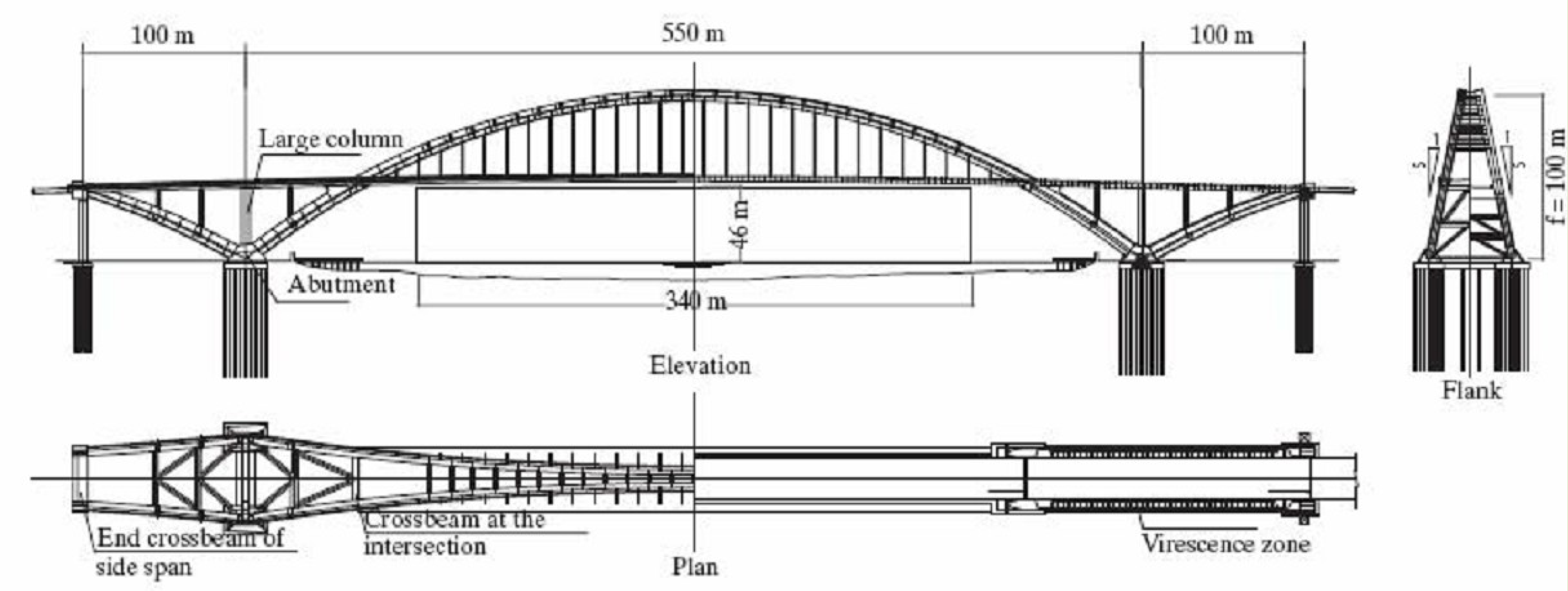
Influence line diagram of Model arch bridge

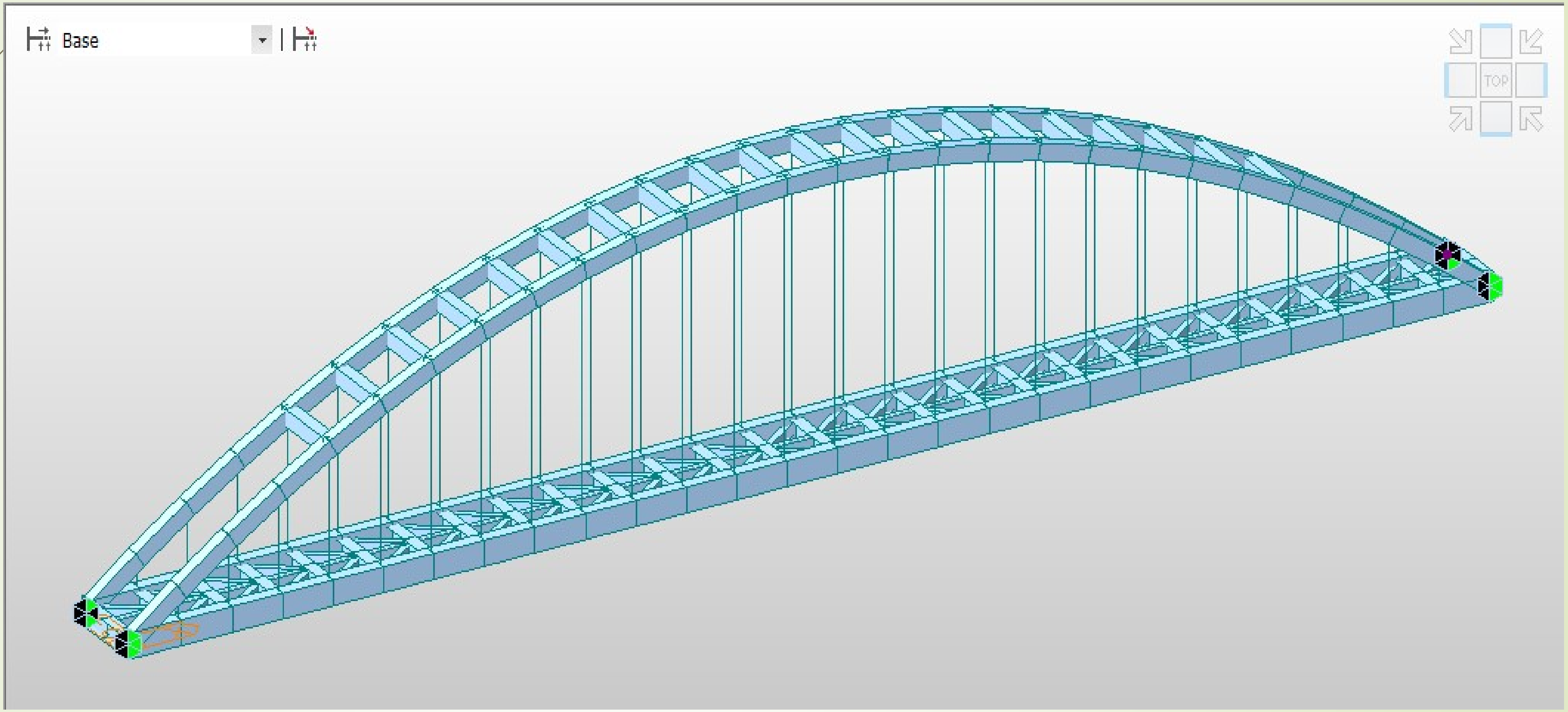
INTRODUCTION

The Lupu Bridge is located in Shanghai, China. It is currently the seventh crossing to be constructed over the Huangpu River in the city. The bridge is located in the south of the city with the aim to ease congestion in the quickly developing areas around the southern side of the river and the city centre and also to help with the increasing traffic expected at the 2010 world Expo. The venue for this is set to be surrounding the river at the location of the bridge, so it will not only be a vital part of the infrastructure for this event, it will also act as a showpiece for Chinese engineering.The bridge was officially opened in June 2003 at a total cost of $302 Million US. On completion the Lupu Bridge was the largest spanning arch bridge in the world with a main span of 550m overtaking the New River Gorge Bridge in the United States by 32m. This record is set to be broken in 2008 by the under construction Chaotianmen Bridge in China by only 2m.

The total length of the bridge is 3,900m including the approach bridges on either side of the river. The bridge was originally heavily criticized as it was seen as wasteful by many people in respect to the type of bridge that was actually needed for the project. Many feel that it is just a show piece for the city and the price tag reflected that status. Other designs were proposed that would have been more economical but were rejected in favor of the tied arch design. The Lupu Bridge is a steel box section through tied arch bridge. The central span of the deck is suspended from two sets of 28 double cables attached to the two inclined arches. The ground conditions on either side of the bridge are not suitable for the large thrusts that would be caused by a normal arch bridge and this is what lead to the decision of using a through tied arch which will be discussed further later in this paper. Below are two elevations of the bridge, the side profile and a view looking longitudinally along the deck.



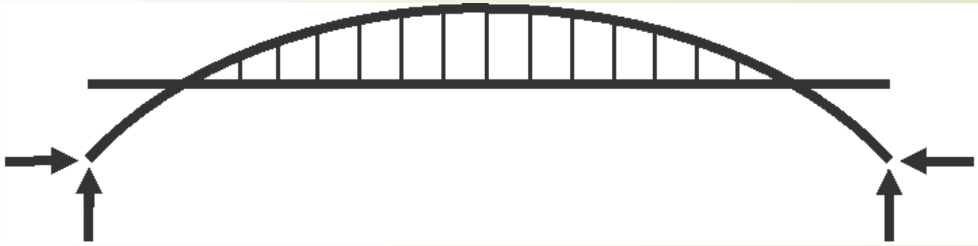
Plan and two elevations.



