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DOUBLE COMPOSITE BRIDGES – THE MAIN CONCEPT AND EXAMPLES OF ITS IMPLEMENTATION

In the paper the issue of a double-composite steel-concrete bridges have been presented. The basic assumption of idea of double-composite structures have been discussed and examples of design solutions of selected bridges with double composite action constructed in Europe in 1992-2012 have been shown and characterized.

Keywords: double-composite steel-concrete bridges, bottom concrete plate, large spans, variable thickness

Development of the steel-concrete composite bridges

Beside the classic structural solutions of the composite steel-concrete bridges, where the cooperation between concrete deck and steel beams is realized, in development of the composite bridges new trends still appear. One of them is the idea of the bridges with double composite action developed in case of multi-span continuous bridges, in which over the intermediate supports the bottom fibers of the cross section are compressed.

The main purpose of the idea of double composite action is strengthening of the steel cross-section in region of the negative bending moments by means of the concrete plate placed in bottom parts of the cross-section. The bottom concrete plate cooperates with steel girders in transmission of compressive forces, protects the bottom compressed flanges before buckling, allows to reduce the height of the steel girders, decreases the consumption of the steel and enables to increase the bridge span length.

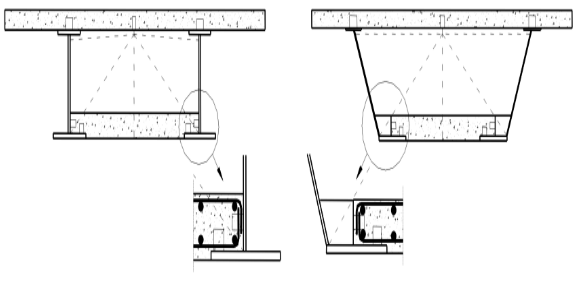


Fig. 1. Cross-sections with double composite action in region of negative bending moments

The bottom concrete plate is used mainly in bridges with large spans. The thickness of bottom plate varies along the length of the bridge due to the increase in compressive force towards the pillar. Since the bottom plate is not applied on the entire length of the span its appearance over the entire width in one section will result in rapid change of the girders stiffness and stresses accumulation. Variable thickness of the bottom plate enables alleviate the stresses accumulation. However the main way of the reduction of the stresses accumulation is application of an arched hole in bottom plate in order to ensure a progressive appearance of the plate in cross-section.

Fig. 2. The bottom concrete plate in road viaduct near Těšice, Czech Republic [1, 2]

The plate thickness is determined taking into account the load capacity of the compressed part of the cross-section in longitudinal direction of the composite girder and bending load capacity of the plate in transverse direction. Because of occurrence in region of negative bending moment the bottom plate is always compressed in longitudinal direction. In transverse direction acts the dead load of the plate and alternatively also weight of dehydration and/or other equipment devices. Moreover the bottom plate carries the horizontal loads perpendicular to the longitudinal axis of the bridge. The bridge moving loads causes the strain of the bottom plate only in longitudinal direction.

The bottom plate can achieve a significant thickness becoming a massive concrete part. In that case the plate can be concreted in two stages. Then the first layer of the bottom plate will carry the load of fresh concrete of the second layer.

