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Search for the true structural solution

En la búsqueda de la verdadera solución estructural

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ABSTRACT

For a long time, I have been admiring the design work of the engineering firm Carlos Fernádez Casado, S.L., Madrid and his president Prof. Javier Manterola Armisén. His structures express the unity of function and form as well as unity of structural and architectural solution. I always wanted to work similarly. However, since I am living in different social, historical, technological and physical environments, my structures are different. Here I present several structures on which examples my continuous search for the true structural solution will be demonstrated. The presented structures were designed by engineering staff of the design firm Strasky, Husty and Partners, ltd., Brno, Czech Republic. The presented structures utilize different architectural and structural forms that are inherent in the constraints of the site and are economical and structurally efficient. They were well accepted both the public and professional.

KEYWORDS: Viaducts, cable-supported bridges, arch bridges, stress ribbons, pedestrian bridge.

RESUMEN

Durante mucho tiempo, he estado admirando el trabajo de la oficina de proyectos Carlos Fernádez Casado, S.L. y su presidente Prof. Javier Manterola Armisén. Sus estructuras expresan la unidad de función y forma, así como la unión de la solución estructural y arquitectónica. Siempre quise trabajar de manera similar. Sin embargo, como vivo en un entorno social, histórico, tecnológico y físico diferente, mis estructuras son diferentes. En este artículo les presento varias estructuras en las que se demostrará mi continua búsqueda de la verdadera solución estructural. Las presentes estructuras fueron diseñadas por ingenieros de la empresa de proyectos Strasky, Husty y Partners, Ltd., Brno, República Checa. Utilizan diferentes formas arquitectónicas y estructurales que son inherentes a las limitaciones del lugar y son económica y estructuralmente eficientes. Fueron bien aceptadas tanto por el usuario como por los profesionales.

PALABRAS CLAVE: Viaductos, puentes sustentados por cables, puentes arco, bandas tesas, pasarelas.

1. INTRODUCTION

For a long time, I have been admiring the design work of the engineering firm Carlos Fernádez Casado, s.l., Madrid and his president Prof. Javier Manterola Armisén. He designs structures which architecture is developed from true structural solutions that simply and clearly express the flow of internal forces through their static system. He develops new architectural and structural forms making use of the latest technological and scientific innovations to achieve the most appropriate solutions for each individual case. His structures express the unity of function and form as well as unity of structural and architectural solution.

What is more, he designs bridges that are developed from the social and cultural history of Spain, from Spanish tradition of understanding of the plastic richness of concrete and the strength of steel. Furthermore, his structures are personal and express his personal attitude to work and life.

I always wanted to work similarly. However, since I am living in different social, historical, technological and physical environments, my structures are different. In Spain, I had several

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Figure 1. Bridge across the Lazny Creek Valley.

opportunities to present our design philosophy, our structures and our approach to design [1] and [2]. Therefore, I will present here several new structures on which examples my continuous search for the true structural solution will be demonstrated. The presented structures were designed by engineering staff of the design firm Strasky, Husty and Partners, ltd., Brno, Czech Republic

2.
VIADUCTS WITH PROGRESSIVELY ERECTED DECKS

Bridge structures formed by concrete or steel box girders with large overhangs supported by struts represent an optimum solution for crossings of deep valleys. These bridges are esthetically pleasing and structurally very efficient. Their economy can be enhanced by a progressive erection of their decks. This is illustrated on a construction of several viaducts built in the Slovak and Czech Republic.

2.1 Concrete Viaducts

Thirty years ago, a cable stayed bridge across the River Elbe near a city of Podebrady was erected. Its 31.80 m wide deck is formed by a spine girder with large overhangs supported by not mutually connected precast slab struts [3]. The one cell box girder assembled from precast segments was constructed first, then the struts were erected, and the overhangs were cast in simple formwork that was supported by these struts. After that similar arrangement was used in a construction of the Vrsovice cable stayed bridge built in Prague and in several bridges designed by others.