Elevation of Lupu Bridge by MIDAS Civil2014 software.

Working of Tied Arch Bridge

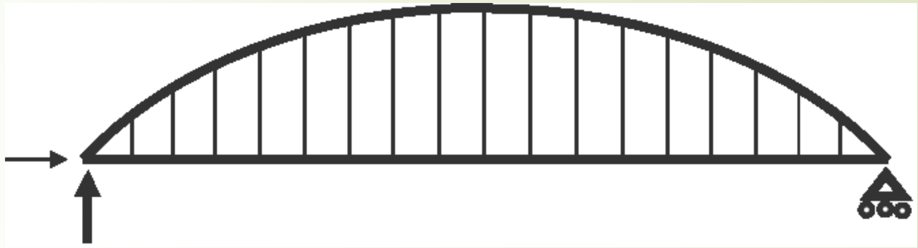
Thrust arches rely on horizontal restraint from the foundations, as shown right. The vertical and horizontal reactions resolve into a force along the arch members – the horizontal component is of significant magnitude. This will be the most satisfactory solution when the arch bears onto good foundation material such as competent rock.



Reactions for a thrust arch bridge

The ends of the arches are normally pinned. However, rock is not always available and so a thrust arch will not be the most economical solution at these locations, as the horizontal reactions lead to heavy uneconomic foundations

The tied-arch offers a solution when it can be arranged that the deck is at such a level that it can carry the horizontal force as a tie member, as shown on right side.

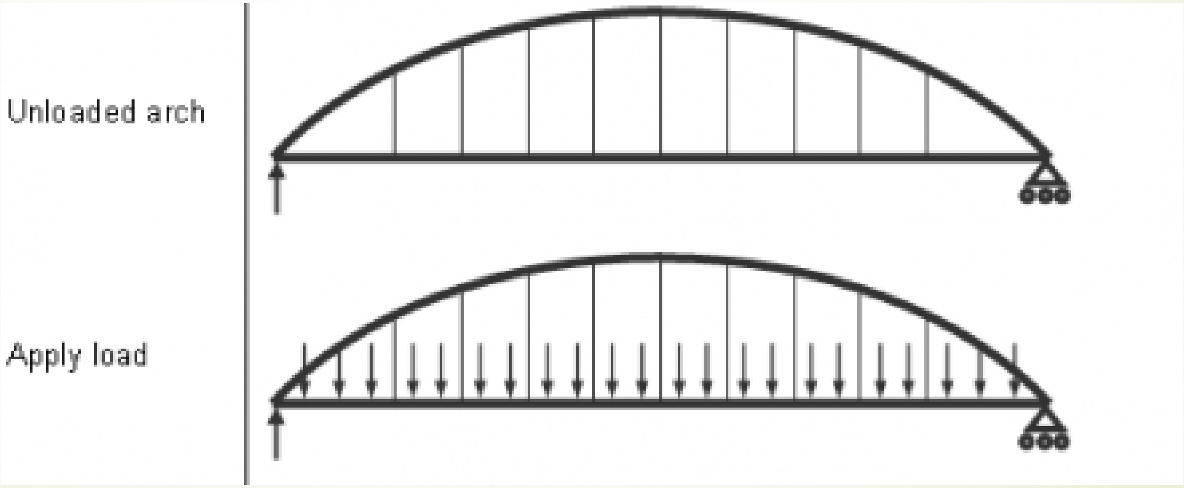


Tied arch

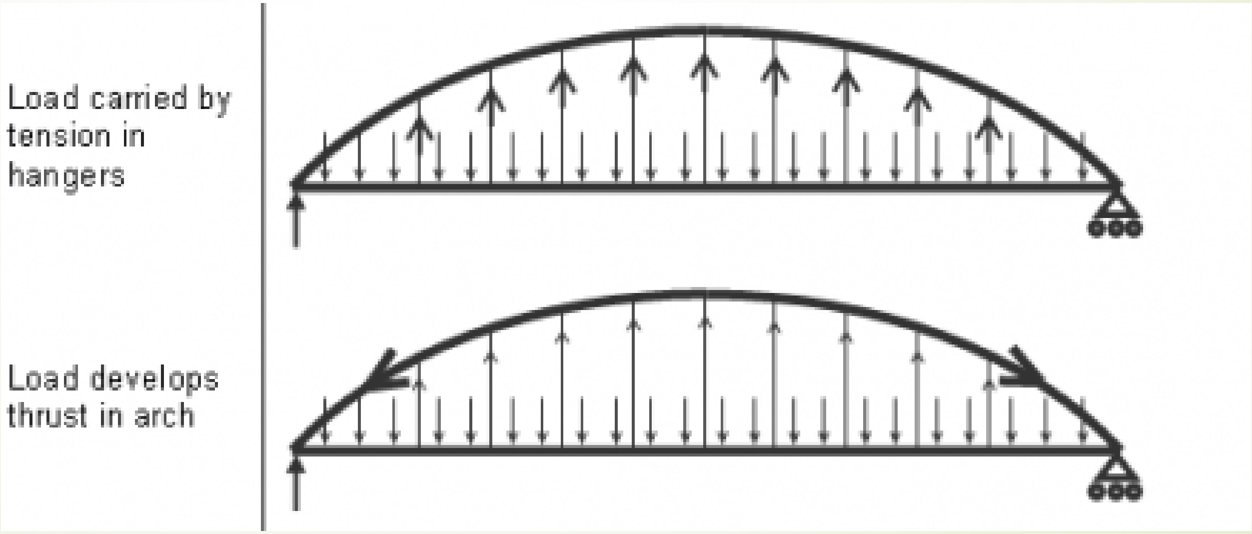
The tied-arch is sometimes referred to as a bowstring arch. By taking the arch thrust through the tie member, the primary requirement for the substructure reduces to only carrying vertical loads. It can be seen that one end will still require a longitudinal restraint to carry wind, braking, acceleration and skidding forces, and that the other end is permitted to move longitudinally.

Overall structural behaviour

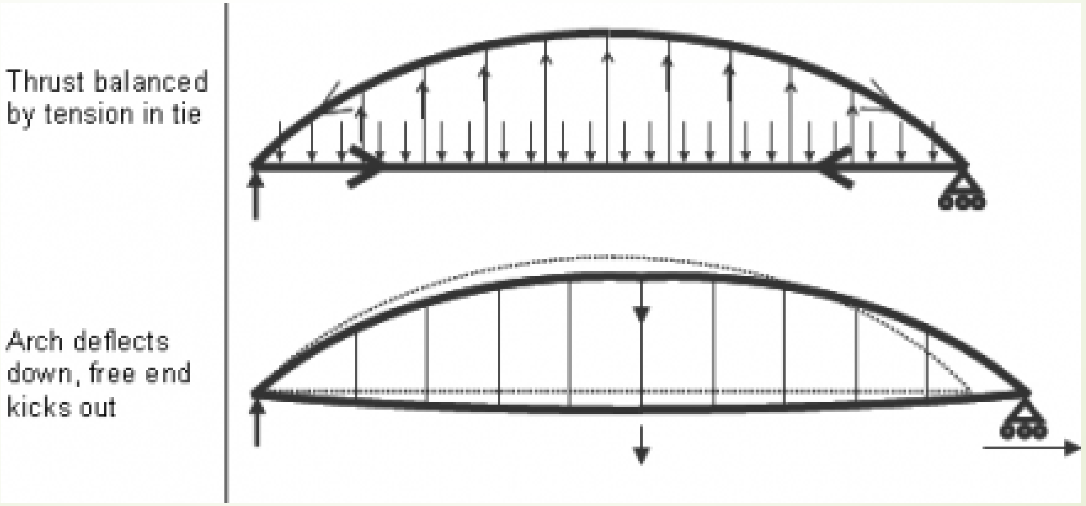
Looking at the diagram above, it can be seen that a tied-arch is really just a simply supported beam. The arch is held longitudinally at one end, with the other end free to expand or contract under varying temperatures.



