AN INNOVATIVE SOLUTION FOR SMALL SPAN BRIDGES – PRECOBEAM

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BIOGRAPHY

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SUMMARY

The European sponsored research project called "Precobeam" was launched in 2003. The purpose of the project was to develop a durable, price competitive, prefabricated solution for medium to short span bridge structures. The outcome of this work resulted in an innovative beam section that utilizes steel T-sections monolithically connected to a concrete top chord.

To simplify fabrication of the Precobeam, high-strength rolled I-beams are cut in half with a special pattern to create two T-sections. The unique pattern of the cut allows for the shear transmission between the steel T-sections and concrete top chord. To validate the structural performance and the design equations proposed, the beams were tested at the ultimate, service, and fatigue limit states.

The Precobeams are specifically designed to reduce on-site impacts, and to simplify and accelerate bridge construction. Through the use of a precast toping, the need to install on-site formwork is eliminated. Once the beams are set, a cast-in-place deck topping can be placed. For a given span length, the Precobeams offer a shallower profile when compared to conventional I-girder alternatives. Shallower beam depths reduce the need to raise profile grades -which simplifies the roadway tie-in and minimizes impacts to the surrounding area.

Already, this innovative construction method has found interest among bridge owners and general contractors due to its ease of use and low profile. Over the past few years, about 20 bridges (roadway, railway, and pedestrian), have used this technology - which further validates its use for the European bridge market.

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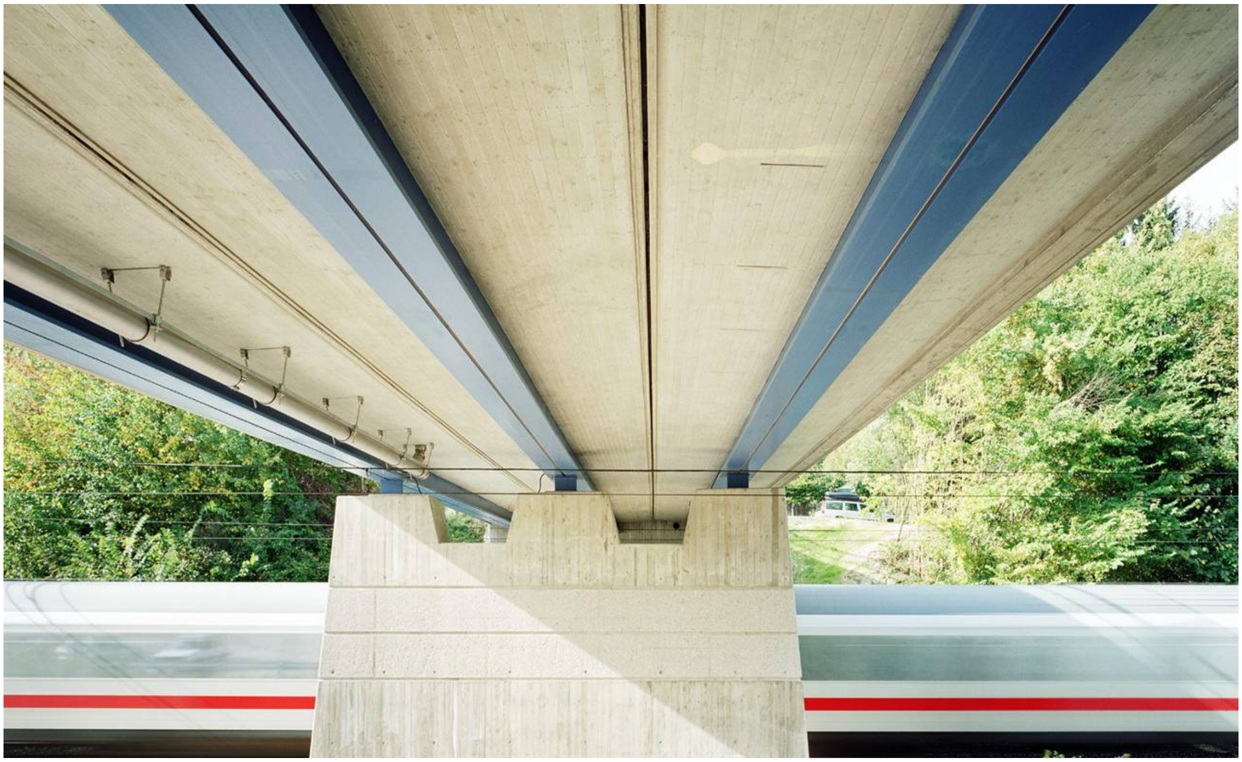
Figure 1: View beneath Pöcking Bridge (Germany) with Precobeam elements

1. Introduction

Various R&D projects have been launched over the last 10 years in Europe in order to develop the Precobeam solution. First of all the RFCS project Precobeam, who has put the basis of the concept. Following this, RFCS Preco+ Dissemination project, in which seminars have been organized to present the concept in various european countries, and RFCS Ecobridge Demonstration project, which has guided the implementation of the technology in three real bridges. Some literature references are given under [1], [10], [11], [6].

