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Design and Tests of New Steel-Concrete Slabs

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Summary

Results of analysis and full-scale tests of new deck and roof slabs, designed as composite steel-concrete structures are presented. The new system of anchors was used for connetion of steel load-bearing profiled sections and concrete, filled in their. Shear bond resistance of the anchor connectors and strength of the slabs were researched with tests.

1.Composite deck -slab

New structure of composite steel-concrete deck slab was worked out with CNIIPSK(Moscow) and EXERGIA Co (Lipetsk). The slab is consisted of profiled steel sections like cassettes, manufactured from galvanised steel sheet of thickness from 0,8 to 1,2 mm with cold-forming. Depth of section's wall -300 mm, flange width-110 mm, length-up to 13 m. Sections are supported with their walls on deck beams and connected each other with edge folds of flanges using seaming machine. The sections are fixed to beams with screws, nails or welded studs. The sheeting of sections is used as permanent shuttering and work reinforcement of the composite deck. Concrete of strength classes from B20 to B40 is located into sections with layers of thickness from 80 to 110 mm. Lightweight concrete is accepted to use with unit mass not less than 1800 kg/m^3 and compressive strength not less than 17 MPa.
Composite behaviour between steel sections and concrete is ensured (after it became hard) by corrugated steel strips of width from 30 to 50 mm as transverse pieces of cold - formed profiled sheets of thickness 0,8-1,0 mm with trapezoidal waves (Fig. 1) The strips are located along each section and fixed to its wall with pop-rivets or weld spots. Exept concrete sound-proofing or heat insulation layers can be located within depth of the slab.

2.Analysis of the slad

Ultimate desing moment for bending composite slab are calculated as for reinforced concrete structure with external reinforcement assumpting full interaction between steel sections and concrete, provided Eurocode 4 and Building Standard of Russia. Safety factor of steel section as main reinforcement is assumed equal 0,7 .Results of analysis of slabs with sections from steel of thickness 0,8-1,0 mm and concrete of different classes are as given in Table.

3. Testing

Standard full-scale test of new composite slab was carried out to control analysis results.

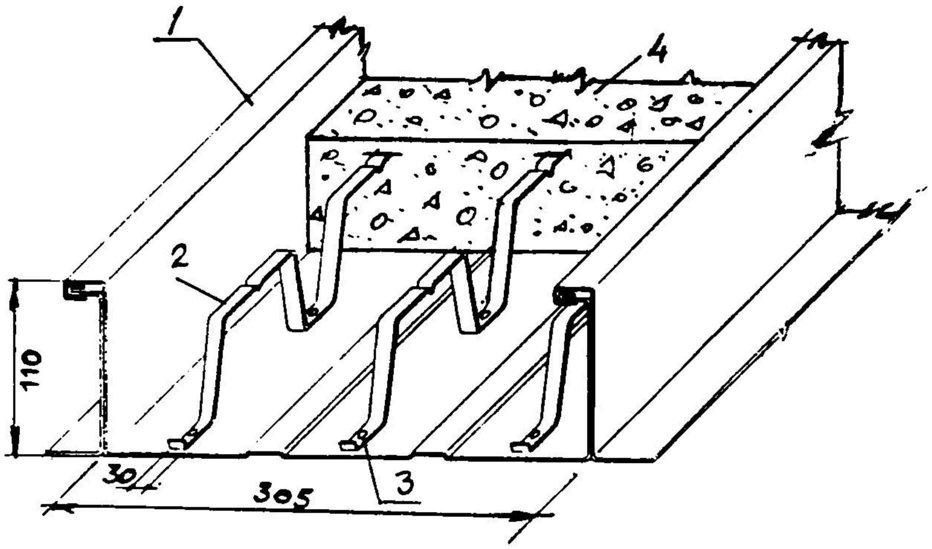

Fig. 1. Anchor connectors in composite slabs
1 - steel section; 2 - anchor; 3 - pop-rivet or weld spot; 4 - concrete

The specimen was represented a simply supported slab with length of 4,1 m, width of 0,9 m and span of 4 m. Thickness of steel sections was of 1,0 mm. Corrugated sheet anchors with width of 30 mm, wave depth of 44 mm and thickness of 0,8 mm are fixed with pop-rivets to the sections, which was filled in with concrete completely. Cubic concrete compessive strength was 20-20,6 MPa (cubics). Two equal concentrated line loads P were applied at thirds of the span. The deflection of the slab at the middle of its span was equal 7,3 mm when P=10 kN, relative movement between the sections and concrete at the ends of the specimen was less than 0,3 mm. Ultimate failure moment on the slab was equal 20,5 kNm (with calculation of its weight).
Recomended maximum span of the new slab is up 4,0 or 5,5 m without or with a temporary support at the middle of the span accordingly during packing of wet concrete.

