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Bridge design – the Spanish approach by Javier Manterola and similarities in Germany

Diseño de puentes: el enfoque español por Javier Manterola y su similitud en Alemania

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ABSTRACT

For Javier Manterola engineering is both rationality and emotion, function and form, science and art. His bridges combine such classic virtues of structural engineering as efficiency and structural truth with a permanent search for innovation and progress. His work follows a tradition, which before him was defined by the now classic work of Carlos Fernandez Casado and Eduardo Torroja. He has further shaped and evolved this Spanish tradition for decades and sees it now taken over by the next generation. Similarly, in Germany the classic Fritz Leonhardt was followed by Jörg Schlaich, who is of the same age as Javier Manterola, and now the present generation of engineers. The two engineers know and respect each other and there is also a similarity in their approach to bridge design. To illustrate this and to pay tribute to Manterola, some projects by schlaich bergermann partner will be presented here.

KEYWORDS: Cable-stayed bridges, composites deck, shell bridges, carbon fiber, stress-ribbon bridge, innovation, structural art.

RESUMEN

Para Javier Manterola la ingeniería es racionalidad y emoción, función y forma, ciencia y arte. Sus puentes combinan las virtudes clásicas de eficiencia y verdad estructural, en una búsqueda permanente de la innovación y el progreso. Su trabajo sigue una tradición, que antes de él fue definida por la obra ahora clásica de Carlos Fernández Casado y Eduardo Torroja. Él ha forjado y desarrollado esta tradición española durante décadas y que ha sido ahora asumida por la próxima generación. Del mismo modo, en Alemania, el clásico Fritz Leonhardt fue seguido por Jörg Schlaich, que tiene la misma edad que Javier Manterola, y que es ahora seguido por la generación actual de ingenieros. Los dos ingenieros se conocen y respetan entre sí y también existe una similitud en su enfoque del diseño de los puentes. Para ilustrar esto y rendir homenaje a Manterola, algunos proyectos de schlaich bergermann und partners se presentan aquí.

PALABRAS CLAVE: Puentes atirantados, tableros mixtos, puentes lámina, fibra de carbono, puentes en banda tesa, innovación, arte estructural.

1.
INTRODUCTION

A very recommendable little book which contains a series of papers and lectures by Manterola and that gives good insight into his thinking, is *"la obra de ingeniería como obra de arte"* [1]. It is the writing of an intellectual who knows all aspects of his profession and can connect them with ease to other fields like the arts, painting and sculptures, as well as music, politics and philosophy.

It shows that Manterola feels obliged to the classic tradition with its leitmotiv *"lo resistente en la forma construida"* and *"la verdad estructural"*. But this should not become "toda una religion". His work always shows the search for new solutions to leave behind the engineering classicism of the 1960s, because *"la ingeniería no podía quedarse en una repetición al infinito de las buenas soluciones encontradas"*. However, he opposes so-called landmark bridges and bridges designed by architects, especially if the engineer is not called at an early stage but only late in the design to make things stand up. It is the engineer who designs bridges and now *"es el momento de crear formas resistentes nuevas que amplien las muy optimizadas formas*