In Germany, several FOSTA Research projects have followed to clarify and enlarge the scope of the solution, as well as the implementation in the german market (FOSTA P804 [4]; FOSTA P 967). In France, a chapter of the national MIKTI project was on this topic [2]. In Poland and in Austria several PhD thesis were developed on this subject; some of them are given under [5], [9], [14].

It is important to mention the partners of some of these projects which have contributed to the development of the project, but due to lack of space are not co-authors of this article: *Acciona Infrastructures SA, CTICM – Centre Technique et Industrielle de la Construction Metallique, Forschungsverein Stahlanwendung e.V., Ramböll Schweden AB, RWTH Aachen - Lehrstuhl für Stahlbau und Leichtmetallbau, Technische Universität München - Lehrstuhl für Metallbau, Universität der Bundeswehr München - Lehrstuhl für Stahlbau, Universität Lüttich – Argenco.*

2. Double T-Sections

The use of composite steel structures has gained significant market shares in road bridges across Europe over the last decades. In the field of medium span bridges (25m – 50m span), the common solution with a concrete plate and downstand steel I-girders results often to be the most economic one. Twin girder decks offer a simple and very effective structural solution. Technical advantages in term of possibility of erection (launching, crane lifting, assembling), lightness linked with resistance, flexibility in design (curved girders, variable inertia) make steel concrete composite bridges the solution of choice [6], [7].

Nervertheless, in the field of spans below 25m, this kind of structures becomes often less economic face to prefabricated prestressed concrete solutions. Some of the main reasons are:

1. The benefits of lighter structures, resulting to a decrease of self-weight and consequent decrease of design actions, become less important by decreasing the span.
2. Erection by crane lifting of prefabricated elements is a quite easy and cost effective construction method for spans up to 30m and element weight up to 40 tons. More complex erection phases are usually not economic, except special construction site constraints.
3. In most cases, the twin-girder concept is not optimized for spans < 30m due to low span / deck width ratio; for these cases the multi-girder concept is more convenient.

From the structural point of view, let's have a simplified consideration concerning steel concrete composite girders. With the current normative approach, very often the design of road bridges is governed at ultimate limit state by bending moment resistance. This resistance is calculated as the plastic moment assumed the sections is not slender – which turns out to be the most common case for composite sections subjected to sagging moment.

In the usual case of bridges for medium span, the plastic neutral axis lies in the web (Figure 2, Case 1). The upper flange is therefore designed for overtaking compression forces during construction phase and final phase.

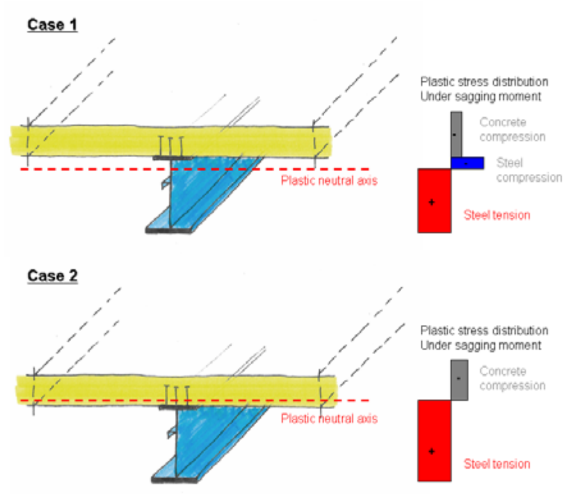

Figure 2: Bending moment in classic composite beam

Conversely, in the case of small span bridges a traditional concrete plate is usually enough to overtake all the compression forces, with the plastic neutral axis lying in the slab itself (Figure 2, Case 2). The upper flange is therefore used in compression during the construction phase, whereas during final phase it receives tension stresses, since it is placed below the neutral axis.

The flange should anyway have minimum dimensions in order to place an adequate number of shear connectors. This turns in a quite low utilization factor of the upper flange at serviceability limit state, whereas at ultimate limit state the contribution to the plastic bending moment is relative small. This disadvantage may turn in a weakness of the structural solution in particular in the case of multi-girder decks, often used for small span bridges.

