Composite Bridges Built in the Area Influenced by a Mining Subsidance

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Summary

Composite bridges built in the area influenced by the effects of the mining subsidence are described in terms of their static and structural solution and function of the composite deck slab. The bridges are formed by two different static systems: plate girders and trough sections that are composite with transversely post-tensioned deck slab. The girders are erected in progressive cantilevers; the composite deck slab is progressively cast in the traveler moving along the already erected steel structure.

Keywords: mining subsidence, composite structure, plate girder, box girder, internal and external post-tensioning, progressive casting of the deck slab, time-dependent analysis.

1. Introduction

Recently a construction of four large freeway composite bridges has started in a city of Ostrava in North Moravia, Czech Republic. The bridges are built in the area that is influenced by the effects of the mining subsidence – see Fig.1. The structures have to resist not only the effects caused by different deflections of supports, but also effects caused by their horizontal movements and rotations – see Fig.2. So far only statically determined structures were built in this area.

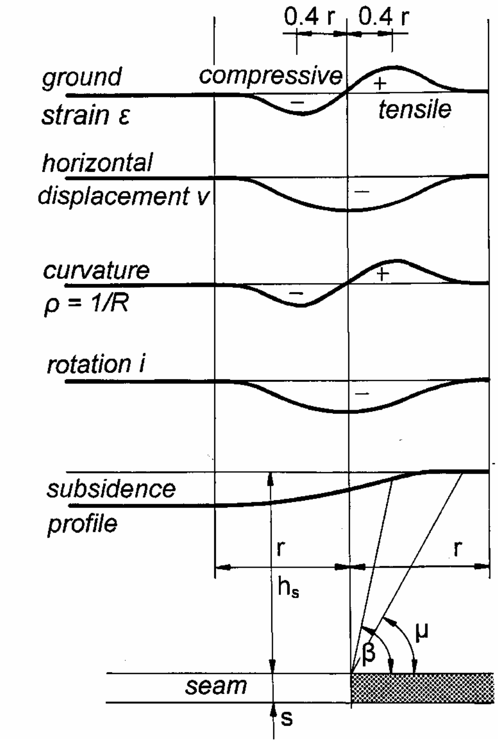


Fig. 1 Effects of the mining subsidence

The aim of the design was to develop structural solutions that are inherent in the constraints of the site and best fulfil the function of bridging the site. The solutions that proportionally fit the surroundings, clearly articulate the flow of internal forces, express the progress of science and technology, can be easily erected, and have clear, simple and easy maintenance details.

2. Development of the Structural Types

Since continuous structures require less maintenance, the designer tried to develop continuous structures with expansion joints situated only at the abutments. In view of the fact that the subsidence causes a significant horizontal movement of the substructure both in the longitudinal and transverse direction of the bridge the deck of all bridges is always supported by one or two fixed bearings, the other bearings are multi-directional – see Fig.2b. The horizontal stability of the structures is given by stoppers (shock

