BRUNEL SWIVEL BRIDGE, BRISTOL

Avon Industrial Buildings Trust

Inspection of Bridge Superstructure

January 2016

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1 INTRODUCTION

1.1 Background

1.1.1 The Brunel Swivel Bridge is an historic bridge, designed in the office of Isambard Kingdom Brunel and under his direct overall supervision. The bridge was completed in about 1849. Microfilm copies of some of the original drawings survive and these have been consulted to inform the inspection process.

1.1.2 Originally, the bridge was about 4m wide and 36m long. However, the bridge is known to have been altered in the past when the bridge was moved from a former location to its current location. At that time, the span of the bridge was reduced and the end section of the forward cantilever was cut to remove a length of about 3m.

1.1.3 The bridge is now about 4m wide and 33m long and is currently located alongside the Howard Lock, which forms the main entrance lock to the Cumberland Basin floating harbour in Bristol. The bridge is intended to swivel about a pintle, which is about 10m from the rear of the bridge, thus creating a forward cantilever section of about 23m, which spans across the Howard lock when the bridge is in the closed (usable) position, and a back span of about 10m.

1.1.4 The bridge is constructed of wrought iron plates and sections, which are shaped and riveted to form the various elements of the bridge superstructure.

1.2 Inspection

1.2.1 This report summarises the results of an inspection of the bridge superstructure, which took place over the spring and summer months of 2015. The findings of the report are limited to the extent that no intrusive inspections, investigations or tests were carried out.

1.2.2 This report should be read in conjunction with drawings produced to show the results of the inspection, viz Drawing Nos 511 to 516 and 520 to 589 and with the associated files of photographs taken during the inspection process.

1.2.3 This report outlines areas where repairs are required, but does not intend to provide method statements or specifications for such repairs.

1.3 Summary

1.3.1 The superstructure of the bridge is not currently in a state where the structure could be put immediately back into use. Although not in a satisfactory state, the damage was mainly confined to specific elements or areas of elements where long term corrosion damage had occurred.

1.3.2 The elements which showed significant damage were:

- the top segments of bottom flange (the inner and outer plates of the triangular section – see *Figure 1*);
- the bottom plates of bottom flange (the lower plate of the triangular section – see *Figure 1*), particularly adjacent to the turntable;
- small sections of the typical transverse beams near their ends;
- the curved turntable beams; and
- some of the straight turntable beams.

1.3.3 Other elements showed slight or insignificant damage.

1.3.4 Some of the elements showing significant damage have been repaired in the past, but these repairs are now generally unsatisfactory.

1.3.5 The majority of the significant damage will require repair, as part of the renovation process, using patch plates to replace damaged or seriously corroded existing plate.

1.3.6 The bottom plates of the bottom flange will need to be reinforced to replace the significant loss of section that has occurred in some locations.

1.3.7 The internal surface of the bottom flanges to the edge beam will require protection against the future ingress of water and corrosion damage.

1.3.8 The internal ties within the top flange of the edge beams may require re-tensioning, unless detailed structural analysis shows this to be unnecessary.

1.3.9 Local or small-scale repairs will be required to such items as: the web stiffeners to the edge beams; deep gouge marks on the upper flange section of the edge beams; bolt holes on the web to the edge beams; replacement of missing rivets or bolts; and, other damage that is shown on the inspection drawings.

1.3.10 The entire superstructure will require refurbishment of the external paint protection system to provide a very long life to future maintenance. It is probable that this may need to be supplemented by extra corrosion protective measures for elements such as the lower 'flange' of the edge beams and the ends of the transverse beams.

2 DESCRIPTION OF BRIDGE & INSPECTION PROCESS

2.1 General Bridge Description

2.1.1 The bridge, as noted above, is constructed principally of wrought iron plates. The form of the bridge is a through bridge with the principal structural elements comprising two deep beams forming the outer longitudinal edges of the bridge. These edge beams are connected to a number of transverse beams, most of which are placed diagonally with respect to the longitudinal axis of the bridge. For convenience, the edge beam, closer to the side of Howard Lock, is referred to as the North edge beam and the other edge beam is referred to as the South edge beam. Near the pintle, about which the bridge is intended to rotate, a further series of transverse beams connect to the edge beams. These beams are supported by the turntable rail, which is supported by four wheels that are fixed to the bridge foundations. These wheels, the turntable rail and the turntable beams together form the main support for the bridge superstructure.

