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Inhalt

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Search for the true structural solution

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1 Professional career

I started my professional career in 1969; one year after Russian troops occupied our country and ruined our hopes for a free and creative life. Some of my colleagues have decided to emigrate; many of the others have resigned and became passive. I was lucky to have collaborated with engineers who have tried to prove, that we were still able under the given difficult circumstances to develop and build progressive bridge structures. We were supported by some professors, who mostly had to leave the universities for their opinions and who created together with us a group of similarly thinking people.

In the firm *Dopravni stavby Olomouc* we have developed our own prestressing system and our own segmental technology for constructing highway overpasses and viaducts, we have built cable-stayed bridges and – most of all – realized stress ribbon and suspension pedestrian bridges.

Our first cable stayed bridge built across the River Elbe near a city of Podebrady built in 1987 has three spans widths of 61.6, 123.2 and 61.6 m; the width of the bridge is 31.8 m, see Fig. 1. The deck is suspended on two towers situated in the bridge axis. The deck is formed by a spine box girder with large overhangs supported by not mutually connected precast slab struts. The one cell box girder assembled from precast segments was constructed first, then the struts were erected and the overhangs were cast in a simple formwork that was supported by these struts. Similar arrangement was used in a construction of the 394 m long cable stayed bridge built in Prague-Vrsovice.

We have built seven stress ribbon pedestrian bridges of one, two, or three spans of lengths up to 102 m; their maximum length is 250 m, see Fig. 2. The deck is an assembly of precast segments suspended on bearing cables. Prestressing introduced after concreting the joints insures the stiffness of the structures.

Experiences we have gained in construction of stress ribbon bridges were utilized in design of our first suspension pedestrian bridge across the Swiss Bay of the Vranov Lake, see Fig. 3. The deck, which has a span length of 252 m, is suspended on two cables with spans of 30, 252 and 30 m. The deck is assembled of precast segments of variable widths from 10.0 to 6.5 m and depth of only 0.42 m.

Fig. 1: River Elbe (Photo: Jiri Dobrovolny)

We have not only built these structures, but we have also verified their function by detailed static and dynamic tests. We have also published the structural solutions and results of the tests in outstanding technical magazines and we received first design awards. In 1987 I was invited to participate in the design of the first US Stress Ribbon Bridge that was built across the Sacramento River in Redding, California, see Fig. 4.

Based on Prof. Leonhardt's recommendation I got first international prize – the Fritz Schumacher Award. After the ‚velvet revolution' in 1989 a lot of things have changed. I have started to work in the USA, together with my friends we have opened our own design firm and I have been teaching bridges at the Brno University of Technology. For eight years I was a member of the presidium of the FIP (Fédération Internationale de la Precontrainte) that has been transformed into the fib (Fédération Internationale du Béton – the International Federation for Structural Concrete). I also had an opportunity to participate on the design of large scale projects that have been built in California and Japan.

My research work at the University is connected with further development of stress ribbon structures suspended on cables or supported by arches, curved suspension and arch structures, prestressed membranes and shells. My Ph.D. students not only analysed them, but verified their function on space models, see Figs. 5 and 6.

Fig. 2: Prague-Troja Pedestrian Bridge – load test (Photo: Jiri Strasky)

Fig. 3: Vranov Lake Pedestrian Bridge (Photo: Jiri Strasky)

Fig. 4: Sacramento River Pedestrian Bridge (Photo: Charles Redfield)

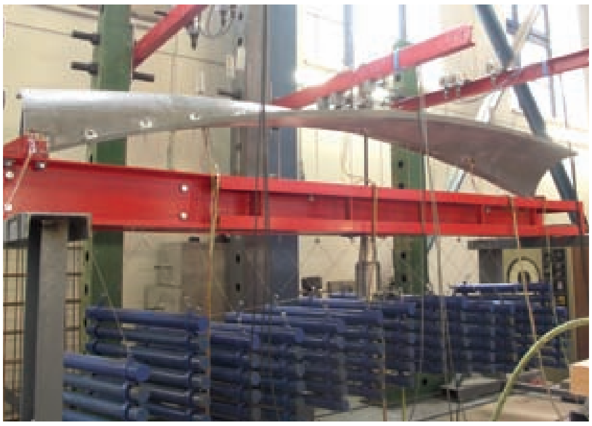

Fig. 5: Model of the shell bridge (Photo: Jiri Strasky)

Fig. 6: Model of the curved bridges (Photo: Jiri Dvorak)

We have built a strong design office which designs bridges not only in the Czech Republic, but also in Slovakia and Poland. We also participate in design of bridges built in Spain, United Kingdom, Sweden and Brazil. My office in California has been involved in design of progressive bridges built in the USA and Canada. Our designs got many international awards. For my work I got Medal of Merit and Freyssinet Medal from the fib, CTU Award from University of Dundee (UK), Ícaro Award from University of Coruna (Spain) and Prix Albert Caquot from French Association for Civil Engineering.