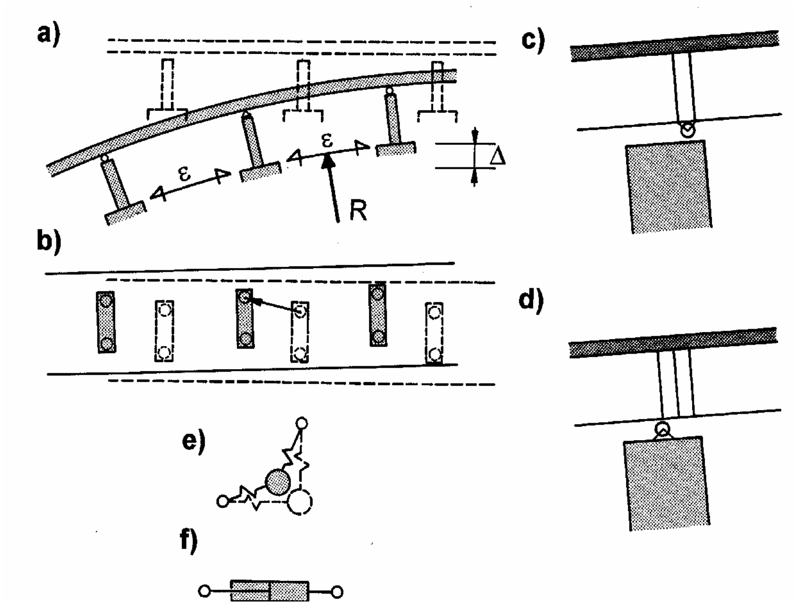


Fig. 2 Deformation of the structure: a) due to the vertical curvature, b) horizontal movement, c) inverted bearing, d) classical bearing, e) movement of the stopper, f) stopper.

transitions), that allow slow movement of the structures caused by temperature changes and by a movement of the foundations, but resist forces due to live load and wind – see Figs. 2e and 2f.

The design of the bridges was influenced by two opposing requirements. On the one hand, the structures had to be sufficiently stiff to be able to resist the design load; on the other hand, the structure had to be sufficiently flexible to be able to resist the effects of the mining subsidence. Therefore slender ductile composite structures were designed.

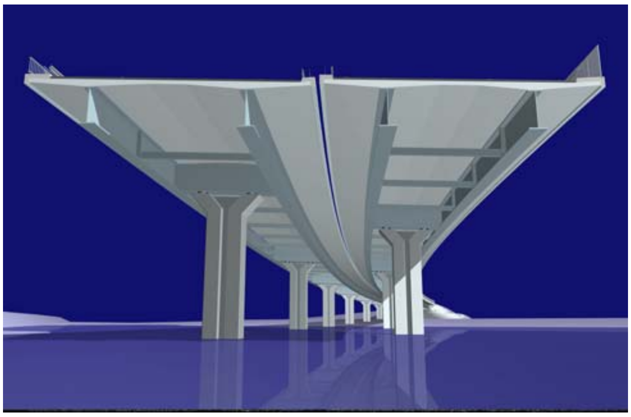


Fig. 3 Bridge Rudna – typical spans

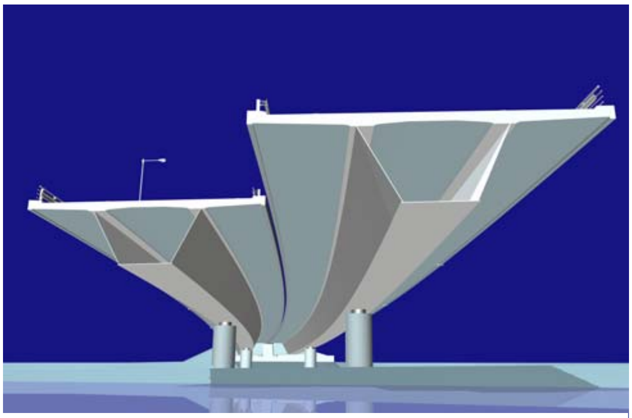


Fig. 4 Bridge Odra

Possible different rotations of the supports represent another significant problem of the design. To address this problems two type of structures were developed. The Bridge Rudna, Bridge Opava and Overpass D201 of the total lengths of 588, 717 and 58 m with span lengths from 33 to 70 m are formed by two plate girders mutually connected by low cross beams and transversely post-tensioned concrete deck slab – see Fig.3. Since the deck has open, torsionally weak cross section, the different rotations of supports do not cause significant additional stresses – see Fig.5.

For crossing of the rivers Odra and Ostravice bridges of lengths of 402 and 303 m and spans up to 102 m were required. Due to the limited clearance, the structures had to have the smallest possible depth. Therefore their deck is formed by box girders – see Fig.4. Since the relative different rotations of the supports caused by the effects of subsidence decrease with the length of the bridge, the points where the rotations are transferred into the deck was designed at the longest possible distance – at the abutments.