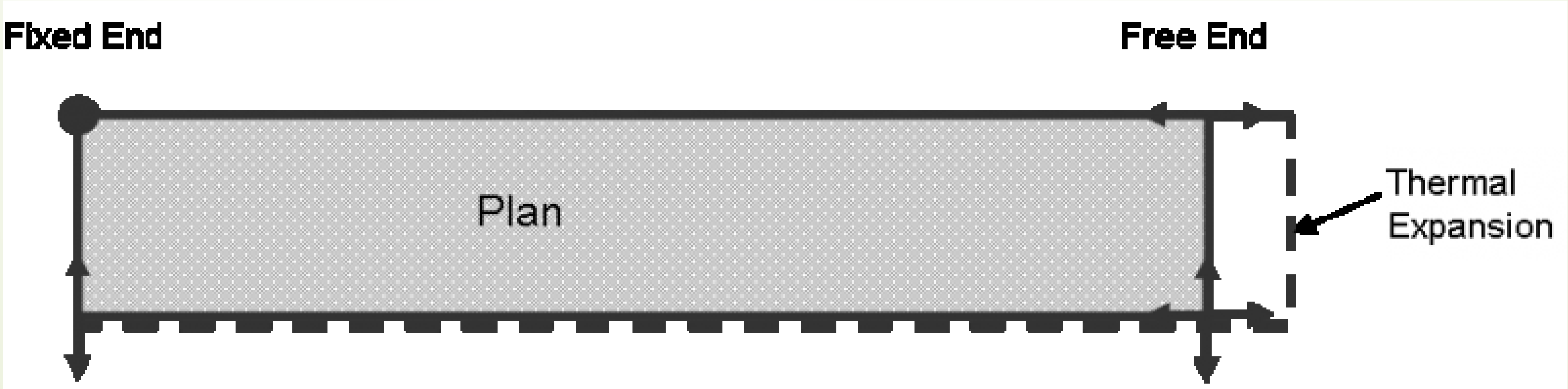
If a load is placed on the deck, it is transferred to the arch via the hangers, as the global stiffness of the arch is greater than the bending stiffness of the deck. This creates thrust in the arch, which is balanced by tension in the tie beam.



The arch will deform downwards, and it will try to spread its feet, but this is limited by having to stretch the tie beam. Hence there will be an outward movement at the free end.



The deck is conventionally **articulated** using the principles mentioned previously. An example is given in the figure below. In this case global longitudinal loads on the bridge are shared between both bearings at the fixed end.



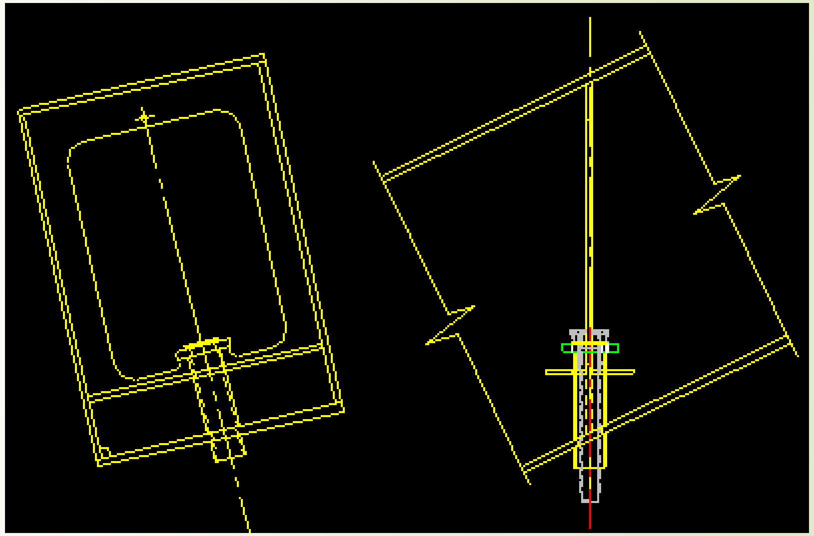
Components and choice of materials

The arch is primarily a compression member and so a closed box section will be the most efficient. **Steel S355** national standard has been used in the sections. There is a choice of whether the arch should be stiffened longitudinally or not. The balance to be considered is one between the loss of efficiency when using 'thin' plates (b/t >24), and the additional fabrication cost of stiffened panels. To minimize future internal maintenance, arches are frequently fabricated from weathering steel, painting the exterior, but leaving the interior unpainted.

Bracing between the arches can take a number of forms, and can even be omitted in small to medium spans. Tubes are commonly used, and are generally too small for man access. They can either be sealed, or vented into the arch boxes with provision for drainage. Note that hot rolled hollow sections are not available in weathering steel.

Hangers

Design rules for tension components are given in BS EN 1993-1-11. As a rule of thumb, it is convenient to size the cables under SLS loading, limiting tensile stresses to 45% of breaking load. Proprietary system manufacturers can provide data on various forms of rope, strand and bar. Under accidental loss of a hanger, adjacent remaining hangers are permitted to work at higher stress levels. Cable anchorages (sockets etc) and their fixings are usually sized such that their strength exceeds the breaking load of the cable. Local steelwork details should be designed with robustness in mind. Fatigue loading will need to be considered using data from manufacturer's tests.



Inside of Hanger

- Hangers can be either terminated inside the arch or below it. This is a preference decision as there are pros and cons for both. Internal connections will be neatest, but requires installation and subsequent inspection and maintenance inside a confined space (assuming it is large enough to enter). External connections will require specialist access equipment such as cherry pickers, use of which may involve unacceptable disruption to traffic.
- Hangers must be adjustable to allow for geometrical tolerances between arch and tie, and for initial stressing and subsequent adjustment. Allowance may need to be made for space to accommodate, and reactions from, jacking equipment.

Loading

- Dead load effects will normally comprise a large proportion of the design stresses for main elements, and it becomes very important to allow fully for the erection method. This particularly applies to bending in the arch; for the tie beam, the locked in bending moment can be controlled by adjusting the hanger lengths.
- The application of traffic load is straightforward, but there will be a variety of loaded lengths and positions of tandem axles and special vehicles must be chosen to suit the influence lines.

Aerodynamic instabilities are unlikely to be a problem due to the inherent stiffness and high natural frequency of the arch. However, for longer spans and when in doubt, wind tunnel tests should be considered. Depending on the type and nature of barriers between the highway and hangers, it may be necessary to design the bridge for the accidental loss of a hanger. The criterion is to prevent progressive collapse of the whole span. This is an accidental design situation and thus is normally considered with characteristic values of permanent and variable loads. However, it will be necessary to allow for the routine replacement of hangers. As this will be a planned action, it is usually possible to reduce traffic load for this transient design situation through traffic management (e.g. no abnormal loads, contraflow on opposite carriageway).

Material and Section properties

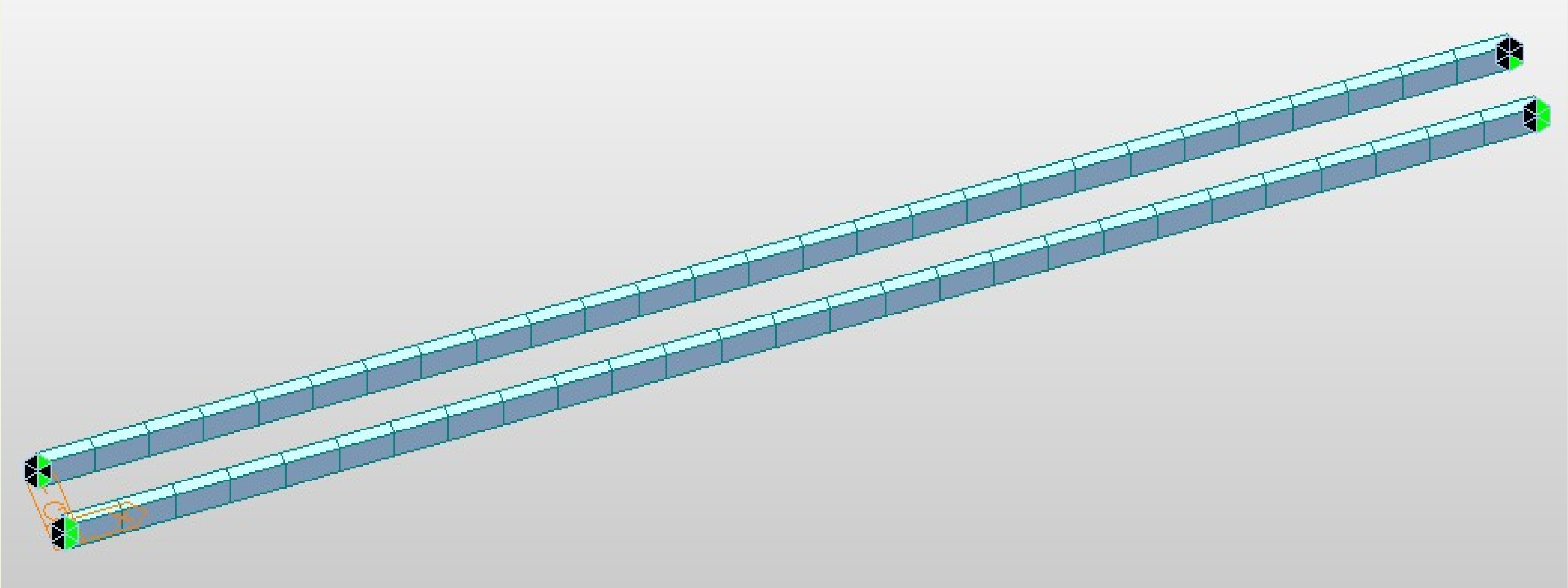
- **Material used** – Steel S355 national standard section :

a) Main girder – 9 x 5 m , shape : box
b) Cross beam – 7 x 5 m, shape : I
c) Arch rib – 6 x 5 m, shape : box
d) hanger - 0.18m dia, shape : solid round
e) struts – 6 x 5m , shape : box
f) Bracing & stringers – 4 x 2 m , shape : I