2.1.2 At the rear of the bridge superstructure, kentledge in the form of iron castings provides the counterbalance to the main cantilever span of the bridge. These cast iron kentledge sections have two wheels mounted within the section. These wheels run on a radial rail track, which is supported by the foundations. These wheels and the rail track provide a secondary support for the bridge superstructure.

2.1.3 There are wrought iron longitudinal ties within the top section of the edge beams. These ties are present over the entire back span and the majority of the forward span of the bridge.

2.1.4 At the cantilever end of the bridge, there are two roller bearings (concealed within each of the edge beam sections) as part of the mechanism for setting up the end of the bridge on the north abutment.

2.1.5 Originally, the bridge was provided with timber deck beams, which spanned across the transverse iron beams, and timber decking above the timber beams. All this timber has been removed.

Edge Beams

2.1.6 The cross section of the edge beam is constructed, typically, as shown in *Figure 1*. Individual plates vary in length (along the bridge span) from about 1m to a maximum of about 6m.

2.1.7 As can be seen from *Figure 1*, the typical section comprises a curved top plate and two curved side plates forming the top 'flange' of the beam. The web is a single flat plate. The bottom 'flange' comprises two curved side plates and a curved base plate. In some areas (the sections adjacent to the turntable support), the curved base plate is a double plate. The horizontal joints between adjacent plates making up the section are riveted.

2.1.8 The thickness of the various plates making up the typical cross section varies along the length of the bridge. Assessment of the plate thicknesses is subject to further investigation.

2.1.9 At the vertical joints between plates, splice plates are provided, which vary in width from about 0.15m to 0.23m. These splice plates are riveted to both adjacent plates. The positions of the joints between plates are staggered along the length of the beam so that the joints in the web plates do not line up with the joints in the adjacent top and bottom 'flanges'.

2.1.10 At specific locations along the length of the beams, the web of the beam is provided with web stiffener plates and angles.

Transverse beams

2.1.11 The 'typical' diagonal transverse beams are fixed across between the two edge beams at a spacing which is typically about 1.6m (measured along the length of the edge beam). However, the spacing is not uniform and varies to a minimum of about 1.3m.

2.1.12 The transverse beams are formed from double angles forming each of the top and bottom flanges and a plate forming the web. The double angles are riveted to the web plate. Near the ends of the beams, the web plate is curved in plan (as are the flange angles) to enable the ends of the beam to abut the edge beams and to be connected to them with rivets.

2.1.13 There are a few non-typical transverse beams fitted across between the edge beams. These beams vary in cross section, but are generally constructed in a similar manner to the typical transverse beams, ie with double angles for the top and bottom flanges and a single web plate.

Turntable Assembly

2.1.14 The turntable assembly comprises a number of beams as shown in plan in *Figure 2*.

2.1.15 Eight straight beams are connected to the pintle; two beams are connected from the pintle casting to the north edge beam; two beams are connected from the pintle to the south edge beam; and four beams are connected from the pintle to one of the (non-typical) transverse beams, two in each of two directions east to west and west to east.

2.1.16 Four beams, which are curved in plan, are attached to the edge beams and to the non-typical transverse beams.

2.1.17 The straight beams vary in depth along their length, being deeper at the pintle end and shallower at the other end. The top flange of the beams is formed of double angles with a top plate. The bottom flange of the beams is formed of double angles with a bottom plate which is also connected to the adjacent beam to form a pair of beams, effectively braced at the bottom flange. All angles are riveted to the adjacent web plate and flange plates.

