SWAN RIVER PEDESTRIAN BRIDGE IN PERTH – STRUCTURAL DESIGN STORY FROM THE CONCEPT TO THE CONSTRUCTION

Massimo MAJOWIECKI
Professor
Alma Mater Studiorum Bologna
Bologna, Italy
massimo.majowiecki@majowiecki.com

Stefano PINARDI
Civil Engineer
Studio Majowiecki
Bologna, Italy
stefano.pinardi@majowiecki.com

Giovanni BERTI
Civil Engineer
Studio Majowiecki
Bologna, Italy
giovanni.berti@majowiecki.com

Summary

This paper resume the story of the design of the new “Swan River Pedestrian Bridge” now under construction in Perth, Australia. The bridge is formed by three steel decks connected with cable hangers to three steel arches, the central span is 144[m] and the two lateral 84[m]. The geometry of the steel arches follow the free form shape designed by DCM Architects, in order to achieve an iconic image as required in the tender of 2014.

Studio Majowiecki has been involved as structural designer from the tender phase to the executive design in the team of York Rizzani Joint Venture. During the concept phase of the tender proposal many static and architectural schemes have been analyzed in order to find the solution that combine in the best way the requirements in terms of aesthetic image and structural efficiency.

Due to the complex geometry of the bridge it has been necessary to adopt particular solutions for the design and analysis of the arches and deck structures, such as the joints between the steel elements of the lattice structures, the connections between the membrane cladding and the chords and some details that allow the completion of assembly procedures.

Keywords: Bridge design, membrane cladding, space reticular frame, punching shear verification, erection sequence.

1. Story of the architectural and structural conception

1.1 The public tender and the design team

In February 2014 the government of Western Australia called on industry to submit expressions of interests to design and build the bridge that will connect Burswood Peninsula, near the new Perth Stadium to East Perth. The Minister of transport said contractors would need to consider bridge design and construction objectives that included functionality and build quality, innovation and creativity, efficiency and sustainability, as well as responsiveness to the context and environment within which the structure would exist.

York Rizzani Joint Venture (YRJV) involve DCM Architects and Enigma Engineering (Studio Majowiecki and Ingeco from Bologna) for the architectural and structural design of the footbridge from the concept to the construction phase.

1.2 Architectural and structural concept

Denton Corker Marshall architecture started the first conceptual studies in the 2014, shearching the best solution in terms of iconic image of the bridge and integration in the landscape. In Fig. 1 the first schemes proposed but not pursued due to their lack of structural efficiency.

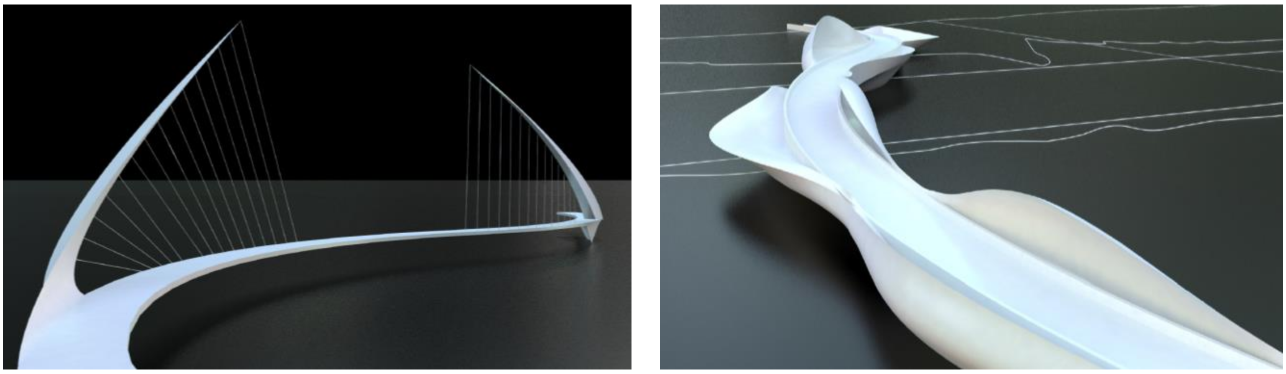


Fig. 1. Schemes proposed by DCM architecture in 2014

An intensive exchange of informations and proposal between DCM architecture and studio Majowiecki has lead to the definition of a structural geometry composed by three arches (Fig. 2-a). This solution has been interpreted architecturally as the sinuous shape of two swans with the heads connected (Fig. 2-b).