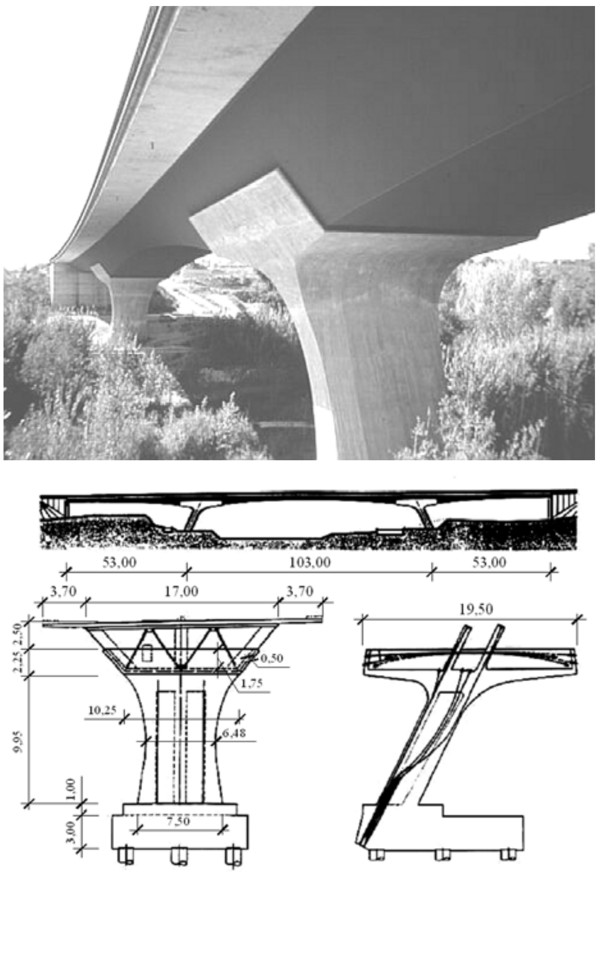
The bottom plate is constructed mostly as partially fixed in the webs of the steel beams. Particular difficulties can be related to the design of anchorage of reinforcement carrying of negative bending moments nearby the webs.

The problem of cracking of the bottom plate occurs only in the transverse direction. The calculations of the stresses and cracks should also take into account the bending moments from non-uniform deflection of the main girders.

A variations of the above solution are structures with specially formed supporting areas where the steel section is partially (compressed part of the cross-section) or entirely replaced by concrete cross-section over a distance of negative bending moments (Fig. 3).

The first realization of a double composite bridges, with main span of 80,0…180,0 m appeared in the 70's of XX century in Spain. The idea has been developed by Spanish engineer prof. Julio Martínez Calzón [3]. In the last two decades, mainly in Europe, new projects were implemented in Czech Republic, Germany and Spain: highway bridge over the Odra River in Ostrava, highway bridge over the Ostravice River in Ostrava, bridge over the Elbe River in Torgau, highway bridge over the Inn River in Neuötting, bridges over the river Nalón in Langreo and Soto del Barco, bridge over Sella River in Cangas de Onis. The characteristics of selected objects are presented in a following part of the paper.

a)



b)

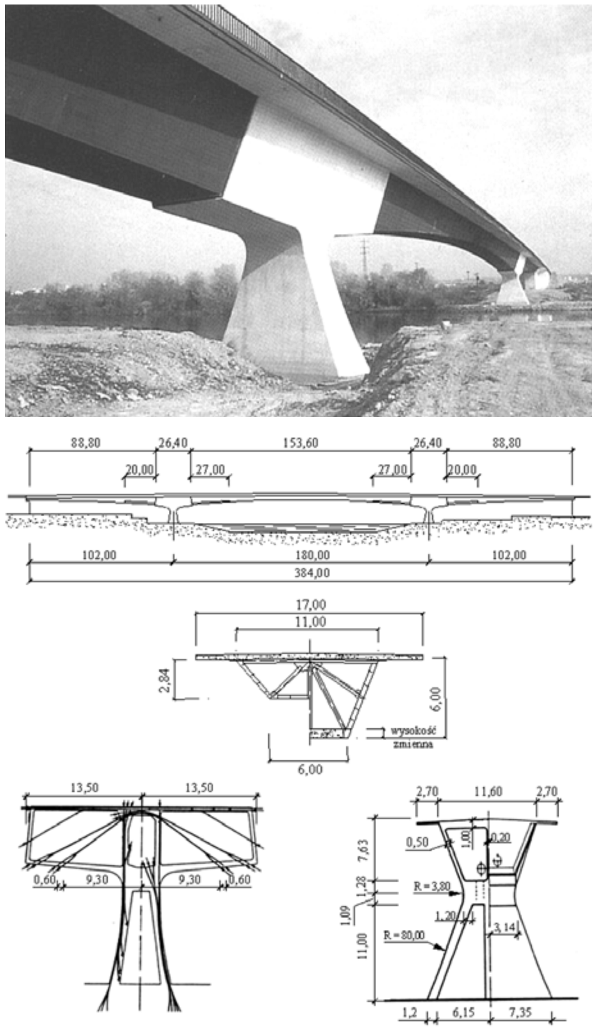


Fig. 3. Examples of variations of double composite bridges:
a) – bridge over Turia River, Valencia;
b) – Milenario Bridge over Ebro River, Tortosa [2, 3]

Double composite bridges – examples

1. Highway bridge over the Odra River in Ostrava, Czech Republic

The bridge is located within the highway D-1 "Via Moravice" near the Polish-Czech border crossing Chałupki-Starý Bohumín. The construction was completed in 2007. The bridge is five span continuous beam with spans: 40,0+50,5+84,5+50,5+40,0=265,5 m.