2.1.18 The beams, which are curved in plan, are formed of a composite of a curved web plate (actually formed from three plates along the section) and a straight web plate riveted to the curved plates near the meeting point. The top flange comprises an angle attached to the straight web plate; a curved angle attached to the curved web plate and a shaped top plate connected to both angles, effectively bracing the top flange of the beam. The bottom flange comprises double angles connected to the curved web plate. All angles are riveted to adjacent web and flange plates. A curved rail track section is attached to the bottom of the curved beams.

Kentledge Assembly

2.1.19 The kentledge assembly comprises two edge iron castings parallel to the north and south edge beams respectively and six transverse iron castings connected across from north to south.

2.1.20 The edge castings vary in cross section along the longitudinal axis to form a curved end to the bridge. The castings are attached to the ends of the edge beams with a series of large diameter bolts screwed into threaded holes in the casting.

2.1.21 The transverse castings are connected to the edge castings with large diameter bolts with nuts on the outer side of the edge castings.

2.2 Inspection Process

2.2.1 The inspection of the bridge was carried out over a number of weekends during the spring and summer of 2015. Inspection was carried out by volunteers including teams of graduate structural engineers led by a structural engineer.

2.2.2 The inspection was visual only, but generally from a close viewing distance. No intrusive tests were carried out.

2.2.3 In three local areas, steel plates, which were part of earlier repairs, were removed to allow inspection of the internal parts of the closed lower edge beam section. It is intended that further repair plates will be removed in the near future to extend this inspection where possible.

2.2.4 An endoscope was inserted into the closed upper edge beam section to inspect the section locally. However, the presence of internal castings and longitudinal ties limited the scope of this inspection.

3 CONDITION OF BRIDGE SUPERSTRUCTURE

3.1 Edge Beams

Top segment of top flange (Upper rolled plate)

3.1.1 Generally, the top segment of the top flange of the edge beams appears to be in satisfactory condition. The outer surface has a paint protective coating and although this coating is in a poor condition, it appears that this coating and previous coats (which have clearly been replaced from time to time) have protected the outer surface from significant corrosion.

3.1.2 The inner surface of the top segment has not been inspected, but there are no obvious signs of corrosion reflected at the outer surface or at joints. The only source of corrosion is likely to have been minor moisture condensation within the closed section (which is not entirely sealed). The inner surface does not appear to have been provided with any protective coating originally, but if it was, it is likely to have been only a primer coat. It seems likely (subject to internal inspection) that the inner surface may be only slightly corroded with generalised surface corrosion, which may have only affected a thin layer of the iron surface.

3.1.3 The only exception to this general condition is on the South edge beam where the original top flange has been replaced by a modern steel circular hollow section over a length of about 12m. The area which has been replaced (and associated damage and repairs to other parts of the cross section) are consistent with accidental damage by the bow of a ship striking the bridge when it was in the closed position ie across the lock. No historical records of this accident and subsequent repairs have been so far discovered, but it seems likely that the damage and repairs took place in the post WW2 period (when circular hollow sections of this size were available – 16in outside diameter of $^5/_{16}$ in, $^3/_8$ in, $^7/_{16}$ in or $^1/_2$ in thickness were available in the 1960s and onwards. See for instance Stewarts and Lloyds. Ref 1).

3.1.4 It appears unlikely that any significant repairs will be required to this element of the edge beam section.

Bottom segments of top flange (Inner and outer lower rolled plates)

3.1.5 Generally, the bottom segments of the top flange appear to be in satisfactory condition. The outer surfaces have a paint protective coating and although this coating is in a poor condition, it appears that this coating and previous coats (which have clearly been replaced from time to time) have protected the outer surface from significant corrosion.

3.1.6 The inner surfaces of the bottom segments have not been inspected, but there are no obvious signs of corrosion reflected at the outer surface or at joints. As with the upper segment, the only source of corrosion is likely to have been minor moisture condensation within the closed section. It seems likely (subject to internal inspection) that the inner surface may be only slightly corroded with generalised surface corrosion, which may have only affected a thin layer of the iron surface. As noted above, a 12m section of these segments has been replaced by a steel hollow section at the damaged area.