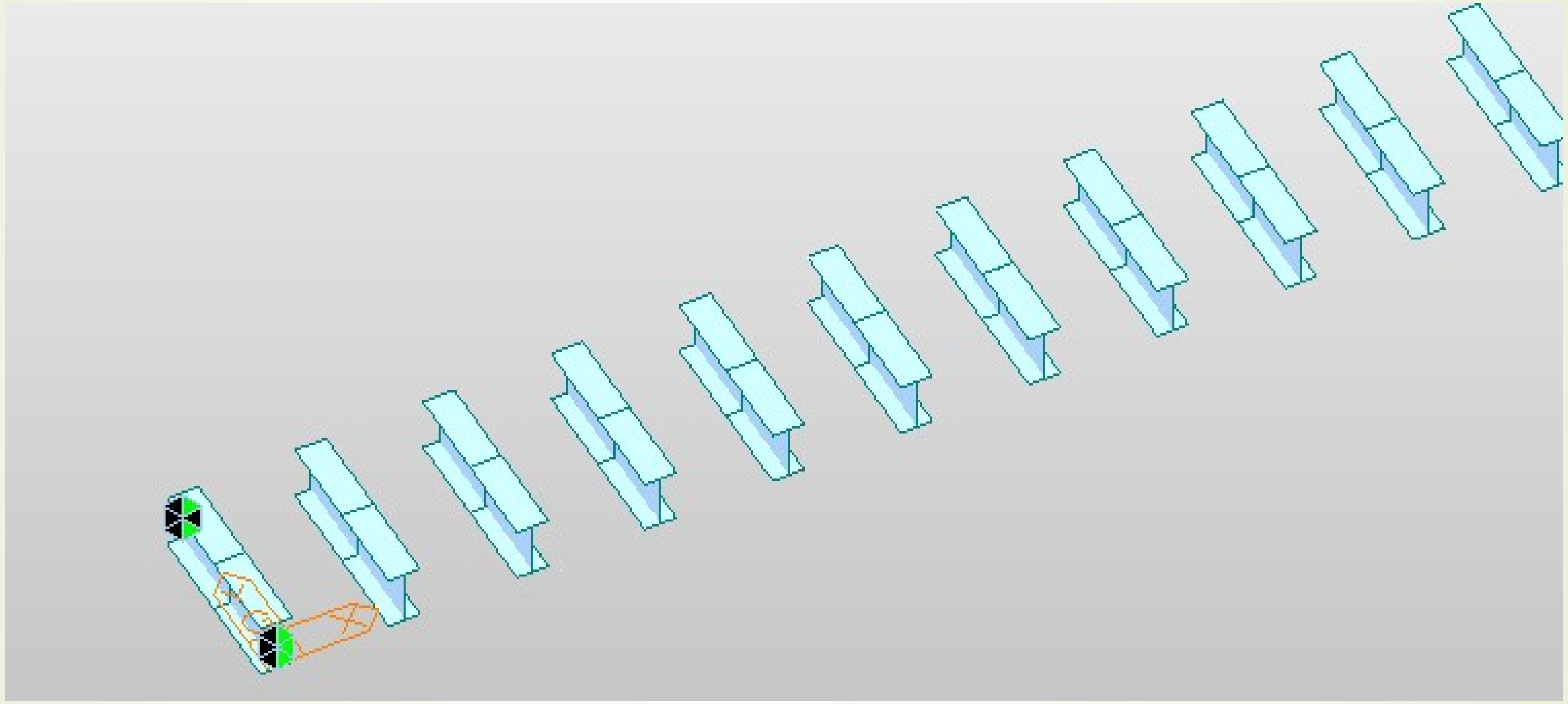
- **Load Cases** :