I am extremely grateful to the fact that my design work has helped me to get acquainted with many engineers who are not only outstanding experts, but – most of all – extremely good and cultural people. Due to my design work I have become a member of a family of professionals who combine the technical knowledge with aesthetic feeling and create bridges whose architecture is developed from perfect structures.

2 Design philosophy

At present time the designing of bridges has become more and more difficult. On the one hand ambitious structures using non-effective structural systems designed by star architects are built; on the other hand common bridge engineers are forced to design so called the most economical solutions. And, if public ask for a better solution, the designers are required to add some kind of architectural treatment that would improve the solution. The public funding agencies like to know, how much they are paying for so-called beauty.

That policy is ineffective and misguided, because it is based on a fundamental misunderstanding of the relationship between structural and architectural bridge design. Architecture is not some kind of treatment added to, or performed on the structural design of a bridge. Really, the architecture of the bridges has to be developed from the true structural solution and design has to emphasize the beauty of effective structures.

The author is still convinced that the true architectural solution of bridges is given by their true structural solution. The best structural solution should be some particular form inherent in the constraints of the site itself which best accomplish the function of bridging the site. The task of the structural designer is to discover and realize that form in a way that is economical and efficient. This structural form is appropriate only when the design uses the inherent structural and material characteristics of the form to advantage. Of course, a bridge structure must be safe, should invite use, be comfortable for the user, and should be designed and constructed to human scale

Criteria of aesthetics are perhaps somewhat more subjective when evaluating structural concepts for bridge designs. However, architects and engineers generally agree that the whole structure and the structural members forming the bridge should express by their shape the flow of internal forces through the structural system, which is integrated into the surrounding social, historical/time, technological and physical environments.

From our point of view as structural designers, I believe that each conceptual design should advance or enhance our understanding of the arts and sciences of engineering. Structural solutions should in some way lead to the development of new details, new processes of construction, or new applications of engineering technology. But we have to be aware that the structures should be always designed and constructed to a human scale.


Fig. 7: Bridge across the Olichovsky Creek Valley (Photo: Jiri Dvorak)

The above design philosophy is illustrated on the following structures for which the author had an opportunity to develop their conceptual design.

3 Viaducts

Viaducts with spans up to 45 m usually have a double tee cross section and are usually progressively cast – span-by-span – in the formwork supported or suspended on launch-

Fig. 8: Bridge Kninice (Photo: Jiri Dvorak)

ing gantry. When under-slung gantry is used, the tee girders are usually directly supported; when overhead gantry is used, the girders are indirectly supported by pier's diaphragms. Whenever it is possible, semi-integral bridges are designed. As an example, a bridge built across the Olichovsky Creek Valley on Expressway R1 in Slovakia can serve. The twin bridge of the total length of 273 m forms a continuous structure of seven spans with span lengths from 33 to 41 m. With respect of the limited clearance, the double tee deck has a variable depth: from 1.90 m at mid-spans to 2.60 m at supports, see Fig. 7. The deck was incrementally cast span-by-span in the formwork suspended on the overhead movable scaffolding that was supported by pier's diaphragms. All piers are connected with the pier's diaphragms by concrete hinges, the side piers have concrete hinges also above footings.

In several projects another type of bridge structure has been used. For span lengths up to 45 m a solid cross section formed by a spine girder with large overhangs is still economical. To transfer the mass to supports, the girder has a variable depth from 2.60 to 1.40 m and a haunch's shape is formed by a fourth degree parabola. The arrangement of the structure in the transverse direction follows the arrangement in the longitudinal direction. The deck is supported by narrow piers that are continuously widened and linked up the curved overhangs. The transverse widening of the piers and the deck has also a shape of a fourth degree parabola. The simple and clean shape of the deck enables span-by-span construction utilizing under-slung movable scaffolding formed by two steel girders situated outside of the spine girder. So far viaducts of the total length of 2 × 2.635 km have been built.

An excellent example of this type represents Bridge Kninice on the motorway D8 near the German border, see Fig. 8. The bridge is formed by two parallel bridges of the deck's length of 1,027 m and 1,077 m. The decks of both bridges are formed by continues structures with a typical span of 42 m.

