Alternative construction methods were considered due to the curved alignment

CURVING THE CROWN

An advanced and novel BrIM workflow has streamlined several key construction processes on what is set to become Finland's longest cable-stayed bridge. Georg Pircher and Sami Soppela report

For cable-stayed bridges, typical tasks such as cable force tuning, stability checks, and careful and detailed construction staging need to be addressed by designers and contractors. To maximise efficiencies and accuracy in these processes, the design team behind Kruunuvuorensilta – or Crown Bridge – employed a new BrIM workflow. This article will review the design-stage tasks involved in this new system, with the contractor's viewpoint to be detailed in a future piece.

The sea crossing is part of a bigger urban development north of the city of Helsinki and started with the launch of a design competition in 2012-13, which was won by WSP Finland and Knight Architects. In 2021 the project was tendered to Kreate and YIT joint venture, which chose Sofin Consulting and Ramboll as consultants for detailed design and construction engineering.

For these tasks, fully parametric structural modelling and smart BrIM thinking was required. Bridge construction was initially proposed as using the balanced cantilever method from the pylon. However, the contractor encouraged all parties involved to think about an alternative concept to cut down construction time and costs. One motivating factor was that the deck geometry is curved in plan, so it would have been a real challenge to build using the balanced cantilever method.

Second, the contractor wanted to avoid a 'BrIM on paper' approach and connect the workflow in such way that all construction data could be submitted quickly and digitally, as well as combined into a single model.

A third challenge was the fabrication shape of the deck, and the BrIM workflow described herein was developed to combine the precamber resulting from the detailed construction stage simulation with the actual shape of the prefabricated girders and their connections to form the deck geometry and, subsequently, the final geometry.

The link has four approach spans at the eastern end of the alignment (one with a length of 53m and three spans of 66m), two 260m cable-stayed main spans either side of the pylon, and seven approach spans at the western end, six of 62m each and one of 48m. The deck comprises two I-shaped steel main girders with cross-beams and a 19.3m-wide cast-in-situ slab, with capacity for a tramline, bike and footpaths.

Under the original design, developed in 2011-13, the idea was to first build the approach spans and then to erect the pylon and cantilever the deck by stressing the cables symmetrically, one by one, as the cantilever grew.

In the revised design, the main steel girders will be incrementally launched from both sides over the approach spans onto the permanent piers. Then, the steel girders for the main span will be placed on temporary piers, five per span, without being connected to the approach spans, leaving the space needed for pylon erection. Pylon erection and deck casting will occur simultaneously instead of one after the other, reducing construction time. The pylon and steel girders will be connected when the pylon reaches deck level and pylon construction will progress from there until reaching its full height.

The stay cables will be installed alternately left and right of the pylon by installing and checking two cables on each side at a time. Once all the cables are in place, the temporary piers of the main span will be removed, allowing the deck weight to settle into the cables. The last four pairs of cables on each side will then be installed, allowing for deck edges adjustments if needed before connecting the main spans with the approach spans.

Finally, the approach-main span joint will be cast to create a continuous deck.

This complex erection sequence brings several time and cost saving advantages, but also comes with geometry challenges associated with containing the precamber of the deck and the girder fabrication shape. Hence, a full blown, detailed construction staging sequence which provides this information was required.

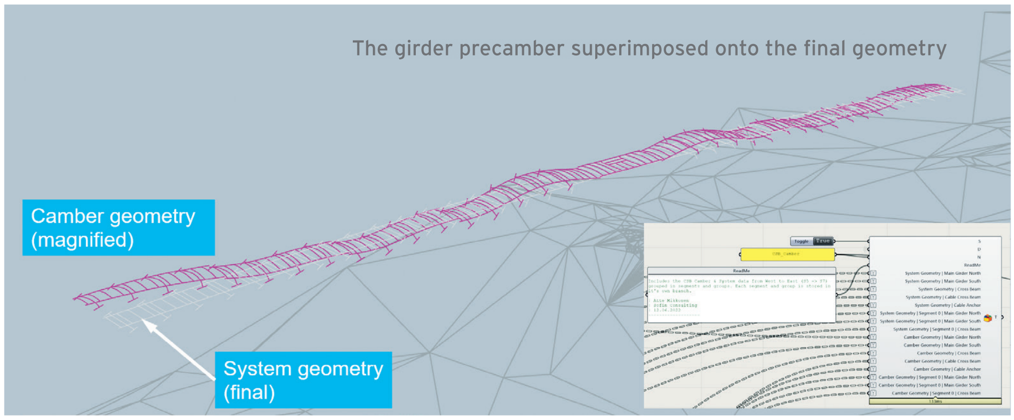
Indeed, the steel girder launching, considering the fabrication shape, raised a couple of geometrical issues that had to be examined, and the image on the right compares the final girder position with the precambered girder geometry.