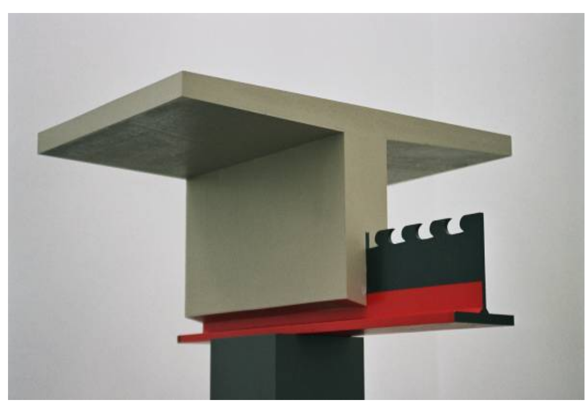

Figure 3: Precobeam conceptual section

In order to inverse this trend, the Precobeam concept has been developed. Main idea is to combine the advantage of prefabricated prestressed concrete beams – being the upper T of the section, with the steel girders – being the lower T of the section.

In a general case, two steel Ts are obtained by oxycutting of a stock H rolled section longitudinally. This is a very economic procedure and permits quite a flexible choice thanks to the wide range of standard sections. The use of high steel strength is advantageous.

The upper T is a reinforced concrete part which is prefabricated in the usual installations for the prefabricated elements. The oxycutting line is special in such a way that the steel concrete connection is obtained by simple compenetration of the two materials through a composite dowel.

In the cases where the concrete plate is able to overtake the whole compression force, this kind of section results of course optimized. The main amount of steel corresponding to the lower flange is positioned with a maximum lever arm to overtake the tensile force.

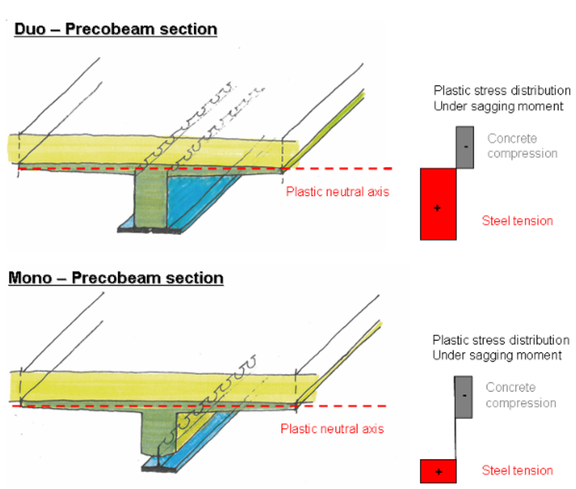

Figure 4: Bending moment of Precobeam

For the time being, two types of sections have showed to be convenient for beam bridges: Duo-Precobean and Mono-Precobeam (see Figure 4).

Where two halved sections are positioned beside and filled with concrete, we will speak about Duo-Precobeam. This ensures a consistent torsional inertia, a more slender section and the shear connection quite near to the neutral axis.

If only one halved section is used like in the Mono-Precobeam, then it is convenient to let a deeper reinforced concrete web. In this case the property of the sections are similar to a prefabricated concrete one, but with the significant increase of the bending moment resistance thanks to the steelwork used as "external reinforcement".

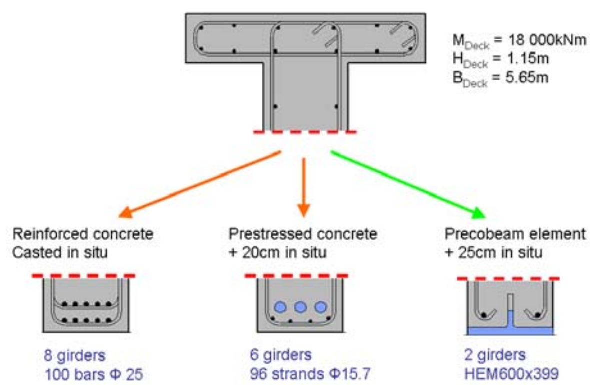

Figure 5: Comparison of different solutions for the same bridge deck

To understand the interest of this Mono-Precobeam compared to traditional prestressed concrete girders, we can consider the cross section of a deck, corresponding to the example of Vigaun bridge presented in chapter 6:

- Precobeam permits to decrease the number of prefabricated elements compared to prestressed concrete; in the considered case from 6 to 2;
- Precobeam permits a full utilization of the steel T at ultimate limit states, since serviceability limit states criteria like limitation of cracking are not decisive (concrete is not in the external fiber);
- Precobeam solutions is reducing the self-weight and therefore the bending moment;
- Precobeam is less affected by creeping and shrinking phenomena;
- Precobeam has a simple inspection and maintenance procedure, differently from embedded prestressed strands.

3. Composite Dowel

The steel-concrete shear connection is ensured by the special shape of the cutting line. This shape has been object of intense research to optimize its resistance. Initially, three different shapes were used: shark cutting (SA), proposed by Marc Hever (Arcelor), puzzle (PZ), proposed by Günter Seidl (SSF Ingenieure), and clothoidal (CL), proposed by Jacques Berthellemy (Setra). In a series of campaign these three shapes were tested.