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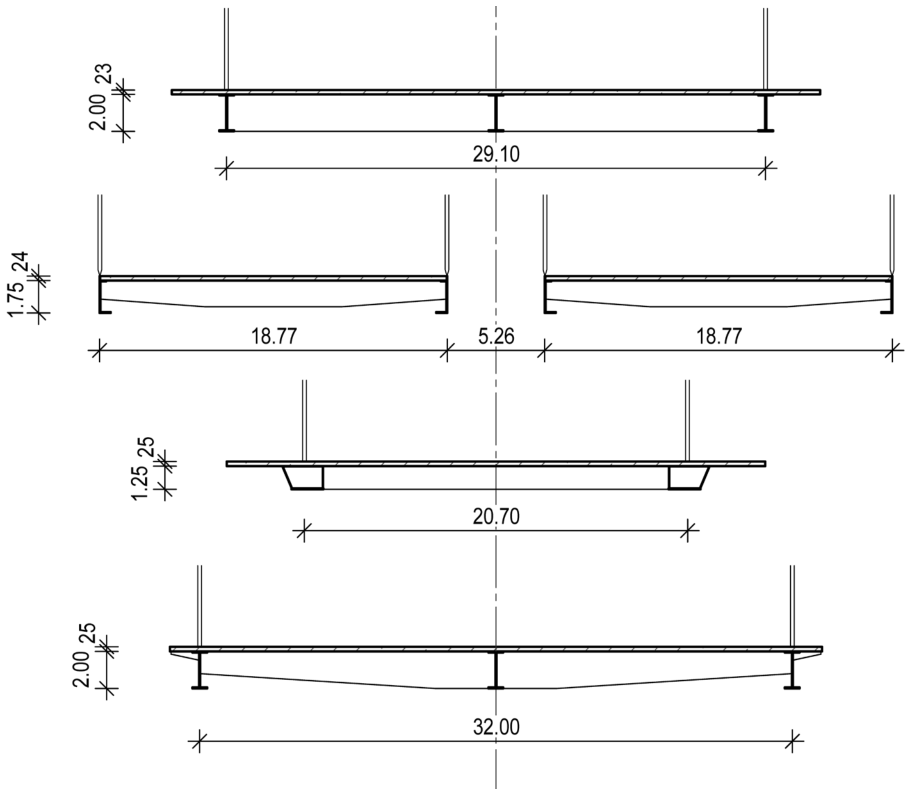

Figure 1. Schematic cross sections of composite decks in the same scale from top to bottom: Second Hooghly Bridge, Ting Kau Bridge, K03 over Albert Canal, Signature Bridge in New Delhi. ©schlaich bergermann partner

heredadas". He sees the future of bridge design in the use of new materials such as glass and carbon fibers and in the introduction of 'intelligent' structures which can change their stiffness and flexibility according to exterior requirements. He goes as far as foreseeing a revolution in construction like the one at the beginning of the XIX century when science entered engineering.

The final chapter of the booklet contains a fictional dialogue between an old and a young engineer. The younger person attacks the elder one for the views just given in the paragraph above which shows Manterola´s inner discussion and how carefully he has studied all points and reasons of other views. But he, the elder stays firm *"yo estoy muy lejos de pensar que la fuente de las formas que se obtienen con un enfrentamiento serio con los materiales, su disposición structural y los nuevos métodos de construcción se haya agotado"*.

In our office, schlaich bergermann partner we are following an approach that subscribes to such points of view. There is proven technology which we use and develop further over the years and there is the search for new approaches. Manterola is often working on bridges with concrete decks and has refined them further and further, coming up also with beautiful bridges made of well-shaped precast concrete segments. We have often worked with composite decks. Four cable-stayed bridges, all with such decks (Figure 1), will be presented. Regarding new technologies, two small bridges will show that we are also testing the new ways Manterola is looking at. An 'intelligent' carbon fiber bridge and a shell bridge, which combines state-of-the-art techniques with traditional methods in form-finding and fabrication will be introduced.

2.

PROVEN TECHNOLOGY - FOUR CABLE-STAYED BRIDGES WITH COMPOSITES DECKS

Composite decks for long-span cable-stayed bridges have numerous advantages: they are comparatively light and robust, because both concrete and structural can be exploited ideally, concrete mainly in compression and steel mainly in tension. They are cost effective because of ease of construction and maintenance. The light steel grid can be transported and installed in large segments and it acts as falsework for an *in-situ* concrete slab or, even better, as support for precast concrete panels.

The actual configuration of main girders and the arrangement of the cable planes needs to be decided individually depending on the boundary conditions of each project. A composite deck should be supported along the edges, as this leads to compression of the concrete also in the transverse direction. For deck widths above 25 to 30 m an additional central main girder, that distributes local loads over several cross girders, usually pays off. For deck widths beyond 30 m and very windy conditions four cable planes can be envisaged in order to reduce the span of the cross girders and hence the overall depth of the bridge deck.

Figure 2. Second Hooghly Bridge (Vidyasagar Setu), Kolkata, India. ©Roland Halbe

Figure 3. Ting Kau Bridge, Hong Kong. ©schlaich bergermann partner

The choice of open or closed steel sections and welded or bolted connections depends on the context, mainly on the possibility of transporting large segments, on-site welding, lifting capacities and experience of the contractor. Precast concrete panels for the deck slab are always advantageous, because formwork is saved and, due to their age, creep and shrinkage effects are reduced. The hoop joints in between the precast panels, that were developed and thoroughly tested for the Ting Kau Bridge, allow for fast erection and result in a continuous, durable and robust bridge deck.