3.1.7 The only other damage noted on this element of the edge beam was a series of deep gouge marks and indentations. Local repairs will be required to these areas where corrosion damage was also noted. Apart from these localised areas, it appears unlikely that any significant repairs will be required to this element of the edge beam section.

Internal Ties

3.1.8 The internal ties could not be inspected except locally to the fixing locations. Due to their protected location within the closed section, it appears unlikely that they have suffered significant corrosion damage. However, it is not clear whether the ties were replaced intact when the hollow section was replaced on the south edge beam.

3.1.9 It is probable that the entire tie system will require re-tensioning as part of the renovation process, unless detailed structural analysis shows this to be unnecessary.

Web (Girder Plate)

3.1.10 The webs of the edge beams appear, generally, to be in a satisfactory condition. Both sides of the edge beams were available for inspection and little evidence of corrosion was noted. The surfaces have a paint protective coating. This coating is in a poor condition and, along with the remainder of the exposed iron surfaces, the coating will need to be entirely refurbished as part of the renovation process.

3.1.11 In the majority of cases, the webs appeared to be original wrought iron plate. It is possible that on part of the south edge beam the web has been replaced where the apparent ship collision, referred to above, occurred.

3.1.12 Defects found in the web include quite a large number of small bolt holes, some still containing bolts, studs or the remains of the same. It appears likely that these bolts were used in the past to fix brackets for pipes, electrical conduits and the like. Although these are very minor defects, localised corrosion was noted adjacent to many of the holes. Any remaining parts of bolts will need to be removed and the small areas made good as part of the refurbishment and renovation process.

3.1.13 Localised corrosion is present in two other areas. The first area is close to a cover plate near the turntable on the south edge beam. Based upon the original drawings for the bridge, this plate is in an area previously occupied by the hand winder mechanism for the bridge. It appears that the corrosion is due to moisture ingress to the plate-to-plate interface. Removal and refurbishment of the cover plate (and the area of web plate presently covered) will be required as part of the renovation work.

3.1.14 The second area of localised corrosion is at the interface between the web and the shelf angle along the inner surface of the edge beam. This was noted particularly along one section of the south edge beam. Localised replacement of small sections of the shelf angle appears to be necessary.

3.1.15 It is unlikely that the web plate will need significant repairs, although localised repairs, as noted above will be required. The coating to the web plates will need to be entirely refurbished as part of the renovation process.

Top segments of bottom flange (Inner and outer plates of the triangular section)

3.1.16 The top segments of the bottom flange are in variable condition. Signs of corrosion along some lengths of the edge beam indicate these areas to be in poor condition. The corrosion damage appears to be due to corrosion of the (relatively thin) plates from the inside surface outwards rather than from the external visible surface. The original drawings for the bridge indicate that the plate thickness was intended to be either ¼ in or $^{3}/_{8}$ in. Modern practice would require thicker plates than ¼ in when used externally.

3.1.17 The bottom triangular ‘flange’ sections of the edge beams are not sealed. They are at a level where water from the dock system can enter and remain when and after flooding occurs. Flooding of the local area is a regular occurrence and occurs, principally when high spring tides (sometimes with a surge component) on the Avon estuary leads to overtopping of the quay walls. Based upon the period when volunteers have been working on the bridge, flooding is likely perhaps twice or three times a year.

3.1.18 Three sections of the top segments of the bottom flange were taken off for inspection by removing existing plates, which had been welded into position as part of a previous repair regime. Two of these plate areas were on the outer side of the south edge beam where trial repairs were completed. The other area was on the inner side of the north edge beam. Very significant corrosion was found at some but not all of the exposed sections of the top segments. The worst areas of corrosion are probably co-incident with areas where the build-up of corrosion products has allowed moisture to become trapped within the section. *Plates 1 and 2* show very significant corrosion and insignificant corrosion (to the upper segments) respectively.

Plate 1 – Very significant corrosion within closed bottom section

Plate 2 - Slight or insignificant corrosion to upper segments within closed bottom section

3.1.19 However, it can be seen that corrosion has taken place at the crevice where the upper segments meet the base plate and this is reflected in observations on the outer surface.