4 Progressively erected concrete viaducts

Progressive erection of the deck used in the construction of the cable stayed bridge across the River Elbe (see Fig. 1) has been recently applied in a construction of five long viaducts built in Slovakia. These bridges have span lengths up to 69 m, their widths are up to 28.70 m. Their deck is formed by a spine girder with large overhangs supported by not mutually connected precast slab struts, see Fig. 9. When the spine box girder was cast, the struts were erected, see Fig. 10 and 11, and

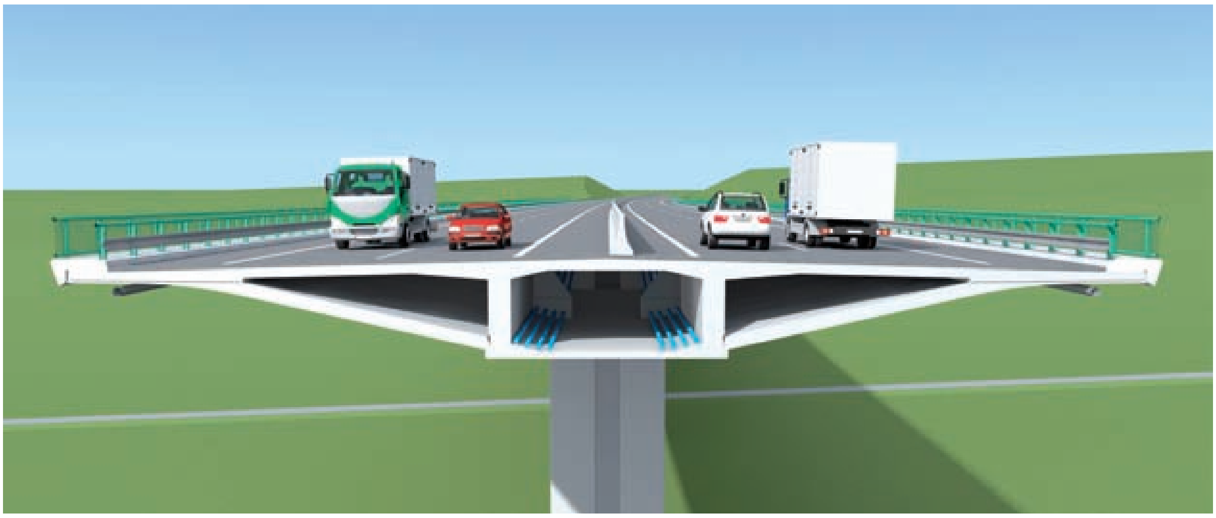

Fig. 9: Cross section of bridge across the Hostovsky Creek Valley (Graphic: Jaroslav Baron)

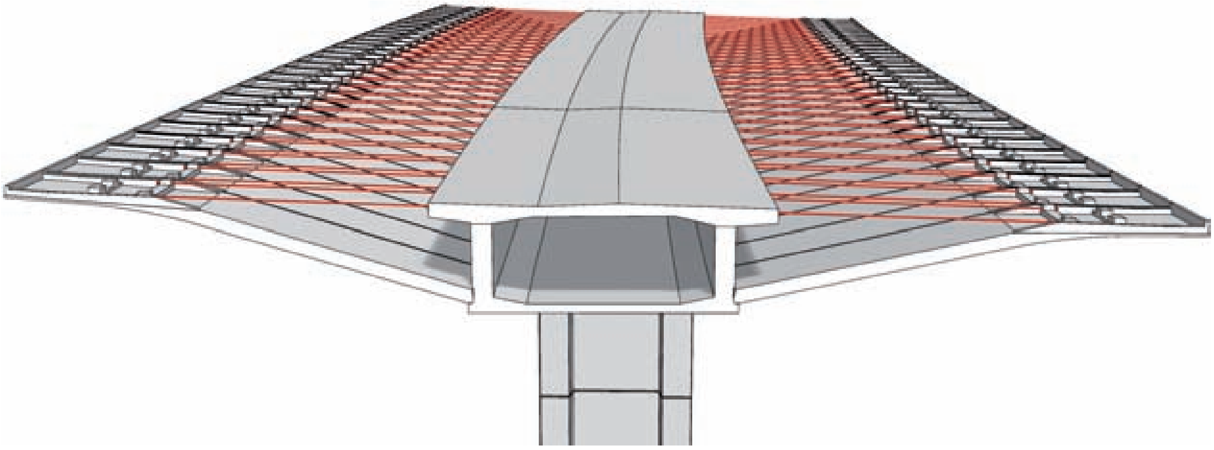

Fig. 10: Suspension of precast struts on the spine girder across the Hostovsky Creek Valley (Graphic: Jaroslav Baron)

