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Expertise
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Company
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Location
Italy

El Ferdan Bridge over theSuez Canal

How Maffeis Tackled the Design of A New Record-Holding Bridge

Take the longest swing bridge in the world, design a new one for a double train line, and create a new world record for swing bridges: this was the challenge offered to Maffeis Engineering when it was assigned to design the new El Ferdan Bridge which will cross over the historic Suez Canal at El-Ismailia in Egypt.

The new bridge is a twin of the existing one, which was originally designed in 2000 for a single train line. In its design of the new bridge, Maffeis had two objectives: to make the overall structure suitable for a double train line and to use and preserve the same architectural shape of the existing bridge, the same front appearance, and the same beams with the same outer size. Ultimately, the bridges will carry a double track railway of standard gauge across the canal between El-Ismailia and El Kantara East stations.

This article presents an overview of several specific topics relevant to the design of the El-Ferdan Bridge and describes the state-of-the-art structural design approach developed and utilised by Maffeis.

This approach can be summarised in the “One-Single-Model” approach to design: a specific tool and unique environment designed to boost interconnectivity and interoperability between different software programs and disciplines.

The model uses experiences collected from past projects as a foundation to enhance the possibilities offered by a parametric design approach and by the automation of complex processes. Using this model allowed Maffeis and partners to create something truly special.

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The total length of the bridge is 640 m, and the interaxis between the central piers is 340 m - Doug Kerr

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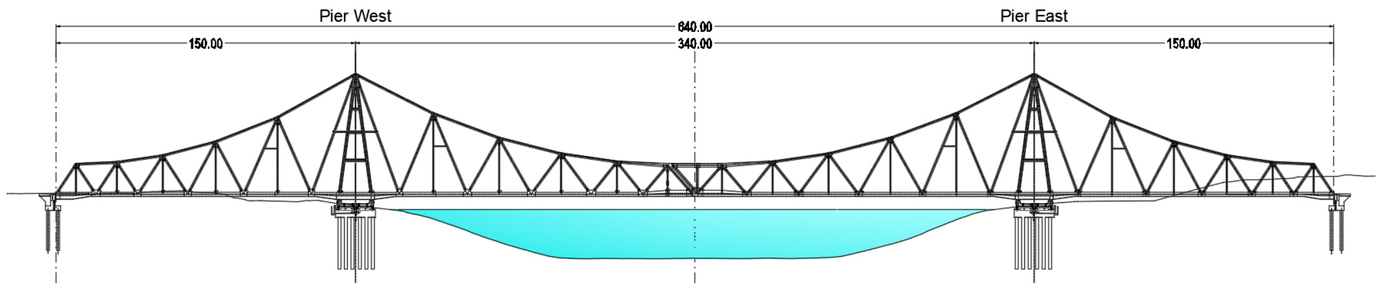

Figure 1 El Ferdan Railway Bridge, the longest swing bridge in the world, runs from the west of the Suez Canal to the east into Sinai, opens most of the time to allow sailing ships to pass in the canal.

Figure 2 El Ferdan Railway Bridge, the longest swing bridge in the world, runs from the west of the Suez Canal to the east into Sinai near Ismailia Editorial credit: byvalet / Shutterstock.com.

Figure 3 The layout of the bridge.

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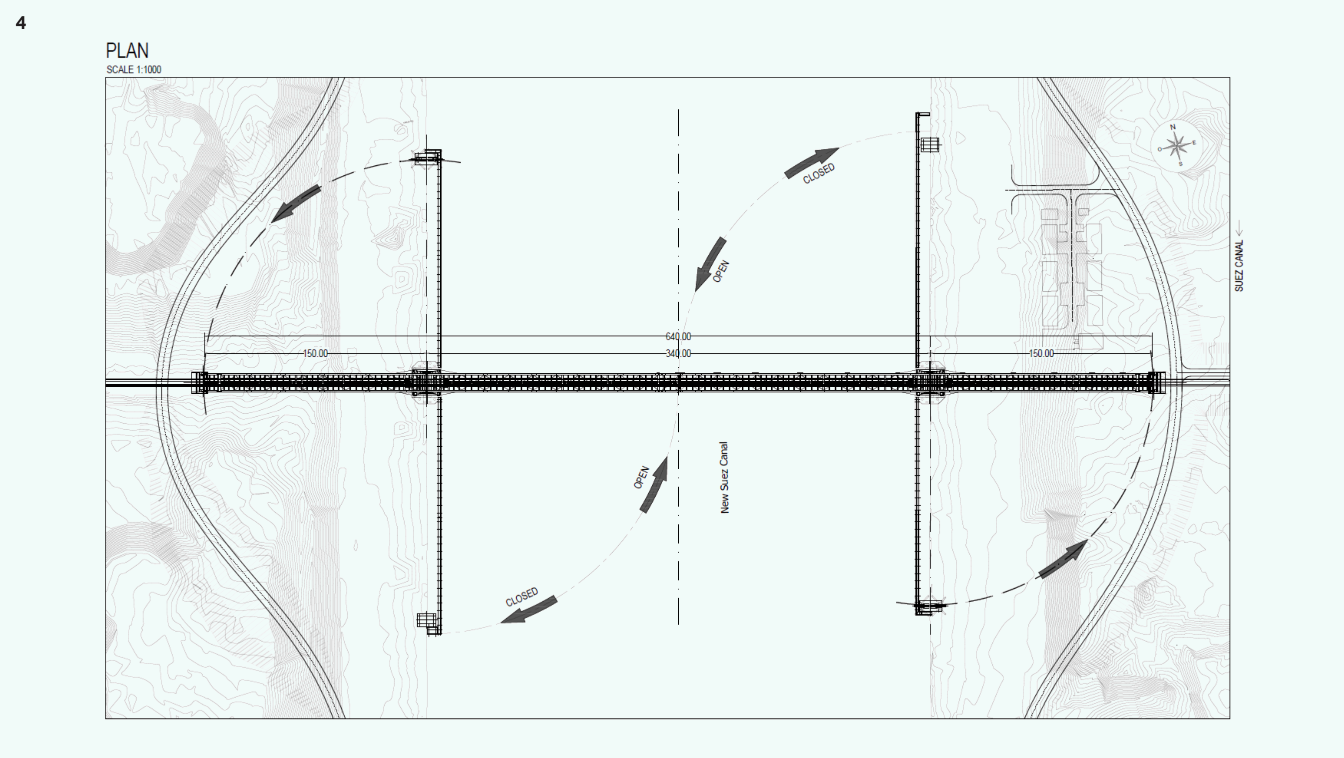