Dead load- 259kN/m
Side walk load – 6kN/m
Moving load case

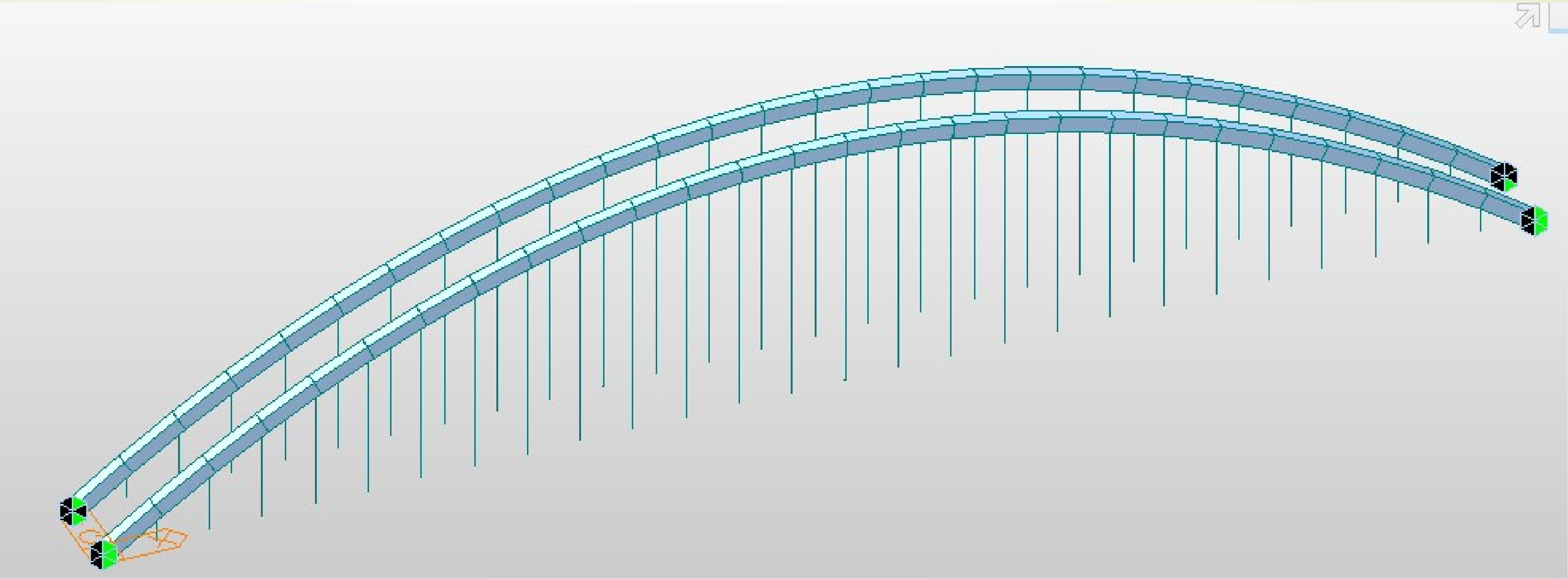
Components



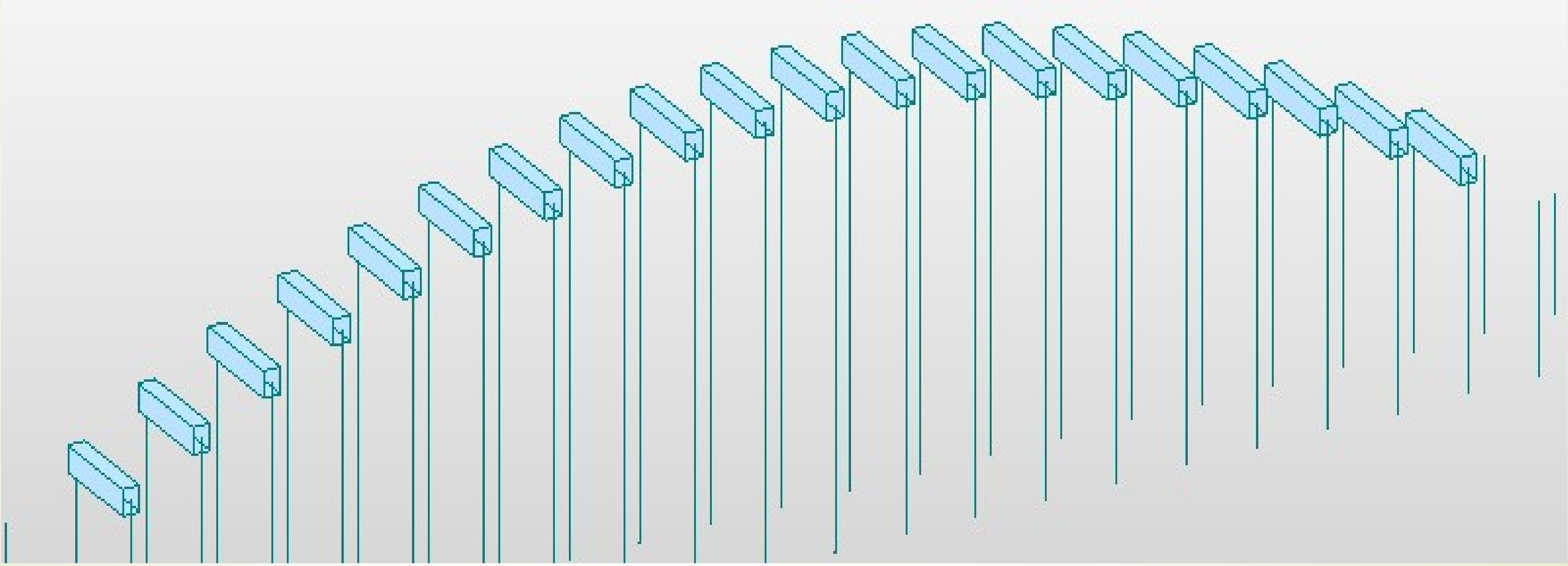
Main Girder



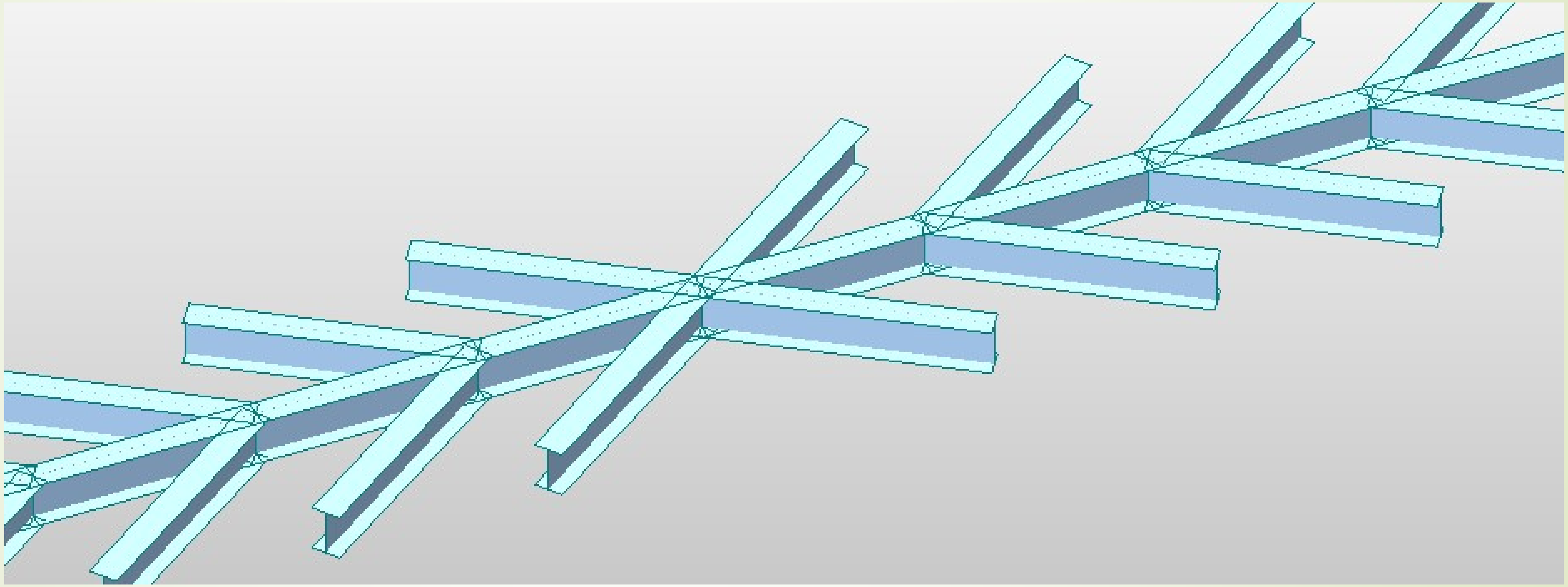
Cross Beams



Arch Rib and Hangers

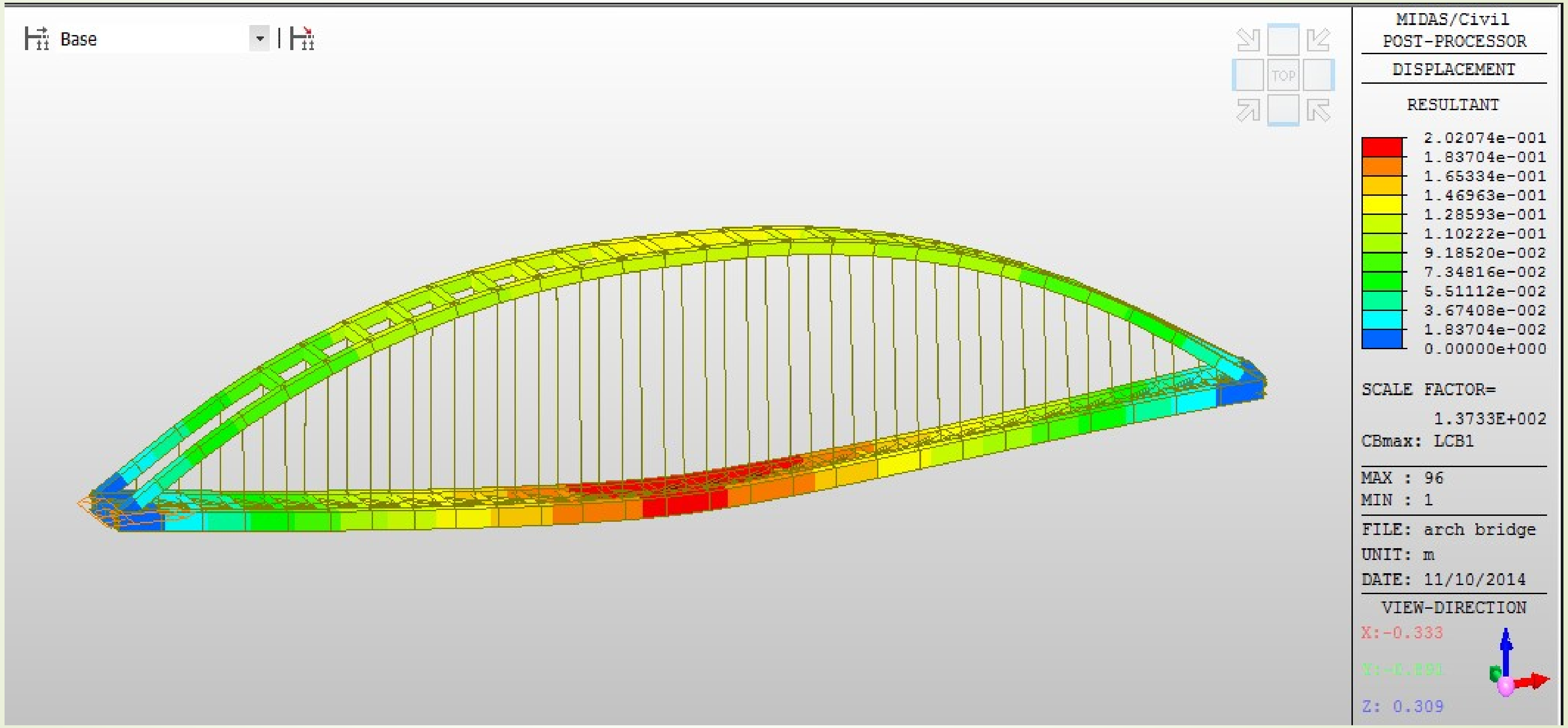


Struts