Recently similar approach has been used in construction of several long viaducts that have been built in Slovakia - see Figures 1 and 2. These bridges have span lengths up to 69 m, their widths are up to 28.70 m. The spine girders were cast span by-span in a formwork suspended on a special overhead gantry with 'organic' prestressing system (OPS) which eliminates the deflection of the gantry - see Figure 3. To reduce the self-weight of the spine girder as much as possible, the girders are very narrow. Therefore, the transverse projection of the overhangs up to 11.00 m.

The first structure of this kind was a 975 m long viaduct across the Hostovsky Creek built on the Expressway R1 near a city of Nitra. The bridge of the width of 25.66 m has 17 spans of lengths from 33.0 to 69.0 m. The depth of the girder varies from 4.00 to 2.60 m.

Two bridges of similar arrangement were being built on a motorway D1 section Fricovce – Svinia near a city of Presov. These bridges built across the Lazny (see Figure 1) and Stefanovsky Creek Valley have total lengths of 269 m and 182 m; typical span length is 45 m. Both motorway directions are carried by one bridge of a total width of 29.5 m. The depth of the girder is 2.60 m. Since the bridge decks are frame connected with H shaped piers, the bridges form semi-integral structural systems.

Another two bridges of similar arrangement were also built on a motorway D1 section Janovce – Jablonov near a city of Levoca. The bridges across the Lodina (see Figure 2) and Doliansky Creek Valley have total lengths of 367 m and 414 m; typical span length is 65 m. Both motorway directions are carried by one bridge of the total width of 28.70 m. The depth of the girder is from 4.00 to 2.60 m. Since the bridge decks

Figure 2. Bridge across the Lodina Creek Valley.

Figure 3. Movable scaffolding - Bridge across the Lodina Creek Valley.

are hinge connected with twin piers, the bridges form semi-integral structural systems.

The spine girder of all bridges was progressively cast span–by-span in a formwork suspended on overhead gantries. The girders were cast with short overhanging cantilevers. The decks of all bridges are longitudinally prestressed by internal bonded tendons situated within the basic cross section and by external non-bonded tendons situated inside the central box. The bonded tendons are coupled in each construction joint. External cables are anchored at pier diaphragms and are deviated at pier and span deviators.

In the transverse direction the deck slab is prestressed by tendons composed of strands installed in flat ducts spaced 1.50 m. During erection the struts are suspended on two prestressing bars anchored at outer cantilevers of the basic cross section - see Figures 4 and 5. The struts of a nominal width of 3.00 or 2.50 m are supported by short bottom corbels of the box girder. The cast-in-place deck slab was cast in the formwork supported by already erected precast struts. After the transverse prestressing of the deck slab is applied, the longitudinal external cables are post-tensioned.

The structural solution was developed on a basis of very detailed static and dynamic analyses. The first structure, the Viaduct across the Hostovsky Creek Valley, has been carefully monitored during construction, in depth loading tests and during service. The measurements confirmed the static loading assumptions and showed a very good agreement between the measured and the expected behaviour.

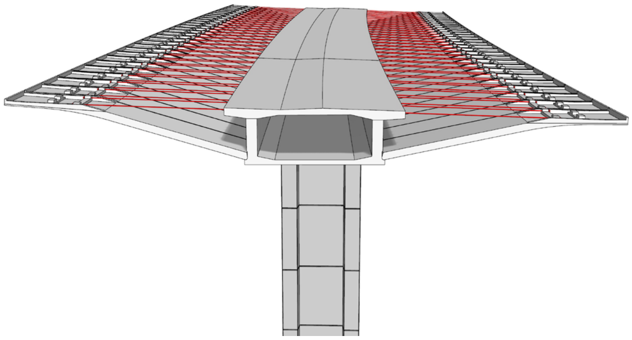

Figure 4. Progressive erection of the deck.

Figure 5. Precast struts - Bridge across the Lodina Creek Valley.

Figure 6. Bridge across the Kremlice Creek Valley.