A record breaking bridge for a historic canal

The bridge is a moveable double-swing bridge which rotates on two central piers over a rim-girder system equipped with rollers. Both parts of the bridge are composed of two cantilevered lattice trusses that are 150 and 170 metres long. The lateral trusses comprise a built-up rectangular hollow section, the width of which is kept fixed at 1.2 m while its height varies between 1 and 3.5 m.

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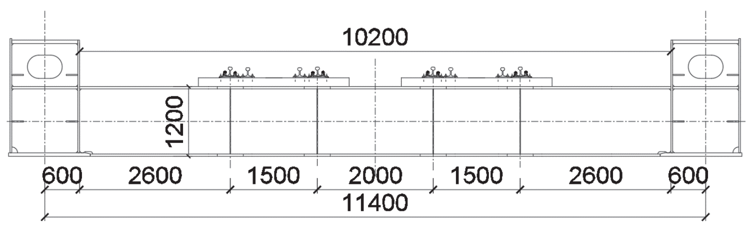

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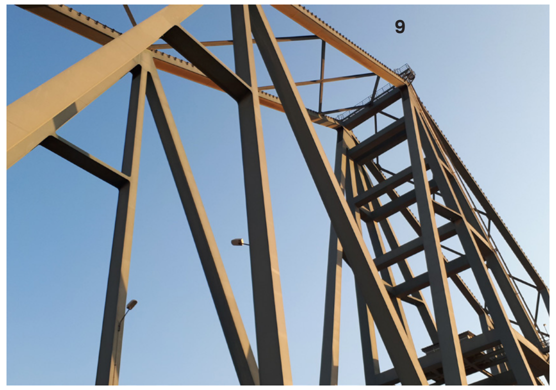

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The total length of the bridge is 640 m, and the interaxis between the central piers is 340 m.

After the final expansion of the Suez Canal, the allowed navigable channel will be 316 m which corresponds to the distance between the new permanent protection jetties. The height of the bridge increases gradually from 15 m at the middle-span to 60 m over the abutments. The transverse interaxis between the main lattice trusses is equal to 11.4 m. The lower deck has the same width which is locally enlarged to 15.8 m over the central piers in order to accommodate the bearings over the rim-girder.

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Figure 4 General plan view.

Figure 5 Typical section.

Figure 6 View of the bridge from the deck level.

Figure 7 Sideview of the bridge West Span.

Figure 8 Rim-girder area.

Figure 9 View of upper chord and top pylon.

Figure 10 Node detail.

Figure 11 Longest swing bridge in the world.

Figure 12 Global view of the FEM model.

The rails are supported by four longitudinal stringers, continuous over cross girders with the average interaxis equal to four metres. The deck portion is fully composed of built-up I section with a height of 1.2 m.

Lateral stabilisation of the bridge is provided by two bracing systems: the deck bracing system, shaped as a CHS profile with a diameter of 0.3 m, and the upper wind bracing system, made with built-up I section with a height of 0.4 m. The longitudinal view and typical transversal section are shown in the pictures below.

Managing a complex weight optimisation process

The design of the El-Ferdan Bridge had to rise to a number of challenges. First, it had to comply with the requirements of the Egyptian code of practice for railway bridges, namely ECP205. Moreover, with respect to other international codes, two main issues were introduced: meeting ECP requests for allowable stress design and imposing a deflection limit fixed at L/800, which is a much stricter limit than the L/600 limit suggested by the Eurocode approach.

Given the severe design requirements, weight optimisation and maximum exploitation of members were the key objectives for the earliest stage of the project. In order to complete these tasks and transfer the results to the client, Maffeis employed parametrisation of the numerical model coupled with a genetic algorithm and a visual representation of the optimisation results.