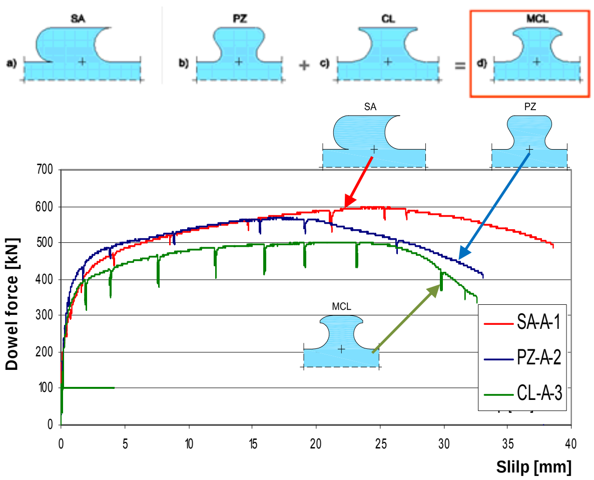

Figure 6: Dowel shapes and Push-Out tests

The shark shape gave the best static results in term of resistance, followed closely by the Puzzle shape. For these reasons these shapes were used in the first bridge realizations (see chapter 4 and 6).

Nevertheless, concerning the fatigue behaviour the clothoidal form showed better resistance thanks to a lower hot-spot stress at the basis of the dowel. On this basis, a new form combining the advantage in fatigue behaviour and the facility in fabrication, the MCL shape – modified clothoidal shape – was developed. Thanks to this shape also bridges with significant fatigue load can be realized with composite dowels.

An extensive campaign of experimental tests was undertaken to verify the composite dowel resistance, accompanied by numerical tests. This has lead to a design concept which is nowadays well accepted. Since 2013 this design concept is included in a German technical agreement, which corresponds to a normative status.

Figure 7: Fabrication of the MCL composite dowel

The application of this design concept to bridges will be explained in the following lines. Figure 8 shows the geometrical notations of the elements composing the composite dowel are given as well as their range of application.

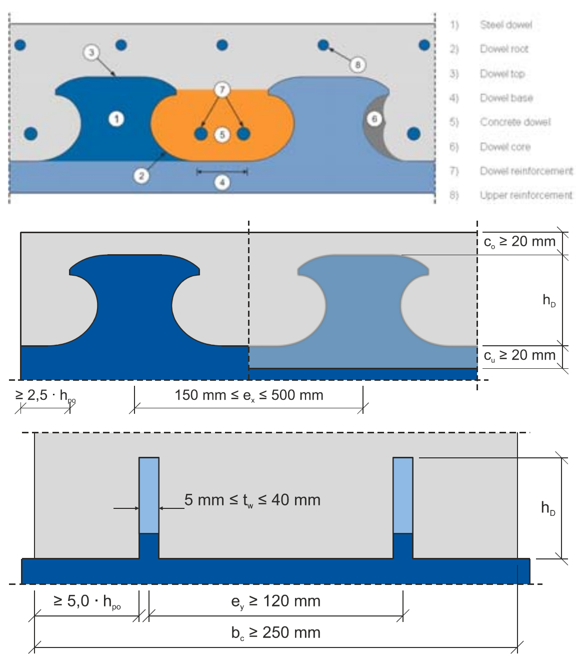

Figure 8: Notations and geometrical limits

The composite dowel resistance at the **ultimate limit state** ULS is given by the minimum of three below criteria:

1) Resistance of steel dowel:

$$P_{pl,k} = 0{,}25 \cdot e_x \cdot t_w \cdot f_y$$

2) Resistance of concrete dowel:

$$P_{sh,k} = \eta_D \cdot e_x^2 \cdot \sqrt{f_{ck}} \cdot (1 + \rho_D)$$

Where:

$$\rho_D = \frac{E_s \cdot A_b}{E_{cm} \cdot A_D}$$

$$\eta_{D,CL} = \left(3 - \frac{e_x}{180}\right)$$

$$\eta_{D,PZ} = \left(2 - \frac{e_x}{400}\right)$$

3) Pry-out resistance:

$$P_{po,k} = \chi_x \cdot \chi_y \cdot 90 \cdot h_{po}{}^{1,5} \cdot \sqrt{f_{ck}} \cdot (1 + \rho_{D,i})$$

Where:

$$\rho_{D,i} = \frac{E_s \cdot A_{sf}}{E_{cm} \cdot A_{D,i}}$$

$$\chi_x = \frac{e_x}{4{,}5 \cdot h_{po}}$$

$$\chi_y = \frac{1}{2} \cdot \left(\frac{e_y}{9 \cdot h_{po}} + 1\right)$$

Pry-out failure mode may be avoided under the condition that a minimum confinement reinforcement is provided. The minimum confinement reinforcement is given by:

$$A_{s,conf} = 0{,}3 \cdot \frac{P}{f_{sd}}$$

The reinforcement should satisfy the geometric rules shown in Figure 9.