The cross-section consists of two steel plate-girders made of Cor-Ten weathering steel combined with a reinforced concrete deck. Over the intermediate supports the steel beams are strengthened by bottom concrete plate. The edges of the bottom plate have a parabolic shape in order to ensure its progressive growth in cross-section.

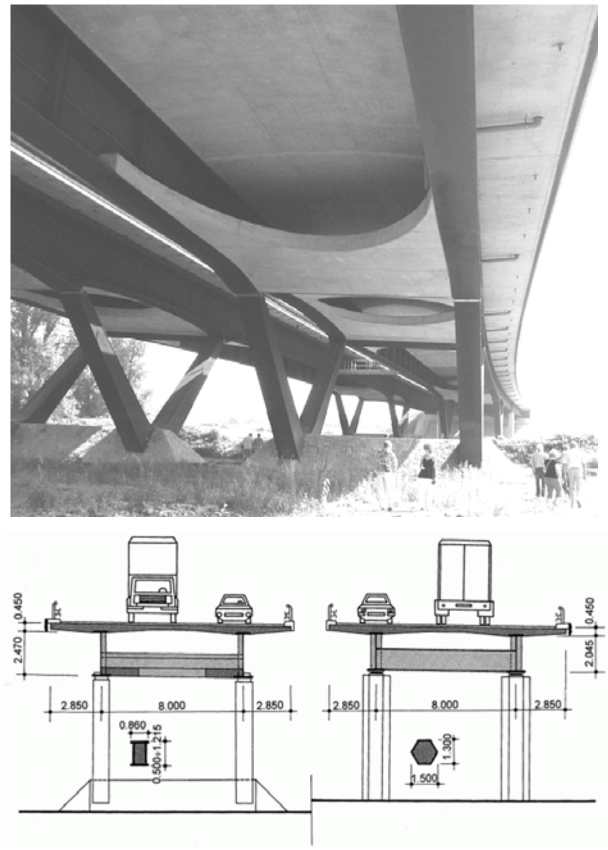


Fig. 4. Double composite bridge over Odra River in Ostrava, Czech Republic – bottom view and cross-sections of the bridge [4]

The main girders are hinged connected with intermediate supports constructed as a V-shaped CFST elements (Concrete Filled Steel Tube). The supports cross-section has a variable height of 0,5…1,215 m and constant width 0,86 m. In order to increase the efficiency of cooperation of the steel section and filling concrete inside the steel box section a shear connectors and steel ribs with semicircular cutouts has been used (Fig. 5).

Fig. 5. The V-shaped bridge supports – general view and interior view of the supports [4, 5]

The bottom part of the supports is welded to steel crossbeam anchored to the base plate by means of Macalloy high-strength anchor rods.

The bridge was built using the incremental launching method and temporary supports. The bottom plate over the intermediate supports was concreted after launching the steel structure and before concreting of the deck. The bottom plate was connected with main girders by means of shear stud connectors. The bridge deck was built in two stages: stage 1 – concreting of the span sections, stage 2 – concreting of the support sections. The construction details and bridge construction stages are presented in Fig. 6.