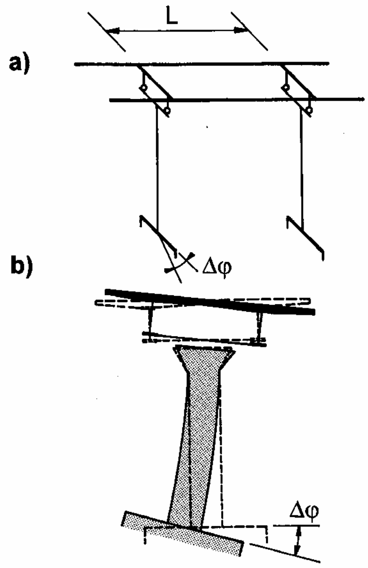


Fig. 5 Bridge Rudna – distortion of the supports

The deck is supported by single bearings situated in the bridge axis on all intermediate supports – see Fig.6.

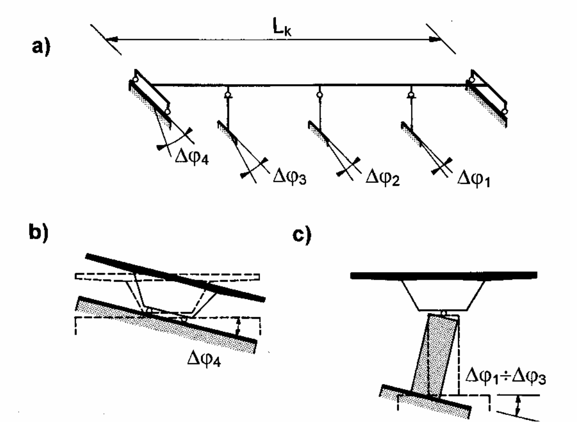


Fig. 6 Bridge Odra – distortion of supports

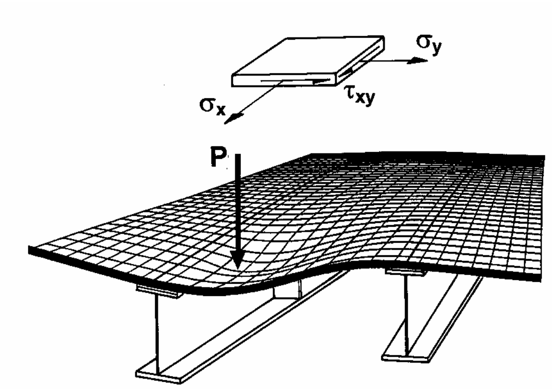


Fig. 7 Space deformation of the plate girders

The deck slab is stressed not only by bending and shear stresses caused by a local load but also by significant membrane stresses caused by global bending and torsion - see Figs 7 and 8.

The integrity of bridges with the deck of the open cross section is given by the cross beams and deck slab. The stresses that originate in the concrete deck slab due to the global bending are relatively small. Therefore the deck slab is designed as a transversely post-tensioned reinforced concrete member. The 3D analysis included the reduction of stiffness of the concrete slab that is caused by transverse cracks originating above the intermediate supports and by longitudinal cracks developed due to the local bending caused by a wheel load. The detailing included checking of the crack's width and fatigue stresses both in the prestressing and reinforcing steel.

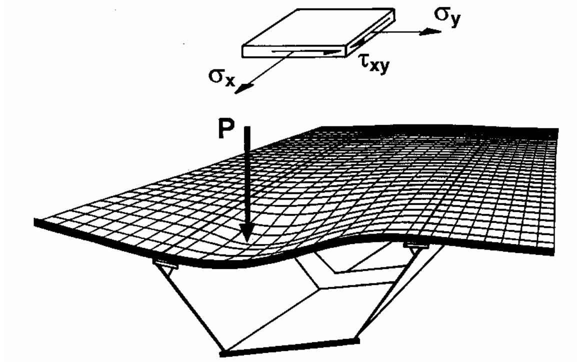


Fig. 8 Space Deformation of the Box Girder

On the other hand the integrity of the box girder structures is guaranteed by a concrete deck slab.