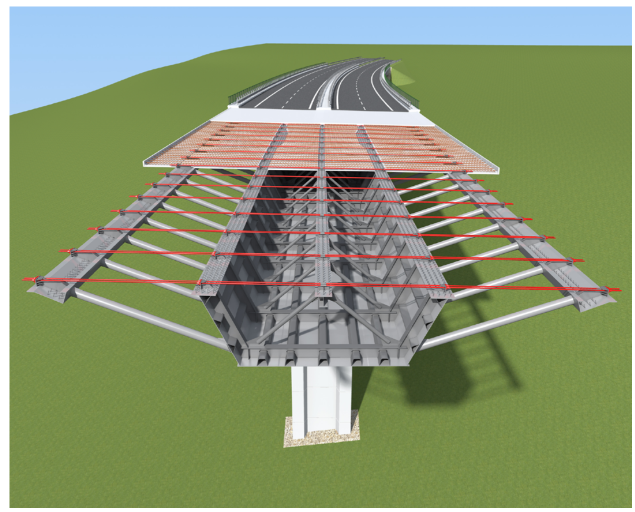

Figure 7. Progressive erection of the deck.

Figure 8. Steel structure - Bridge across the Kremlice Creek Valley.

Figure 9. Progressive erection of the deck - Bridge across the Kremlice Creek Valley.

2.2 *Composite Viaducts*

Progressive erection of the deck was also utilized in construction of two composite viaducts that were built on the highway I/11 in the North Moravia, Czech Republic - see Figure 6. The first viaduct, the Bridge across the Hrabynka Creek Valley of a total length of 330.0 m, consists of a 6 span continous girder of lengths from 39.0 to 66.0 m, the second one, the Bridge across the Kremlice Creek Valley of a total length of 528.0 m, consists of a 11 span continous girder of lengths from 33.0 to 57.0 m. While the Bridge 206 has a straight axis, the Bridge 207 includes a 900 m radius horizontal curve plus an horizontal agreement.

Both directions of the highway are carried by carried by single deck composed of a steel girder and a 25.5 m wide concrete deck slab – see Figure 7. The steel girders of the

Figure 10. Progressive casting of the deck - Bridge across the Kremlice Creek Valley.

trough cross section assembled of top and bottom flanges and inclined webs are supplemented by central stringer and two edge stringers. While the central stringer has I cross section, the edge stringers have V shape with smooth surface that simplify the bridge maintenance. At distance of 3.0 m the stringers are supported by diagonal pipes attached to the girder's bottom corners. The shape of the structure is secured by top transverse ties anchored at the top flanges and at the edge and central stringers – see Figure 8. The deck slab is composite of precast slab members and additionally cast deck slab. The precast members of thickness of 100 mm are stiffened by steel trusses welded from reinforcing bars. Their function both, for erection and service load, was verified by loading tests done at a Brno University of Technology.

Both bridges were incrementally assembled beyond the abutments and consequently launched into their final position. The steel structure of the first bridge was divided into 20 segments of lengths from 13.0 to 21.3 m. The steel structure was incrementally launched with precast members; only a part of the structure of the length of 66 m beyond the launching nose was formed by the steel section. When launching was completed, remaining precast members were erected and the deck slab was progressively cast.

The steel structure of the second bridge was divided into 25 segments of lengths from 13.0 to 29.0 m. Due to the complex bridge geometry the steel structure is assembled from two parts and it was launched from both abutments. At first, the part of the steel structure close to the abutment 1 was incrementally assembled and launched, and then the part of the structure close to abutment 12 was assembled and launched. Due to the variable plan curvature the launched structure was temporarily supported by pier transverse steel girders that allowed a transverse movement of the deck. To reduce the weight of the launched structure, the steel structure was launched without precast members. After connection of both parts, the precast members were progressively erected, and the deck slab was cast – see Figure 9 and 10.

3. SEMI-INTEGRAL CANTILEVER BRIDGES

Recently we have designed three semi-integral cantilever bridges with decks supported on twin twin piers. All these bridges were built on the motorway D3 in Slovakia.