The first step in this process consisted of defining a FE model, generated by a parametric approach in Rhino/Grasshopper and assigning, at first, the sections of the original bridge as tentative. Each of the members was then assigned a scalar number corresponding to the multiplication factor of the sectional properties.

As a second step, the model was linked with a specifically defined tool for structural optimisation based on a genetic algorithm. Through a mathematical approach, this method defines a number of tentative solutions and selects the most promising which, in turn, will subsequently produce another population of potential optimum solutions. This process can be reiterated and this procedure led to what is defined as Pareto Front, namely a boundary of optimal solutions. In this specific case, the target was defined in terms of the total weight of the bridge and the boundaries' conditions were given by strength, fatigue, and deformation requirements.

The results of this analysis were then provided in terms of contouring with the multiplication factors of the member size. These results allowed the team to offer the client tangible proof of the soundness of the proposed design.

Subsequently and based on the outcome of the optimisation procedure, the design was developed completely according to code requirements.

Considering the large dimensions of the members of the main truss, a major topic at this stage was the optimisation of the spacing of transverse diaphragms and the location of the longitudinal stiffeners. This is a critical topic considering that stiffeners and diaphragms are mandatory if the section is to be adequately exploited. They also play a significant role in terms of total weight contingency.

For this purpose, specific in-house sub-routines were developed, based on analytical formulations, according to EN1993-1-5. The user could adopt such routines through a specific GUI integrated in the general design flowchart. The optimisation process was completed for each member. Then, the data was stored in the general database to allow for an automatic looping and updating of design verifications.

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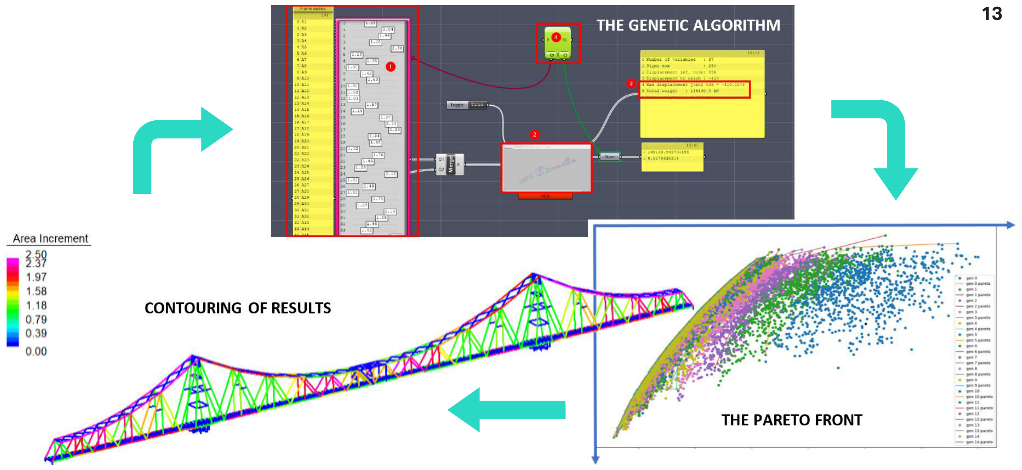

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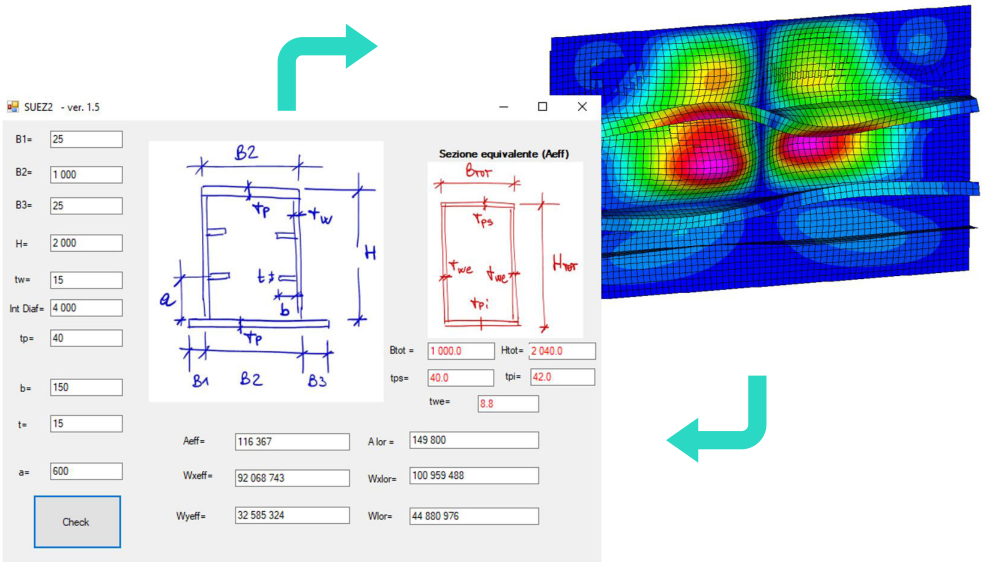

Figure 13 Optimisation looping procedure with genetic algorithms.

Figure 14 Design tool for local design of members.

Figure 15 One Single Mode framework.