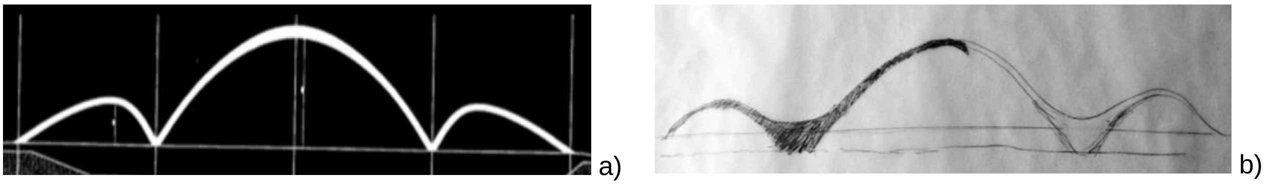


Fig. 2. a) Structural scheme with 3 arches proposed by Studio Majowiecki, b) Elaboration of the Architectural image by DCM

After the definition of the bridge shape DCM architecture has developed different 3D render models that have been analyzed by studio Majowiecki in order to find the system that complies with the aesthetic requirements ensuring at the same time a good structural efficiency. In Fig. 3-a is shown the architectural concept with the arches composed by independent legs; in Fig. 3-b the structural solution adopted where the legs are realized with triangular cross - section reticular space frames connected in the top part in order to increase the lateral rigidity.

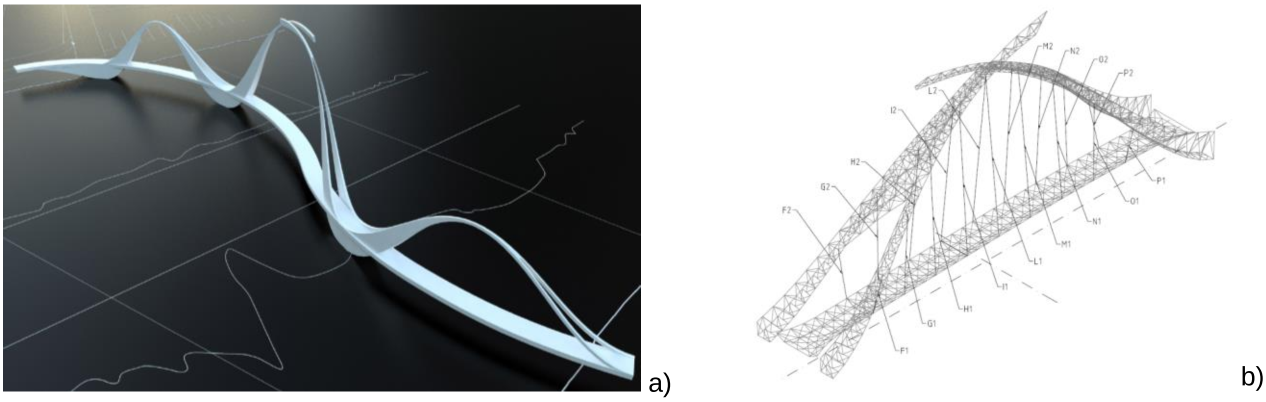


Fig. 3. a) Architectonic proposal for the bridge, b) Wireframe of the structural geometry in reticular space frame

The structural forces are expressed clearly and uniquely in the black and white articulation of the arch ribbons reflecting both structural interdependency and the symbolic coming together of diverse cultures. The design can remember the shape of two swans, a group of snakes or a dolphin shape, which are perfect for this river environment. The team proposal won the competition since it was considered as the best in terms of interpretation of tender requirements, such as iconic figure and integration in the landscape (Fig. 4).

Fig. 4. Final render of the structure

The bridge structure will be covered with a Teflon coated fabric with allow to fit the complex geometry of the arches and deck and achieves a translucent effect in presence of internal lighting.

1.3Static scheme

The bridge is formed by three steel decks connected with cable hangers to three steel arches. The geometry of the steel arches follow the free form shape designed by the architects. The total length of the bridge is about 400[m] with a central span of 144[m] and the two lateral of 84[m].