3.1 Bridges Valy and Rieka, Motorway D3, Slovakia

These bridges were built across the deep valleys on the section Svrcinovec – Skalite see Figure 11. The Bridge 'Valy' is a 591 m long continous structure consisting of nine spans with lenghts ranging from 30 to 92 m. The bridge Rieka of the total length of 500 m is formed by a continuous structure of eight spans is a 500 m long continous structure consisting of eight spans with lenghts ranging from 25 to 92 m. The deck of both bridges consist of by box girders of a variable depth from 2.70 to 5.00 m that were segmentally cast in balanced cantilevers starting at piers m - see Figure 12.

The slender piers that are monolitically coonnected to the deck consist of by twin walls which bottom portions are mutually connected by longitudinal walls. The piers height is up to 76 m. The bearings are situated only on short side piers

Figure 11. Bridge Valy.

Figure 12. External continuity cable.

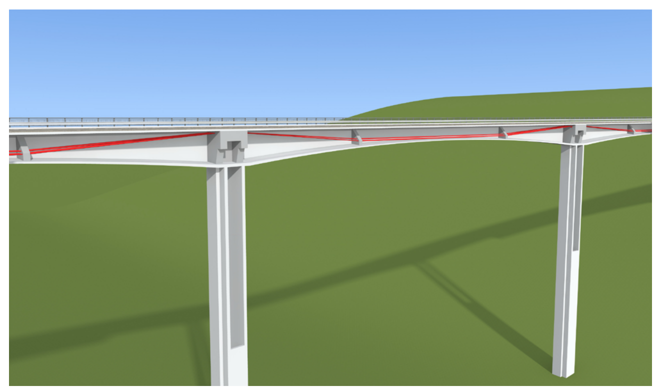

Figure 13. Cantilever construction of the Bridge Valy.

and abutments. The horizontal distance of the twin walls and height of the connecting wall were determined by a parametric study in which a bridge stability during the progressive erection of the bridge and a flexibility of the integral structural systems were compared.

The deck is post-tensioned by cantilever tendons situated in the deck slab, span tendons situated in the bottom slab and by external continuity tendons situated inside of the box section - see Figure 13. The prestressing tendons balance not only bending moments, but also shear stresses. Therefore, the box girders' webs thickness is only 350 mm.

3.2 *Bridge across the River Vah's Reservoir Hricov, Motorway D3, Slovakia*

In December 2017 a 1.50 km long viaduct across the River Vah's Reservoir Hricov, on the Motorway D3, Slovakia was opened. The viaduct consists of a continous structure of span lengths from 30.50 to 110.00 m. The central spans bridging the River Vah consist of a box girder of a variable depth from 3.00 to 6.00 m that were segmentally cast in balanced cantilevers - see Figures 14 and 15; the remaining spans have a double tee cross section of a constant depth of 3.00 m - see Figure 16. These spans were cast span-by-span on stationary or movable scaffoldings. The bridge forms a semi-integral structure with expansion joints situated only at the abutments.

The cantilever spans are supported by twin piers that consist of two transversally inclined columns directly supporting the box girder's webs; the approach spans are indirectly supported by single elliptical columns. Although these supports have a different static function, their shape is consistent – see Figure 17.

Figure 14. Cantilever construction of the Bridge across the River Vah's Reservoir.

Figure 15. Deck of the main spans of the Bridge across the River Vah's Reservoir.

Figure 17. Piers of the Bridge across the River Vah's Reservoir.

Figure 16. Deck of the approach spans of the Bridge across the River Vah's Reservoir.

4. CABLE-SUPPORTED BRIDGES

According to the nature of the obstacle and local conditions, classical cable -stayed, extradosed and suspension structures are designed. Some of them are described below.

4.1 Bridge across the Odra River and Antosovice Lake, Czech Republic

Near the city of Ostrava the motorway D1 crosses the River Odra and Antosovice Lake on a twin bridge of a total length of 589 m. Due to a limited clearance, the deck of the structure had to be as slender as possible. Since the bridge is situated in a nice recreation area, it was necessary to design a structure of high aesthetic value that can become a symbol of the new freeway. Therefore, a cable stayed structure suspended on one single pylon was accepted - see Figure 18. The bridge crosses the river

Figure 18. Bridge across the Odra River.