Figure 16 Verification of primary members.

Figure 17 Deformed shape of the bridge.

The subroutine was integrated with a specific tool to automatically develop local finite element models in order to confirm the validity of results provided by the analytical values and also to equip the designer with direct control over the influence of spacing and rib layout on the local response of the structure.

Thanks to the process outlined above, the design of the bridge was driven to the maximum exploitation ratio, taking the verification of most of the beams close to unity, while satisfying the deflection limits required by the Code.

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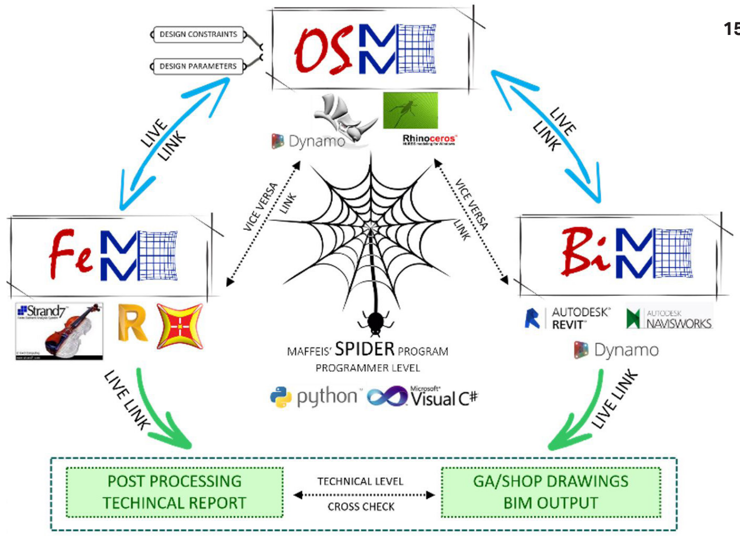

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Maffeis employed parametrisation of the numerical model coupled with a genetic algorithm and a visual representation of the optimisation results.

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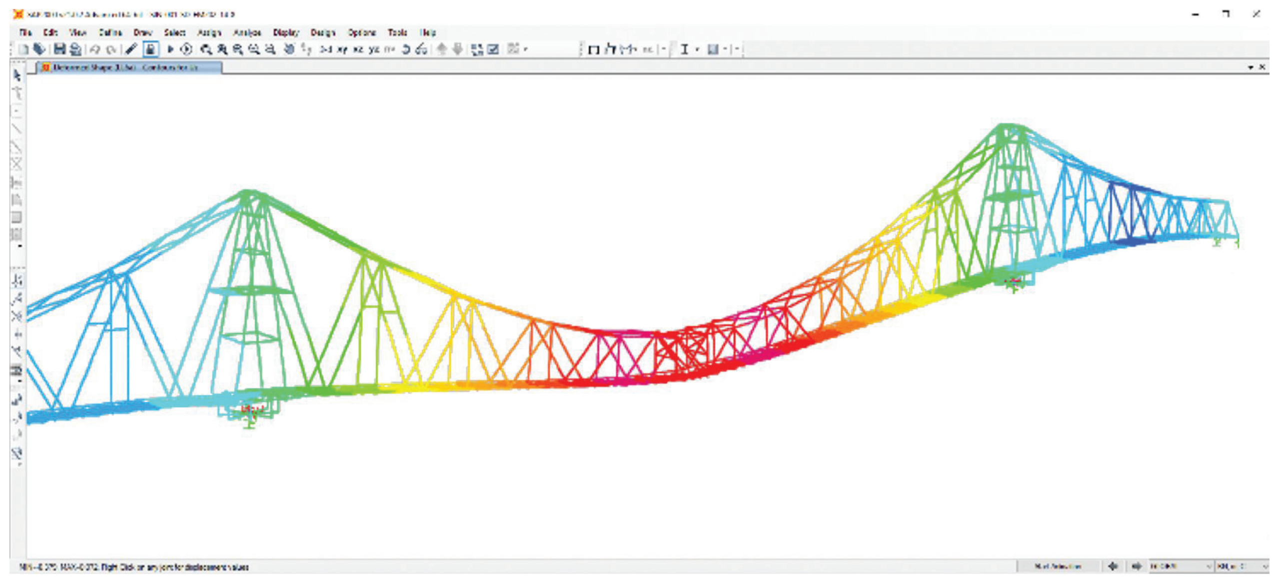

After the beam size and geometry of the bridge were fixed, the final stage of the optimisation process aimed at optimising the nodal zones. Starting with analytical approaches and engineering judgement, the design moved to define the input rules and requirements for the definition of the optimal node geometry.

The design was completed via numerical approach, which linked the data of internal forces, provided by the global SAP model, to the local sub model of the joint, which was generated in Rhino environment: a clear example of how the FEM, geometry, and results are strictly interconnected by a single click thanks to the One-Single-Model approach.