Vidyasagar Setu – Second Hooghly Bridge, Kolkata, India

The Second Hooghly Bridge in India, now known as Vidyasagar Setu, was designed in the early 1970s by Jörg Schlaich and Rudolf Bergermann when they were still working in Fritz Leonhardt´s office and later became the first large project of their own office. It bridges the Hooghly River and connects the suburb Howrah with central Kolkata (Figure 2). The total length of the bridge is 823 m with a main span of 457 m and a width of 35 m. The construction finally started 1978 but could not finish before 1992 due to local political issues [2].

Since weldable steel and High Strength Friction Grip (HSFG) bolts were not available at that time in Kolkata, only a riveted structure was possible. Vidyasagar Setu was not only record span for cable-stayed bridges at the time, it also became the first cable-stayed bridge designed with a composite deck. In-situ concrete was used for the deck slab, which is in good conditions today still.

Ting Kau Bridge, Hong Kong

The Ting Kau Bridge in Hong Kong is one of the few multispan cable-stayed bridges built so far. It crosses the rambler channel and an under-water hill in its middle offered the opportunity to build a central mast, which led to economical deck span dimensions and a total cable-supported deck with a length of 1177 m (Figure 3). The design was also governed by the typhoon wind loads in Hong Kong. Aerodynamic stability of the deck for wind speeds up to 95 m/s had to be achieved. A slender deck of only 1,75 m height supported by four cable planes reflects this. The high wind loads also led to slender masts, shaped for minimum wind resistance, which are stabilised in the transverse direction by cables just like the masts of a sail boat. The bridge was completed in 1998, after only 44 months for design and construction [3].

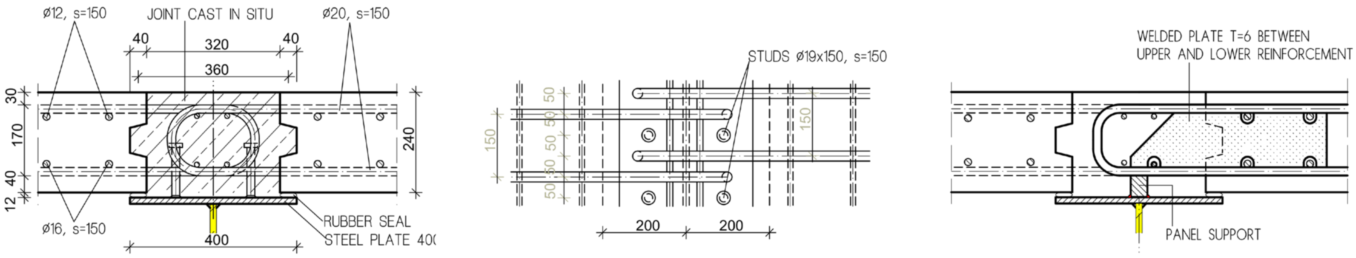

Figure 4. In-situ concrete joint to connect the precast concrete panels and the steel work. ©schlaich bergermann partner

Figure 5. Bridge K03 over Albert Canal, Belgium. ©Jan de NUI, Patrick Henderyckx

The cables are spaced at 13,5 m with cross girders at 4,5 m distances. They support precast reinforced concrete panels with a thickness of 24 cm and 30 cm closer towards the masts. The panels have a size of approx. 4,5 m by 4,5 m and are made of a concrete grade 60 (equivalent to C50/60 in Eurocode terms). All the panels have been cast three to six months prior to their installation in order to reduce creep and shrinkage effects.

The in-situ concrete joints between the panels mentioned above guarantee the continuity of the deck slab and connect it to the steel grid (Figure 4). Tests on site not only confirmed the load bearing capacity of the connection but also showed a pattern of closely spaced small cracks not exceeding 0,25 mm at SLS.