Thickness, mm		Ultimate desing moment (kNm) on 1 m of slab width for concrete classes				
concrete	section	B15	B20	B25	B30	B40
80	0,8	10,6	10,8	11,1	11,2	11,3
	0,9	11,7	12,0	12,3	12,4	12,6
	1,0	12,8	13,2	13,6	13,7	13,9
110	0,8	14,1	14,3	14,6	14,7	14,8
	0,9	15,7	15,9	16,3	16,4	16,5
	1,0	17,2	17,6	18,0	18,1	18,3

Table 1. Results of analysis of the slabs

Arch Bridge Crossing the Brno-Vienna Expressway

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Summary

A composite arch bridge formed by a steel tube in-filled with concrete that supports a cast-in-place concrete deck of a trough cross section is described in terms of the architectural and structural solutions, static function and process of construction. Results of the static and dynamic tests are compared with the results of the static and dynamic analysis.

1. Architectural and Structural Solution

A new 67.50 m span steel-tube arch bridge carries local road traffic across the new Brno-Vienna Expressway in the Czech Republic. In evaluating the angle of skew of the crossing, it was determined that using only one arch as the load-bearing member would be the most aesthetically and structurally preferable solution. The arch is formed in a circle with a radius of 74.75 m by a single steel tube with a diameter of 900 mm and a thickness of 30 mm in-filled with concrete. Internally, the steel tube is stiffened by diaphragms at a distance of 2 m. The arch is fixed in concrete foundations on each side of the expressway - see Fig.1. The arch supports a slender trough-shaped cast-in-place concrete deck using edge girders in the shape of New Jersey barriers which serve as stiffening girders as well as safety barriers. The deck is post-tensioned by cables situated at the edge girders and in the deck slab.

The deck is connected to the arch by steel struts situated perpendicular to the axis of the arch at a distance of 6 m. These steel struts, which are connected to the stiffening diaphragms of the steel arch tube, are of a small box-cross section and are also filled with concrete. To guarantee the stability of the arch not only in the vertical direction but also in the transverse direction, these struts are triangular in shape; the width of the triangle is always constant, but the length is variable. In the middle of the bridge, the arch is fix-connected directly with the deck. The first and last side spans, which are relatively long, are supported by inclined cast-in-place concrete struts that are pin connected with the deck and with the concrete foundation of the arch. These concrete struts are arranged directly under the edge girders to transfer the loading directly from the edge girders to the foundations, and thus assure the stability of the structure in the transverse direction.