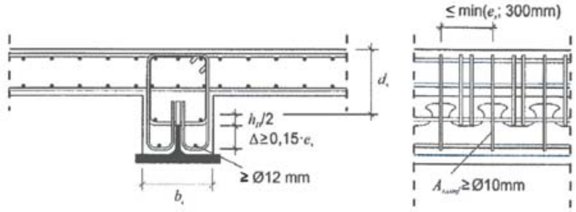

Figure 9: Geometrical arrangement of confinement reinforcement

At **serviceability limit state** SLS it shall be verified that the shear force in the composite dowel shouldn't exceed the minimum of:

1) Maximal steel stresses:

$$\sigma_s = k_{f,L} \cdot \frac{V x S_y}{I_y \times t_w} + k_{f,G} \cdot \left(\frac{N}{A} + \frac{M}{I_y} \cdot z_D\right) \leq 1.3 f_y$$

Where:
$f_{Global} = 1{,}5$ $f_{Local} = 7{,}3$

2) Maximal concrete utilization:

$$P_{LD,ser} \leq 0.7 \min\left(P_{sh.k}; P_{po.k}; P_{co.k}\right)$$

3) Maximal dowel cyclic utilization:

$$P_{LD,ser} \leq P_{cyc} = 3.1 \cdot t_w \cdot h_d \cdot f_{ck}$$

At **fatigue limit state** ULS it shall be verified that the steel :

1) Maximal steel stresses:

$$\Delta\sigma = \left|k_{f,L} \cdot \frac{\Delta V \cdot S_y}{I_y \cdot t_w}\right| + \left|k_{f,G} \cdot \left(\frac{\Delta N}{A} + \frac{\Delta M}{I_y} \cdot z_D\right)\right|$$

Where:
$f_{Global} = 1{,}5$ $f_{Local} = 7{,}3$
$\Delta\sigma_S = 125$ for cut edge
$\Delta\sigma_S = 140$ for grinded edge

The fatigue categories are conform with the EN1993-1-9 : 2005 Table 8.1.

At a first view this design concept may look quite complex, but it recalls in fact the principle for the headed studs shear connectors. Once that the whole procedure is implemented in a software, the effort for the verification becomes quite reasonable.

4. Duo Precobeam Road Bridges

4.1 Germany

The first realization with the Precobeam technology has been the bridge of the Hindenburgstrasse in Pöcking over the railway line München – Mittenwald (Germany). The project was the replacement of an existing filler beam deck in service since over 100 years.

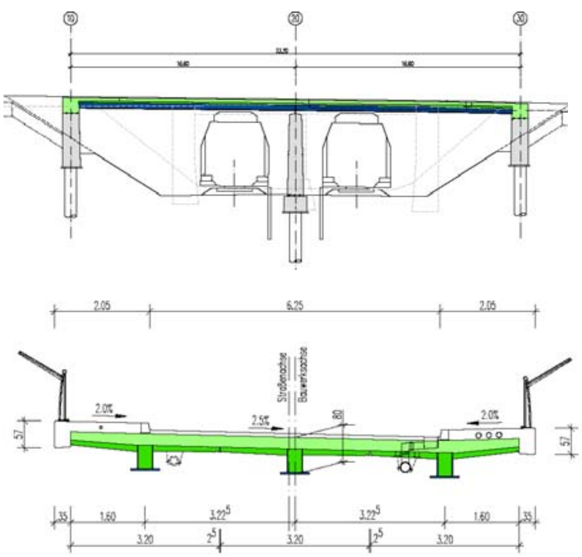

Figure 10: Longitudinal view and cross section

The bridge is foreseen as two span deck of 16.6m with monolithic connection with abutments and one intermediate pier between the tracks. With a construction height of about 80cm, the deck can considered in slender field (L / h = 21). The total deck width is 10.5m.

Figure 11: Steel fabrication

Due to the fact that the reconstruction was taking place over an existing railway line, the choice of a prefabricated solution to minimize the trafic disturbance was mandatory. For technical and economical reason, from the three options initially foreseen, the Precobeam solution was choosen.

The whole deck width is realized by only 3 Precobeam elements. Rolled sections HE1000M in S460M steel grade (equivalent to W1000x300x350 in Grade 65) are cut into two halves and recomposed in small open box girders in full length of 32.5m. The connection was ensured by composite dowels with puzzle shape.