Bridge K03 over Albert Canal, Kempen, Belgium

This semi-integral bridge forms part of a large infrastructure project in Belgium, Kempen North South Connection, which comprises several bridges, tunnels and underpasses (Figure 5). The design is characterized by the harp configuration of the cables and a relatively short back span. Its axis crosses the canal at a skew angle of 70º. The harp configuration was chosen to have a harmonic appearance of the cables even with the skewed alignment of the masts. The main span of 122 m has a lightweight composite deck with precast slab elements placed on hollow box steel main girders. The relatively short back span with no intermediate tension ties required a heavy and stiff deck for the back span. This led to a thicker concrete slab and to a stiff frame configuration between the masts and the back-span girders in the cable planes. The back-span deck was cast monolithically with the southern abutment to make the bridge semi-integral. The bridge is the results of a successful BOT competition where the winning contractor not only constructs the bridge but also operates it for several years after its completion in 2013 [4].

A large portion of the steel grid, about 70 m by 30 m in size and consisting of main and cross girders, could be prefabricated in the workshop and transported to site on large barges. After completion of the concrete side span, the masts and abutments, the steel grid was lifted to temporary towers

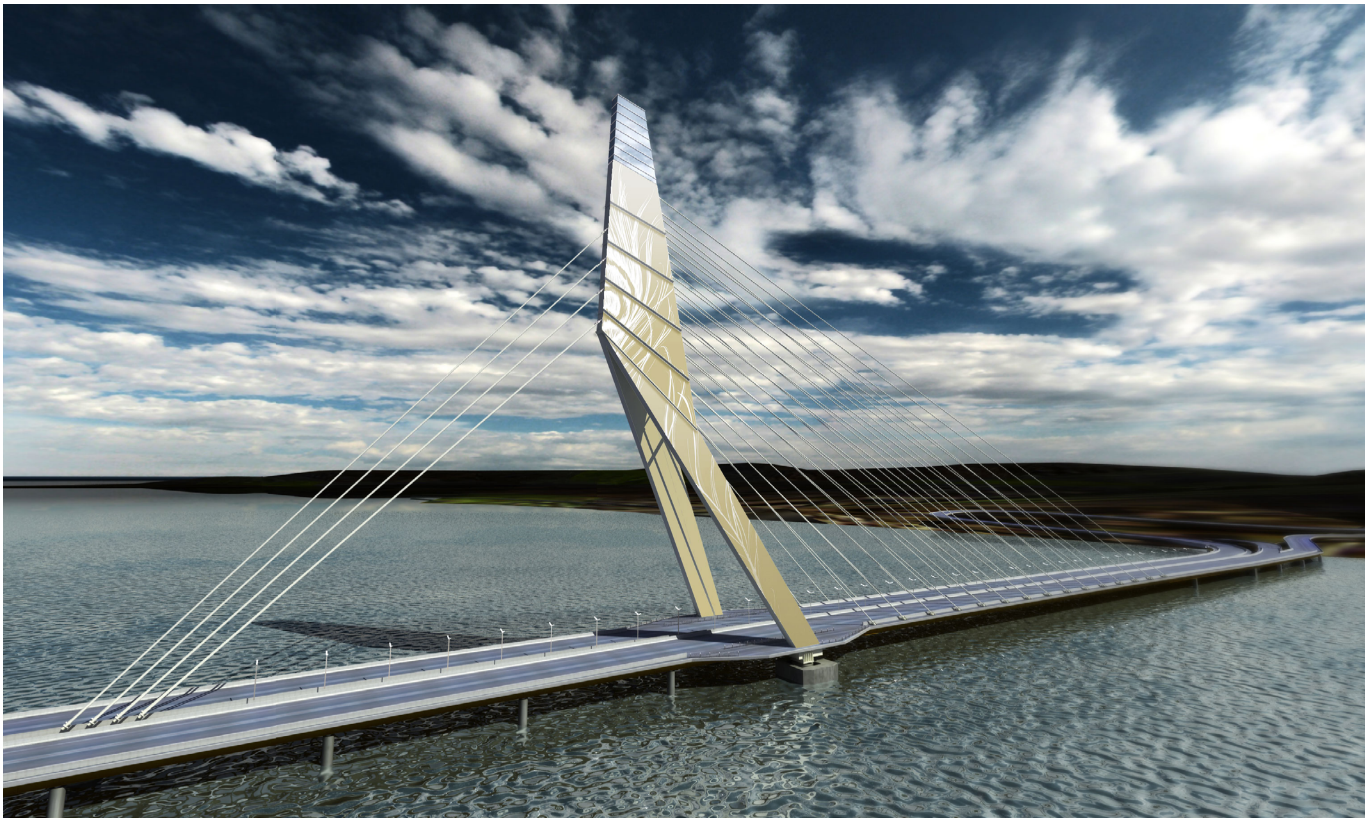

Figure 6. Image of the Signature Bridge in New Delhi, with ornamental painting on the pylon. ©schlaich bergermann partner

that rested directly at the quay walls and was welded together during a remarkably short closure period of the channel. Once connected with the remaining steelwork at the mast and the opposite abutment, the cables with a spacing of 12 m and the skewed precast panels with a typical size of 9 m by 4 m and thickness of 25 cm have been installed step by step beginning from the mast. The deck cantilevers are also made of precast panels which were supported by temporary steel girders.

Signature Bridge, New Delhi

This "Signature Bridge" in New Delhi connects the city Ghaziabad and its surrounding across the river Yamuna to the inner city (Figure 6). The bridge shall be the landmark to a new park and recreation area which shall be created from a now heavily spoiled and contaminated site. In this sense the bridge can be looked at as the signature under the promise to improve a neglected neighborhood. The dynamically shaped pylon consists of two inclined legs, which are rigidly connected to the deck girders and bend mid-way. The upper portion of the pylon anchors the back-stay cables as well as the main-span cables, arranged in a semi-harp like manner. The tip of the pylon is created by a 30 m high steel-glass structure, which can be illuminated to create a landmark visible from afar at night. The bridge was completed at the end of 2018 [5].