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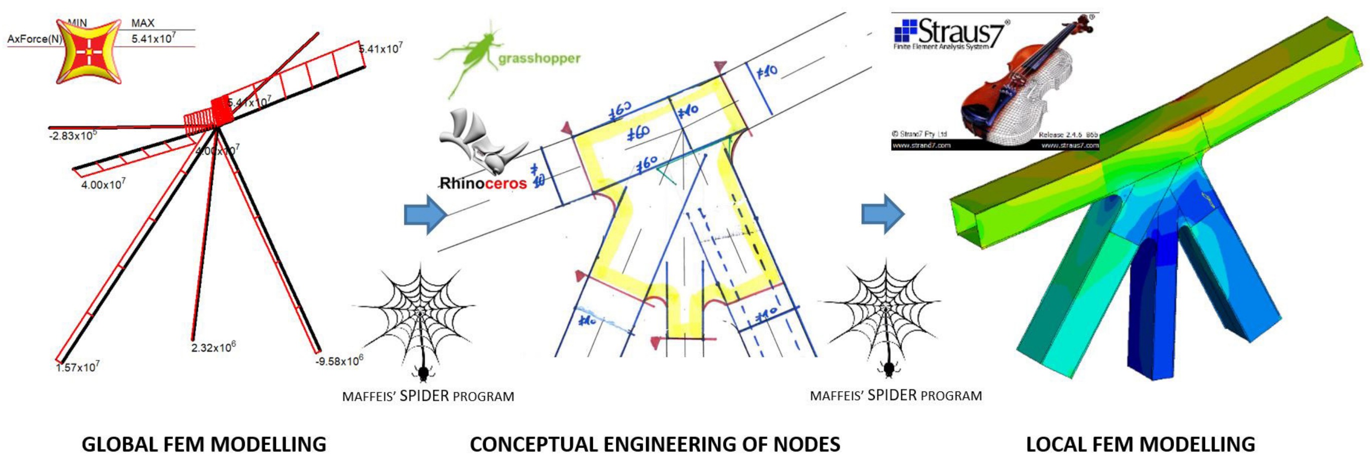

Interaction of structure and mechanical devices

Maffeis was appointed not only for the structural design of the bridge itself, but also for an integrated design of the mechanical devices.
The bridge is equipped with several mechanical devices. Under the main pylon, the rotation is performed by two 55 kW electrical motors. The rim girder has a diameter equal to 17.1 m.

On the upper part, the bridges are bearing on the rim girder by means of eight pot supports. On the lower portion of the rotation-gear, the load is transferred to the foundation by means of 112 forged rollers with conical section and average diameter of 400 mm.

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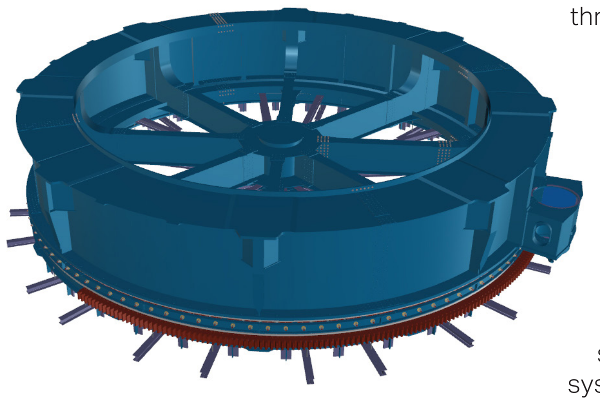

The dimension of the rotation gear allows the transfer of vertical forces and bending moments in both directions.

At midspan, the connection between the east and west parts is guaranteed through four forged pins with dimensions of 1200 x 650 mm, activated by hydraulic pistons with more than two metres of stroke and able to support a shear load of more than 25000 kN.

Since the locking devices are placed at the tip of the 170 m cantilever, a sophisticated alignment system has been designed to guarantee the connection between the two portions of the bridge within all possible differential movement scenarios between the east and west spans.

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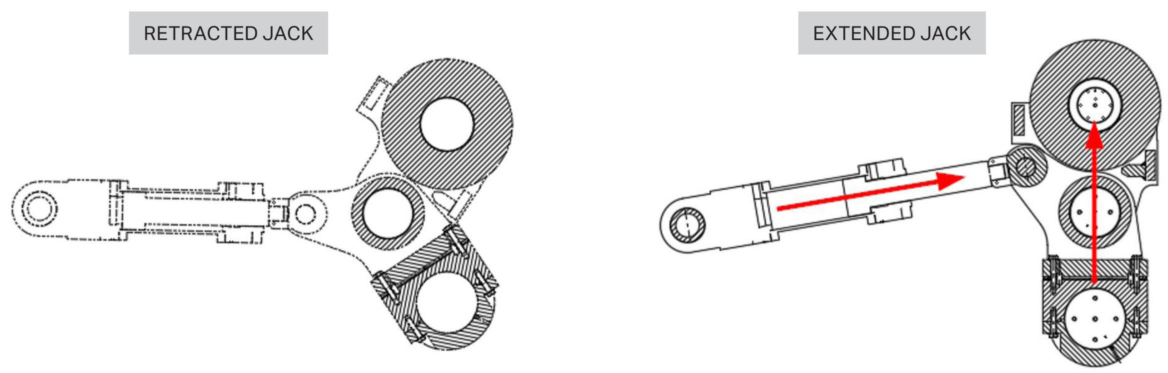

On the back side, at the connection with the abutment, a "scissor system" has been developed, to guarantee the vertical and horizontal alignment simultaneously.