The main arches are connected at the top by an hinge joint that allow a rotation in the longitudinal plan but ensure a rigid connection in the transversal plan. This kind of restrain and the particular geometry of the arches leads to the static behavior of the semi arch as a cantilever beam supported at the end (see axial forces diagram in Fig. 5). This structural behavior is due to the geometry that does not follow the thrust line of the arch but achieve an iconic architectural figure.

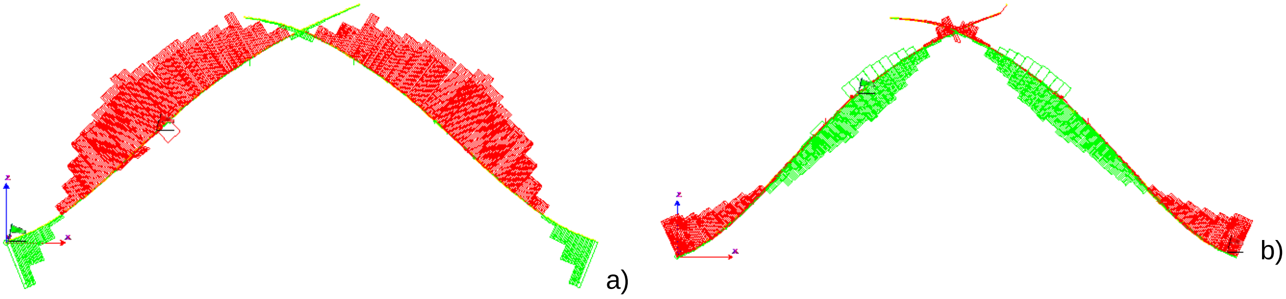


Fig. 5. Axial forces diagram in the upper a) and lower b) layer of the main arch in the permanent load ULS load case

In the apex of the main arches there are two cantilever part of the structure of about 25[m] length: the dimension of these apex has been limited in order to maintain their natural frequencies within acceptable limits.

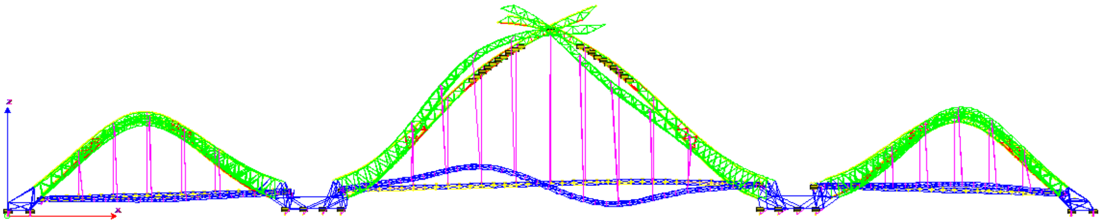


Fig. 6. Mode number 9: Pier and main arch longitudinal movements

2. Specific aspects of the design

2.1 CHS connection details

2.1.1 Chord can and punching shear check

In the tender phase the design considered a global welded structural system (factory and site welding). Due to site assembly difficulties, YRJV decided to proceed with bolting segmentation of the arches that are made up of different types of steel trusses using circular hollow sections (CHS).

All connections between CHS elements are welded by means of profile cutting, which tends to be the most economical solution for joining tubular sections at a node.

Australian Standards do not explicitly address a method to perform to perform punching shear checks; therefore the checks have been developed accordingly to: Eurocode 3 Part 1-8 Design of Joints (BS EN 1993-1-8:2005). Two checks are introduced for uniplanar joints:

1) In brace member connections subject only to axial forces, the design internal axial force $N_{i,Ed}$ should not exceed the design axial resistance of the welded joint $N_{i,Rd}$:

$$N_{i,Ed} \leq N_{i,Rd} \tag{1}$$

2) Brace member connections subject to combined bending and axial force should satisfy:

$$\frac{N_{i,Ed}}{N_{i,Rd}} + \left[\frac{\left| M_{ip,i,Ed} \right|}{M_{ip,i,Rd}} \right]^2 + \frac{M_{op,i,Ed}}{M_{op,i,Rd}} \leq 1 \tag{2}$$

