foundations will have needed to be designed to sustain moments, a high price to pay for the aesthetic enhancement provided by the piers. The piers could have been designed so that they continued the curve of the arch whilst transferring the arch reactions vertically to foundations.

**Bridge Details**

These are incredibly important to the final experience of the bridge. The stainless steel shackles that attack the hangars to the deck where they join the seat had to be a bespoke design to allow for movements as the bridge responds to changes in temperature and changes in loading frequency and size of these shackles means that their design needs to be elegant and purposeful, or they had to be hidden allowing allow a more practical design. The resulting design has the seat running along the main span of the bridge frequently punctured by thick steel plates where the cables are attached [4], this could have been improved by having the cables attached further back in the seating area, possibly forming part of the back of the seat. This is because this area of the bridge is meant as a meeting and viewing platform which is unnecessarily broken up by the cables, however moving the cables back would reduce the distance between the fore and aft cables thereby reducing their effective triangulation.

4) Loading

York Millennium Bridge will have been designed to British Standard BS 5400 (BS 5400) [5], which is a limit state design code. This means it will have been checked at the Ultimate Limit State (ULS), to prevent collapse, and Serviceability Limit State (SLS), to check the serviceability of the bridge. There are five main load types to be considered: dead load, super-imposed dead load, live load, wind loading and temperature effects. Combinations of these will need to be checked at both limit states. In this paper each individual load has been identified and analysed, however they have not been combined because the errors associated with the assumptions made would accumulate, resulting in an unrealistic and unhelpful value.

4.1) Load Factors

Partial load factors are applied to the load conditions, which are then combined to form the worst possible realistic circumstances. There are two factors, $\gamma_f$ is the factor introduced to account for any inaccuracies in the analysis of the bridge, and $\gamma_p$ is the partial load factor. For the Millennium Bridge the value of $\gamma_f$ will be 1.00 for SLS checks and 1.10 for the ULS check irrespective of analysis technique. The values of $\gamma_p$ can be found in BS 5400, Part 2 [5].
4.2) Live Loading

Under BS 5400 the live loading applied to footbridges is 5KN/m², because the millennium bridge is over 80m this can be reduced by factor \( k \),

\[
k = \frac{\text{nominal HA loading for bridge length}}{30\text{KN/m}}
\]

Nominal HA loading = 18.8KN/m for an 80m long span

\[
k = 18.8/30
\]

Therefore, live load = \( 5\text{KN/m} \times 0.63 = 3.13 \text{KN/m}^2 \). This load may need to be increased since the bridge forms the focus for the Millennium Bridge Fun Run, if it had been known that this annual event would occur then special loading considerations should have been applied, increasing the load acting on the bridge to \( 5 \text{KN/m}^2 \).

Since the bridge has bollards at either end preventing vehicular access there is no need to apply HB loading on the bridge.

4.3) Vibrations

In order to analyse the dynamic response of the bridge based on Euler's differential equation it was assumed that the deck section was as below in fig 9. This simplification is representative of the initial calculations that would have been carried out on the bridge prior to finite modelling being used. To calculate the value of \( I_{xx} \) for the inclined member it has been treated as a vertical member with the thickness being the horizontal thickness of the original slanting member.

![Figure 9: Simplified deck profile](image)

Several other assumptions were made, including the steel plate thickness being 10mm, the dimensions of the deck are estimated based on a dimensioned drawing, the mode of vibration was based on a clamped, clamped beam when the bridge would be better represented using a pinned, pinned beam. For this analysis the contribution of stiffness provided by the arch is ignored and so the value of fundamental frequency, \( f_0 \), calculated will be lower than the actual value.

\[
\omega_h = (\beta_h.d)^2 \sqrt{E.I.1/m^4}
\]  

\[
\omega_h = 22.37 \sqrt{(200 \times 10^9)(1.093 \times 10^{-3})/(680.80^4)}
\]

\[
\omega_h = 22.37 \times 0.078
\]

\[
\omega_h = 6.26\text{Hz}
\]

From eqn (1) it can be shown that the bridge is within the permissible range of frequency of vibration, being 5Hz < 75Hz. It would actually have a higher fundamental frequency than this because of the added stiffness of the arch, which has been neglected in this example. Further analysis of vertical acceleration of the full bridge should be completed to ensure that the acceleration, \( a \), is limited to;

\[
a = 0.5\sqrt{f_0} \text{ m/s}^2
\]

Which based on the results of eqn (1) the acceleration should be limited to;

\[
a = 1.25\text{ m/s}^2
\]

The horizontal vibrations should be within acceptable limits due to the use of the stiff box girder. This means that no damping should be required to alter the natural frequency of the bridge.