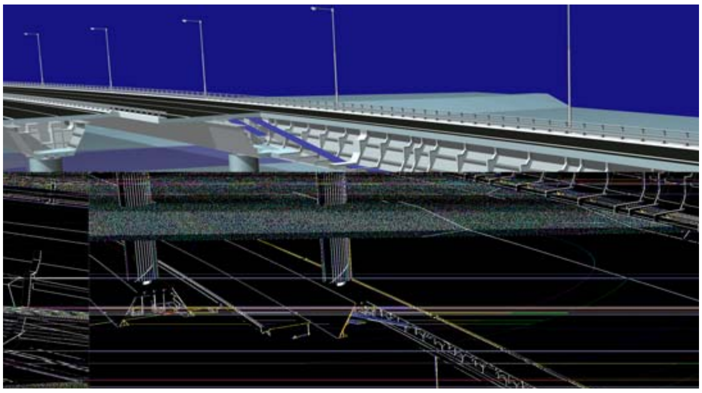


Fig. 9 Layout of the External Tendons

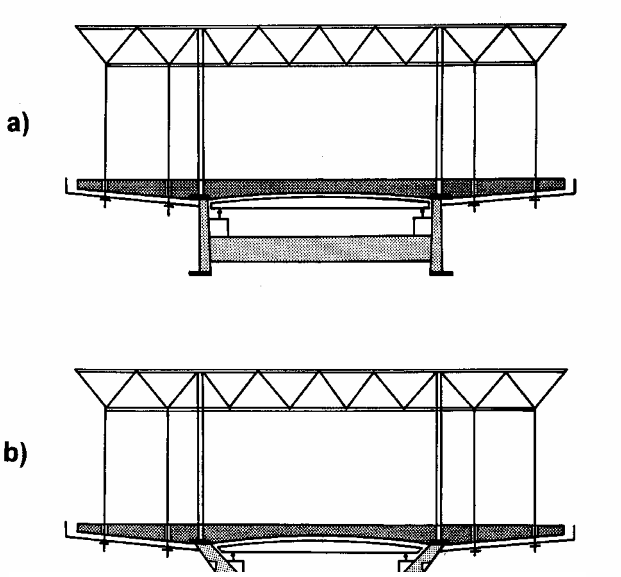


Fig. 10 Form traveller: a) plate girders, b) box girder.

Since the reduction of the stiffness of the deck slab reduces the torsional stiffness of the box girder and consequently increases its distortion, we tried to eliminate the cracks. Therefore the deck is post-tensioned both in the transverse and longitudinal direction of the bridge. The transverse post-tensioning is provided by traditional internal cables formed by strands grouted in flat ducts, the longitudinal post-tensioning by external cables situated inside the box. The cables are continuous across the whole length of the deck and they are bent above the intermediate supports and at the internal diaphragms situated close to the quarters of the spans - see Fig. 9. Since the cables are situated in PE tubes, the friction losses of prestressing force are within reasonable limits. The process of construction and a level of post-tensioning were designed in such way that the tension stresses in the deck slab are smaller than the allowable ones.

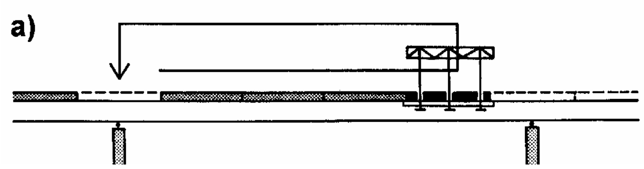


Fig. 11 Progressive casting of the deck Slab

The shape of the deck of both types of bridges allows progressive casting of the deck slab in the formwork supported by travelers that move along the already erected steel structure – see Fig.10. The travelers allow progressive casting of sections of length up to 22 m. During the progressive casting the portion of the deck slab above support is left free. After all sections in the span are cast the traveler returns to the support and remaining sections are cast- see Fig.11.

3. Static Analysis

All structures were analyzed as 3D structures by the ANSYS program system. The deck slab was modeled by 3D solid members, the steel girders by 2D shell members that have both bending and membrane capabilities - see Figs. 12 and 13. In structures formed by the plate girders, where cracks can originate, reduced stiffness of the deck was considered.