The asymmetric cable-stayed bridge has a main span of 251 m (corresponding to a symmetric bridge with two pylons of 500 m span) and total length of 675 m. Its composite deck carries 8 lanes (4 in each direction) and is approximately 35 m wide. The main span is supported by lateral cables spaced at 13,5 m intervals. Towards the approaches the same deck section continues with piers supporting it at 36 m intervals. The height of the steel tower is approximately 150 m.

The bridge deck consists of three main girders with a height of 2 m and cross girders at a spacing of 4,5 m, very similar to the Second Hooghly Bridge. To provide sufficient space for 8 lanes, the two outer main girders, supported by cables, are spaced 32 m apart from each other. The emergency footpath has been placed on 1,5 m long cantilevers outside of the cable planes. Similar to the Ting Kau Bridge, all steel joints have been designed as HSFG connections.

A major difference between the bridges presented above and the Signature Bridge in New Delhi is that the latter is relatively low above water which is shallow outside of the monsoon period. Therefore, it was possible to erect the entire deck on temporary trestles and not by free cantilever method. This way, full composite action, also for dead load, could be achieved, so that the concrete slab is transmitting even more compression force than in the other cases. This is reflected in the distribution of the concrete slab thickness. Outside of the cable-stayed part the precast reinforced concrete panels have a thickness of 25c m which gradually increases to 35 cm thick panels towards the pylon and ends in a 70 cm thick in-situ portion around the pylon legs. The deck panels are made of grade 50 concrete (equivalent to C40/50 in terms of Eurocode) with a size of 4,5 m by 8 m to minimize the amount of transverse joints. Due to the positive experience gained from the joint detail developed for the Ting Kau Bridge the same detailing has been used again (Figure 7).

The four examples described above show the wide variety of solutions only in the field of composite decks for cable-stayed bridges. We are far from having exploited all the

Figure 7. Deck erection with precast elements (left) and in-situ joints between precast elements and steel girder (right). ©schlaich bergermann partner

possibilities this method of building offers but we should also look for new approaches in bridge design. Small structures, footbridges, offer the possibility for experiments.

3.
NEW APPROACHES IN BRIDGE DESIGN

Carbon fiber stress-ribbon bridge, Technische Universität, Berlin.