Figure 19. Deck of the viaducts - Bridge across the Odra River.

in a skew angle of 54°. The horizontal alignment comprises a 1500 m radius horizontal curve followed by a transition while the vertical alignment is a crest elevation with radius of 20000 m.

The span length varies between 24.5 to 105.0 m. The main span bridging the Odra River is suspended on a 46.8 m high single pylon. Since the stay cables have a symmetrical arrangement, the back stays are anchored in two adjacent spans situated on the land between the river and lake. The stay cables have a semi-radial arrangement; in the deck they are anchored at distance of 6.07 m, at the pylon they are anchored at a distance of 1.20 m.

The decks are formed by two cell box girders 2.20 m

Figure 20. Deck of the suspended spans - Bridge across the Odra River.

Figure 21. Bridge across the Railway Station at Bohumin.

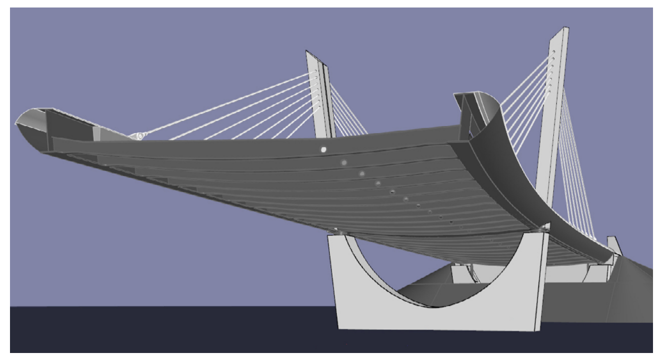

Figure 22. Structure of the Bridge across the Railway Station at Bohumin.

deep without traditional overhangs. The bottom slab of both cells is inclined, and it is curved in the middle of the girder - see Figure 19. In the suspended spans the box girders are mutually connected by a top slab cast between the girders and by individual struts situated at distance of 6.07 m. The stay cables are anchored at anchor blocks situated at the connected slab. The struts connect the curved bottom of the girders and together with the inclined slabs create a simple truss system transferring the force from the stays into the webs. Between the stays' anchors there are circular openings at the connected slab. All piers have an elliptical cross section of the width of 4.10 m and depth of 1.60 m - see Figure 20.

The bridge deck was cast span-by-span in two formworks suspended on two movable scaffoldings. With respect to the span length of the movable scaffoldings, temporary piers had to be built in the suspended spans. As soon as the spans adjacent to the pylon were cast, the pylon's steel core was erected, and concrete fill and cover were progressively cast.

Simultaneously, the concrete struts between the girders were erected and top slab between the girders was cast and transversally prestressed. After that, the stay cables were erected and tensioned. Then the temporary piers were removed.

4.2 Bridge across the Railway Station at Bohumin, Czech Republic

For the crossing of the railway station in a city of Bohumin, a structure of a minimum structural depth had to be designed. Since the bridge is located close to historic center, the new bridge should be as modest as possible. Therefore, an extradosed structure suspended on low pylons was built – see Figure 21.

The bridge is 140.30 m long distributed in three spans of length of 30.0+70.0+30.0 m that are suspended on transversally inclined low pylons situated above intermediate supports. The bridge axis is in a plan curvature with a radius of 256 m. The deck is formed by two edge box girders that are mutually connected by floor beams and a composite deck slab – see Figure 22. The deck's steel structure was incrementally assembled beyond an abutment and consequently launched into its final position.

4.3 Bridge across the River Ebro, Spain

Together with the Spanish firm Tec-Cuatro, from Barcelona, we won a competition for the design of the new bridge across the Rio Ebro. The bridge replaces a ferry that connected the small cities Deltebre – Sant Jaume D'Enveja situated close to the river's estuary into the Mediterranean Sea. The client required a signature structure that, however, corresponds to a scale of these decent cities. The bridge crosses the river in a skew angle and it is in a crest elevation. The bridge forms a self-anchored suspension structure of three spans of lengths 69.00+ 112.00 + 69.00 m - see Figure 23.