Forced vibration damage to the bridge should be considered especially since it is used for marathons [6] when there is a high risk of the runners joining step causing large vertical and lateral loads for which the bearings need to be able to withstand.

4.4) Wind Loading

The wind acting on the bridge would have been calculated so that the forces it exerts on the structure could be assessed. The forces the wind exerts on the bridge are based on the maximum wind gust, \( v_c \), giving a return period of 120 years. \( v_c \) is calculated using eqn (2);

\[
\begin{align*}
v_c &= v.K_1.S_1.S_2 \\
v_c &= 30 \times 1.47 \times 1.00 \times 1.00 \\
v_c &= 44.1 \text{ m/s}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Table 1: Wind coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean hourly wind speed, ( v )</td>
</tr>
<tr>
<td>Wind coefficient, ( K_1 )</td>
</tr>
<tr>
<td>Funnelling factor, ( S_1 )</td>
</tr>
<tr>
<td>Gust factor, ( S_2 )</td>
</tr>
</tbody>
</table>

There is a further reduction factor, \( R_1 \) that can be applied to footbridges; this reduces the gust speed by
taking into account wind break action. This is when the wind flow breaks up due to friction with the ground.

\[ R_1 = 0.8 \]
\[ \therefore v_c = 44.1 \times 0.8 \]
\[ v_c = 35.28 \text{ m/s} \]

4.41) Transverse wind loading

This value of \( v_c \) is used to calculate the loads acting on the bridge in the transverse and longitudinal directions. The transverse wind load acting at the centroid of the section of bridge under consideration is given by;

\[ P_t = q.A_1.C_d \] (3)
\[ q = 0.613.v_c^2 \]
\[ q = 0.613 \times 35.28^2 \]
\[ q = 762.99 \text{ N/m}^2 \]

The table below shows how the depth of section to be used in calculating the area, where \( A_1 \) is the horizontal projected area.

<table>
<thead>
<tr>
<th>Table 2: Deck depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unloaded bridge</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Live loaded bridge</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

4.42) Parapet and pier wind loading

The wind loading on all elements of the bridge must be considered and size of this is related to the plan shape of the element. The parapet protection on the bridge is all designed so the elements it is made up of are circular or rectangular with their shortest side facing the wind. This results in lower values for \( C_d \), meaning the wind load acting on it is lower.

The loading could have been reduced had all the elements been circular, however this would have created a less “see through” parapet reducing the light feel of the bridge. The use of cables would solved the transparency issue but the bridge would have looked strange with the hangar and parapet cables travelling in perpendicular directions.
The profile of the piers changes along their length, with the side facing the wind increasing in length with respect to the breadth as the pier gets closer to the abutment. This aesthetic change in cross section means the wind loading on the pier will increase towards the abutment, it would have been more efficient to use circular piers. However these would not have continued the flow of the rectangular arch.

Whilst considering wind loading it has become apparent that having a circular section arch would be superior to the rectangular section arch, which is not ideal since it itself attracts significant wind loading and its rectangular design has dictated the section shape of other elements which could have been made more streamlines to lower their wind loading.

4.43) Vertical wind loading

The effect of vertical loading is especially important on the York Millennium Bridge since any uplift created would have the effect of relieving the cable, to avoid them going slack they should be pre-stressed so instead of going slack some of the pre-tension is relieved. The vertical force, $P_v$, is calculated using the following equation;

$$P_v = q.A_s.C_L$$

$$P_v = 762.99 \times 320 \times \pm 0.75$$

$$P_v = 183 \text{ KN}$$

For this calculation it has been assumed that the super-elevation of the bridge is 4°. However this assumes the whole deck is at an angle whereas for York bridge it is only the soffit that has an angled profile. Due to this difference in profile between the walking surface and soffit wind tunnel testing would need to be carried out. The extra wind tunnel testing required due to the trapezoidal deck profile will have cost a significant sum of money which could have been saved had a more standard section shape been used which can be analysed by hand using BS 5400.