Up to now, Carbon Fiber Reinforced Plastics (CFRP) are used in structural engineering mainly to reinforce existing structures. However, its economic and structural potential for new structures is still largely unused. To show this potential, in 2007 a stress-ribbon bridge with carbon fiber ribbons was built in the laboratory of the Department of Civil and Structural Engineering at the Technische Universität Berlin (Figure 8). Stress-ribbon bridges are among the most elegant and lightest bridges. The ribbons are anchored in the abutments on both sides. Pedestrians walk directly on the ribbons that are covered and stabilised by open-jointed concrete plates. Usually the ribbons are steel plates or steel cables. The use of carbon fiber ribbons instead of normal steel ribbons gives an opportunity for progress in the design of stress-ribbon bridges. Compared with normal structural steel, the tensile strength of this material is ten times higher and the specific weight is five times lower. This allows building longer spans and smaller cross sections but also makes such lightweight structure lively.

The high vibration sensitivity of the bridge led to studies on new new damping or control strategies. Active control strategies allowed to make the bridge ‘intelligent’. Sensors in the deck detect any movements of the bridge an their signals are sent to a processor unit, which in real time triggers the inflation of artificial pneumatic muscles installed in the handrail. These muscles contract and counteract the movements of the bridge (Figure 9). This way damping can be increased by a factor of ten and the rocking bridge is calmed [6]. The system has been working now for more than ten years and has become a very useful tool for research and for the students as a ‘life’ introduction into the field of dynamics.

Another very interesting application of carbon fibers in concrete bridge design and construction is pre- and posttensioning. At the TU Berlin a research project for integral road bridges of some 45 m span made of precast concrete girders which are post-tensioned with carbon fiber elements is showing considerable benefits of such an approach.

Shell bridges

The stainless-steel footbridge in Ditzingen, Germany, is a shell that forms both structure and deck (Figure 10). The double-curved shell spans 20 m with a plate thickness of only 20 mm. Laser cut holes in the shell not only make the structure lighter and translucent, but also the remaining steel work reveals the path of the principal membrane forces, thus making the bridge more understandable [7].

In spite of all the modern form-finding techniques available, in this case initial form-finding was done in a most traditional way. Oranges in a German supermarket come in quadrilateral plastic nets, which, when tensioned, deform in a way that loads are carried only by principal membrane tensile forces because the net cannot take shear in its plane. A simple

Figure 8. Load test with Department of Civil and Structural Engineering at TU Berlin. ©Technische Universität Berlin

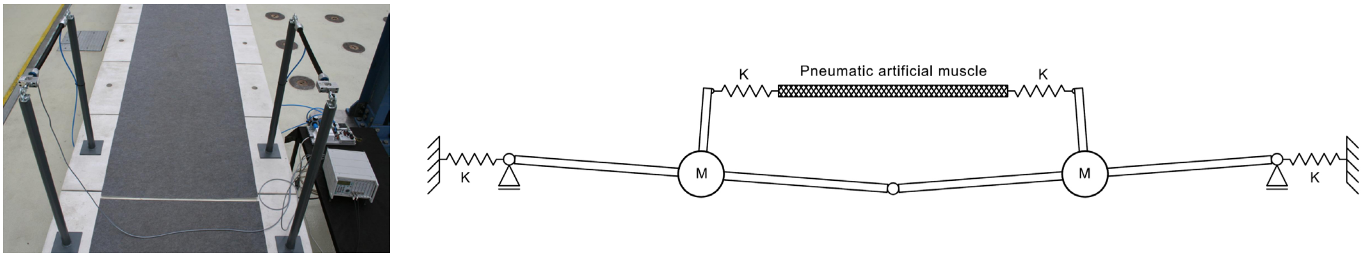

Figure 9. Simplified system for damping the first mode vibration and the first installed pneumatic muscles. ©Technische Universität Berlin

Figure 10. Shell bridge (TRUMPF-Steg) in Ditzingen, Germany. ©sbp / Andreas Schnubel