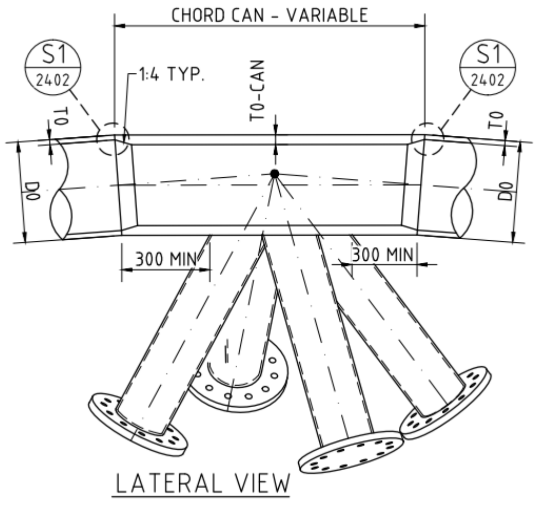


Fig. 7. Typical chord can connection

For the connection between the chord and diagonal elements has been adopted a chord can connection as shown in Fig. 7.

The advantage of using “Chord Cans” is that the welded joint between chord and braces can be performed on a straight segment of tube (rather than on a kink), and that the can section thickness can be increased if necessary to strengthen the joint and fulfil punching shear check.

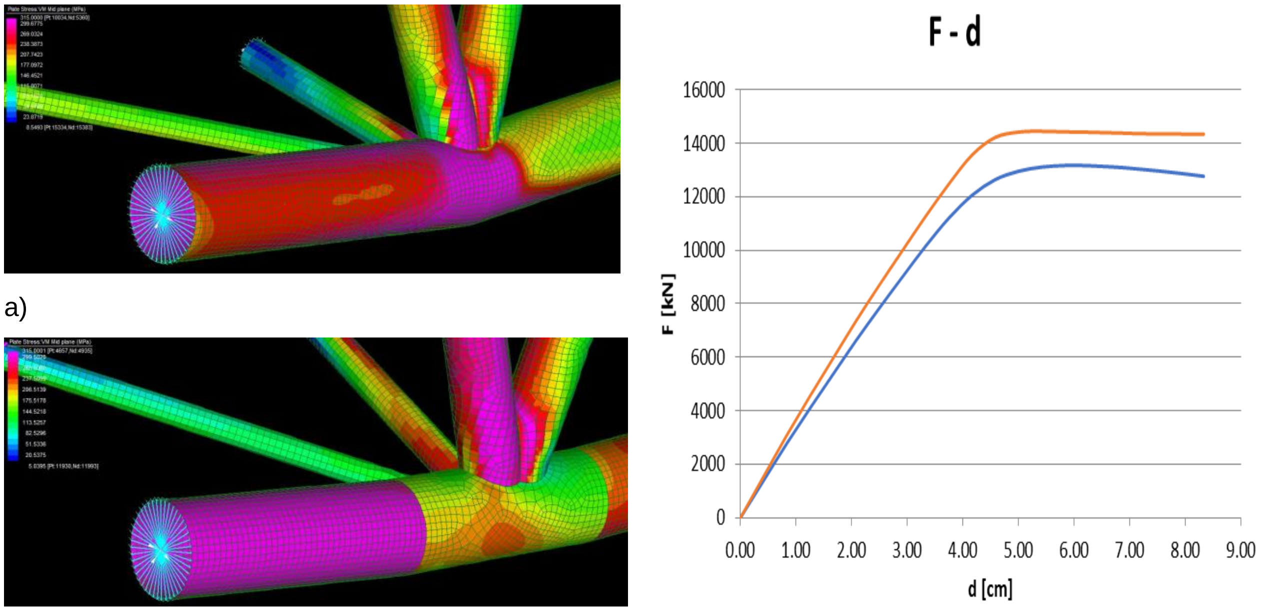
According to AS 5100.6 prototype testing of typical 3D CHS connections is proposed as an alternative calculation (design assisted by testing) in order to check the reliability of this numerical simulation with a cross – control between mathematical model and experimental test.

In fact, under the special circumstances, generated by the free-form spatial configuration of the bridge steel structural system and the lack of calculation method provided in AS building code, design assisted by testing is required in order to remove uncertainties in reliability assessment.

The tests are addressed principally to check the acceptance for strength of the welding and punching shear performance; therefore, the check of the welding design and verification, execution methodology and acceptance criteria of the levels of non-destructive examination (Clause 7.4 of AS/NZS 1554.1) have to be reported by a qualified Institution as required by the client.