The 19.30 m wide deck is suspended on four suspension cables situated in the bridge axis. The torsionally stiff deck is consist of a four-cell box. The central web of a variable depth that protrudes above the deck slab and substitute suspenders of the classical suspension structures naturally divides a local highway from pedestrian and cyclist routes. At a distance of 3.00 m the steel structure is stiffened by transverse cross beams that support the composite deck slab. At the abutments

Figure 23. Bridge across the River Ebro.

Figure 24. Lifting of the deck of the Bridge across the River Ebro.

the deck is stiffened by the end cross beams transferring the load from the bearings into the central webs.

The main suspension cables are consist of four BBRV cables anchored at the end diaphragms and are deviated at the saddles of the low pylons. For the construction of the side spans and piers, artificial peninsulas were consecutively created on both river banks. They served for drilling of 46m long piles, casting the footings and construction of the piers. Then the steel structure forming the side spans and cantilevers protruding into the main span were erected. After that the pylons were erected, the pylons' saddles were connected with the central walls by steel pipes forming the stays. In this way a cable-stayed structure was created.

The whole central portion of the main span being 61.40 m long and 500 tons heavywas assembled on one bank and consequently floated and lifted into its final position – see Figure 24. When the central portion was connected to the already assembled structure, the suspension cables were pulled through the pipes and were partially tensioned. In this way the weight of the steel structure was transferred from the steel pipes to the suspension cables and the cable stayed structure was transformed into a self-anchored suspension structure. Consequently, the deck slab was progressively cast, and stresses in suspension cables were adjusted. The construction was finalized by loading tests. The structure was tested for five positions of the live load that creates maximum bending and torsion.

4.4 Pedestrian Bridge across the motorway D1, Czech Republic

The bridge that crosses the motorway D1 near a city of Bohumin is used both by pedestrians and bicycles - see Figure 25. The bridge deck of two spans of 54.94 and 58.29 m is in a plan curvature with a radius of 220 m. The bridge is suspended on a single mast situated in the area between the freeway and local roads.

Figure 25. Pedestrian Bridge across the motorway D1.

Figure 26. Deck of the Pedestrian Bridge across the motorway D1.

The bridge deck is fixed into the end abutments consisting of front inclined walls and rear walls. Due to heavy bicycle traffic the city of Bohumin has required to separate the pedestrian and bicycle pathways. Therefore, the deck is consists of a central spine girder with nonsymmetrical cantilevers carrying the pedestrians and bicycles. To balance the transverse load, the shorter cantilever is solid, while the longer is consists of a slender slab stiffened by transverse ribs - see Figure 26. The mast is consists of two inclined columns of two cell box sections that are tied by top and bottom steel plates connecting the boxes' central webs.

5. ARCH BRIDGES

An arch by its own shape naturally expresses an effort to bridge the obstacle. For the dead load a correctly designed arch

Figure 27. Wildlife Overpasses, Czech Republic.

Figure 28. Wildlife Overpasses, Czech Republic.

is stressed primary by compression stresses. Therefore, it can be light and transparent. Recently we participated in a design of several arch bridges built in the Czech Republic and in the USA. The most interesting bridges are described below.

5.1 Wildlife Overpasses, Czech Republic

For motorway wildlife crossings, a new structure consists of two continuous shell arches that are supported by an intermediate support situated in the motorway median have been developed – see Figure 27. The shell structure is continuously widened in the plan and smoothly link up the side embankments - see Figure 28. To enable design these structures also in areas with poor geotechnical conditions, a self-anchored structural system that stresses the footings only by vertical forces has been developed. The arch horizontal force is resisted by prestressed ties (stress ribbons) that are situated above the shells.

Eliminating the abutments and substituting the wings by a continuously widened shell allows to design structures naturally connected with surroundings. So far two structures of this type have been built.