3.1.20 Significant amounts of repair work will be required to these segments of the edge beams as part of the bridge renovation. In the first place, there are significant areas where replacement of plate is required because corrosion has removed the entire section thickness or a very substantial proportion of that thickness. Secondly, there are areas where previous repairs have been carried out and these repairs have also corroded. Additionally, measures will be needed to protect the internal portions of the triangular segment from future corrosion, bearing in mind the lack of maintenance access to the area. The external coating to the flange segments plates will need to be entirely refurbished as part of the renovation process.

Bottom plates of bottom flange (Lower plates of the triangular section)

3.1.21 The bottom plate of the bottom flange is in variable condition. Unlike with the upper segments, not many corroded holes could be seen through the base plates, although there was generalised surface corrosion visible on exposed surfaces. This generalised surface corrosion may have removed a small portion of the total plate thickness from the outside. However, as can be seen from *Plates 1* and *2*, significant corrosion was found internally in the three areas that were opened up for inspection. It appears likely that some areas of plate will need to be replaced or reinforced as part of the renovation process.

3.1.22 Specific deep pitting corrosion was noted externally on the base plate in the area adjacent to the turntable rail. This appears to be a case of bi-metallic corrosion in the immediate area around the turntable. A considerable portion of the total plate thickness has been removed by this process. A thin layer of metal (discovered to be lead) is sandwiched between the turntable rail and the base plate of the edge beams. It appears that this lead was introduced to level up the bridge (probably when the bridge was re-set in its current location).

3.1.23 Corrosion tables suggest that lead is widely separated from iron in the galvanic series for seawater (lead more cathodic, iron more anodic). As a result, wrought iron is likely to corrode in preference to lead. It is likely that the solution will require the removal of the turntable rail section; the removal and disposal of the lead section; repairs to the base plate; and, reinstatement of the turntable rail. It is likely that the turntable rail itself will need to be refurbished to ensure that it is flat and level and adequate to bear onto the rotor wheels below.

3.1.24 The external coating to the base plates will need to be entirely refurbished as part of the renovation process. In view of its location relative to the flood water and the difficulty of access for recoating, additional measures should be considered, such as cathodic protection, to ensure the long-term serviceability of the bottom flange.

Web Stiffeners

3.1.25 The web stiffeners are in variable condition. Some of the stiffeners are now ineffective, either having corroded locally or in two cases having been cut locally. Although these elements form a small portion of the bridge superstructure, these sections will require repairs to restore the stiffeners to functionality.

Fasteners and Connections

3.1.26 Nearly all of the fasteners on the bridge superstructure are rivets. The rivets are less rounded on the driven head than might be found with more modern rivets and for this reason, replacement rivets can be usually identified on the bridge. Although less rounded heads may not be as intrinsically strong as domical rivets, the vast majority of these appear to be in satisfactory condition as far as can be established from visual inspection. In some cases, it was noted that the rivets were originally 'overdriven' causing depressions in the adjacent plate. However, no signs of local plate tearing failure were noted adjacent to such rivets. Relatively few rivets are missing and these will need to be replaced as part of the renovation work.

3.1.27 A few of the fasteners on the bridge superstructure are bolts. These occur principally where wrought iron plates are connected to iron castings, such as at the connection between the edge beams and the edge castings for the kentledge assembly. Some of these bolts are missing and should be replaced as part of the renovation process.

3.1.28 Some welded connections were noted. In all cases, such welding appeared to be connected with earlier repairs to the bridge. Although most of the welding appeared to be adequate, the standard of workmanship on the welding is generally poor and if any of these weldments are to remain after renovation (some will be removed as plates are removed), then remedial work would be required to the welds.