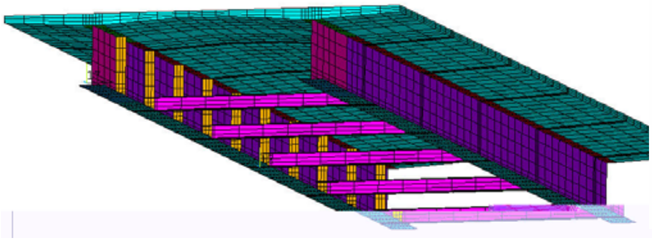


Fig.12 Modelling of the plate girders.

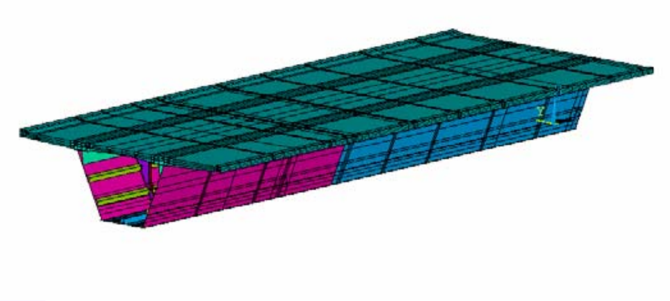


Fig.13 Modelling of the box girder.

Great attention was also devoted to the time-dependent analysis that was performed by 'TDA' program described in [2]. The deck was modeled by a series of parallel elements which represent: steel girders, composite slab, and rebars – see Fig.14. The analysis covers the effects of the progressive casting of the deck slab, and activation, adjustment and removing of temporary supports. In structures formed by plate girders, where transverse cracks above supports can originate from the effects of the live load, the portion of the deck slab was also re-moved in the time when the structure is put in ser-vice.

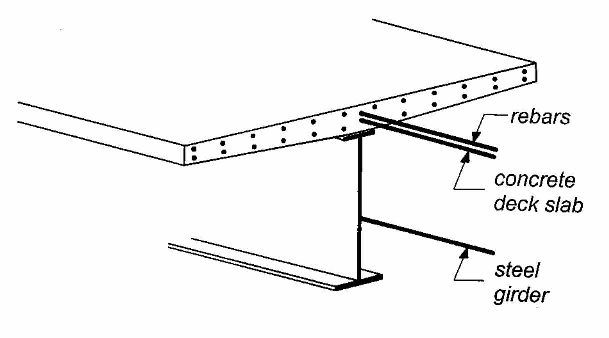


Fig.14 Time-dependent modeling.

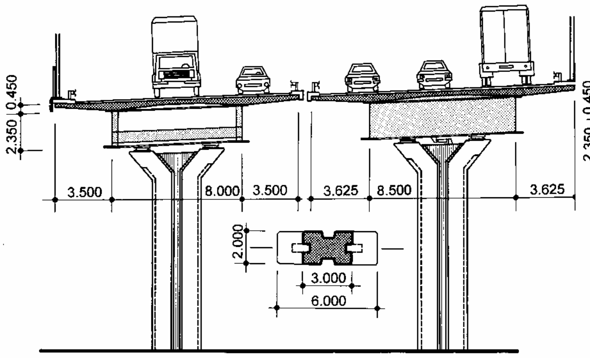
4. Description of Bridges

4.1. Bridge Rudna

The twin Bridge Rudna crosses the local highway, lake and railway. Due to the skew crossing the west-bound and east-bound bridge have different number and different span lengths. The west-bound bridge has 11 spans of the length from 33.45 to 70.00 m; its width is from 15.00 to 24.78 m.

The east-bound bridge has 12 spans of the length from 28.45 to 69.00 m; its width is from 14.50 to 22.88 m.

The prevailing part of the deck of both bridges is formed by two plate girders connected by low cross beams and transversely post-tensioned deck. Above the intermediate supports the plate girders are connected by deep cross beams that transfer the load into two bearings situated on the narrow piers – see Fig.15. In the portions of the bridges where the deck is widened, additional longitudinal plate girders are inserted between the edge plate girders – see Fig.16.