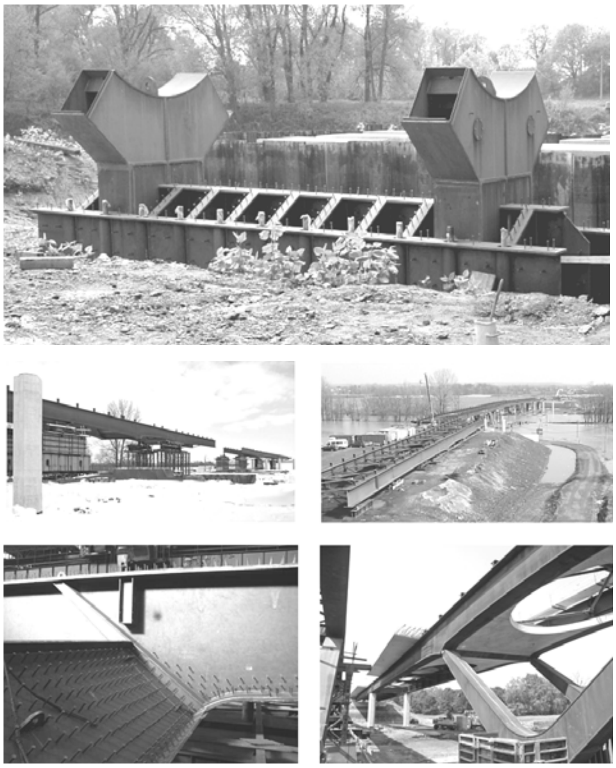


Fig. 6. Construction details and bridge construction stages [4, 5]

2. Highway bridge over the Ostravice River in Ostrava, Czech Republic

Fig. 7. The highway bridge over the Ostravice River in Ostrava, Czech Republic

The bridge is located within the highway D-1 «Via Moravice» in Ostrava over the Ostravice River. The construction was completed in 2005.

The bridge is four span continuous beam with spans: 54,0+70,0+100,3+66,7=291,0 m. The main girder is a single cell composite box girder with variable height 2,70…5,00 m, longitudinally prestressed and strengthened over intermediate supports by means of bottom concrete plate. The bottom plate was connected with steel box by means of shear stud connectors.

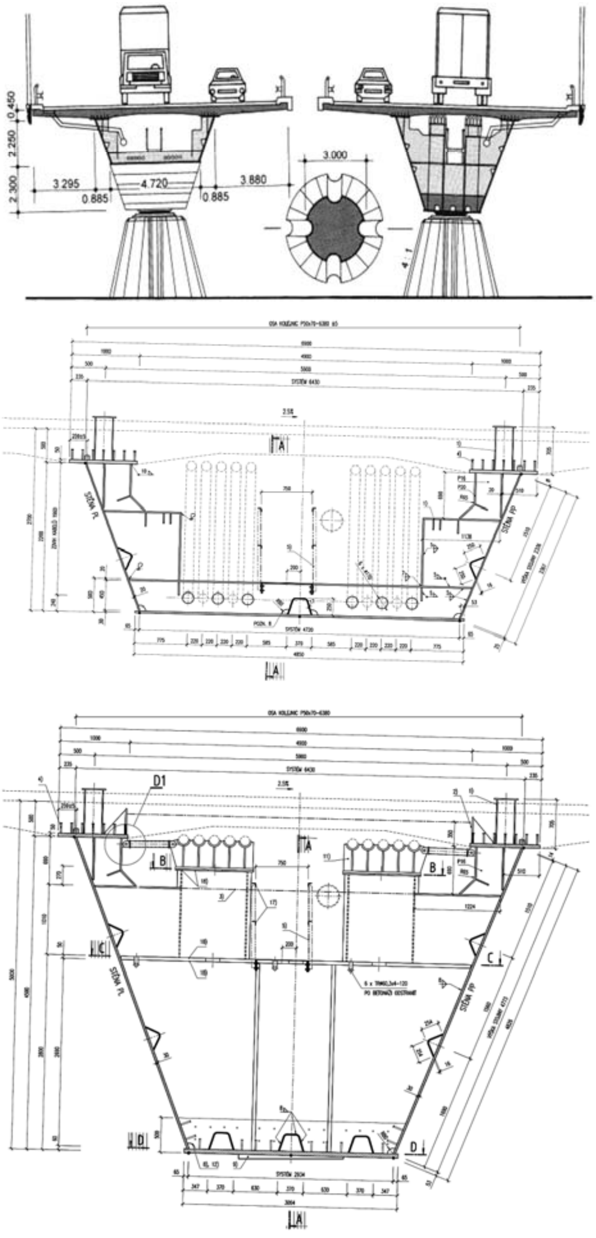


Fig. 8. The bridge cross-sections at midspan and over the support [4, 5]

The box girder is made of Cor-Ten weathering steel. The thickness of metal sheet are: bottom flange 30…60 mm, webs 20…30 mm, top flange 30…50 mm (width 1,0 m). The webs and bottom flange are strengthened by longitudinal trapezoidal and triangular closed ribs and the transverse ribs in distance 4,0 m.