3.2 Transverse Beams

Typical diagonal beams – Beams 1 to 16

3.2.1 Generally, the typical transverse beams are in satisfactory condition. However, there is an apparent systematic defect on many of these transverse beams. The majority of the beams appear to be sound over the middle $^{3}/_{4}$ of their span. Near the ends where they are close to the edge beams, there are widespread areas of corrosion. This corrosion has generally affected the web plate. On many of these beams, the corrosion is worst at the crevice where the web plate meets the top angles of the beam section; on some beams, there is also similar corrosion at the crevice where the web plate meets the bottom angles. On a number of the beams, the corrosion is obviously of long standing and supplementary steel web plates have been welded (in a somewhat unworkmanlike way) into the corroded web at some time in the past. In some places, it can also be seen that crevices have been filled with what appears to be cement grout. There are other isolated defects but these are more random in nature.

3.2.2 It seems most likely that the systematic defect was caused by rain falling onto the edge beams and then dripping onto the timber decking before finding its way through gaps in the decking into the crevices in the iron section. Once there the moisture will have remained for substantially longer periods than elsewhere, leading to the localised corrosion damage that has been found. The areas which are corroded, ie the ends of the web plates, are the areas near the beam supports where shear forces in the beams are highest and therefore the web plate is most required to be sound. Repairs will be required to these local areas followed by refurbishment of the entire external coating as part of the renovation process. In addition to the normal corrosion protection system, additional protection to the areas where this systematic defect has occurred may be required.

Other transverse beams – Beams 17 to 21

3.2.3 The other transverse beams are in variable condition. Beams 20 and 21, in particular, have been repaired extensively in the past and such repairs will require further repairs as part of the renovation process.

Turntable Beams

3.2.4 The turntable beams are also in variable condition. Some of the beam sections appear to be satisfactory with little need of repair. However, other beams in this area are in a very poor state of repair. Corrosion and loss of metal section is extensive, particularly on the circular beams attached to the turntable rail. Significant replacement of web and angle sections will be required as part of the renovation process.

3.2.5 In common with the remainder of the superstructure ironwork, these beams will require full refurbishment of the paint protective coating.

3.3 Kentledge Assembly

3.3.1 The iron castings for the kentledge appear to be in satisfactory condition. Generalised surface corrosion was noted on the base of the sections which are not normally exposed to view, but this did not appear to be detrimental to the serviceability of the kentledge.

3.3.2 The top surface of the transverse kentledge sections are presently covered with a layer of tarmac. This tarmac will need to be stripped and replaced as part of the renovation process.

3.4 Mechanical Assemblies

3.4.1 The condition of the mechanical assemblies, including the wheels and associated bearings within the kentledge section and the roller bearings at the cantilever end, are not covered by this inspection and report.

4 CONCLUSIONS

4.1 Assessment

4.1.1 Based on the inspection carried out, the superstructure of the bridge is not currently in a state where the structure could be put immediately back into use.

4.1.2 Although not in a satisfactory state, the inspection revealed that damage was mainly confined to specific elements or areas of elements where damage had occurred due to long-term corrosion.

4.1.3 The elements which showed significant damage were:

- the top segments of bottom flange (the inner and outer plates of the triangular section);
- the bottom plates of bottom flange (the lower plates of the triangular section), particularly adjacent to the turntable;
- small sections of the typical transverse beams near their ends;
- the curved turntable beams; and
- some of the straight turntable beams.

4.1.4 Other elements showed slight or insignificant damage.

4.1.5 Some of the elements showing significant damage have been repaired in the past, but these repairs are now generally unsatisfactory.

4.2 Required Repairs

4.2.1 The majority of the significant damage will require repair, as part of the renovation process, using patch plates to replace damaged or seriously corroded existing plate.

4.2.2 The bottom plates of the bottom flange will need to be reinforced to replace the significant loss of section that has occurred in some locations.

4.2.3 The internal surface of the bottom flanges to the edge beam will require protection against the future ingress of water and corrosion damage.

4.2.4 The internal ties within the top flange of the edge beams may require re-tensioning, unless detailed structural analysis shows this to be unnecessary.

4.2.5 Local or small-scale repairs will be required to such items as: the web stiffeners to the edge beams; deep gouge marks on the upper flange section of the edge beams; bolt holes on the web to the edge beams; replacement of missing rivets or bolts; and, other damage, which is shown on the inspection drawings.