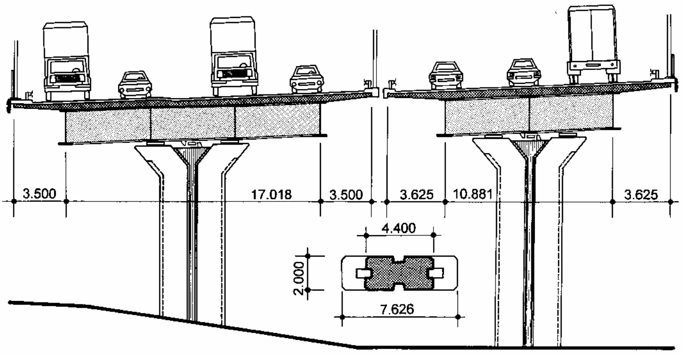


Fig.15 Bridge Rudna – typical cross section. *Fig.16 Bridge Rudna – cross section at widening.*

4.2. Bridge Opava

The twin Bridge Opava of the total length of 717 m crosses the River Opava, railway and future High Speed Rail. The span length varies from 33.08 to 47.25 m. The prevailing part of the deck of both bridges is formed by two plate girders connected by low cross beams and transversely post-tensioned deck. The girders are directly supported by bearings situated on the piers cap – see Fig.17.

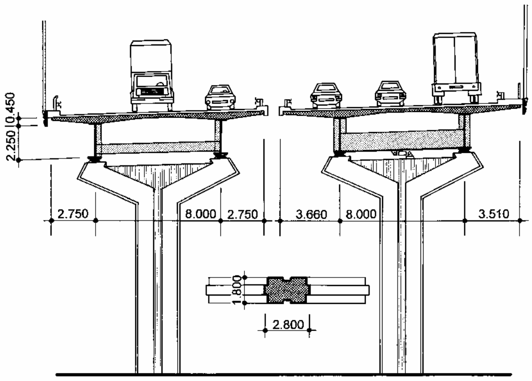


Fig.17 Bridge Opava – typical cross section.

4.3. Overpass D216

The Overpass D216 crosses the freeway in a longitudinal slope of 6%. To overcome an asymmetrical impression of the typical girder structure caused by the large slope, a two span strutted frame with one inclined steel strut was designed – see Fig.18. To eliminate the horizontal loading of the footings (see Fig.19a) a tied frame was developed – see Fig.19b. The footings of the inclined strut and the end abutment are connected by inclined concrete strut that together with the steel strut and side span creates a closed system resisting the horizontal forces.

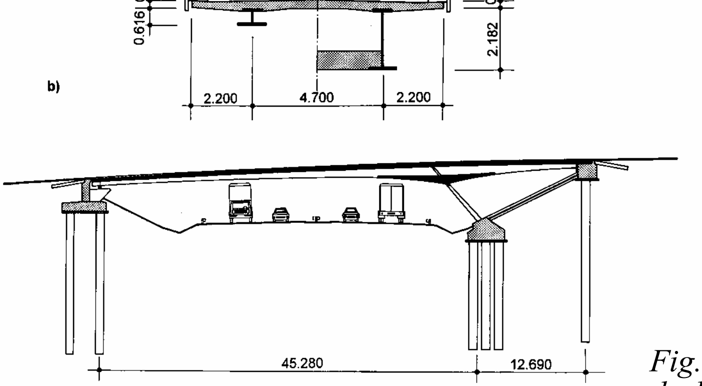
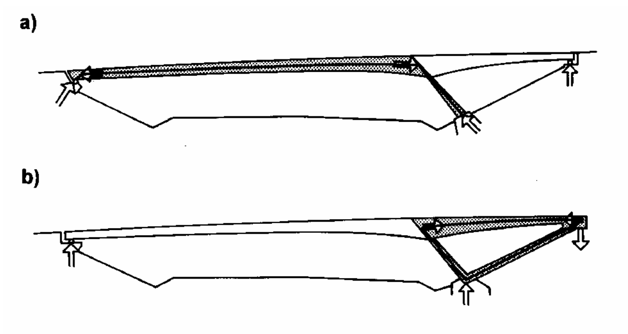


Fig.18 Overpass D216: a) cross section of the deck, b) elevation.