2.1.2 Finite Element Model of the connections

A non linear plastic analysis of some nodes have been carried out (Fig. 8-a e b). The main aim of this analysis is to check if with the introduction of the chord can element the resistance capacity of the node is improved and to verify if the plastic resistance of the node is major of the design load. The graph in Fig. 8-c shows that with the can element the joint can reach all the CHS chord plastic resistance (14425 [KN])



a)

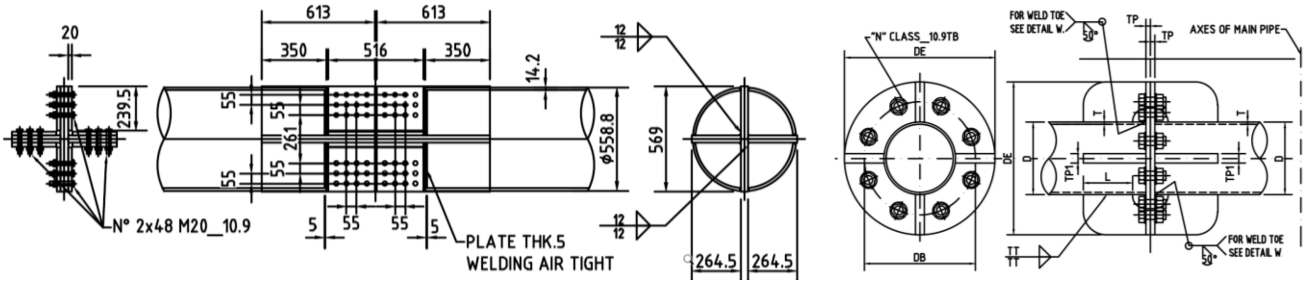
b)

c)

Fig. 8. a) Collapse without the chord can: all the node in plastic tension; b) Collapse with the chord can: the CHS chords arrive at the plastic tension before the node elements; c) Force - displacement graph with the can element (blue line) and without can element (red line).

2.1.3 Connections in the chords

The chords elements of main and secondary arches have been connected with cross plates welded to the CHS and connected with bolts and plates. The steel plates and bolts have been designed in order to ensure that all the axial capacity of the CHS section can be transfered by the joint. Checks on this kind of connection have been made in agreement with AS 4100 and following the indications of professional literature ([1], [2], [3], [4]). The following checks have been carried out: strength check, bearing check of the ply, axial tension force check of the ply, bending check of the ply, shear check of the ply, check of the welded connections, block shear check.



a)

b)

Fig. 9. a) 2D view of the connection detail of the chords in the main arches; b) Flange connection with ribs for main CHS bracing elements under prevalent tension

2.1.4 Connections in the diagonals elements

As shown in the bracing CHS elements in the lateral side of the arches and in the bottom are connected with bolted flanges. The main CHS bracing elements lateral bracing elements have been divided in typical members and mebers under prevalent tension (axial force in tensior greater than the 50% capacity of the

CHS section) as the one in Fig. 9-b. Checks on this kind of connection have been made in agreement with AS 4100 and following the indications of [5] and [6].

2.2 Membrane cladding design

Arches cladding is made up of pre stressed fiberglass membrane fabric coated both sides by PTFE layers and supported by steel purlins. This kind of cladding required an addressed structural mathematical model in order to evaluate the forces transmitted by the membrane to the steel structure and the membrane deformations (Fig. 10).

