Conceptual Design of the new HSL Bridge over Hollandsch Diep

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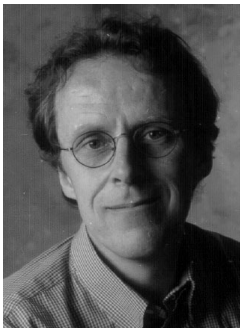

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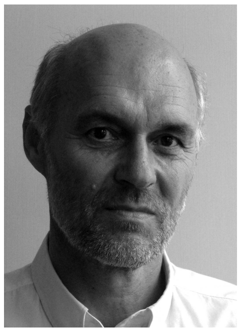

Summary

The new HSL bridge over Hollandsch Diep has been built in a 'design and construct' form of contract based on a Reference Design defining the visual aspects of the bridge and its transition on the banks of the Diep. The Reference Design was the result of an international design competition that took place in 1998 [1]. Both the visual and engineering concept developed in the competition design has been followed by the Contractor, who is responsible for the detailed design of the bridge. This way of procuring bridge design concepts has become more and more common, it ensures that the Owner gets the bridge he wants and at the same time it leaves the Contractor freedom to optimise the detailed design to exactly suit his preferred construction method.

Keywords: Design competition, conceptual design, high-speed railway bridge, composite frame.

1. Introduction

The new bridge over Hollandsch Diep will be the Dutch landmark structure on the Amsterdam – Paris high-speed rail line. The bridge will be seen daily by thousands of people travelling on the busy A16 motorway that runs parallel 500m to the west of the line. Also parallel to the high-speed line, but immediately to the east (Fig. 2), is a through-truss railway bridge, the Moerdijkbrug, which will continue to operate, serving local and intercity rail traffic. The train passengers here will travel at much more sedate speeds than the 300kph experienced on the HSL bridge and will be able to enjoy dramatic views of the new bridge through the light truss girder.

Fig. 1 Hollandsch Diep

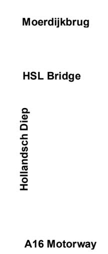

Fig. 2 Plan of Site

The original Moerdijk railway bridge was when it opened in 1872 the longest bridge in Europe. It was replaced after the Second World War by the present through-truss bridge. The Moerdijkbrug, with its 10 equal 105m long spans, is well proportioned and sits comfortably (Fig. 1) in the calm, watery landscape. The proximity of the old bridge, only 30m from the new bridge, has in many ways influenced the design of the new bridge.

2. Design Competition

The design concept for the new HSL bridge is the result of a bridge design competition that took place in the summer of 1998 [1].

The project organisation HSL-Zuid had at the time already developed a fully detailed design for the crossing but realising the potential of the site they decided to invite three international design teams to develop bridge concepts and compete against HSL-Zuid's own proposal. The winning concept would thereafter become the Reference Design in a 'design-and-construct' type contract for the bridge. However, the design team submitting the preferred concept would not be guaranteed any further involvement in the detailed design development of the bridge. The design teams were therefore paid a nominal fee for their submissions in order that HSL-Zuid could secure the intellectual rights to the proposals for the specific purpose of constructing a high-speed rail link across Hollandsch Diep.

It might be unusual in architectural competitions that the winning team is not assured some further involvement in the design but it is not unusual when it concerns bridge design competitions. This can be illustrated by two notable examples, the design competition in 1993 for the Øresund Bridge shown in Fig. 3 between Denmark and Sweden and more recently in 2000 for the Stonecutters Bridge in Hong Kong. These were both so-called paid for competitions where the briefs stated that there would be no guaranteed further involvement for the team with the preferred concept. However, for the Øresund Bridge the Owner engaged the winning design team as bridge consultant during the subsequent stages of the project, while on the Stonecutters Bridge the team that won the design competition lost out in the further stages and was no longer involved in the project.

Fig. 3 The Øresund Bridge

The form of construction contract used for the Øresund Bridge is similar to that of the Hollandsch Diep Bridge, 'design-and-construct' based on the competition winning Reference Design. The contractor is in both cases responsible for the detailed design of the bridge but he must follow the outlines and materials of the Reference Design. The Stonecutters Bridge will be tendered traditionally on a fully detailed design but based on the competition winning concept.

The final outcome of the design competition for Hollandsch Diep Bridge, was that the authors' scheme, described in the following, was selected to become the Reference Design. However, an interesting clause in the tender documents, subsequently issued, was that the successful contractor would have the choice of either employing the Reference Design team as his designer, for a defined % fee, or use his own designer in which case he had to pay a licence fee for the use of the design concept. This license fee was dependent on the actual construction costs of the visible parts of the structure. This was an unusual but very fair way of remunerating the conceptual designers for the real value of their design work.