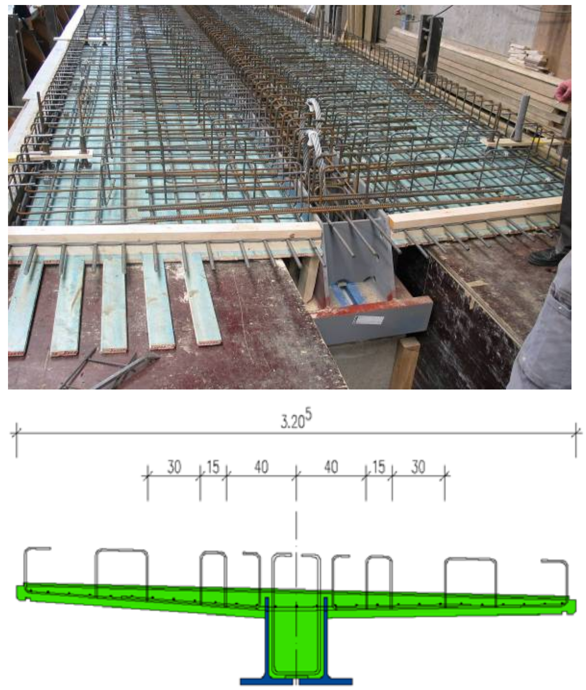

Figure 12: Prefabricated concrete element

The steelwork was then transported to a concrete prefabrication yard. Standard installations for prestressed concrete girders were used to install the reinforcement cages and pour the concrete in quality C45/55.

At this stage we can already understand the interest of the Precobeam technology: the possibility to construct the whole deck with only three prefabricated elements in width 3.205m, in full length of 32.5 with a provisory construction height of 55cm. Such a slenderness during fabrication of nearly 60 is just unconceivable for prestressed concrete elements, who would have needed probably at least 8 prefabricated elements with a site joint on the intermediate pier.

Figure 13: Transport and erection on construction site

With the Precobeam technology the construction phase is therefore reduced to a minimum. After a special transport to the construction site, the three elements were erected at night during the trafic interruption. An height adjustment at the intermediate pier allows for a precompression of the prefabricated concrete part to allow for no cracking in service phase. The high-strength steel flange has enough stress reserves to overtake this without problems.

In a successive phase a topping of 25cm of concrete C35/45 casted in-situ allows for a solidarization of the thee elements. Neither scaffoldings nor formworks are needed. The use of composite elements not prestressed allows for a simple monolithical connection between the deck and the foundations, with frame edge moments only due to live loads.

The bridge entered in service in 2003.

Figure 14: Finished Pöcking bridge

<u>Information:</u>
Bridge owner: Gemeinde Pöcking
Design office: SSF Ingenieure AG
General contractor: Wadle-Ari Bau, Landshut
Steelwork: ArcelorMittal Commercial Sections
Concrete prefabricator: Oberhessisches Spannbetonwerk, Nidda
Tests: Prof. Mangerig, München
Checking: Prof. Mangerig, München

4.2 Poland

The technology has been also applied to various bridges on the highway S7 at Olsztynek – Nidzica sector, in Poland. Wide decks are realized as continous beams over 3 or 4 spans (max. span 18m) with a construction height of 83cm (slenderness L /22).

Precobeam elements are realized out of coupled HE1000A/B/M in S355 (equivalent to W1000x300x272/314/350 in Grade 50) with a slab width of 2.4m. The prefabrication is done directly on the construction site by the general contractor.

The bridges were built between 2009 and 2012.

Bridge	Spans [m]	Width [m]	Skew [gons]	Area [m^2]	Precobeam [-]
MD1	13/ 18/ 18/ 13	18.44 / 17.70	70	810 / 780	6 / 6
MD2	13/ 18/ 18/ 13	10.2	70	430	4
MD3	12/ 18/ 12	17.20 / 18.35	100	720 / 770	6 / 7
MD4	12/ 18/ 12	10.70	100	470	4

Figure 15: Road bridges with Precobeam, S7 Poland

Figure 16: Road bridges with Precobeam, S7 Poland

Information:
Bridge owner: Generalna Dyrekcja Dróg Krajowych i Autostrad
Design office: Europrojekt Gdańsk
General contractor: Energopol - SZCZECIN
Steelwork: ArcelorMittal Commercial Sections
Concrete prefabricator: Energopol - SZCZECIN

4.3 France

In France, the first tender with the Precobeam technology was the overpass of the Arve bridge near Chamonix in 2009. The structure is a frame bridge with main span of 26m with 2 Precobeam elements of variable inertia. Between the two elements, a steel sheeting is positioned as lost formwork in order to realize the foreseen deck width of 7.4m.

The tender is at this day still not launched.