Fig. 11: Bridge across the Hostovsky Creek Valley across the Hostovsky Creek Valley (Photo: Jiri Dvorak)

Fig. 12: Bridge across the Lodina Creek Valley (Photo: Jiri Dvorak)

the overhangs were cast in a simple formwork that was supported by these struts. The one cell box girder was cast span-by-span in a formwork suspended on a special overhead gantry with 'organic' prestressing system (OPS) that eliminates deflection of the gantry, see Fig. 11. To reduce the self-weight of the spine girder as much as possible, the girder is very narrow. Therefore the transverse projection of the hangs over up to 11.00 m.

While the first structure of the length of 975 m is frame connected only with three central piers, remaining shorter bridges of maximum length of 414 m are frame connected with all piers and form semi-integral structural systems, see Fig. 12. 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 formed by four strands, lead at flat ducts situated at distance of 1.50 m. During erection, the struts are suspended on two prestressing bars anchored at outer cantilevers of the basic cross section.

It is evident that this solution requires not only a careful analysis and detailing, but also an experience contractor. Also the construction and service of these bridges have to be carefully checked and monitored. The Viaduct across the Hostovsky Creek Valley has been monitored during construction, loading tests and during service. For monitoring of concrete stresses, strain gauges were placed in four sections. The measurements done so far have confirmed good bridge function and showed agreement between measured and calculated values.

5 Progressively erected composite viaducts

Eight years ago we participated in a design of the bridge across the Lochkov Valley Creek on the Prague ring road, which deck is formed by a steel trough and a composite cast-in-place deck slab. Recently we have designed two other long composite viaducts that were built on the highway I/11 in the North Moravia (Czech Republic). However, to simplify their construction, their deck slabs were cast in a formwork formed by precast members, see Figures 13 and 14.

The first viaduct, the bridge across the Hrabynka Creek Valley of the total length of 330.0 m, is formed a continuous girder of six spans of lengths from 39.0 to 66.0 m. The second one, the bridge across the Kremlice Creek Valley with a total length of 528.0 m, is formed by a continuous girder of eleven spans of lengths from 33.0 to 57.0 m. While the first bridge has a straight axis, the second is in a plan curvature with radius of 900 m that transfers by a transition curve into the straight axis.

Both directions of the highway are carried by bridge decks formed by a steel girder and a 25.5 m wide composite deck slab. The steel girders of the 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 an I-cross section, the edge stringers have a 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. 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 the Brno University of Technology.

Both bridges were incrementally assembled beyond the abutments and consequently launched into a design position. The steel structures are assembled of segments of lengths from 13.0 to 29.0 m. The steel structure of the first bridge 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. Due to the complex bridge geometry of the second bridge, its steel structure was assembled from two parts and was launched from both abutments. Due to the variable plan curvature