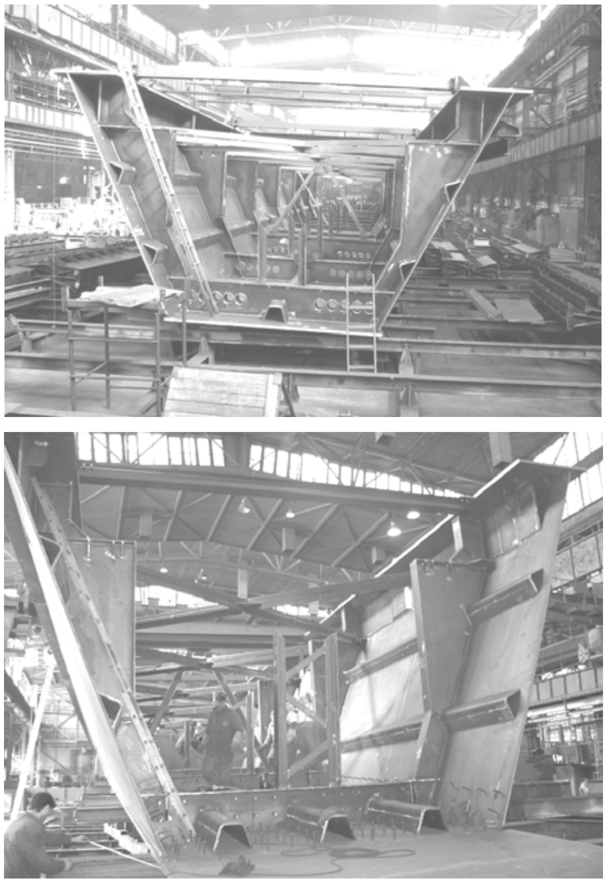


Fig. 9. The steel girders during assembly stage [4, 5]

The bridge was built using the temporary supports and mobile cranes. Side spans were built from the ground level, main span was erected using the crane moving through the previously assembled part of the bridge. The bridge deck was concreted using a moveable formworks moving through a previously assembled steel girders.

Fig. 10. The bridge construction stages [4, 5]

The longitudinal prestressing of the bridge was realized using unbounded tendons connected with girders by means of transverse stiffening ribs with circular holes (Figs. 8 and 11).

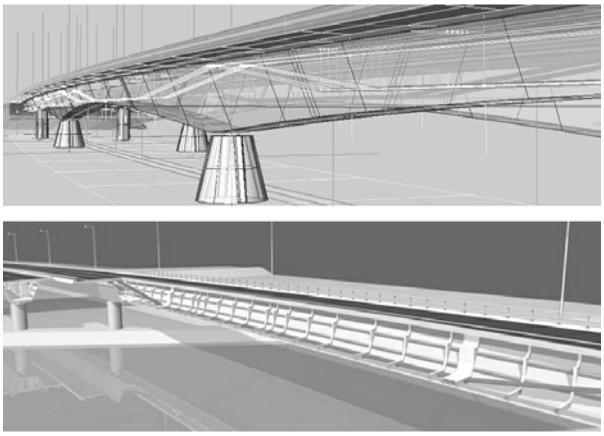


Fig. 11. Longitudinal prestressing of composite girder [4, 5]

3. Bridge over the Elbe River in Torgau and bridge over the Inn River in Neuötting, Germany

The next two examples are bridges in Germany. The bridge in Torgau was opened in 1993, a construction of the bridge in Neuötting was completed in 2000.

The bridge in Torgau is a thirteen span bridge with spans length: 16,0+18,0+20,0+22,0+16,0+ +22,0+53,0+106,0+65,0+3×45,0+36,0=509,0 m. The bridge is constructed with six concrete spans and seven composite spans with single cell composite box girder. Over the pier situated on the right bank of the river main girder is a double composite box girder with bottom concrete plate. The main girder has variable height of 2,30…5,60 m (Fig. 12).