Tekla and Sofistik were selected as the ideal combination for the transfer of data between Sofin and Ramboll (as consultants) and Kreate and YIT (as contractor). In order to accommodate both and to allow data flow in all directions, Rhino and Grasshopper serve as 'the single source of truth'. As for geometry, the detailed 3D precamber (both vertical and horizontal) is taken from Sofistik to Rhino/Grasshopper and sent to Ramboll, where all shop drawings and details including the fabrication shape are updated at the press of a button.

As Sofin provides all the erection information, geometry control is another role within its scope of work. Whenever something is built, there are construction errors influencing and changing the geometry. The loading might not be exactly what exists in the analytical model; some stiffnesses might vary; and construction stages do not progress as planned. For bridges, these errors might lead to a difference between what was designed and what is built. The precamber and fabrication shape will then not result in the perfect final geometry. Therefore, it is necessary to constantly monitor construction and to compare site geometry with the analytical geometry to detect and compensate for any construction errors as soon as possible. The structural model offers the possibility to add a possible construction error in the analytical model to make sure that there is a detailed and permanently updated 'as-built-model'.

The data to be updated cannot be compiled in spreadsheets or PDFs due to the volume: it has to be smart, fast and easy to repeat. Hence, the IFC format is used to extract information from the analytical Sofistik model (or specific parts of a defined construction stage) to the contractor. IFC data is then merged with site data related to the structure during construction; any divergence or mistake can be detected with ease. By way of an example, the image on the right shows the actual geometry against the desired final and analytical geometry.

When incrementally launching the girder following the S-curved plan view for the approach spans of the deck, each girder element itself is straight. The connected girders thus make up a polygonal geometry. Internally this is referred to as a 'snake with kinks'. Launching is not an easy task as the launching bearings are fixed and cannot be changed for every launching segment.



The girder precamber superimposed onto the final geometry

By taking the fabrication shape of the girder elements into account, it appears that not all temporary supports are under compression at every launching stage. The analytical launching analysis must take nonlinear spring behaviour (compression only) into account, which imposes additional criteria for analysis.

Furthermore, as all segments are added stress-free to the launching bed, each girder comes with its own precamber and fabrication shape. Skewed support at the abutments also means that the girders deform differently during the launch, and the girder ends need to be adjusted by jacking to compensate for deformation. In addition, due to the curved-in-plan geometry, the girders twists. This was neglected in steel fabrication to keep the steel plates planar, but needs to be accommodated in installation.

As the BrIM concept includes the 'as-built' concept, how to include any construction error back into the analytical model had to be considered. For this, the contact face at the girder beginning/end was adjusted before welding the next girder. Control points for geometry control are installed at the tail of the main girders.

As the actual geometry on site is constantly controlled and compared to the analytical model, the idea is to also constantly adjust and eliminate potential error accumulation during construction. The analytical model follows the construction model, and both are always identical as far as geometry is concerned.

Sofistik FEA software allows this geometry modification to be incorporated in the overall analysis, including all detailed construction stages. As far as can be seen from the current situation on site, this process allows difference from site monitoring data compared to the analytical geometry to be narrowed down to a few millimetres – and within the given tolerances. So far, the workflow is extremely successful and the basic concept has been proven to work ■

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An overlay of a scan of the site on top of the analytical and final target geometry