The deck is formed by two plate girders of variable depth mutually connected by deck slab; above the inclined strut the bottom flanges are also connected by a concrete deck slab that significantly contributes to resisting of compression stresses.

Fig.19 Overpass D216 – static function of the strutted frame: a) arched frame, b) tied frame

4.4. Bridge Odra

The twin bridge of the total length of 402 m in a very skew angle of 570 crosses the River Odra and local roads. The bridge has five spans of lengths from 49 to 102 m. Each bridge is formed by a single box girder - see Fig.20. On intermediate supports the girder is supported by single bearings, the torsion is resisted at the end abutments. It means that for torsion the span length is 402 m. The deck is assembled of the steel girder of the trough section and the transversely post-tensioned concrete deck slab. Bottom flanges above the intermediate supports are stiffened by concrete. The end diaphragms are also composite sections of steel and concrete. The girders are longitudinally post-tensioned by 2x5 external cables formed by 27-15.5 mm strands grouted in PE tubes – see Fig.9.

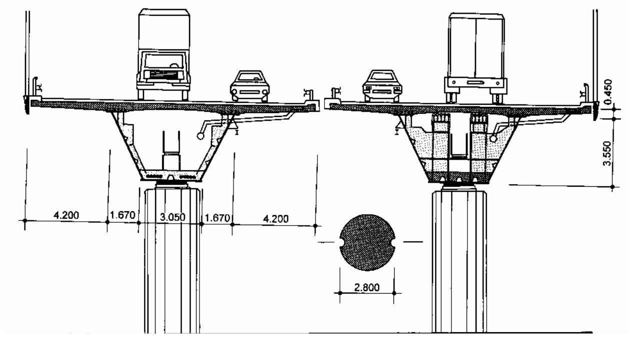


Fig.20 Bridge Odra

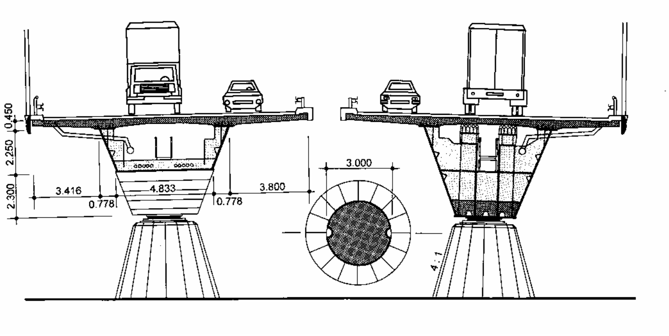


Fig.21 Bridge Ostravice

4.5. Bridge Ostravice

The freeway crosses the River Ostravice and local roads in a very skew angle of 330. The bridge is formed by two parallel structures of four spans of length of 306.4 and 294.9 m. Each bridge has four spans of length from 54.04 to 100.29 m. The bridges are formed by a single box girder of a variable depth - see Fig.21. On intermediate supports the girder is supported by single bearings, the torsion is resisted at the end abutments. The arrangement of the box girder is similar to the previous structure.