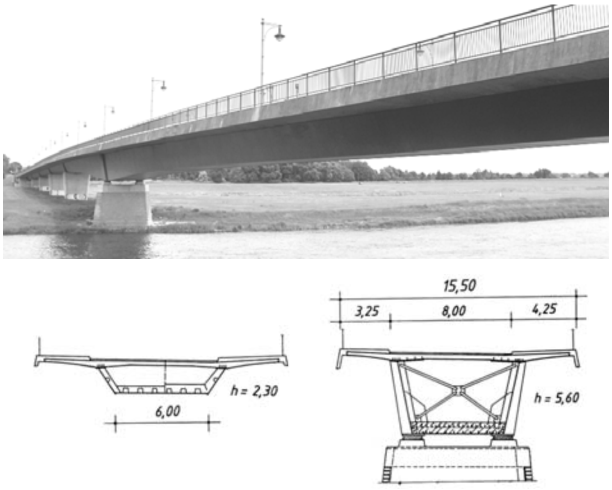


Fig. 12. Bridge over the Elbe River in Torgau – general view and cross-sections of main span [6, 7, 8]

The bridge in Neuötting over the Inn River is a five span continuous beam with spans: 95,0+154,0+95,0+68,0+58,0=470,0 m.

The main span over the piers is a double composite box girder with bottom concrete plate connected with steel by means of shear stud connectors (Figs. 13 and 14).

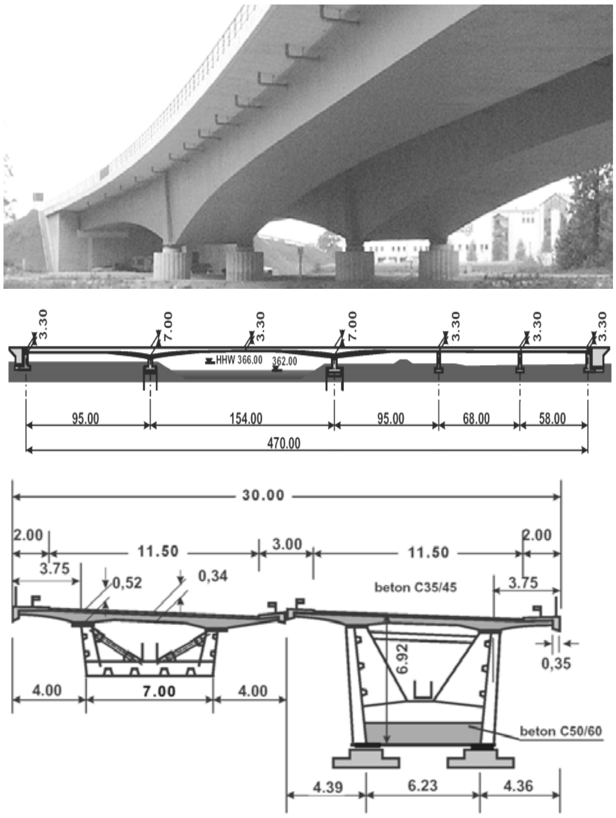


Fig. 13. Bridge over the Inn River in Neuötting – general view, longitudinal section and cross-sections of main span [8]

Fig. 14. The bottom concrete plate connected with steel by means of shear stud connectors [8]

4. Bridge over the Nalón River in Langreo, Spain

The bridge over the Nalón River in Langreo is a three span, double composite, single cell box girder bridge with spans length: 27,5+110,0+27,5=165,0 m. The bridge is located within the road AS-17. The construction of the bridge was completed in 2007.

The bridge is an example of the third variation of idea of double composite bridges with region of negative bending moments made of concrete.