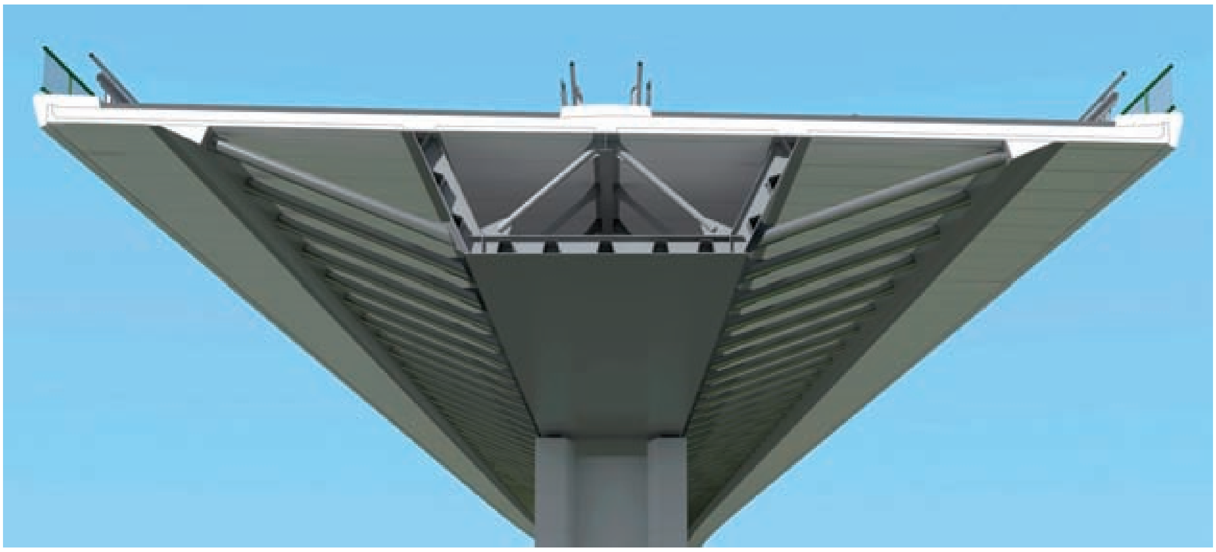

Fig. 13: Cross section of the bridge across the Lochkov Valley Creek (Graphic: Jaroslav Baron)

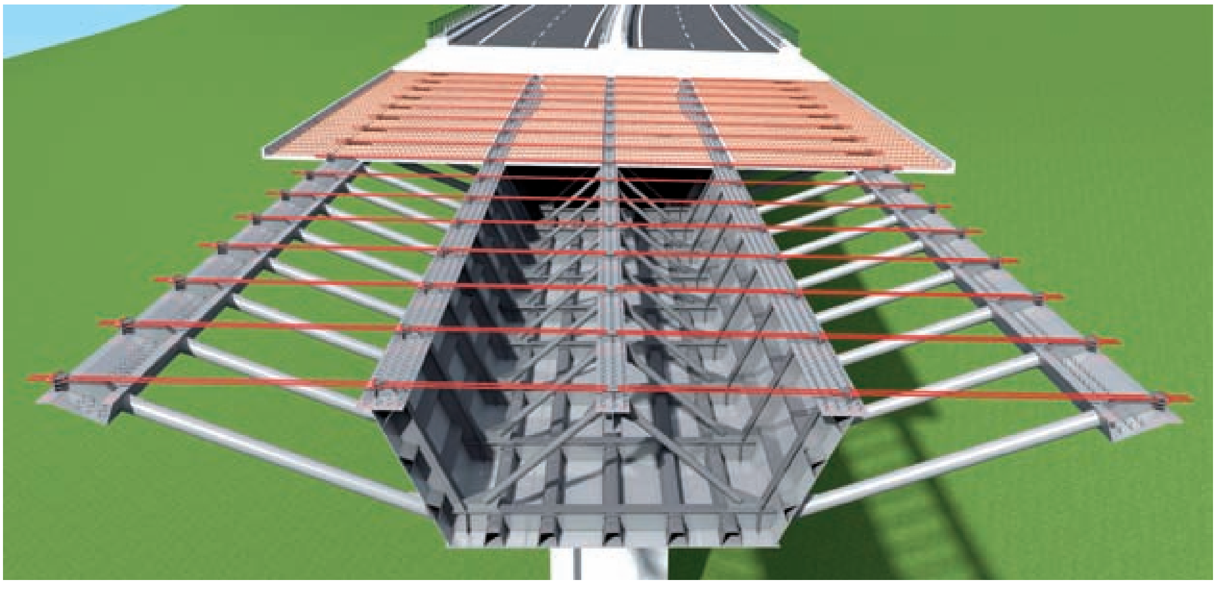

Fig. 14: Progressive assembly of the deck of the bridge across the Lochkov Valley Creek (Graphic: Jaroslav Baron)

Fig. 15: Launching of the Bridge across the Kremlice Creek Valley (Photo: Jiri Dvorak)

Fig. 16: Progressive assembly of the deck of the Bridge across the Kremlice Creek Valley (Photo: Jiri Dvorak)

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, see Fig. 15. After the connection of both parts, the precast members were progressively erected and the deck slab was casted, see Fig. 16.

6 Cantilever bridges on the motorway D3 (Slovakia)

Two large cantilever bridges of the similar structural and architectural arrangement are being built on the D3 motorway's section Svrcinovec–Skalite, see Fig. 17. The bridges cross the valleys at height up to 85 m. At present only one half of the motorway is constructed.

The Bridge Valy of the total length of 591 m forms a continuous structure of nine spans of lengths from 30 to 92 m. The Bridge Rieka of the total length of 500 m forms a continuous structure of eight spans of lengths from 25 to 92 m. The decks of both bridges are formed by a box girder of a variable depth from 2.70 to 5.00 m that are segmentally cast in symmetrical cantilevers starting at piers. During erection cantilever tendons situated at the top slab were progressively installed and tensioned, when central joints were cast, the span tendons situated at the bottom slabs were placed and tensioned. The continuity tendons are formed by external tendons that are deviated at span diaphragms and are anchored at pier diaphragms.