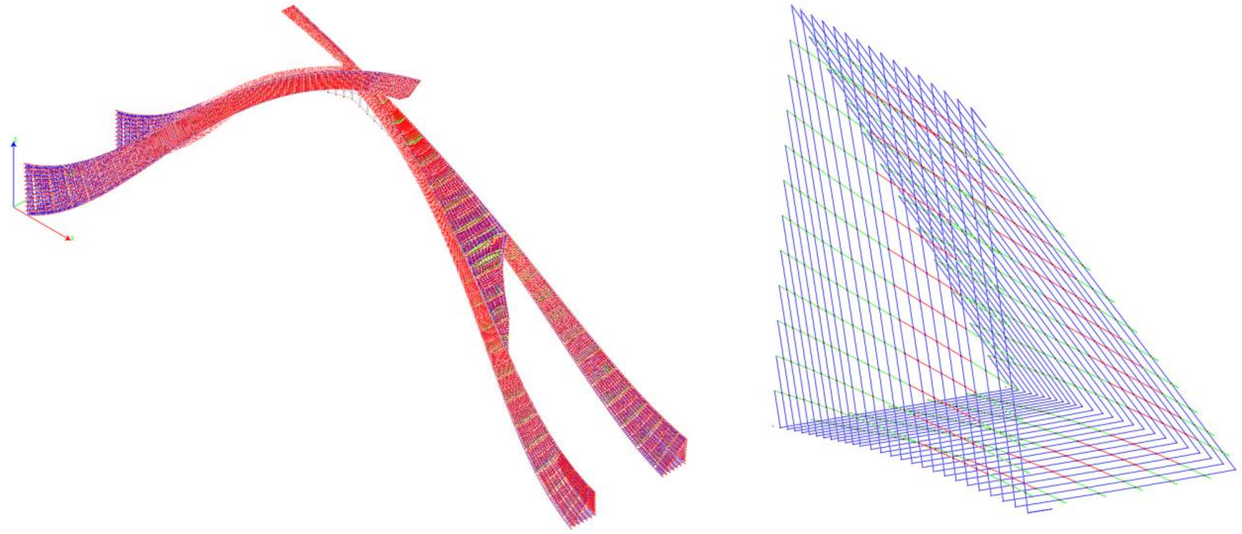
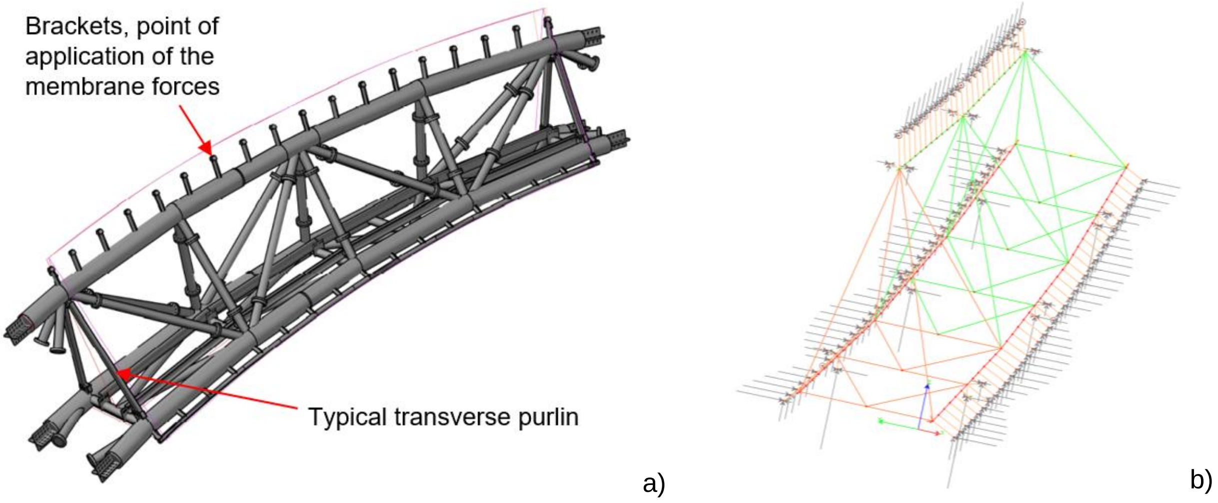


Fig. 10. Isometric view of the mathematical model of the membrane for the main arches

The membrane transfer the load to the arches structure at the top of the connections (Fig. 11-a). Due to the membrane behaviour the force is composed by the load surface load and in addition the axial load of the membrane. To consider this membrane behaviour have been prepared a mathematical model that consider the membrane as a orthotropic net and the supporting frame system as rigid beams.



a)

b)

Fig. 11. a) 3D view of the frame system; b) Load transfer to the frame model and to membrane supports.

In the membrane model the nodes in correspondence with the membrane support system and of the steel frames are restrained in all directions. The reaction forces from the membrane model are transfer to the structural model of the arches directly by the node in correspondence of the membrane support and also by the reaction of the steel frames model (Fig. 11-b).