2.1 Competition Brief

The competition brief and associated material issued in the early summer of 1998 was extensive and contained among others the HSL-Zuid's own design for information and also to act as benchmark for construction cost. A number of drawings of the existing Moerdijk railway bridge were also included. A start-up briefing including a site visit was arranged for the competitors. The site visit was particularly valuable as it clearly showed the importance of the views from the very busy A16 motorway crossing the Diep 500m to the west of the new bridge. From here the full elevation of the new bridge will be visible. Also the rhythm and lightness of the exiting railway bridge could be fully appreciated at this site visit.

The horizontal alignment of the bridge should be straight but vertically there was a choice. Two vertical railway alignments were defined as acceptable alternatives, a low alignment, which was close to the alignment of the old railway bridge, and a high alignment, which lifted the new line to the top chord of the old railway truss. It was a requirement though that the soffit of the new bridge should not encroach on the navigation clearance profile defined by the old bridge.

The design had to satisfy a very severe set of comfort criteria due to the 300kph design speed for the railway setting very high demands on the stiffness of the structural system of the bridge.

In addition to drawings and images of the detailed concept also principal calculations showing conformity with requirements, a construction programme and the estimated construction cost had to be submitted by the competitors.

2.2 Searching for the Solution

A key consideration in the choice of structural form was the desire to create a structure with a strong silhouette that at the same time would not totally dominate the old bridge. We wanted the old bridge to still be perceived, juxtaposed but not superseded by the new bridge. The new bridge should have the same rhythm as the old bridge it should be a clean and simple solution easily read and understood by the onlooker. It should also be a solution that would impress without the central focus of a main span. A main span would be inappropriate, not only for reasons of cost but it would also destroy the calm rhythm of the crossing.

A number of typical solutions were considered: multi span cable-stayed solution, beam solutions, arch solutions with arches above or below the railway line and frame solutions.

Multi span cable-stayed solutions were quickly ruled out due to the stringent stiffness requirements. Also stay cables would not create a strong silhouette, as they would only be faintly visible from the distance of the motorway bridge.

Beam solutions would need to be about 8m deep in order to have sufficient stiffness to span the required 105m and at the same fulfil the comfort criteria. The beam would therefore hide the old bridge almost completely. There would be no relationship, no play with the old bridge other than the common span length.

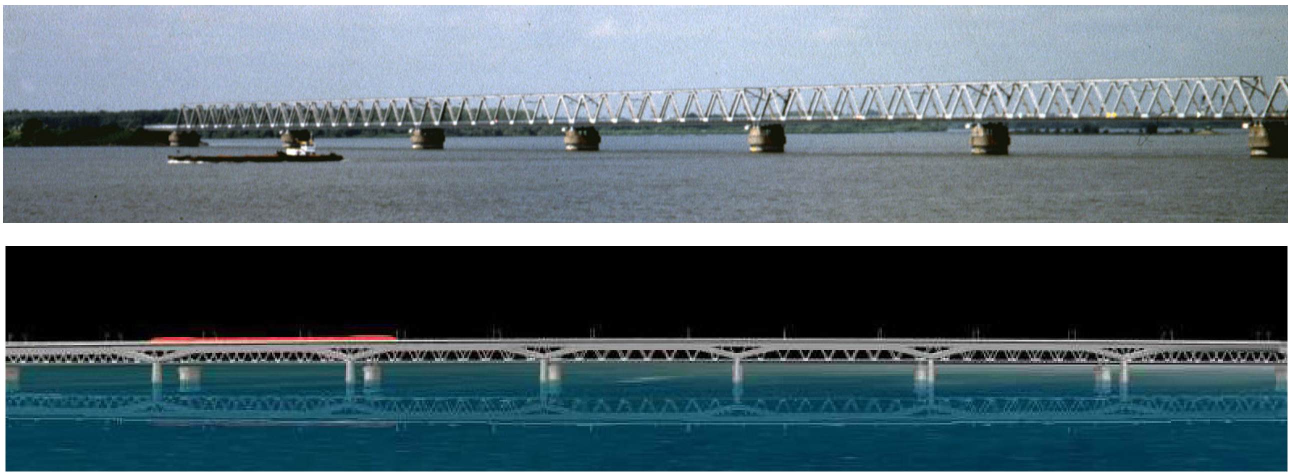

Fig. 4 View from A16

More interesting solutions were developed when looking at arches and frames, which gave the opportunity to open up the superstructure at the piers. In the end a frame was chosen as it offered a more dynamic image - as opposed to a gentle flow of a series of arches the bridge would move in leaps from pier to pier. At the same time, due to the slimmer sections and the opening at the piers, the old bridge would be clearly visible behind the new. The two bridges as seen in Fig. 4 would be juxtaposed without the new bridge superseding the old.