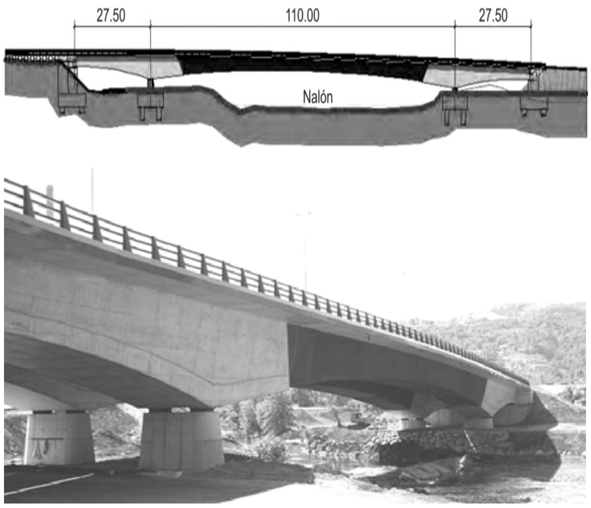


Fig. 15. Bridge over the Nalón River in Langreo, Spain [9, 10]

The main girder in the side spans and on the half length of the region of negative bending moment is entirely made of concrete. In the region of positive bending moments the girder is a composite box girder strengthened at both ends by bottom concrete plate.

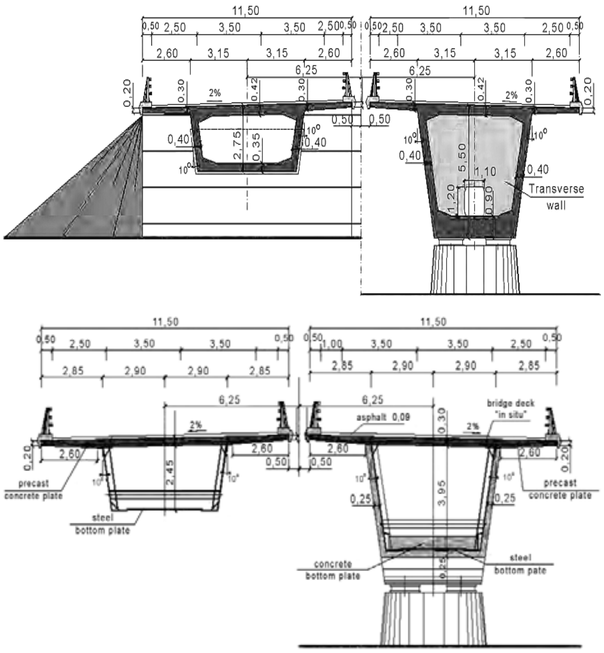


Fig. 16. The bridge cross-sections in side and main spans [9, 10]

The connection of concrete and composite cross-sections, placed in the region of minimum bending moments, was constructed as a prestressed butt joint. Additional prestressing has been used in areas subjected to appearance of tensile stresses.

The composite section was strengthened by bottom concrete plate over a distance 17,9 m. The palate has a variable thickness of 0,25…0,50 m increasing towards the support.

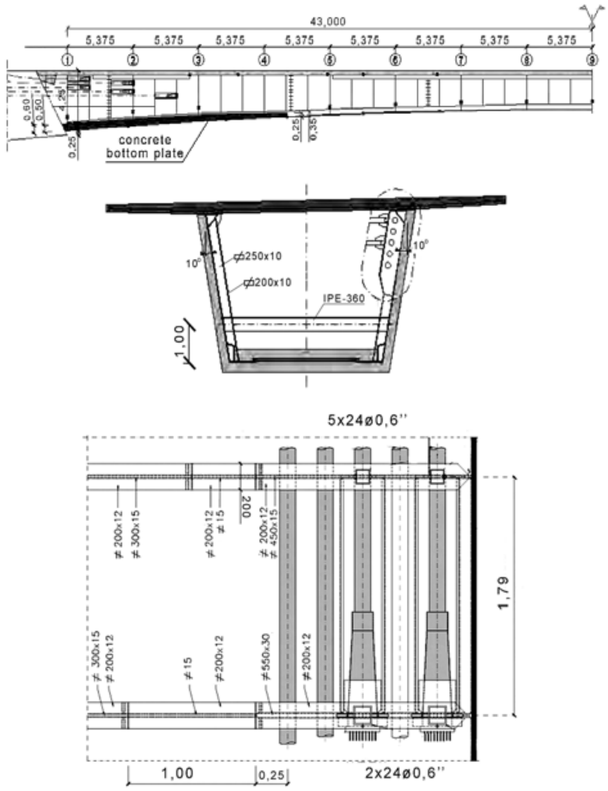


Fig. 17. Region of prestressed butt joint of the concrete and composite sections [9, 10]

The bridge was built using stationary scaffolding system, temporary supports and telescopic mobile cranes (Fig. 18). The bridge deck was built in two stages with use of the precast concrete slabs forming the bottom layer of the deck (lost formwork) and by concreting the top layer of the deck in situ.