5.2 Willamette River Bridge, Eugene, Oregon, USA

A successful realization of the Redmond Arch Bridge has helped getting a project of another arch bridge that was built in a city of Eugene, Oregon, USA. The interstate freeway I-5 crosses the Willamette River, a local highway, a railroad and a junction ramp on north bound and south bound bridges

Figure 29. Willamette River Bridge.

Figure 30. Willamette River Bridge.

Figure 31. Pedestrian Bridge across the Olse River.

of lengths of 604.9 m and 536.1 m. These bridges replace original bridges built in fifties of the last century.

The main bridgeconsisting of two arch spans of length 118.9 and 126.8 m – see Figure 29. The deck that is formed by two girders and deck slab is stiffened by precast cross beams; the arches consist of two ribs without any bracing – see Figure 30. The approach bridges are multi-cell box girders of a variable depth that has the same perimeter as the arch deck. The substructure has a similar architectural and structural arrangement that the arch columns.

The bridge was erected progressively. At first, the arch ribs with the crown precast cross beams were cast. After the jacking, the midspan joints were cast. Then the columns were erected and longitudinal girders with the transverse cross beams are cast. After that the deck slab was cast.

5.3 Pedestrian Bridge across the Olse River connecting the Czech and Polish Tesin

The 95.40 m long bridge across the border River Olse that connects the Czech an Polish cities of Tesin includes an horizontal curve with a radius of 100 m. The bridge has four spans of lengths from 13 to 45 m. The deck consists of a slender box girder of a non-symmetrical streamline cross section that is stiffened by one side inclined arch in the main span – see Figure 31. The deck is fixed into the end abutments and is supported by elastomer pads on intermediate piers. To balance the torsional