4.2.6 The entire superstructure will require refurbishment of the external paint protection system to provide a very long life to future maintenance. It is probable that this may need to be supplemented by extra corrosion protective measures for elements such as the lower 'flange' of the edge beams and the ends of the transverse beams.

5 REFERENCES

1. Stewarts and Lloyds Ltd. Structural Hollow Sections. Birmingham, November 1965

Appendix A

Sketches

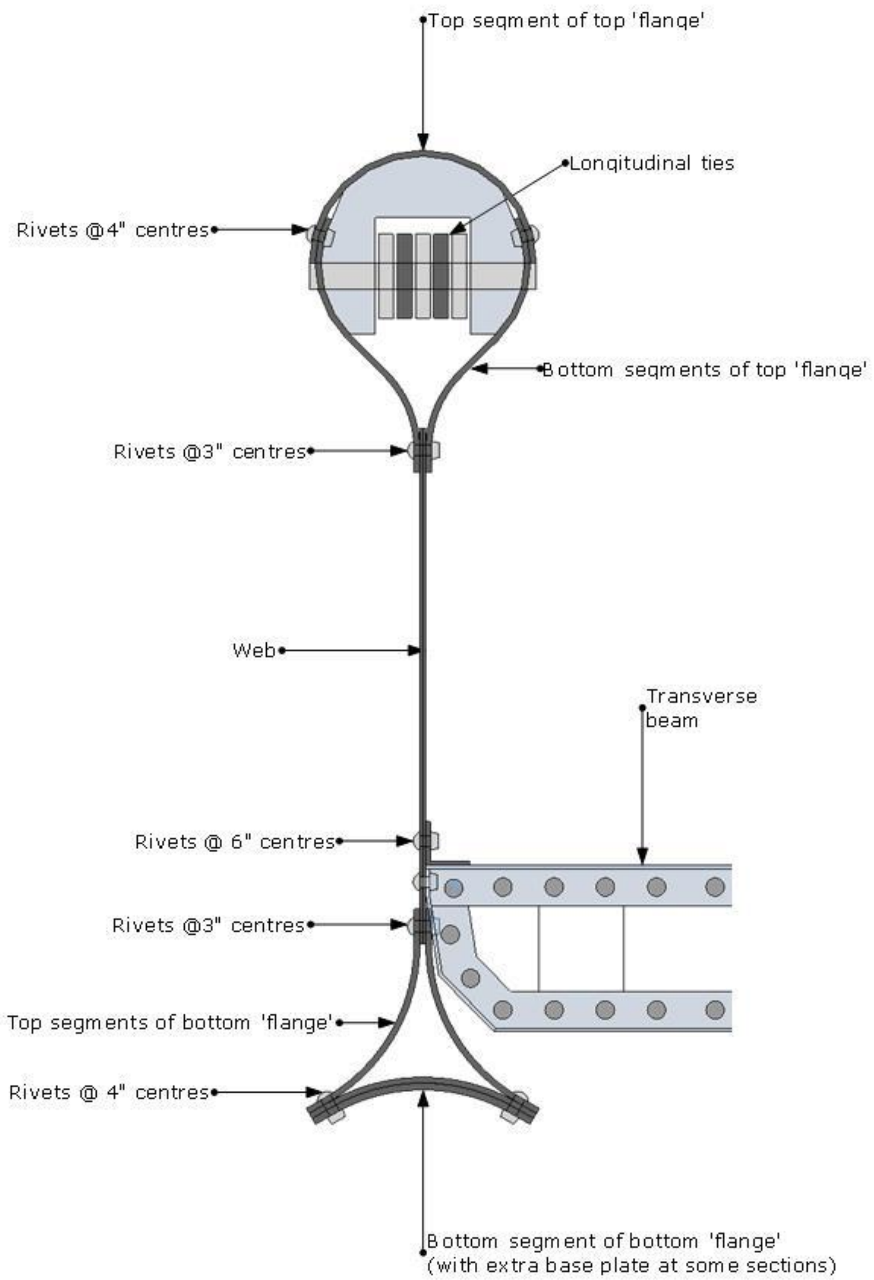

Figure 1 - Typical Section on Edge Beam

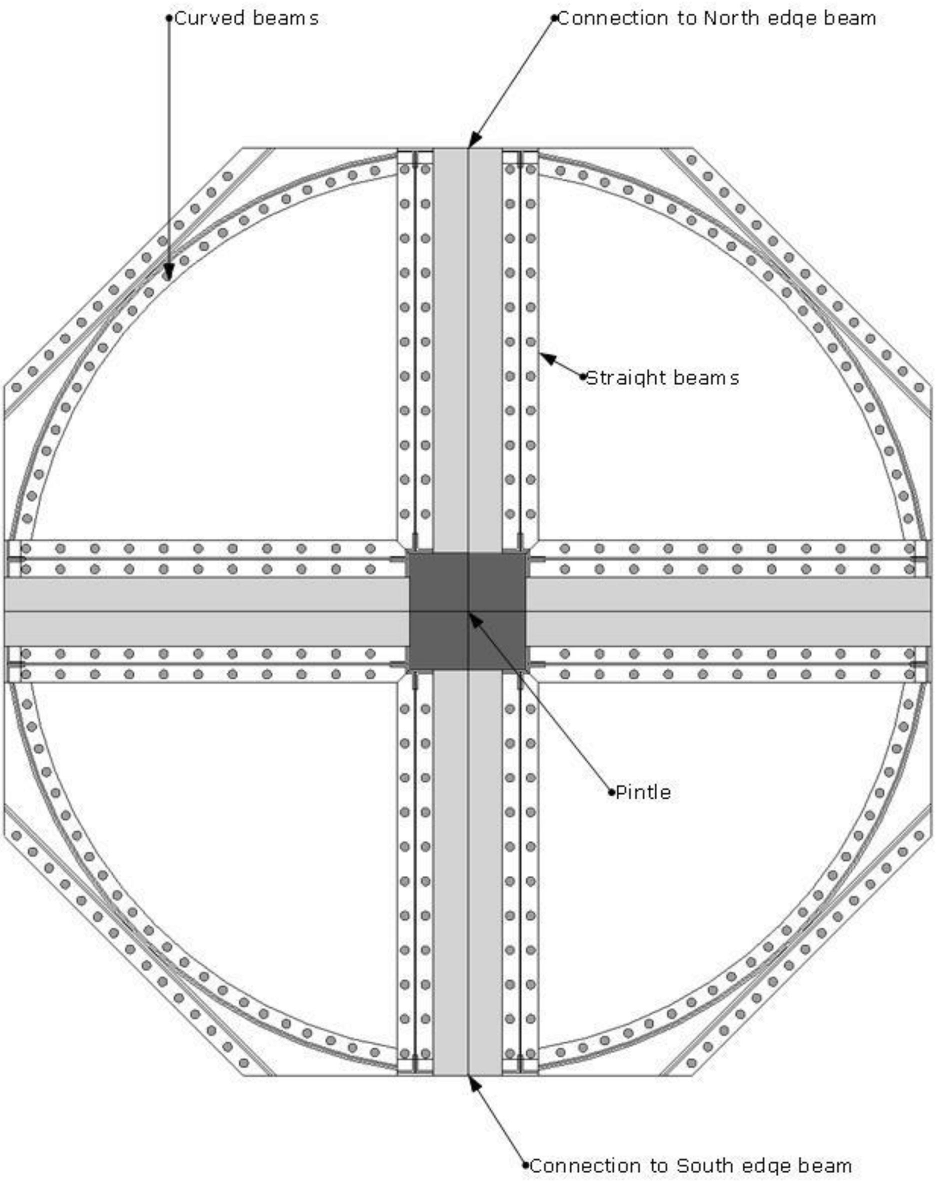

Figure 2 - Plan on Turntable beams