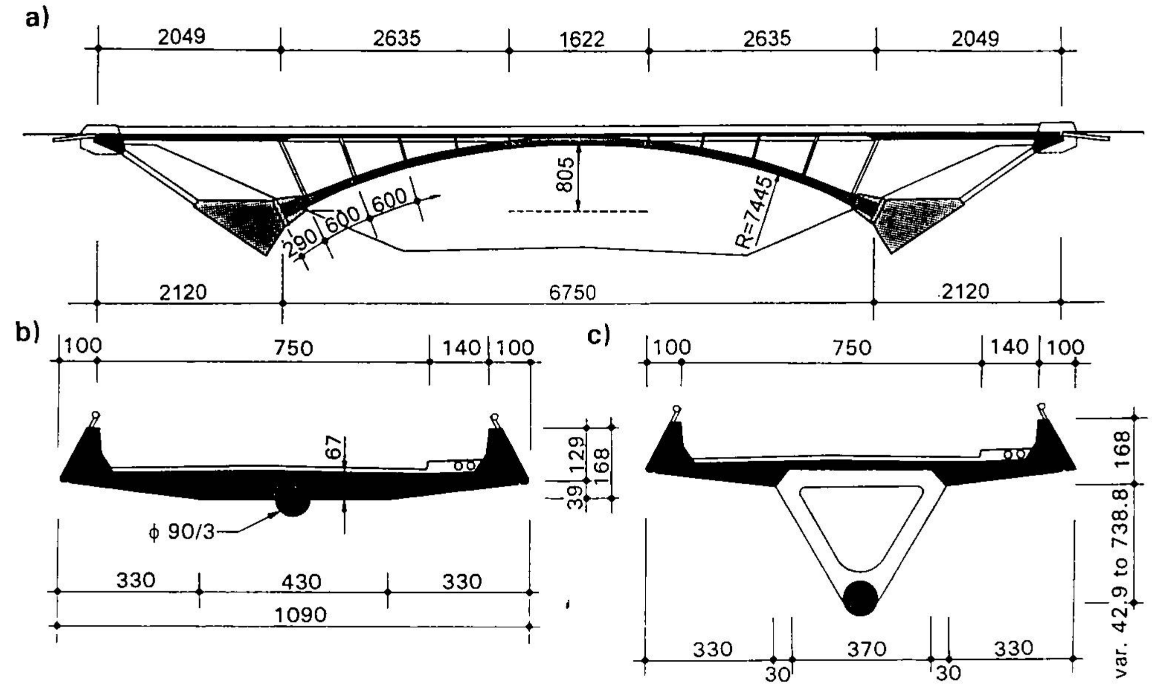

Fig.1 Structural solution: a) elevation, b) cross section at midspan, c) typical section

2. Process of Construction

The steel arch was erected from steel segments with a length of about 12 m. After the erection of the arch, the triangular shaped steel struts were erected. The structure was temporarily supported by hydraulic jacks. Concrete was pumped from the bottom to the top of the arch. To guarantee that there would be no air voids at the top, 3 openings were provided at the top of the arch. After filling the steel tube with concrete, the deck was cast as one unit on traditional scaffolding and post-tensioned. After the deck was post-tensioned, the hydraulic jacks were used to press the arch against the foundation in order to reduce the short-term deformation of the foundation. This operation was repeated after one week.

3. Static and Dynamic Analysis

According to the nature of the problem the structure was analyzed as a 2D, 3D frame, and the 3D structure being assembled of the shell and solid elements. Detailed time-dependent analysis was done by our proprietary program TDA using CEB-FIP functions. The design assumptions and quality of the workmanship were checked by static and dynamic loading tests. The bridge was loaded by eight trucks situated in two positions that created maximum bending and torsion in both the arch and the deck. The structure was also tested dynamically. At first the agreement of excited natural frequencies with theoretical values was checked, then the logarithmic decrement of damping and the impact coefficient was determined. The test confirmed our assumptions and good behavior of the structure. The structure was designed by SHP Brno with the collaboration of Fercon Brno and the Technical University of Brno (Dr.Zak, Dr.Navratil and Ing.Hradil). The structure was developed under support of GA 261635.

The Nevers Bridge: Design of the Steel Concrete Composite Box Girder

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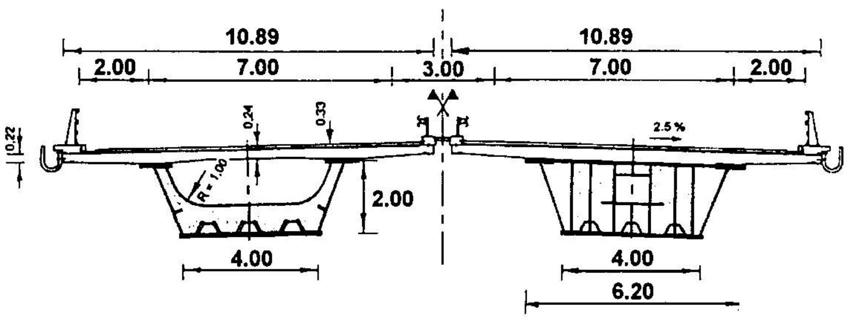
1. General design of Loire crossing bridge for a road by-passing Nevers.

The Nevers Bridge built between 1992 and 1995 was designed by ***SETRA*** . It is composed of two independent composite box girders, each one 420 meters long. ***J. Richard-Ducros*** for the steel structure and ***Dalla Vera*** for other civil engineering works were the contracting companies. For a more complete description of the bridge, see the article "Cracking control in the concrete slab of the Nevers composite bridge" in the same book.
The alignment of the Loire crossing is straight, and with a small 6 degrees skew angle between the river and the bridge. But every unmechanic skew alignments of bearings is avoided for the structure. This type of composite bridge was economically competitive.



Cross section of the steel-concrete composite box girders (half standard and half on pier).

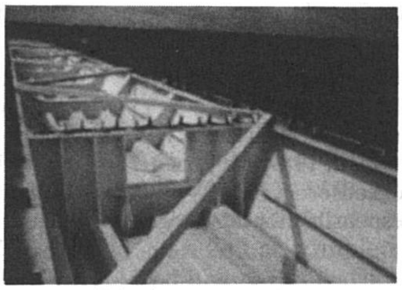
2. Decisive advantages of a composite box girder solution.