Bracings and Stringers

After Analysis



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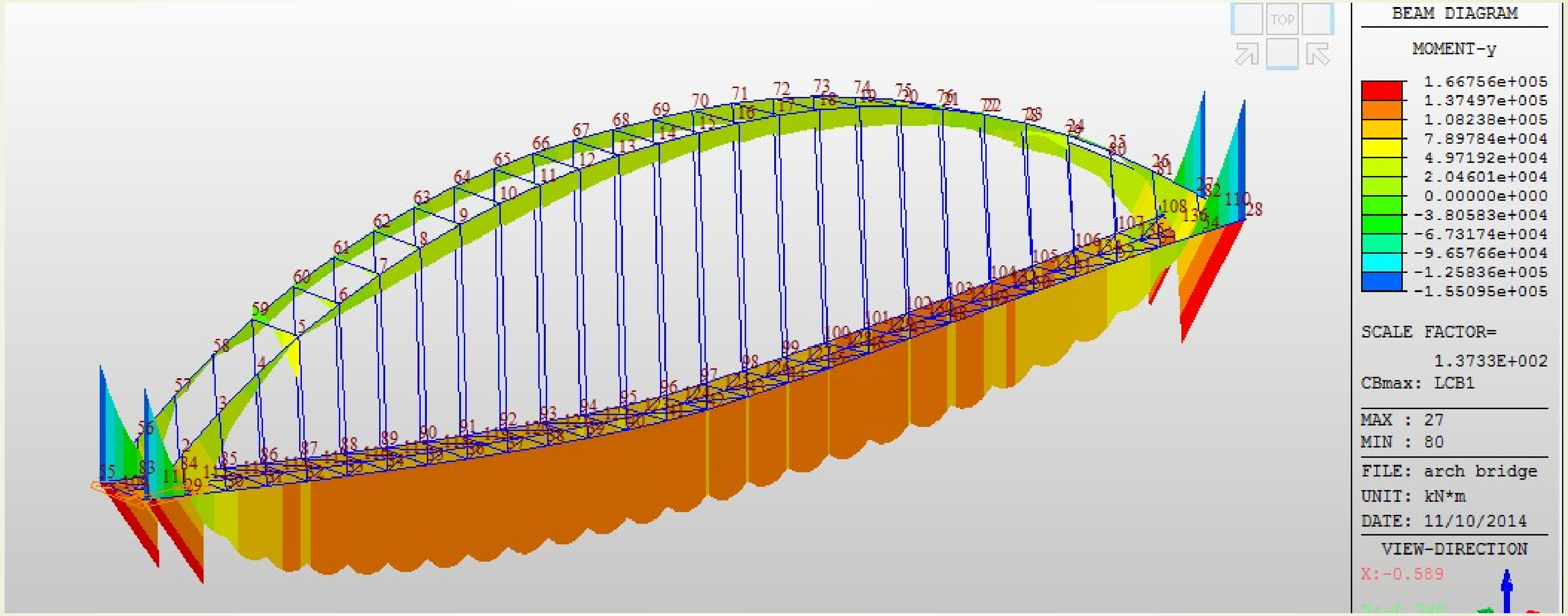
Deformation shape



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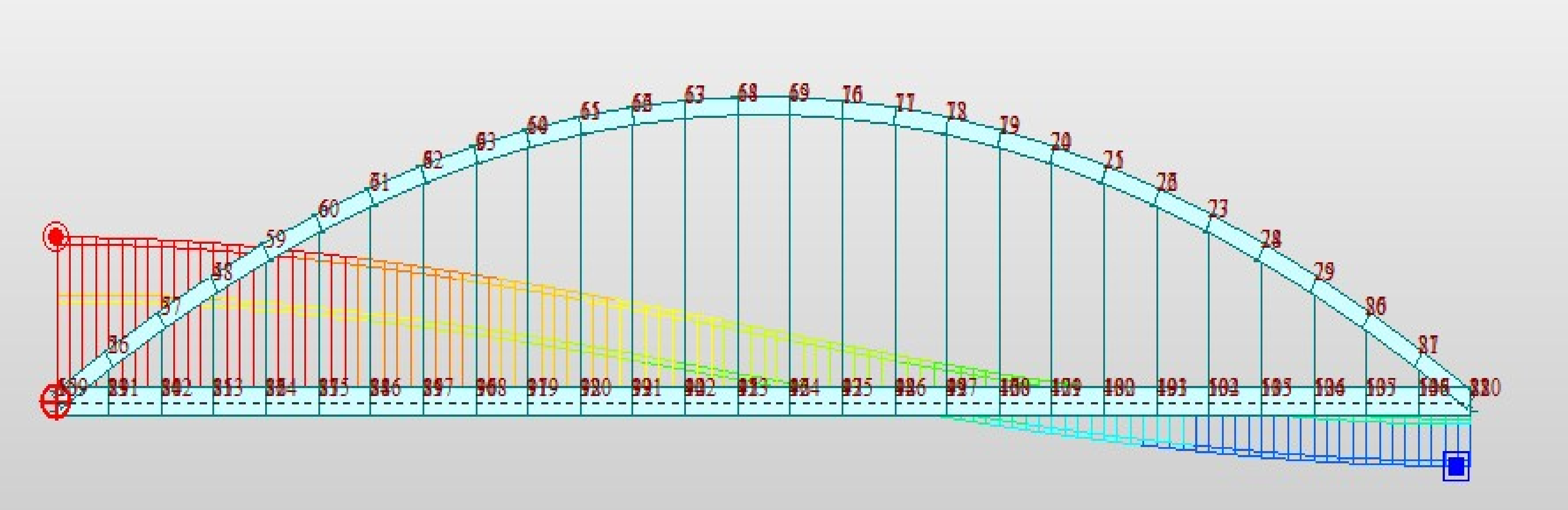
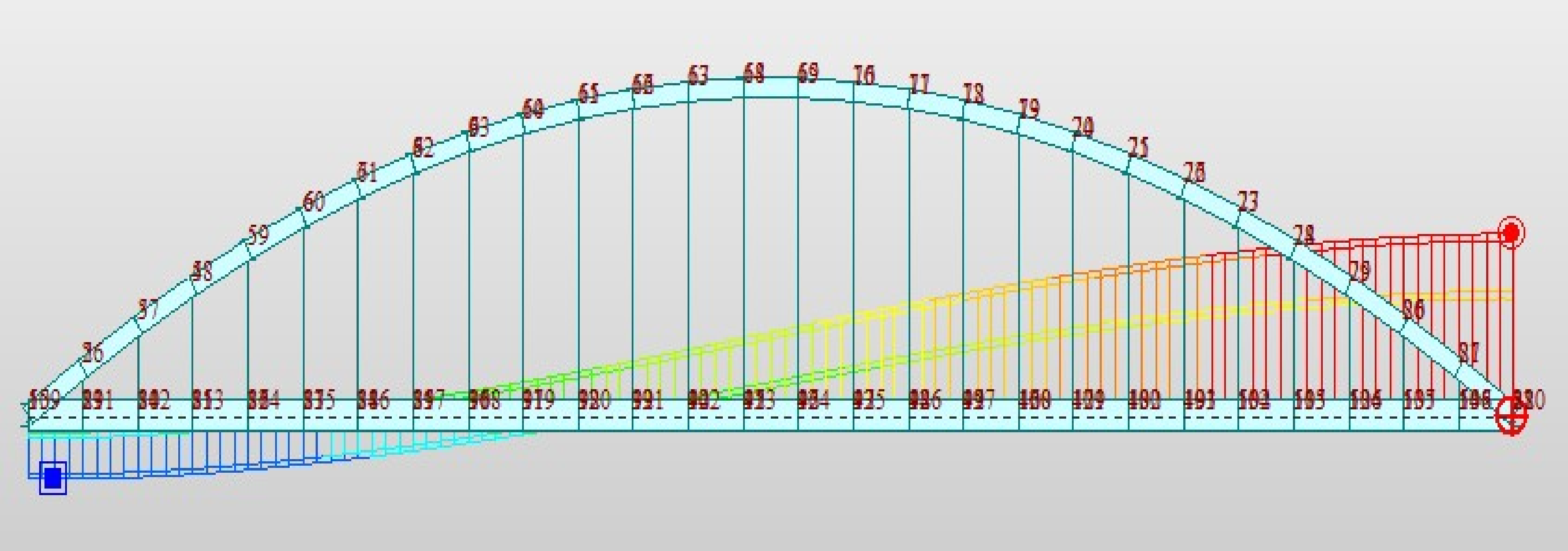
Moment Diagram