The piers of the cantilever spans are formed by twin walls. During construction the lower piers are braced by temporary steel members. The walls of the higher piers are mutually connected by longitudinal walls at their bottom portion. The height of the connected walls was determined by detailed analyses of concrete volume changes and by checking the stability of the piers both during construction and service.

Another cantilever bridge of the total length of 1.50 km is being built across the river Vah's Reservoir Hricov on the D3 motorway section Zilina-Strazov – Zilina-Brodno, see Fig. 18. The twin bridge is formed by a continuous structure of span lengths from 30.50 to 110.00 m. The four central spans bridging the river Vah are formed by a box girder of a variable depth from 3.00 to 6.00 m that are segmentally cast in symmetrical cantilevers; the remaining spans have a double tee cross section of a constant depth of 3.00 m and are progressively cast span-by-span on stationary or movable scaffoldings. The prestressing tendons of the cantilever spans have arrangement similar

Fig. 17: Bridge Valy (Photo: Jiri Dvorak)

to the arrangement of the previous bridges, the approach spans are prestressed by tendons situated in the webs of the bridge decks.

The central piers are formed by twin transversely inclined columns that guarantee the stability of erected structure, resistance of the structure to seismic load and at the same time allow horizontal movement of the deck caused by concrete volume changes. Approach spans are supported by couples of pot bearings situated on elliptical piers.

Fig. 18: Bridge across River Vah Reservoir Hricov (Photo: Jiri Dvorak)

7 Arch bridges

An arch by its own shape naturally expresses an effort to bridge the obstacle. For dead load a correctly designed arch is stressed by compression stresses only. Therefore, it can be light and transparent. For overpasses a self-anchored integral structural system, in which arch footings are connected with deck’s end diaphragms by a compression struts, we designed several times. The arch’s horizontal forces are resisted by a tension capacity of the deck, and moments created by couples of horizontal forces originating in arch footings and end diaphragms are balanced by moments created by vertical forces originating at the arch footings and the end diaphragms. This approach is illustrated by following two examples.

Bridge across the Motorway D1 near Studenka

The deck of the bridge is formed by a slender solid deck of depth of only 0.50 m that is supported by a flat arch of a span of 53.70 m and a rise of 6.157 m, see Fig. 19. The prestressed concrete deck is fixed into the end diaphragms that also serve as abutments. The bridge was cast on a stationary falsework.

Fig. 19: Bridge across D1 near Studenka (Photo: Jiri Dvorak)

Bridge across the expressway R1 near Nitra (Slovakia)

The composite deck formed by edge plate girders, floor beams and a deck slab is suspended on edges on slender arches of span of 70.57 m, see Fig. 20. The arches that are formed by steel boxes filled with concrete are not braced; their stability is given by tension stiffness of the suspenders. The arch footings are connected with the end diaphragms by concrete compression struts. The steel structure was erected on temporary towers. After that the deck slab and end diaphragms were cast. By tensioning the suspenders the designed state of stresses was obtained.

Maple Avenue Bridge, Redmond (Oregon, USA)

Recently we have also participated in a design of two concrete arch bridges built in Oregon, USA.

The Maple Avenue Bridge provides an east-west link for the city of Redmond across Dry Canyon, which bisects the city. The canyon is a scenic natural feature, providing open space and recreation to local citizens. It was a desire to design a bridge that blends with its beautiful natural surroundings, see Fig. 21.

The bridge of three equal spans of length of 64 m is formed by two arch ribs supporting a double tee deck. The girders and arch ribs have the same width; the intermediate supports of octagonal cross section are narrower. The arch ribs are not stiffened by any transverse ribs. A direct connection of the arches with the girders creates a clear and readable structural system that emphasizes the static function – arch and girder. The omitting of transverse ribs not only optically lightens the structure, but also creates transverse ductile frames that increase the bridge's seismic resistance.

Fig. 20: Bridge across R1 near Nitra (Photo: Jiri Dvorak)

Willamette River Bridge, Eugene (Oregon, USA)

A successful realization of the Redmond 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 of lengths of 604.9 m and 536.1 m, see Fig. 22. The bridges replace original bridges built in the fifties of the last century.

Fig. 21: Maple Avenue Bridge (Photo: Nadezda Straska)

The main bridge is formed by two arch spans of length 118.9 and 126.8 m. The deck that is formed by two girders and deck slab is stiffened by precast cross beams; the arches are formed by two ribs without any bracing. The approach bridges are formed by 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 as the arch columns.