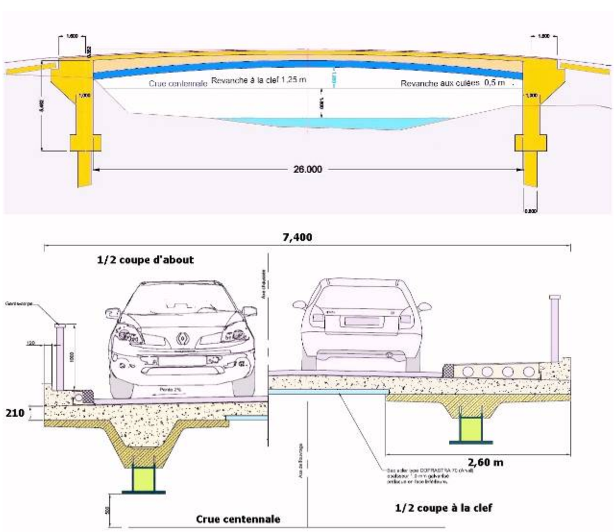

Figure 17: Project for bridge over Arve, Chamonix

5. Duo Precobeam Rail Bridges

In the scope of the refurbishment of the railway line Kielce-Fosowskie (Poland), two railway bridges were realized with the Precobeam technology. Loads had to be upgraded for a heavy rail traffic (LM71 with α = 1.21) with a design speed of 160 km/h. The bridge at km 23.093 over the Łososina river consists with two spans of 16.5m.

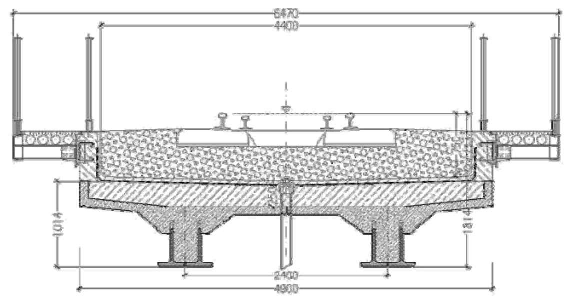

Figure 18: Cross section of one deck

Each railway is supported by two Precobeam elements of 75cm, integrated by an in-situ concrete plate of 25cm, for a total construction height of 1.0m. Rolled sections HE1000x438 (equivalent W1000x300x438) are oxycut and paired into box sections filled up with quality concrete C50/60 to ensure the stiffness of the section. The prefabrication of the composite elements was done directly at the construction site.

Thanks to its clear and relative simple conception, Precobeam have shown to be a possible solution of interest also for railway bridges.

Figure 19: View of the Łososina railway bridge

6. Mono Precobeam Road Bridges

The mono-Precobeam technology was first applied to two road bridges over the railway line Salzburg-Wörgl, in Austria. The first overpass in Vigaun is a frame with three spans of 3 x 26.15m = 78.45m, deck monolithical connected to abutments and intermediate piers.

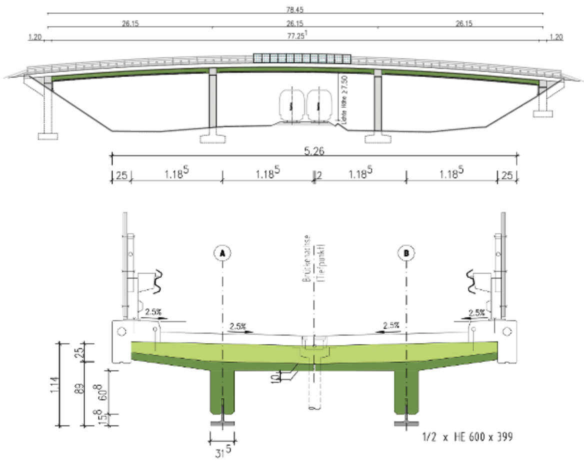

Figure 20: Rail overpass at Vigaun

Two Precobeam elements cover the deck width of 5.26m, with a construction height of 89cm completed by an in situ topping of 25cm (slenderness ratio L / h = 23). Steelwork is realized out of HE600x399 in S460ML.

Figure 21: Construction phases

Figure 22: Rail overpass at Vigaun

The second overpass in Kuchl-Kratzerau is very similar to the first one, with four spans 19.70m / 19.50m / 19.50m / 19.70m. The deck width is realized by three Precobeam elements out of HD400x421 in S355ML.

This bridge marks a step further, since through the initial curvature of the half rolled section it results a prefabricated element with variable construction height (85cm at mid span and 115cm at supports). Beside a material optimizazion from the static point of view, it gives an additional nice esthetic value to the bridge.

The overpass in Vigaun was realized in 2006, whereas the overpass in Kuchl-Kratzerau in 2009.