When the Nevers bridge was designed, the use of plate girders was regarded as less expensive than the use of box girders for steel concrete composite bridges, box girders requiring more fabrication time.
In order to tide over this handicap,

- We designed the steel box with modest outer dimensions to make fabrication, and erection easy. In addition, shear lag and local buckling would make too wide flanges inefficient.
- The alignment of the Nevers box girders is straight, which allowed us to incline webs without geometrical difficulties that appear with highly curved bridges. If webs were vertical, bottom flange would be much too wide to be efficient. Inclined webs reduce the bottom flange width in a favorable way. In addition, the width between upper flanges is free to be optimised. The goal is to reduce distortion solicitation in the intermediate cross frames due to fatigue loads at the connection point between steel and concrete.

- We realized that transport and welding in site of the elements were often in fact the reasons for an overestimated cost of a box-girder solution when compared with the plate-girder solution. The Nevers bridge segments were small enough to be transported in one piece by road. Sections could be fabricated in the full width at the shop, and the best economy was achieved because longitudinal welding on site was avoided all the long of the bridge at the middle of the box.

Transport of segments



Diaphragm on pier

Composite box girders have however several advantages over plate girders which make their use attractive. The following advantages were decisive for the choice of the Nevers bridge structure :

- A neater appearance since the stiffening can remain invisible in the box.
- All places outside of the bridge are avoided where water could be caught in a trap. Most of the common causes of corrosion disappear which increases the service live and reduces the maintenance costs.
- Because of the low renewing rate of oxygen, the inside of a composite box is usually exposed to far less risk of corrosion than the outside. Very light colors were chosen for painting the steel inner surfaces of the Nevers boxes. This facilitates inspection because corrosion points or eventual fatigue cracks will be easier to detect in the future.
  In order to reduce maintenance costs an important point is to avoid birds flying inside the box using smallest openings, birds droppings being very corrosive.
- The width of the box girder plates, especially the bottom plate width, allows large span to depth ratio, to cross the clearance to be allowed for hydraulic, which reduces scale and cost of the road embankments at each end of the bridge.
- Very high torsional rigidity: In closed box girders, torque is resisted mainly by Saint-Venant shear stresses. This is an important advantage for a fatigue sensible structure like a road bridge.

3. Important details : temporary bracings and diaphragms on piers.

The torsionnal stiffness of the box girders is also essential during their construction. Composite box girders only achieve their torsional rigidity after concreting. During erection and concreting, they require temporary bracings.
According to the procedure used by contractors, bracings were only removed on one 20 meters long standard segment just before concreting it, when all other previous concrete segments were hard. This procedure could prevent deformations, that may occur when removing bracings where the deck is not achieved, which dramatically reduces the torsionnal stiffness of an open composite box girder.

Local effects on bearings cause complex states of stress in the supports on piers. We designed a diaphragm on piers to obtain a great rigidity to resist local distortion, and avoid detachment between steel and concrete parts of the composite structure.

The Oeresund Bridge on the Link between Denmark and Sweden

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Summary

The Øresund Link being established between Denmark and Sweden is a 16 km toll-funded road and railway crossing. It consists of a 4 km immersed concrete tunnel, a 4 km artificial island and a 8 km long bridge. The bridge includes a 1.1 km cable-stayed high bridge with a navigation span of 490 m and approach bridges each side with typical 140 m spans. The cross section is composite with the upper road deck in concrete and the lower railway deck in concrete on the approach bridges and in steel on the high bridge. The two decks are separated by two parallel steel trusses.

1. Introduction

Øresundskonsortiet (ØSK), a company owned jointly and equally by the Danish and Swedish governments, is responsible for the project design and construction of the fixed link. The Link will after its scheduled completion in year 2000, be owned and operated by ØSK.

ASO Group is house consultant to ØSK, responsible for technical services and aesthetics of the bridge. The group consists of Ove Arup & Partners (UK), SETEC (F), Gimsing & Madsen (DK) and ISC (DK). Georg Rotne (DK) is the group's architect.

The contract for the construction of the bridge was signed with Sundlink Contractors HB in November 1995. Sundlink consists of Skanska (S), Hochtief (D), Monberg & Thorsen (DK) and Højgaard & Schultz (DK). The detailed design is carried out for the contractor by a joint venture consisting of COWI (DK) and VBB-VIAK (S). The design of the bridge is based on ASO Group's conceptual and illustrative design for a two-level bridge. The conceptual design is included in the contract in the form of Definition Drawings, which must be followed by the contractor in his detailed design.