The bridge was erected progressively. The arch ribs with the crown precast cross beams were cast first and then the mid-span joints were jacked and cast. Then the columns were erected and longitudinal girders with the transverse cross beams were cast. After that the deck slab was cast.

Fig. 22: Willamette River Bridge (Photo: Jiri Strasky)

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8 Bridge across the Odra River and Antosovice Lake (Czech Republic)

Near a city of Ostrava the freeway D47 crosses the River Odra and Antosovice Lake on a twin bridge of the 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 Fig. 23. The bridge crosses the river in a skew angle of 54 °. The freeway's axis is in a plan curvature of 1,500 m that transits into the straight line and it is in a crest elevation with a radius of 20,000 m.

The span length is from 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 a 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 of a depth of 2.20 m without traditional overhangs. The bottom slab of both cells is inclined and it is curved in the middle of girder. 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 stay's 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.

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 was 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.

9 Bridge across the river Ebro (Spain)

Prestressed concrete technology was also used in construction of the Rio Ebro Bridge. The bridge replaces a ferry that connected the small cities Deltebre and Sant Jaume D'Enveja situated close to the river's estuary into the Mediterranean Sea. The arrangement of the bridge is a result of an architectural & structural competition. 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 of 69, 112 and 69 m, see Fig. 24.

The deck with a width of 19.30 m is suspended on four suspension cables situated in the bridge axis.

Fig. 23: Odra River Bridge (Photo: Stefan Spic)

Fig. 24: Ebro River Bridge (Photo: Diego Cobo)

The torsionally stiff deck is formed by a composite 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 the deck is stiffened by the end cross beams transferring the load from the bearings into the central webs.

Fig. 25: Bohumin Drive Pedestrian Bridge (Photo: Jiri Dvorak)

The main suspension cables are formed by four BBRV cables anchored at the end diaphragms and deviated at the saddles of the low pylons. For the construction of the side spans and piers artificial peninsulas were consecutively created at both banks. They served for drilling of 46 m 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. The whole central portion of the main span of length of 61.40 m and weight of 500 tons was assembled at one bank and consequently floated and lifted into the design position.

10 Pedestrian bridge across the freeway D1 near Bohumin

The bridge that crosses the freeway D1 near a city of Bohumin is used both by pedestrians and bicycles, see Fig. 25. The bridge deck with 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.

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

11 Harbor Drive Pedestrian Bridge, San Diego (California, USA)

The bridge that crosses Harbor Drive and several railroad tracks connects a new downtown ballpark with San Diego Convention Center and a parking garage. The City Development Corporation (the San Diego Redevelopment Agency) needed a pedestrian structure that would also serve as a landmark for the New Downtown and was prepared to invest in aesthetic considerations. Therefore a curved suspension was accepted, see Fig. 26.

The bridge that is in a plan curvature with a radius of 176.80 m forms a self-anchored suspension structure suspended by the hangers on the inside of the curve. The suspended span of the length of 107.60 m is monolithically connected to stairs at both ends. The stairs of length of 13.54 and 21.97 m form part of the structural system that transfers the stresses into the abutments supported on piles.

The 39.80 m tall pylon, which supports the main cable, is founded on the convex side of the deck, leans over the deck, and supports the main cable on the inside of the curve. It is stabilized with two backstays and internal post-tensioning. The main cable stretches from the abutment to a deviator at the top of the stairs to the anchorage at the top of the pylon. It is made of prestressing strands encased in stainless steel pipe. The hangers are attached to the steel pipe of the main cable and to the handrail on the bottom. The top of the handrail also carries a large post tensioning cable which is anchored at the deviators at the top of the stairs This cable is overlapped by the internal cables that prestressed the stairs.

The suspended deck is formed by a non-symmetrical box girder with one side overhangs supported by ribs. The girder is prestressed not only by internal tendons situated at the top slab, but also by horizontal components of the hangers forces and by the external cables. Therefore the inner railing, in which the hangers are anchored, is a part of the structural system. The geometry of the deck, position of the anchoring of the hanger, and position of the external cable and internal tendons were determined in such a way that the horizontal forces balance the moment created by eccentricity of the suspension.