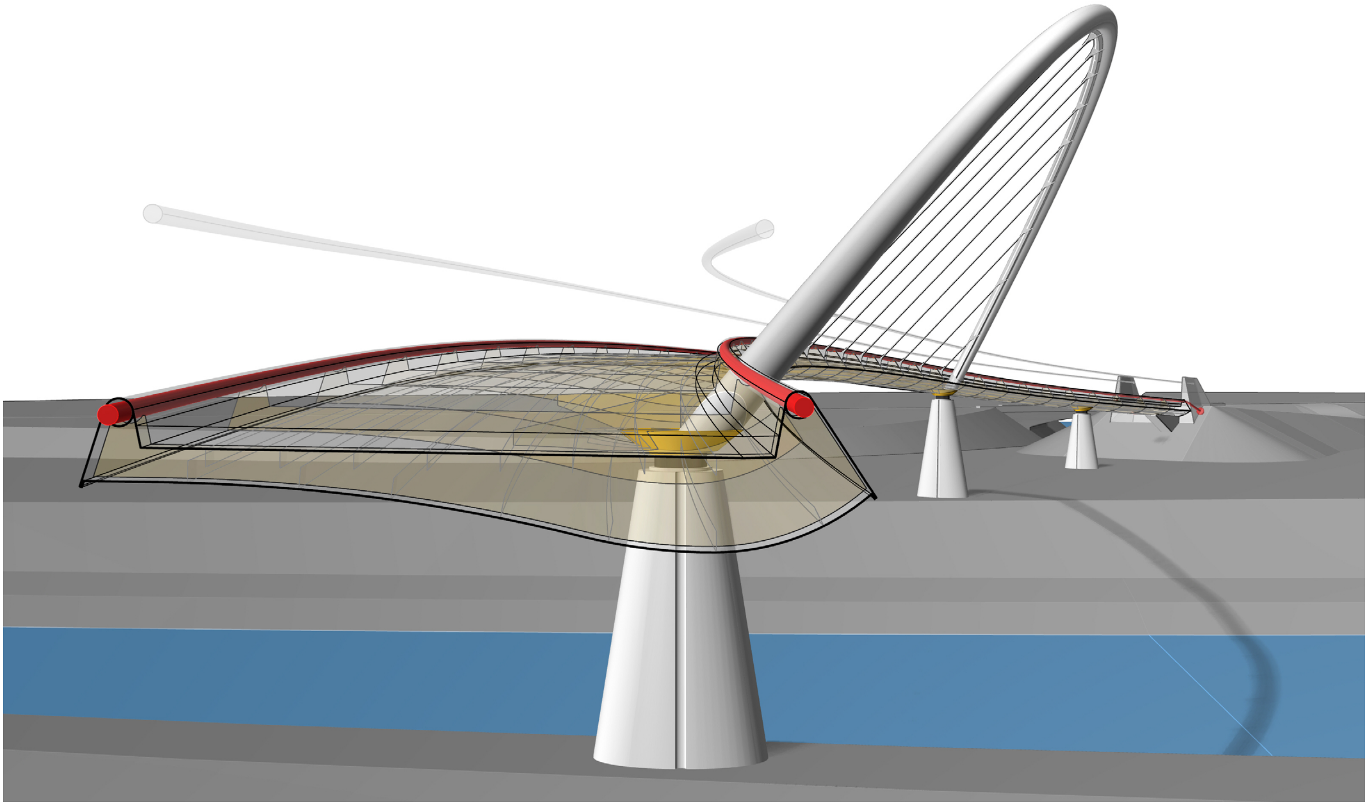

Figure 32. Structure of the Pedestrian Bridge across the Olse River.

Figure 33. Brno-Komarov Pedestrian Bridge.

moment due to the dead load, the deck is prestressed by radial cables situated at edge curbs – see Figure 32. Both, the girder and the arch are composite of steel and concrete.

5.4 Pedestrian Bridge across the Svratka River in Brno-Komarov

In Komarov district, a city, of Brno suburb, another arch structure has been built. The pedestrian bridge connects new sport facilities situated on both banks of the river. The bridge consists of by a spine girder that is suspended on a central arch of a span of 58.5 m – see Figure 33. The arch force is resisted by a prestressed concrete deck that is integrated with the end diaphragms supported by drilled piles.

5.5 Minto Island Pedestrian Bridge across the Willamette River in Salem, Oregon, USA

We also participated in a design of the Minto Island Pedestrian Bridge that was completed this spring in a city of Salem,

Figure 34. Minto Island Pedestrian Bridge.

Figure 35. Svratka River Pedestrian Bridge.

Oregon, USA. The bridge that crosses the Willamette River consists of a continuous girder of 5 spans ranging from 15.24 to 93.88 m. The main span consists of a stress-ribbon deck that is suspended on two inclined arches of the 'butterfly' arrangement – see Figure 34. The stress-ribbon deck is assembled from precast segments and a composite deck slab. The arch force is resisted by prestressed concrete deck.

5.6 Pedestrian Bridge across the Svratka River in Brno, Czech Republic

This pedestrian bridge connects a newly develope business area with the old city center. It consists of a self-anchored stress ribbon & arch structure – see Figure 35. Both, the stress ribbon and the arch are assembled of precast segments made of high strength concrete and were erected without any temporary towers. Smooth curves that are characteristic for stress ribbon structures allowed a soft connection of the bridge deck with both banks.

the main arch span is 42.90 m and its rise 2.65 m, leading to a rise to span ratio of 1/16.19.. The arch consists of two branches that have a variable mutual distance and merge at the arch springs. The 43.50 m long stress-ribbon is assembled of segments of length of 1.5 m. In the middle portion of the bridge the stress ribbon is supported by low spandrel walls of variable depth. At midspan the arch and stress ribbon are mutually connected by 2x3 steel dowels that transfer the shear forces from the ribbon into the arch. The stress ribbon is carried and prestressed by four internal tendons of 12 0.6" dia monostrands grouted in PE ducts. In the transverse direction the segments have variable depth with a curved soffit.

6.
CONCLUSIONS

The presented structures utilize different architectural and structural forms that are inherent in the constraints of the site and are economical and structurally efficient. They were well accepted both the public and professional.

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