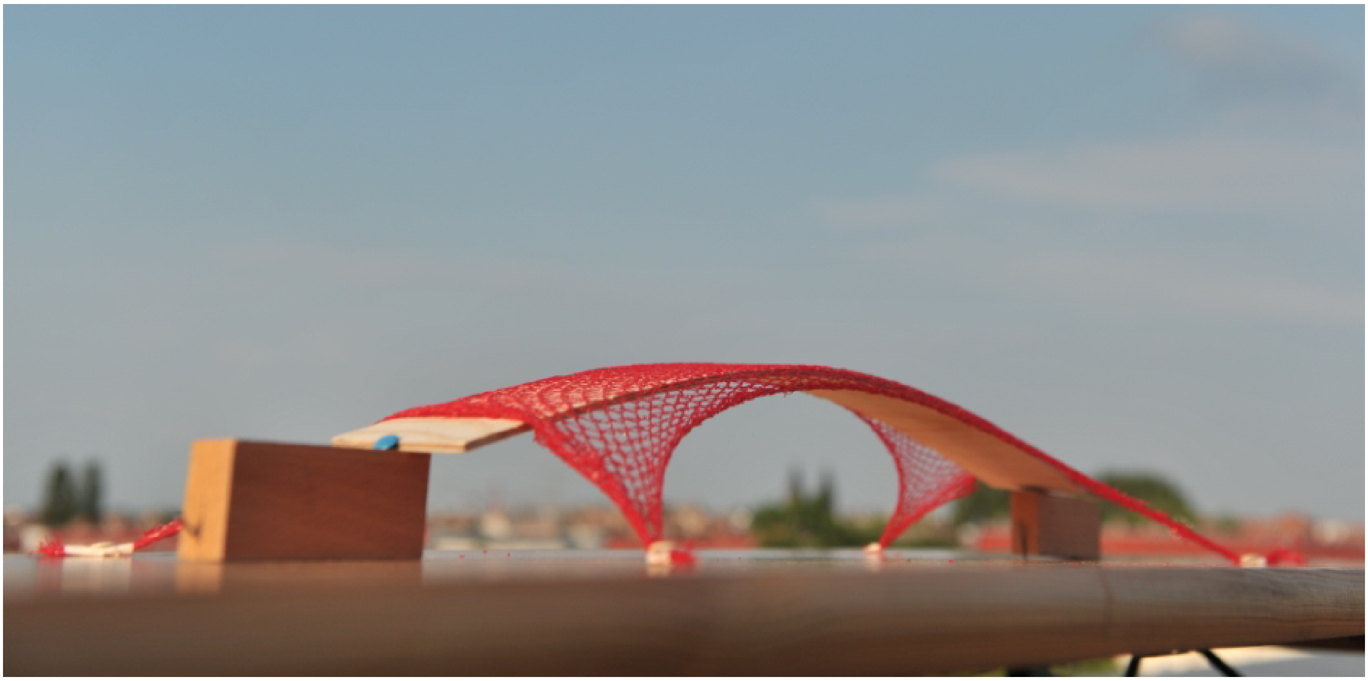

Figure 11. Orange net model. ©schlaich bergermann partner

model made of such a net with a curved timber plate to push the net upward - like an inverted distributed walkway load - was made to achieve a tension-only geometry. The photograph of the model in Figure 11 shows the deformed net and the distribution of the principal membrane forces. Naturally, later modern parametric design tools and nonlinear Finite Element Analysis was used to fine tune the design.

For building the shell, state-of-the-art laser cutting was combined with traditional ship building methods. Steel plates of up to 3x6 m were laser-cut in the Netherlands (Figure 12) and were brought into shape by plastic deformation in a ship building yard in Stralsund, Germany. There, six individual segments, large enough to fit on trucks were welded together and shipped to site. Final assembly of these segments was done under a tent which allowed safe welding and a surface finish with glass powder blasting. Then the entire bridge was lifted into its final position where it is supported on four ball bearings.

This project shows that combining almost traditional techniques with state-of-art technologies is no contradiction. On the contrary, this can lead to surprisingly different results.

4.
SUMMARY

The enormous and beautiful body of Javier Manterola´s work relies on the successful use and further development of proven technologies together with daring new approaches in bridge design. The examples presented here show that this is also the way we are working in Germany. Looking at other recent bridges in France and Great Britain also reveals such approaches. Is the European idea also appearing here with the present generation of bridge engineers, forming a European tradition of bridge design? That would be nice!

Figure 12. Laser cut plate in front of the laser cutter. ©Outokompu

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