Fig. 26: Harbor Drive Pedestrian Bridge (Photo: Nadezda Straska)

Fig. 27: Olse River Pedestrian Bridge (Photo: Jiri Dvorak)

12 Pedestrian bridge across the border river Olse between Czech Republic and Poland

Prestressing cables situated at bridge edge girders that balance the dead load torsional moment was used in a design of the composite pedestrian bridge built across the border river Olse. The bridge connects two cities of Czech and Polish Tesin, see Fig. 27. The bridge of a total length of 95.40 m is in a plan curvature with a radius of 100 m and in a crest elevation. The bridge has four spans of lengths from 13 to 45 m. The deck is formed by a slender steel box girder of a non-symmetrical streamline cross section that is in the main span stiffened by one side inclined arch. The deck is fixed into the end abutments and is supported by neoprene pads on intermediate piers. To balance the torsional moment due to the dead load the deck is prestressed by radial cables situated at edge curbs. Both the girder and the arch are composite of steel and concrete. LED lights situated in the handrails and at the arch illuminate the walkway and the structure.

13 The Lake Hodges Bridge, San Diego (California, USA)

The world's longest stress ribbon bridge is located in the northern part of San Diego County and it is a part of the San Dieguito River Valley Regional Open Space Park, see Fig. 28. The bridge is formed by a continuous stress ribbon of three equal spans of length of 108.58 m. The sag at mid-spans is 1.41 m. The stress ribbon of the total length of 301.75 m is assembled of precast segments and cast-in-place saddles situated at all supports. The stress ribbon is fixed into the end abutments and it is frame connected with intermediate piers.

The precast segments of the depth of 0.407 m are 3.048 m long and 4.266 m wide. Each segment is formed by two edge girders and a deck slab. At joints the segments are strengthened by diaphragms. During the erection the segments were suspended on bearing cables and shifted along them to the design position. After casting of saddles and joints between segments, the stress ribbon was post-tensioned by prestressing tendons.

The saddles have a variable depth and width. Above supports a viewing platforms with benches were created. The saddles were cast after erection of all segments in the formwork suspended on the already erected segments and sup-

Fig. 28: Lake Hodges Pedestrian Bridge (Photo: Jiri Strasky)

ported by piers or abutments. During the erection the bearing cables were placed on Teflon plates situated on steel saddles. The horizontal force as large as 53 MN is transformed into the soil at the left abutment by four drilled shafts of a diameter of 2.70 m at the right abutment by rock anchors.

14 Bridge across the expressway R 3508 near Olomouc

Classical stress-ribbon type structures need to resist very large horizontal forces at the abutments, which determine the economy of that solution in many cases. For that reason, a new system that combines an arch with the stress-ribbon has been developed. The stress-ribbon is supported on an arch. The structures form a self-anchoring system where the horizontal force from the stress-ribbon is transferred by inclined concrete struts to the foundation, where it is balanced against the horizontal components of the arch.

The pedestrian bridge in Olomouc is formed by a stress-ribbon of two spans that is supported by an arch, see Fig. 29. The stress-ribbon of a length of 76.50 m is assembled of 3.00 m long precast segments supported and prestressed by two external tendons. The precast deck segments and precast end struts consist of high-strength concrete of a characteristic strength of 80 MPa. The cast-in-place arch consists of high-strength concrete of a characteristic strength of 70 MPa. The external cables are formed by two bundles of 31-0.6“ diameter monostrands grouted inside stainless steel pipes. They are anchored at the end abutments and are deviated on saddles formed by the arch crown and short spandrel walls. The stress-ribbon and arch are mutually connected at the centre of the bridge. The arch footings are founded on drilled shafts and the anchor blocks on micro-piles.

15 Bridge across the Svratka River in Brno (Czech Republic)

Similar structural system was used in the design of the pedestrian bridge that connects a newly developed business area with an old city centre, see Fig. 30. Close to the bridge an old multi span arch bridge with piers in the river is situated. It was evident that a new bridge should also be formed by an arch structure, however, with a bold span without piers in the river bed. Due to poor geotechnical conditions a traditional arch structure that requires resisting of a large horizontal force would be too expensive. Therefore, the self-anchored stress ribbon & arch structure has been built. Both, the stress ribbon and the arch are assembled of precast segments from 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 arch span is L = 42.90 m, its rise f = 2.65 m and the rise to span ration f/L = 1/16.19. The arch is formed by two branches that have a variable mutual distance and merge at the arch springs. The 43.50 m long stress-ribbon is assembled of

Fig. 29: Willamette River Bridge (Photo: Jiri Dvorak)

segments of length of 1.5 m. In the middle portion of the bridge the stress ribbon is supported by low spandrel walls of the variable depth. At mid-span the arch and stress ribbon are mutually connected by 2 × 3 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″ diameter monostrands grouted in PE ducts. The segments have a variable depth with a curved soffit. The stress-ribbon and the arch were made from high-strength concrete with a characteristic strength of 80 MPa.

16 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.

Fig. 30: Svratka River Bridge (Photo: Jiri Dvorak)

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