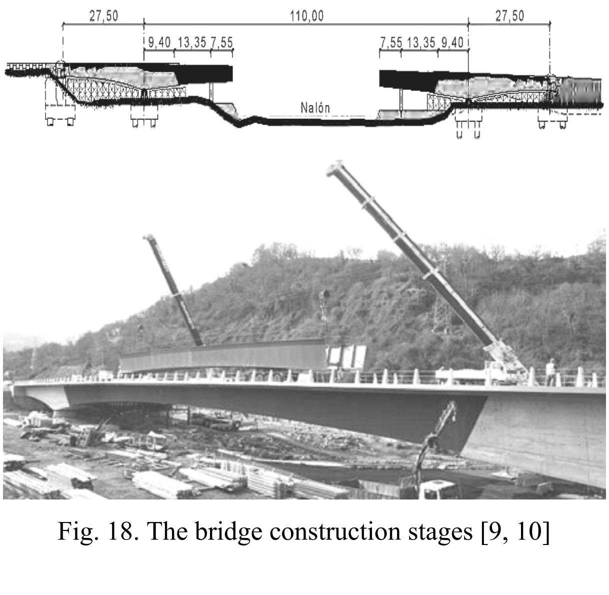


Fig. 18. The bridge construction stages [9, 10]

5. Bridge over the Sella River in Cangas de Onis, Spain

Another example is the bridge over the Sella River in Cangas de Onis. The bridge is an example of the second variation of idea of double composite bridges with region of negative bending moments partially made of concrete placed in compressed part of the cross-section.

The main girder is a composite single cell box girder with double composite action in the region of negative bending moments. The bridge is constructed as a three span, continuous beam with spans length: 17,55+80,00+17,55=115,10 m.

The side spans and compressed part of the cross-section in the region of negative bending moments are made as a suitably shaped concrete cross-section (Fig. 19).

Fig. 19. Bridge over the Sella River in Cangas de Onis, Spain – general view and construction stage [10]

Conclusions

The main aim of the idea of double composite bridges is strengthening of the compressed part of the steel cross-section in the region of negative bending moments by means of concrete plate. Implementation of the bottom concrete plate cooperating with compressed fibers of steel cross-section protects the steel girders from buckling and allows to reduce the steel consumption.

A variation of the main idea are specially shaped structures with supporting areas in which the steel section is partially or completely replaced by concrete section.

By full use of the properties of structural materials (compressed concrete, stretched steel) the project becomes more economical.

In the opinion of prof. J. M. Calzóne bridges with double composite action eliminate all disadvantages of traditional multi-span, continuous plate girder and box girder composite bridges.

The idea of double composite action can be effectively used in bridges with small, medium and large spans.

In the paper several examples of implementation of the idea of double composite bridges has been presented.

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ПОДВІЙНІ СТАЛЕЗАЛІЗОБЕТОННІ МОСТИ – ОСНОВНІ ОСОБЛИВОСТІ ТА ПРИКЛАДИ ЇХ ЗАСТОСУВАННЯ

У статті відображена проблема формування подвійних комбінованих сталезалізобетонних мостових споруд. представлені основні особливості подвійного суміщення мостів, які реалізовані у Європі з 1992 по 2012 рік.

Ключові слова: подвійний комбінований сталезалізобетонний міст, нижня бетонна частина, великі прогони, змінний переріз

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ДВОЙНЫЕ СТАЛЕЖЕЛЕЗОБЕТОННЫЕ МОСТЫ – ОСНОВНЫЕ ОСОБЕННОСТИ И ПРИМЕРЫ ИХ ПРИМЕНЕНИЯ

В статье показана проблема формирования двойных комбинированных сталежелезобетонных мостовых сооружений. Представлены также основные особенности двойного совмещения мостов, реализованные в Европе в 1992-2012 годах.

Ключевые слова: двойной составной сталежелезобетонный мост, нижняя бетонная часть, большие пролеты, переменное сечение