2.3 Details for the construction procedure

The erection sequence of the steel arches start with the construction of temporary towers (Fig. 12-a). Then the arches arrive transported by barges on the river and have to slide in order to match the erection inges at the pier base (Fig. 13).

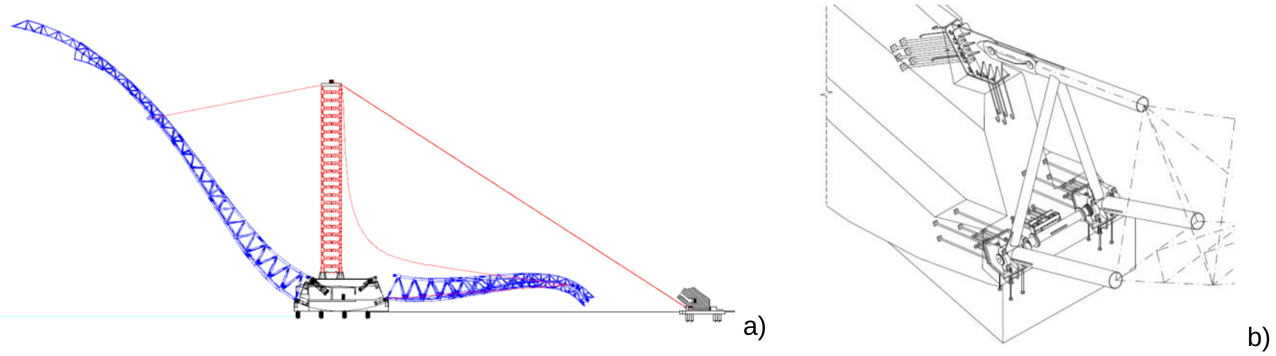


Fig. 12. a) Erection procedure of the steel arches, b) 3D model of the arches connection to the piers

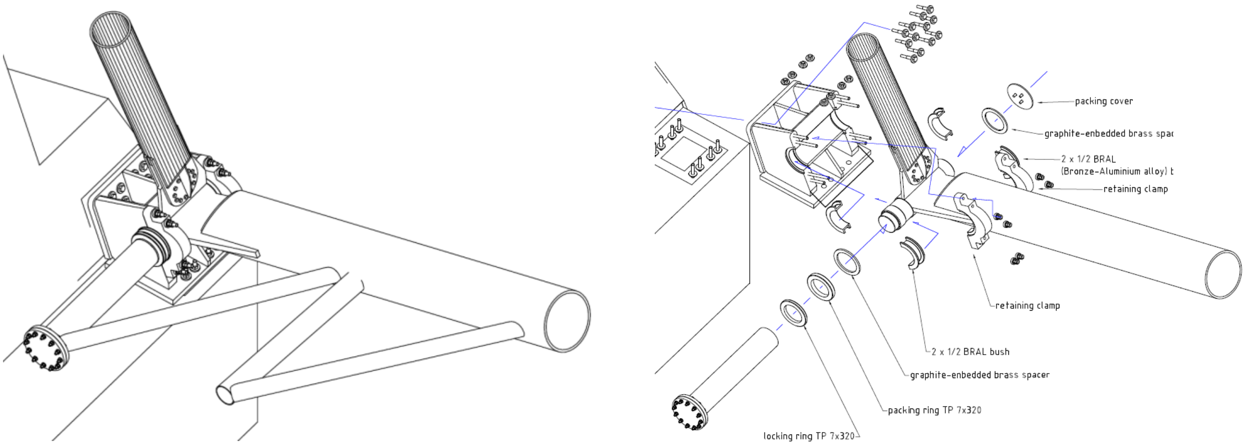


Fig. 13. 3D and exploded views of the hinge connecting the lower chord of the arches to the piers