2.3 Finding the Solution

We chose a composite superstructure (Fig. 5) with a steel box frame with a concrete deck acting as top flange and supporting the tracks for the full length of the bridge. The steel box is 4.5m deep over the central 60m of each 105m span and splays out 22.5m from the supports. The concrete deck is carried across the pier on a 2.5m deep steel box, while the loads are led to the substructure through inclined steel box legs.

We chose the high alignment, and achieved the alignment through varying the pier heights, thus accentuating the feel of the bridge leaping across the water. In this way it is also possible to achieve a constant and repetitive geometry of the steel elements in all ten spans.

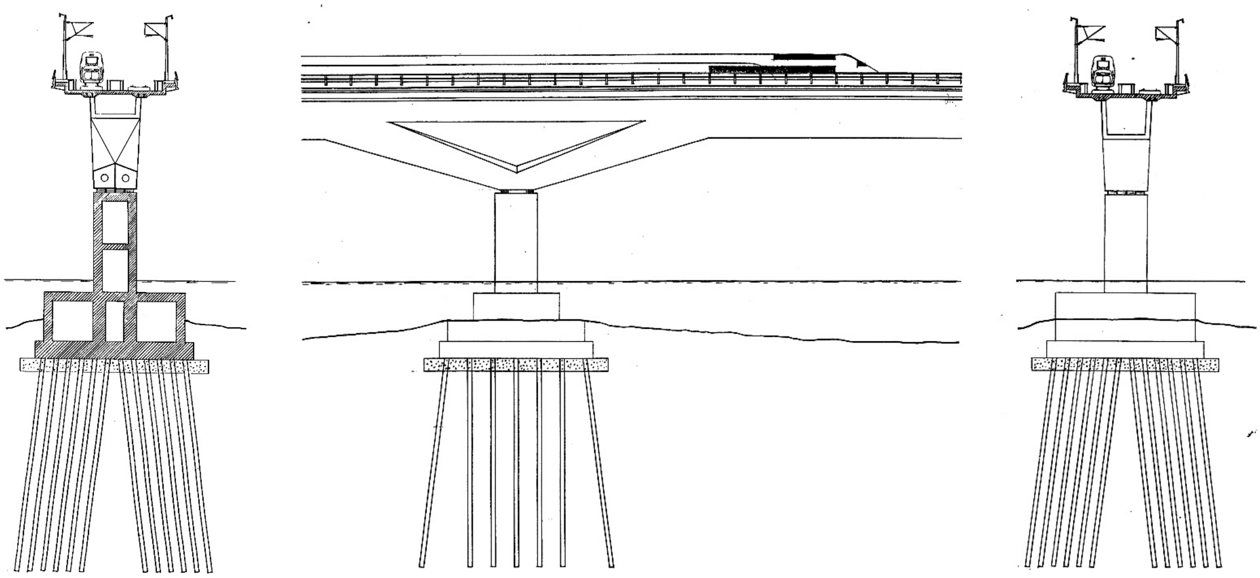

Fig. 5 Sections and Elevation at Pier

Below is a more detailed description of structural dimensions as determined during the short competition period. It should be noted that we did not at the time carry out a full dynamic analysis of the structure but relied on the equivalent deflection and rotation criteria, stipulated in the brief.

The 1.2m wide top steel flanges are 40mm thick. The inclined webs, which are 6.05m apart at the top, are 35mm thick. The bottom flange is 50mm thick. The width of the bottom flange in the central 60m section is 5.6m and in the 2.5m deep section over the piers it is 5.8m wide. The inclination of the webs is continued down the sides of the inclined legs giving a width of the bottom flange of 5.0m at the 4.0m long horizontal section at the bearing level. The sidewalls of the inclined legs taper from 4.2m at the top to 2.0m at the bottom. The top flange of the inclined legs is facetted and consists of three intersecting plane surfaces. The maximum depth of the legs where they meet at the pier centre line is 3.0m.

If required the bottom flange can be stiffened in the inclined legs by the addition of concrete, if detailed analysis showed this to be required. The webs of the longitudinal steel box sections are assumed to have no longitudinal stiffeners only transverse stiffeners are provided every 2.5m with full K-bracing every 7.5m. Full diaphragms are required where the deck splays out. The total height of the steel superstructure at the pier centre line is 10.5m similar to the height of the old railway truss.