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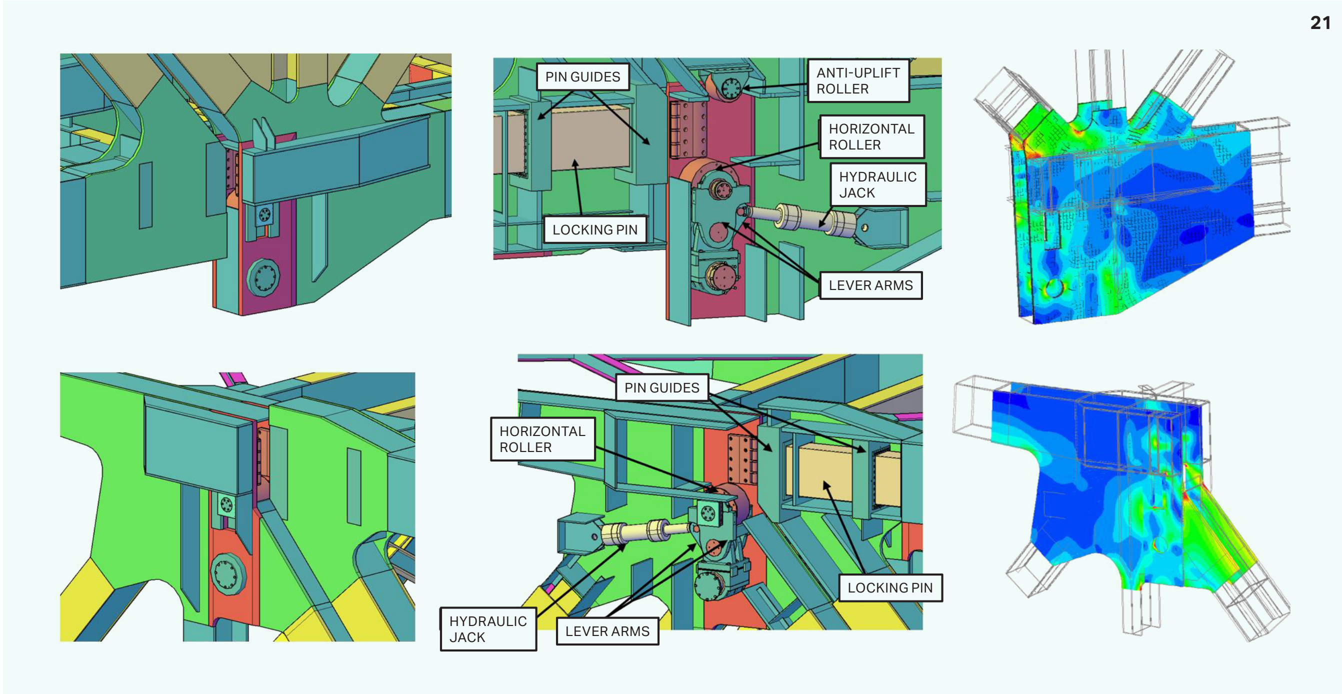

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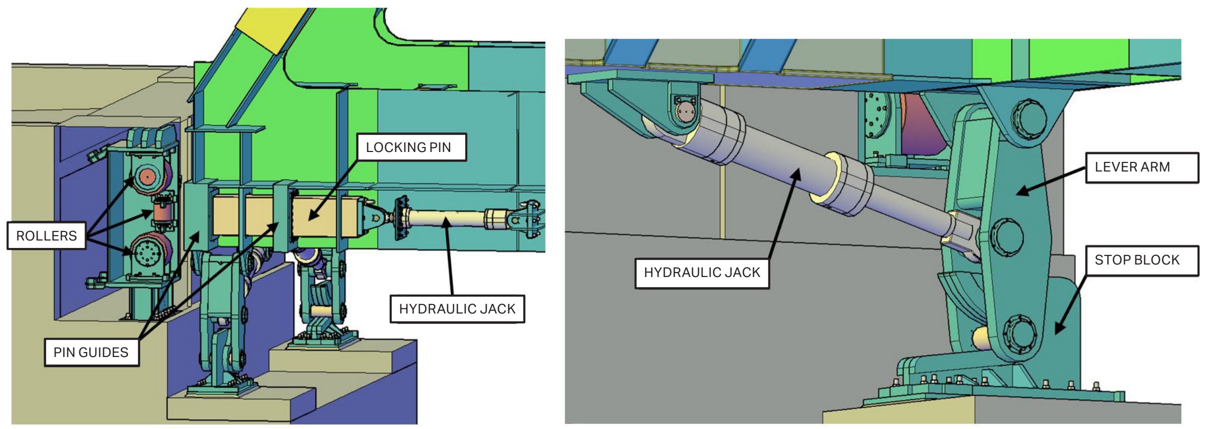

With all these systems, the automation and sequence of movement have been designed to guarantee the rotation and locking of all systems within 20 minutes of the start of the operation.

Figure 18 Flowchart for node design.

Figure 19 Rendering view of the rim-girder.

Figure 20 Vertical alignment device function scheme.