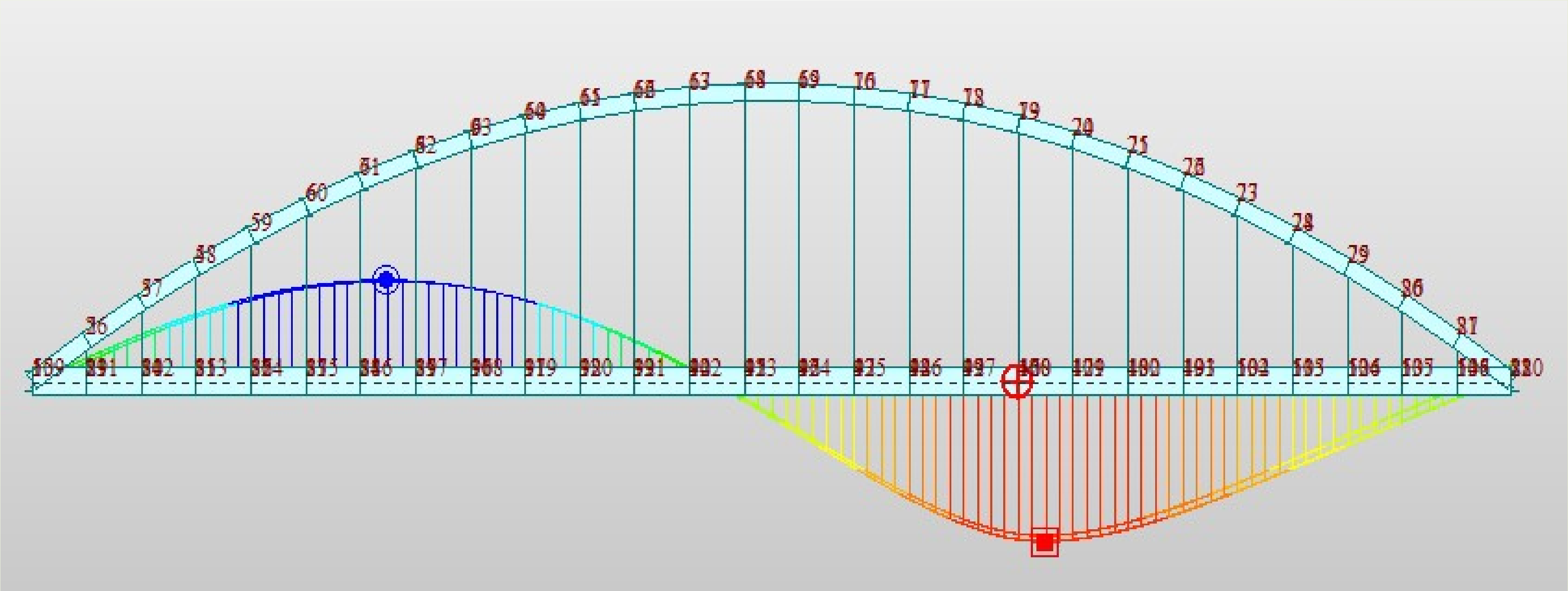


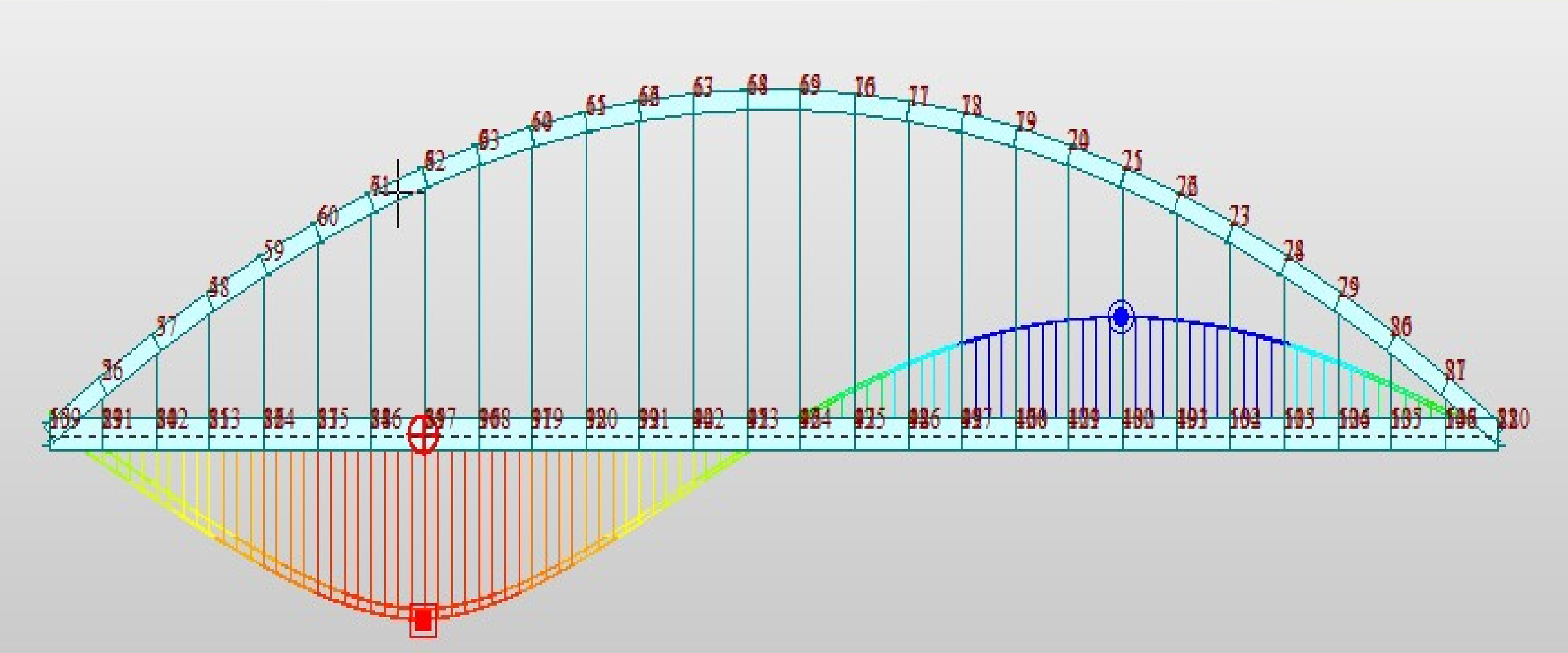
Reactions at support end

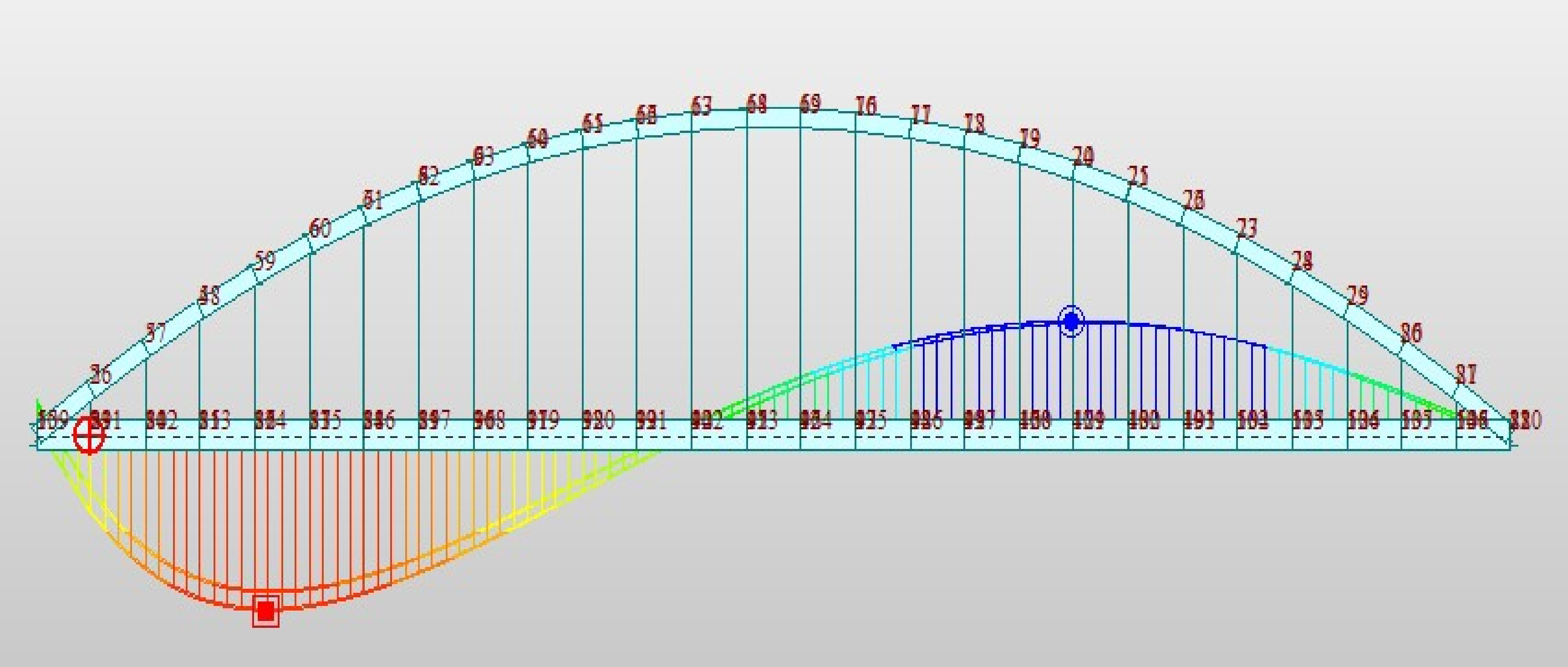


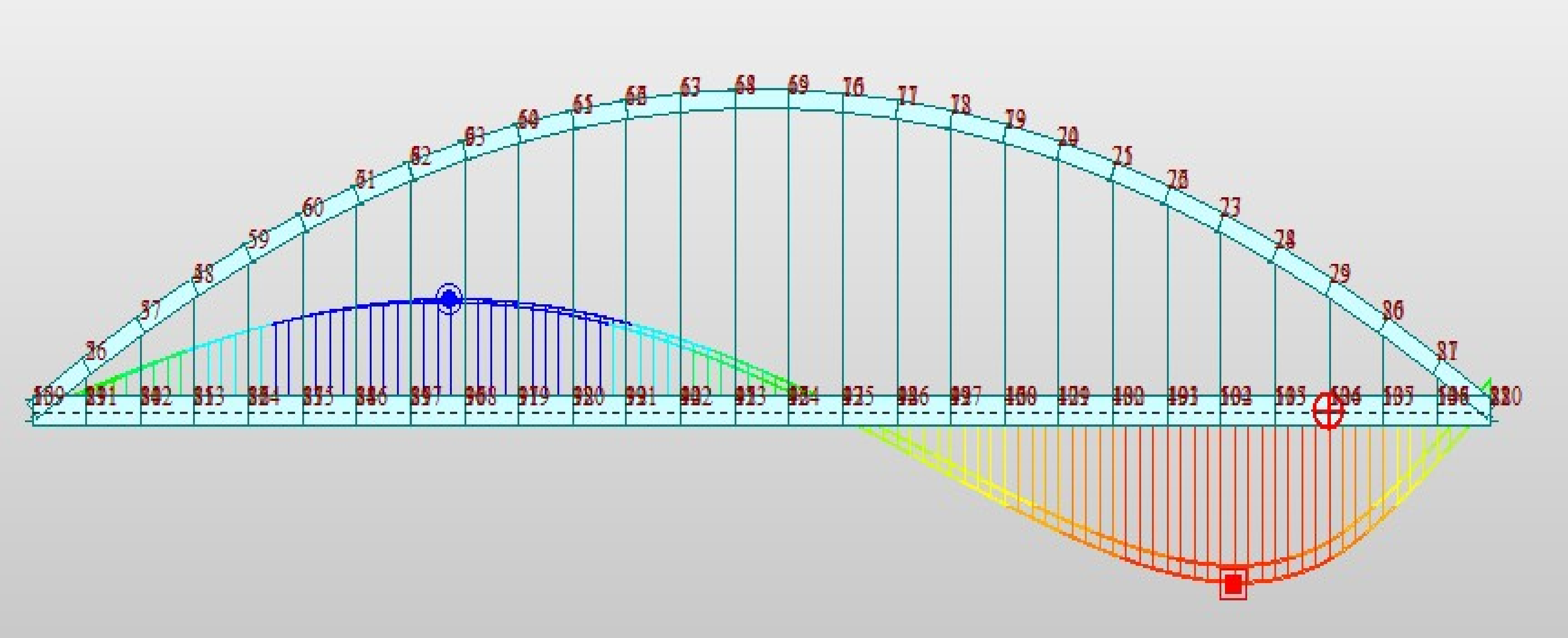
Reactions at other support end

Displacement at 4 different points when moving load is passing through the bridge





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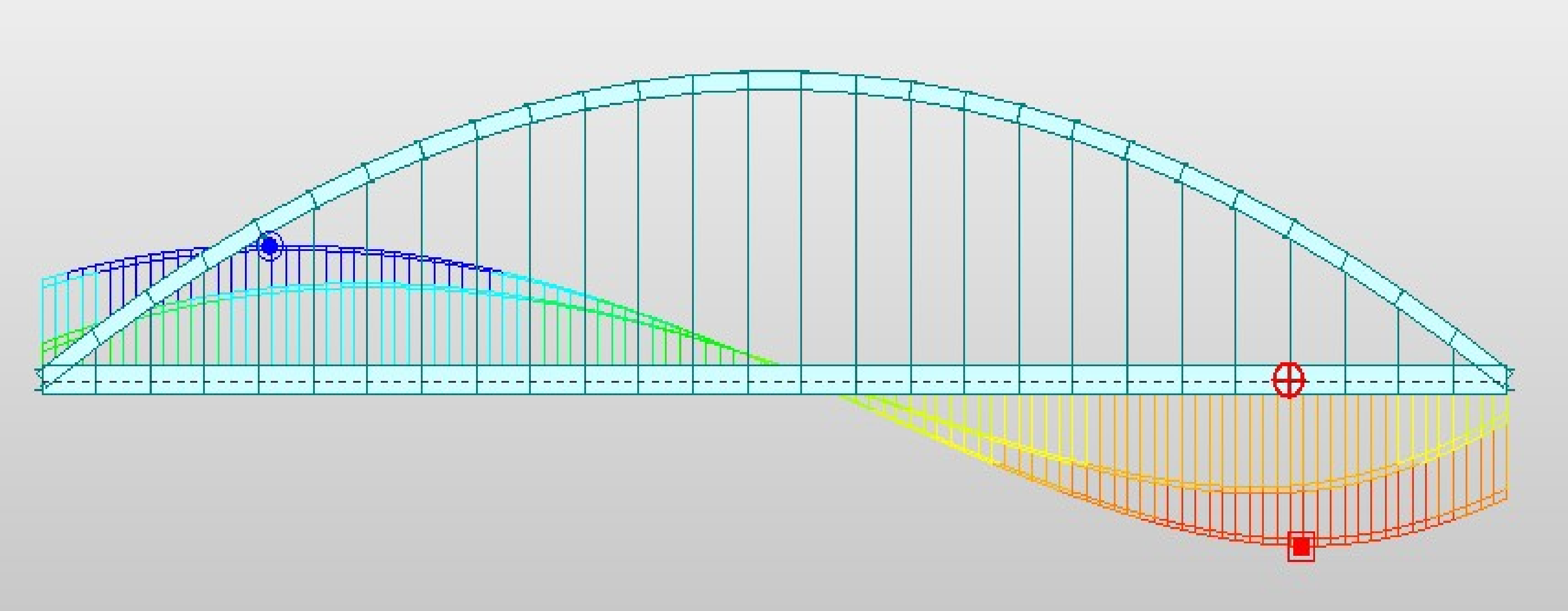
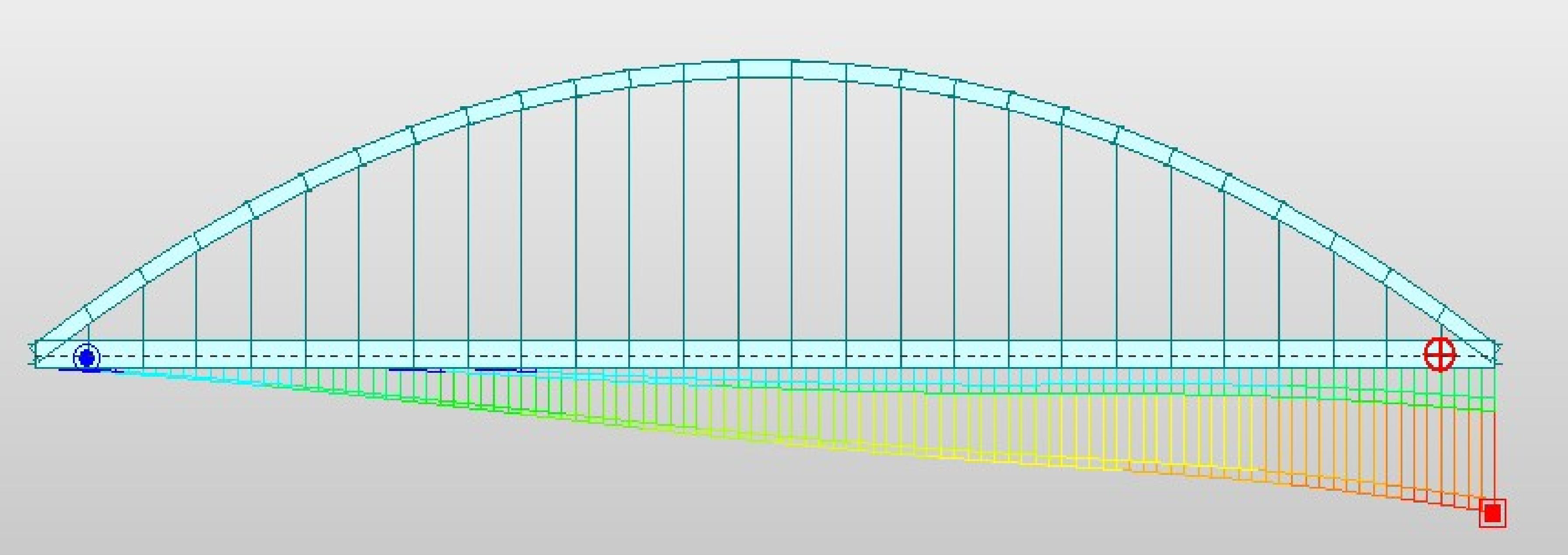
Shear forces acting on to the bridge when combination of load is applied





CONCLUSION

The Lupu Bridge, as well as being a stunning, eye catching and graceful bridge, is also a remarkable feat of engineering. The carefully thought out aesthetics all work together to create what is a seemingly effortless structure across the water. From photographs it is hard to grasp the sheer scale of the elements which go to make up the Lupu Bridge, all of which are necessary to make the large spanning arch possible. Advances in welding techniques and technologies were created in the process of building this bridge and have done a great deal to promote the Chinese standing in the world of steel arch engineering. We also determined the different functions/ participation of the members in distributing the load of the deck to the arch of the bridge through hangers and then to the ground.