The deck is supported on bearings placed on the top of voided concrete piers. Elastomeric bearings are used on the central nine piers while sliding guided pot bearings are used at the abutments and at the penultimate piers where the movements due to temperature gets too large. The elastomeric bearings are 1.0m x 1.0m x 0.25m in size and placed in two rows of four at each of the nine central piers.

The foundations of the piers are piled using Ø508mm steel cased concrete filled piles.

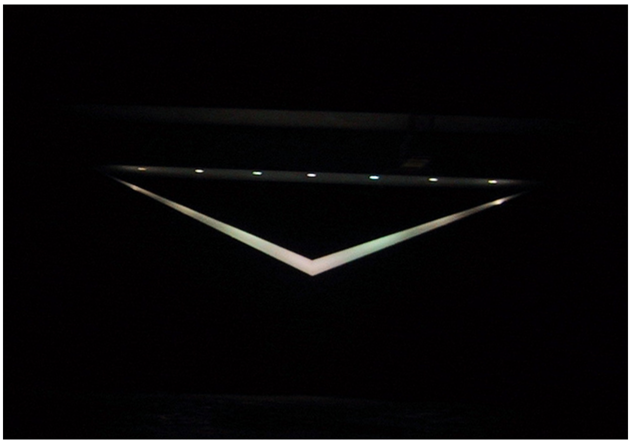

Fig. 6 Architectural Lighting

We took advantage of the facetted top flange of the inclined legs in the architectural lighting concept (Fig. 6). The inclined pier legs become visible through lights from the deck soffit above. However, the effect creates a new exciting visual image - not just a repeat of the daytime image.

2.4 Erecting the Solution

The solution would work equally well in concrete, but composite construction was preferred for ease of construction and also for environmental reasons. Bridge construction offshore has moved towards large-scale prefabrication with large units fabricated onshore where full advantage can be taken of factory conditions. The units are then transported to site on barges and put in position by lifting devices in the form of floating cranes or jack-up arrangements.

Fig. 7 Two Erection Modules

We assumed all structural steel to be fabricated onshore in two erection modules (Fig. 7):

- a splayed pier unit, 45m long, 10.5m high and 7.25m wide weighing 500 tonnes and
- a central unit, 60m long 4.5m high and 7.25m wide weighing 400 tonnes.

The erection sequence assumed in the competition proposal started with the erection of a number of pier units, followed by the installation of the central unit. On-site welding would be required for the final connection to the pier units. After erection of the steel units for a number of spans, concreting would commence by casting of the deck slabs over the central units first followed by the slabs over the pier units to avoid building in tension stresses in the concrete slabs over the piers.

Due to the limited headroom under the two bridges each side of the HSL bridge, access to the bridge line was restricted and it was therefore an important consideration to reduce the Contractor's crane capacity requirement. We therefore assumed that a U-shaped catamaran equipped with an incremental lifting arrangement with a capacity in excess of 500 tonnes would be used. A slight disadvantage with this method was that the pier units would have to be partly submerged when transported and therefore special corrosion protection measures would have to be put in place.

The Contractor has followed the assumed erection sequence. However, by employing a combination of three smaller floating cranes he has managed to float in sufficient lifting capacity thus avoiding the transporting of partly submerged units. The two main erection procedures are shown in Fig. 7.

Fig. 8 Vision and Reality

2.5 The as-built Solution

The bridge as built follows the Reference Design very closely. However, small modifications were required to the geometry in order to increase the efficiency of the elastomeric bearings at the pier tops. The need for the increased efficiency was established through the Contractor's detailed dynamic analysis of the bridge and the problem was solved by modifying the tapers on the sides of the steel boxes to facilitate the use of four instead of eight bearings at each pier. As a consequence the piers were also widened. A very small change considering that no dynamic analysis had been carried out at the competition stage, where the severe comfort criteria had been satisfied through limitation of the deformations due to the static train loading.

3. Conclusion

The Client's design procurement and construction contract strategies have worked successfully for all parties involved. Although the Contractor decided not to employ the Reference Design team as their designer for the detailed design, a number of important discussions/consultations have taken place. These have mainly concerned aesthetic aspects of the design e.g. the colour of the finishing layer of the steel corrosion protection system, the revised shape of piers due to the widening pier tops and the architectural lighting scheme. Also fabrication details have been discussed when these affected the visual aspects of the bridge. It was important that the intersections between the inclined legs and the longitudinal members would appear sharp and not as a rounded corners. Visibly rounded connections would have made the bridge appear less dynamic.

References

[1] Bridge over Hollandsch Diep. Brochure of the design competition proposals issued by Project Organisation HSL-Zuid, 1999