4.44) Longitudinal wind loading

Longitudinal wind causes loads to be applied to both the bridge structure, $P_{LS}$, and the live load on the bridge, $P_{LL}$. The longitudinal load on the bridge, $P_L$, is taken from the most sever of either the nominal longitudinal load on the structure alone, or the sum of the nominal longitudinal load on the structure and the nominal longitudinal load on the live load. These values are fractions of the nominal transverse load applied to the bridge, $P_t$, and are shown below. It can be seen that the sum of structure and live longitudinal loads causes the most sever effect and so it is this that will be used.

<table>
<thead>
<tr>
<th>Table 4: Longitudinal wind load, $P_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{LS} = 0.25 P_t$</td>
</tr>
<tr>
<td>$P_{LS} + P_{LL} = 0.25 P_t + 0.5 P_1$</td>
</tr>
</tbody>
</table>

4.45) Load positions

There are four load combinations that need to be considered for wind loading. These need to be applied to the bridge in order to give the most adverse effect. In the case of York Bridge the load should be applied across the length of the main span only to get the highest values for bending of the deck. This is because plan view in fig 7: shows that the Western approach, whilst long is supported in many places meaning load applied there will not cause a significant hogging moment in the central span. The Eastern approach is so short that load applied there will not cause a significant moment in the central span.

4.46) Aerodynamic vibration

Due to the deck profile damping may be required to minimise aerodynamic vibration. This information is not codified and specialist advice should be sought.

4.5) Temperature effects

Changes in temperature can have two effects upon the bridge. An overall temperature increase or decrease causes the bridge to expand or contract accordingly. This is known as effective temperature.

The other effect is called temperature difference and is when there is a temperature gradient across the top and underside of the bridge.

4.51) Effective temperature

Footbridges are designed to a 50-year return period; this reduces the maximum and minimum temperatures that the bridge is subject to. The worst-case temperature load would be if the bridge experienced an increase from the minimum temperature experience in York, -16°C, to the maximum, 33°C. Equation (4) shows the expansion of the deck, $\delta$, due to the change in temperature;

$$\alpha = \varepsilon.l$$

$$\varepsilon = \alpha.\Delta T$$

<table>
<thead>
<tr>
<th>Table 5: Temperature coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T$</td>
</tr>
<tr>
<td>$\alpha$</td>
</tr>
<tr>
<td>$l$</td>
</tr>
</tbody>
</table>
\[ \delta = 49 \times (12 \times 10^{-6}) \times 80000 \]
\[ \delta = 47 \text{ mm} \]

The bridge would have been designed for this expansion to be freely allowed through the use of expansion joints. However over time these can become blocked, restraining the bridge from expanding outwards. This means the strain from the change in temperature will become a compressive stress, making the bridge feel as though it is being compressed by stress, \( \sigma_{\text{apparent}} \), as shown in eqn (4) below:

\[ \sigma = E \varepsilon \quad (5) \]
\[ \sigma = (588 \times 10^{-6}) \times 200,000 \]
\[ \sigma = 118 \text{ N/mm}^2 \]

This value is a significant proportion of the total compressive strength of standard steels available that would be cost effective to use in the deck construction.

It is important to remember that the arch will also expand and contract with changes in temperature. Most of the expansion of the arch will be contained within the deck expansion, however if the deck is restrained then expansion of the arch will increase the tension within the hangars as it tries to expand upwards. This will increase the stress within the deck where the hangars are connected.

4.52) Temperature difference

This is the most critical temperature effect because a temperature gradient causes both axial and bending forces to be set up in the bridge. Due to the varying deck depth across the breadth of the deck significant stresses will be induced in the deck since there will be a greater temperature and hence stress’s as the deck increases in depth.

5) Durability

The arch of the bridge is made from stainless steel; this means it can be exposed without requiring any further cover. This makes the arch a reflective, eye-catching focal point to the bridge as it catches the light. This feature of the arch gives the whole bridge great visual appeal and stainless steel seems the best material to have made it from due to its advantageous mechanical properties. The cables are also made of stainless steel because it doesn’t need to be coated, this is because it is hard to adequately coat cabling as it is under changing tensions due to the varying loading, these would lead to slight relaxing and tensioning of the cable which damage any coating applied.