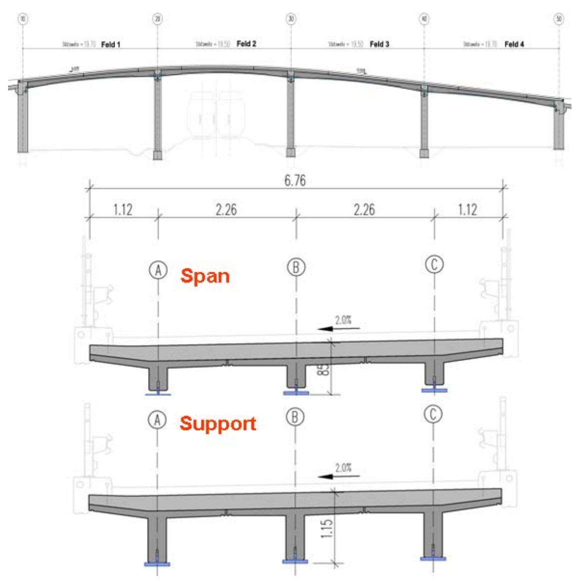

Figure 23: Rail overpass at Kuchl-Kratzerau

Figure 24: Rail overpass at Kuchl-Kratzerau

Information:
Bridge owner: ÖBB DL Büro Linz
Design office: SSF Ingenieure AG
General contractor: Angerlehner, Hoch- und Tiefbau GmbH
Steelwork: ArcelorMittal Commercial Sections
Concrete prefabricator: Röss Bau GmbH Fertigteilwerk
Tests: Technische Universität Wien
Checking: SBVZiviltechniker GmbH

The Mono-Precobeam technology has shown to be very competitive also on the economic side face to prestressed concrete solutions, in particular for this small road bridges. The frame action permits to use only one pier line. The use of composite elements is very robust and permits to have variable inertia, which reduces the deck self weight and ensures a nicer esthetic aspect.

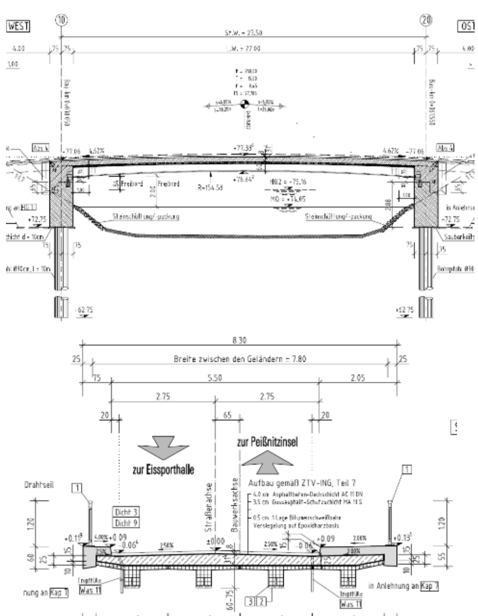

Figure 25: BW 49 an der Eissporthalle Halle/Saale

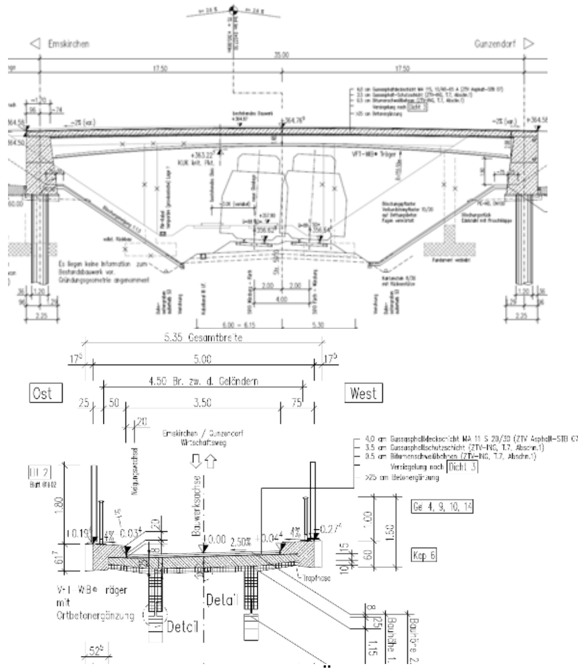

Figure 26: Aurachtalbrücke SÜ

During 2013 two other Mono-Precobeam bridges were tendered in Germany with this concept: in Halle over the river Wilde Saale (23.5m span, Figure 23), the other one in Aurachtal over the railway line Fürth – Würzburg at km 22.1+32 (35m span, Figure 24). Both bridges are at the given day under construction.

Figure 27: Erection phases BW 49

7. Conclusions

In this contribution an overview of recent European recent activities developing the new structural concept Precobeam are presented. This innovative idea should be considered in the future as an alternative to traditional prefabricated pre-stressed concrete solutions in the small span range. Several applications in various European countries realized over the last few years show the interest of this structural concept.

8. Acknowledgments

The Research Fund for Coal and Steel (RFCS) and the Forschung für Stahlanwendung (FOSTA) are kindly for the continuous support in the mentioned projects over the last years.

Special thanks to the railway companies *Deutsche Bundesbahn* (Germany) and *Österreische Bundesbahn* (Austria) for the technical interest and the inputs for building the concept in real projects.

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