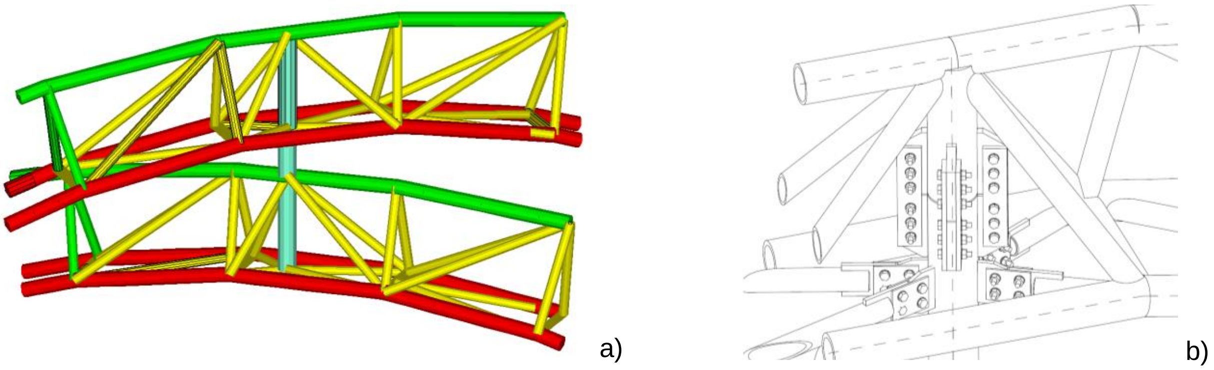


Fig. 14. Top connection of the secondary arches from the mathematical model (a) and from drawings (b).

Then the arches are connected to the temporary towers and rise step by step by rotating around the base inges. After the erection the main arches have to be connected in the top part with a bolted joint (Fig. 15) and the secondary arches with a CS bolted element (Fig. 14). When the top of the arches are joined the connection in the lower part have to be completed connecting the upper chord with the concrete piers, realizing a moment resisting connection at the base of the arches as shown in Fig. 12-b.

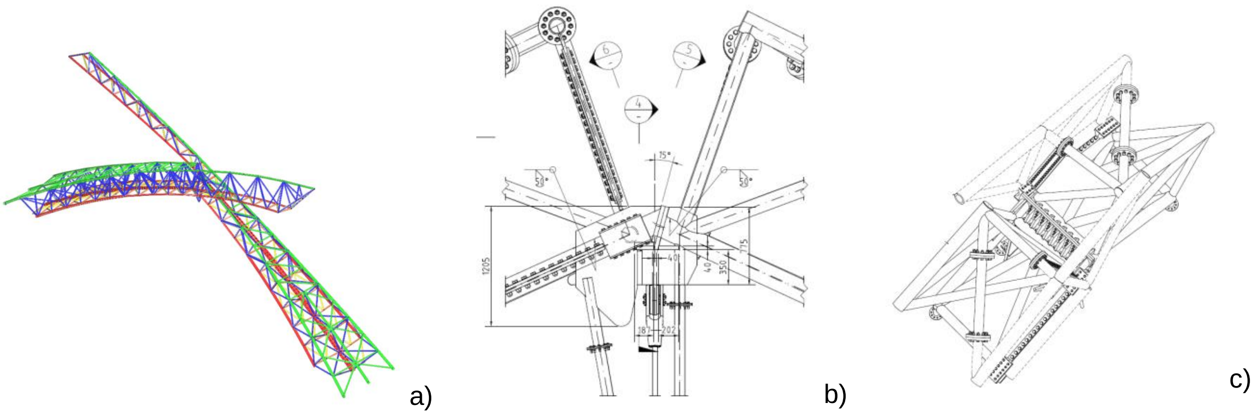


Fig. 15. Connection in the top of the main arches: a) Mathematical model, b) and c) 2D and 3D view of the connection detail from the drawings

2.4 Dynamic aspects

The dynamic aspects of wind and pedestrian action are described in the paper “Wind and pedestrian vibration assessment on the new Swan River Pedestrian Bridge” also submitted in the Footbridge 2017 conference.

3. Conclusions

In free-form architectural objects, whose shape has no direct connection with structural principles, phenomenological design uncertainties play a very important role. Those uncertainties are introduced into designs that attempt to extend the “state of the art”, including new concepts and technologies, and so in this kind of structure in order to guarantee the required reliability level, special expertise is needed in the design and construction phase. That’s why for the Swan River Pedestrian Bridge, due to the complex geometry, it has been necessary to adopt particular solutions for the design and analysis of the bridge structure, as shown previously in this paper.

4. Credits and acknowledgements

Owner of the bridge: Mainroads Western Australia

General Contractor: York Rizzani De Eccher Joint Venture

Architectural Design: Denton Corker Marshall

Structural Design: DEAL, Enigma Engineering

Validation of the design: Mott MacDonald

5. References

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