The main deck is made of steel plates, this is possible because the steel is not exposed to the weather, which would cause corrosion and weaken the material.

6) Susceptibility to damage

Due to the positioning of the piers on the riverbanks with a clear central span there is no risk of boat impact, which would have required the piers to be significantly strengthened. There is also no vehicular access close to the piers, there are bollards preventing this as seen in fig 11.

The bridge has been subject to vandalism and muggings that has resulted in people refusing to use it after dark, instead travelling further to use other bridges [6]. This means the bridge is failing to give confidence to people to use it which is a significant failing. This can be solved in both initial design and retrospectively. The lighting as exists is purely aesthetic, lighting up specific components of the bridge as shown below in fig 11.

![Figure 11: The bridge lighting](image-url)

The picture shows that there are large areas in shadow at night which promotes criminal activity, especially since the bridge is not within the busier town centre. To solve this higher intensity lighting, illuminating more of the bridge should be designed into the bridge superstructure. A well lit route across the river would give people more confidence to use the bridge since they can see further ahead of themselves.

Whilst extra lighting could be fitted retrospectively it would fit better into the structure visually if it was considered from an early design stage. However CCTV is easier to fit after construction since only a few cameras need to attach to the bridge in order to provide comprehensive coverage. This option would work best in partnership with extra lighting but could be implemented successfully on its own. It would act as deterrent for people committing crimes, since their actions would be being monitored remotely.
7) Construction techniques

An advantage of the bowstring arch is due to its horizontal thrust being contained through the use of a tie, tied arch bridges can be prefabricated offsite and lifted into position [1]. This means that the structure does not need to be designed to resist some loading combinations that may only occur whilst the bridge is built in-situ such as wind and impact loading.

The bridge sections were delivered to site and the arch and deck were erected in pre-set positions on stillages, initially without hangars. The arch was released to take its true shape, the hangars were attached and hand tightened, then the deck released to allow the hangars to take up their dead load tension. The main span was launched across the river using barges.

Figure 12: Bridge construction on land

This option will have meant the closure of the waterway for the duration of the launch, disrupting pleasure and commercial craft. Another option would be to use cranes to lift the main span into position [7], this would still have required the rivers closure whilst the main span was suspended it would not have to be shut for as long. Craning whilst quicker would be the more expensive option due to the size of crane required to lift the 80m main span. This method would also require the bridge to have been designed with lifting points, which would need to have high strength to support its own weight during the lift.

Both launching methods would be affected by the wind speed on the day due to the open environment the site is in, but the crane itself would need to be locked into position should the wind exceed a certain speed whereas the pontoons would be relatively unaffected. This would have the potential to delay the launch.

Another option of constructing the arch on site, launching it and then assembling the deck in-situ is unfeasible since the arch would have to be temporarily tied to prevent horizontal forces from being exerted onto the piers from the weight of the arch and the deck sections before they are continuous across the span. This would render the river un-navigable for longer, be a more dangerous form of construction and possibly cost more due to increased construction time and the requirements for considerable temporary works to tie the arch.

8) Conclusion

YMB was conceived as an urban icon and this has dictated the design from initial stages. The structural design of this bridge has been governed by its architecture, whilst this has undoubtedly led to what is considered a beautiful bridge it has created problems within the design that would not exist had the bridge design been governed by structural efficiency. The reduced efficiency and high cost of the bridge is justified because the bridge has satisfied its initial brief, providing the important link across the River Ouse, whilst creating a strong focal point that defines the space it occupies. It has achieved this through combining the inclined arch which provides the main feature of the bridge, with the slender deck that appears to reach out between the riverbanks.

The design of the bridge has complicated the analysis required to determine exactly how the bridge will respond to different load types and combinations, and much of the design drew on the success of Merchants Bridge, Manchester, which provided rough sizing’s that were analysed using finite element analysis.

Most of the improvements or suggestions made about how the structure could be changed are based on increasing its structural efficiency and may negatively alter the aesthetics. Whilst any changes suggested about improving the aesthetics of the bridge could generally be implemented without affecting the structural design.

9) References