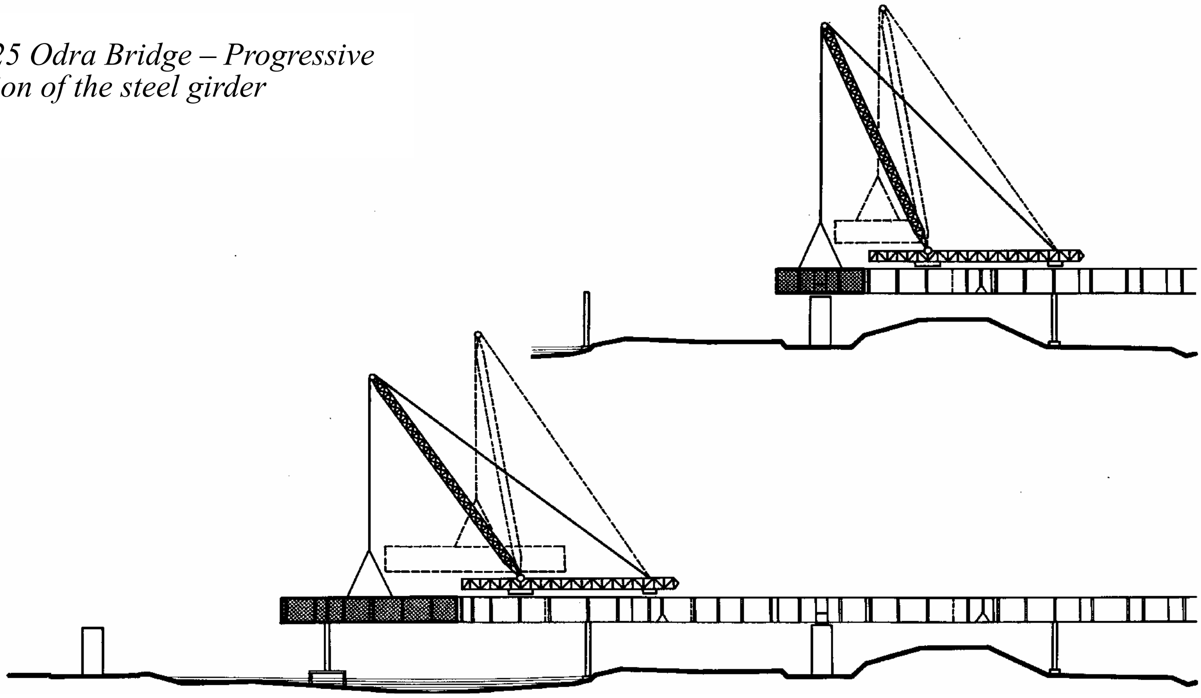
Fig.22 Overpass D216: erection of the plate girder

5. Erection of the Bridges

So far Bridge Odra and Overpass D216 have been completed. All other bridges are prepared to be built. The design supposes that the bridges assembled of plate girders will be erected by movable cranes – see Fig.22. In longer spans the girders will be supported by temporary supports. After the erection of the steel girders the composite deck slab will be progressively cast – see Fig.11. The steel structure of the Bridge Odra was erected in a progressive cantilever from one abutment to the other – see Fig. 23 through 26. Static effects in the erected cantilever were reduced by temporary sup-ports. The segments of length up to 24 m were erected by a special crane that moved along the al-ready erected structure. Then the composite concrete of the end diaphragms and concrete slabs at the bottom flanges above intermediate supports were cast. After that the deck slab was progressively cast and transversely post-tensioned see Fig.27. When all concrete was cast the structure was longitudinally post-tensioned by external cables. The Bridge Ostravice will be erected similarly.

Fig. 23, 24 Odra Bridge - erection of the steel girder.

Fig. 25 Odra Bridge – Progressive erection of the steel girder



The construction of the Bridge Odra was carefully monitored both during the erection of the steel structure and during the casting of the deck slab. At critical sections above the intermediate support and at mid-span both on steel and inside concrete strain gauges were placed and calculated and measured values of strains were compared. The monitoring will continue during the service of the bridge. The assumptions of the static and dynamic analysis and a quality of the workmanship will be also checked by static and dynamic loading tests. The structure will be tested for loading that causes maximum bending at critical sections above supports and mid-spans, and maximum torsion at the sections above the abutments. The dynamic loading test will check natural modes and frequencies and a dynamic response to the dynamic load.

Fig.26 Odra Bridge – progressive erection of the deck

Fig.27 Odra Bridge – progressive casting of the deck slab

6. Acknowledgment

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7. References

[1] VIRLOGEUX,M.: *Association of Prestressed Concrete and Steel for Bridge Construction. Contribution of French Group.* IABSE Symposium. Leningrad 1991.

[2] STRASKY,J.- NAVRATIL,J – SUSKY,S: *Applications of Time-Dependent Analysis in the Design of Hybrid Bridge Structures.* PCI JOURNAL, July – August 2001.