Figure 21 Bottom locking pin at midspan – from design to FEM modelling.

Figure 22 Details of the new scissor allignement system at abutment.

Figure 23 El Ferdan Railway Bridge detail.

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Designing the erection process

An integrated design platform such as the OSM allows relevant parties to manage multiple issues related to the design flowchart. The study of the method statement, for example, was simplified by the possibility of easily defining groups of members for the staged construction analysis and rapidly defining alternatives to identify the best approach.

From the beginning, it was clear that the erection sequence must be designed to avoid relevant residual stresses in the final structure. For this reason and given the huge length of the bridge, the hypothesis of supporting the bridge on all points was immediately discarded. In fact, during the assembly period – which is considerably long given the tons involved – this would have led to the generation of important tensions because of thermal variations.

Moreover, according to the theoretical camber geometry, erecting a bridge of such important dimensions on towers at fixed elevations would lead to the risk of making incorrect assessments of the final movements. In fact, the teams could not rule out the possibility that the rigidity estimated in the design phase would not completely match reality. It was similarly difficult to rule out the possibility that errors will occur in the workshop assembly phases.

The effects of such errors would be known only after assembly, when it becomes difficult if not impossible to remedy the errors found.

For this reason, the best erection sequence is the sequence in which the new elements are installed after the temporary towers have been dismantled. This leaves the erected part of the bridge free to move and deform according to its 'natural' (final) static scheme, under the action of its own self-weight and of the thermal actions.

The exact height of the temporary tower used for the installation of the new elements will be defined during the erection with the support of the Maffeis design team, and the information will be based on the movements matured by the structure.

In this way, we can be certain that the erection method is not affecting the functionality of the structure and that the final structure respects the tolerances set for the mechanical connections at the abutments and at the middle-span connection.

One of the peculiar aspects of this method statement is the stability analysis of the bridge standing on the central rim girder without temporary towers: the structure must remain stable during all the erection phases and must avoid the supports uplift for outside factors such as earthquakes or winds.

This task becomes more and more delicate as the external parts are fitted since the corresponding eccentricities gradually grow bigger and the counterweight is not completely installed. Therefore, to carry out the process successfully, extremely accurate and true-to-life modelling is needed. ◆

Figure 24 Countraflexure line.

Figure 25, 26, 27 Erection phases.

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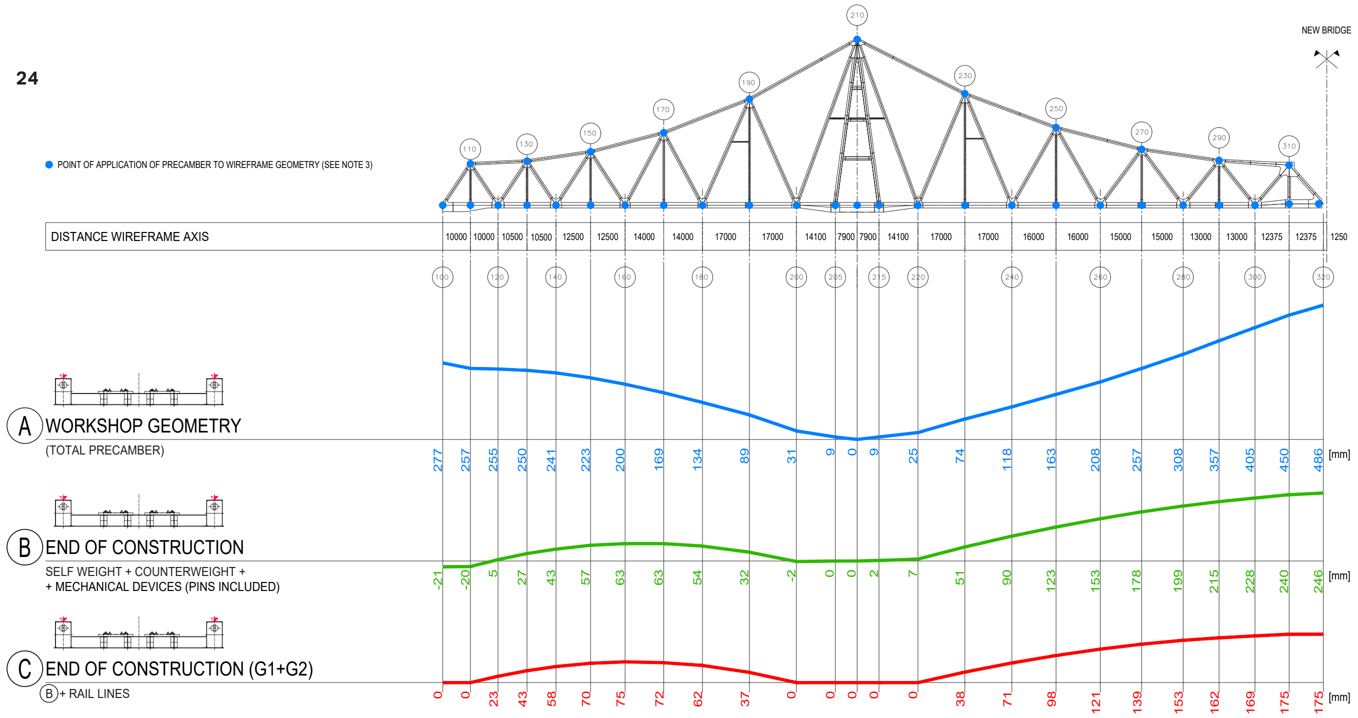