2. The Bridge

The cable-stayed high bridge (Fig 1) consists of a central navigation span with two side spans each side. Minimum headroom in the main span is 57 m. The high bridge is connected to the artificial island and the Swedish coast at Lernacken via a number of 140 m approach spans. The bridge deck is in two levels with a dual two-lane motorway at the top and a two-track railway at the bottom. The two levels are separated by two parallel Warren type steel trusses.

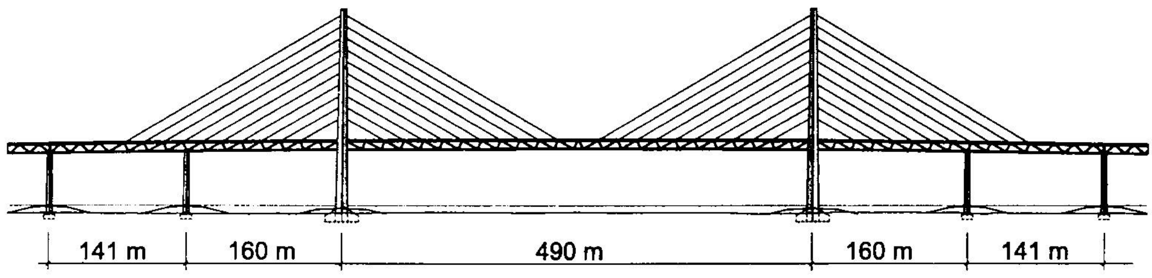

Fig. 1 The cable-stayed high bridge

The steel trusses have a more open bracing (45°) than generally used in truss bridges, and vertical members are only installed at truss ends at expansion joints. The 20 m bay length of the truss is constant along the bridge, but the configuration is modified at the cable-stayed spans so that every other diagonal has the same direction as the stay cables. The 490 m main span will at completion be the longest cable-stay supported span in the world carrying both road and heavy rail traffic.

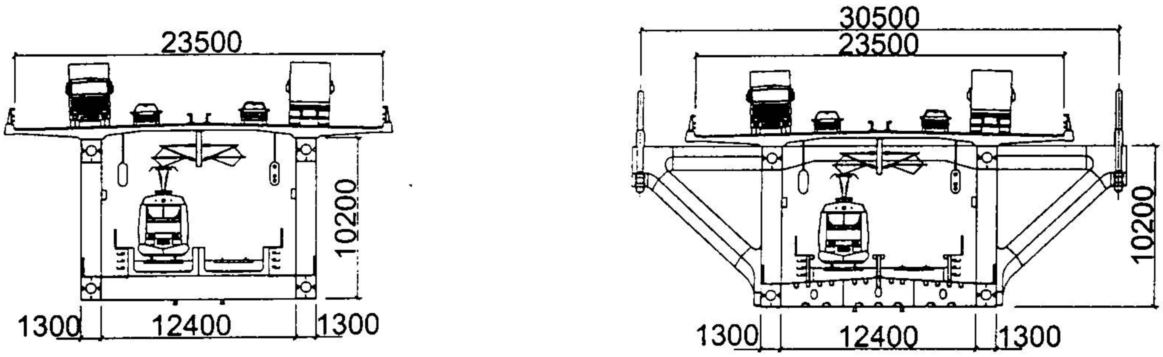

Fig. 2 Cross sections

2.1 Details

The trusses are placed 12.4 m apart and are in composite action with the concrete top flange. The transversely prestressed concrete slab has an average thickness of only 0.30 m. Hogging moments in the slab over the supports are transferred to the torsionally stiff upper steel chords. The transfer of tension at the top of the deck to the steel is secured by normal reinforcement anchored to long studs over the webs of the chords. The transfer of normal forces from the truss to the upper deck is concentrated at the nodal points, where 150 mm Nelson studs are provided closely spaced over the 7 m length of the nodes.

On the approach spans, the railway at the lower deck is carried in two concrete trough sections supported on 2.6 m wide transverse steel box beams spanning between the lower nodes. The troughs are in composite action with the chords. The width of the cross beams is determined by the large horizontal forces to be transferred from the truss diagonals to the concrete. The connection between cross beam and concrete is similar to the one described for the upper deck: long studs concentrated at the webs of the troughs to transfer tension from the local hogging moments in the troughs, and short studs concentrated at the outer trough webs to transfer horizontal shear from the steel to the concrete. The troughs are in reinforced concrete. As for the upper deck it was found uneconomic to apply longitudinal prestressing after the shear connection to the steel is made, as a major part of the prestress force would be transferred to the steel. In the cable-stayed spans the concrete troughs are substituted by a shallow steel box between the lower chords, as the advantages of the lighter deck prevailed over the extra cost of the steel.