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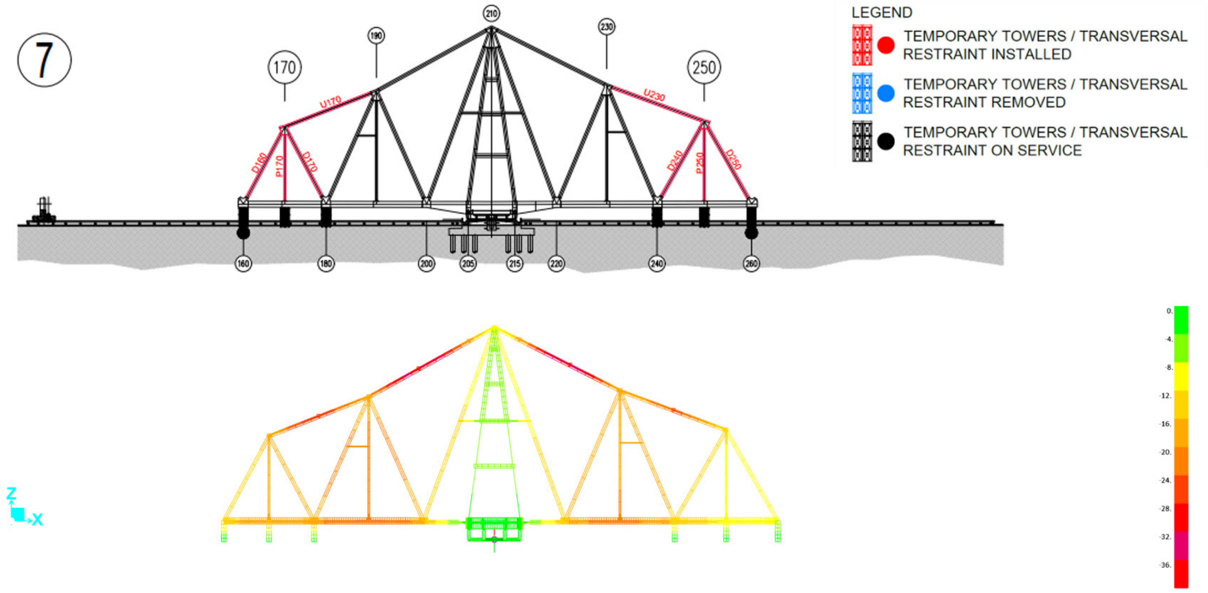

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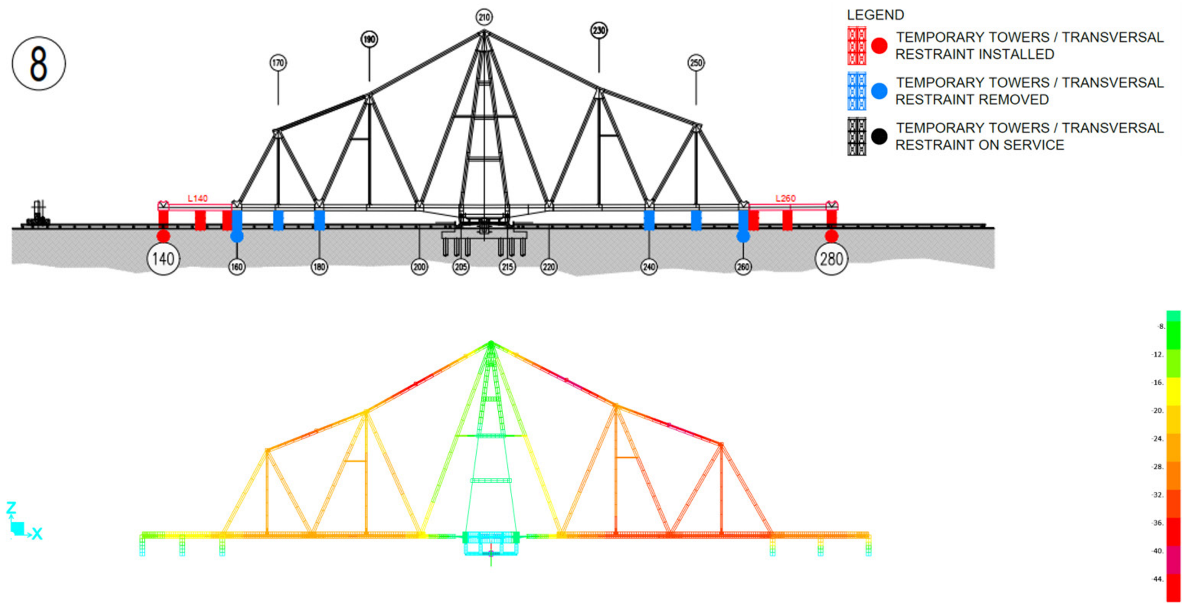

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