CONNECTIONS BETWEEN PRESTRESSED CONCRETE BRIDGE DECKS AND COMPOSITE BRIDGE DECKS – HYBRID CONSTRUCTION

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Abstract
Bridges that can be constructed with prestressed concrete decks economically might lead to difficulties in some spans. These difficulties for example can be river-crossings. Here the question arises what is the best concept for the superstructure. The rigid connection between prestressed concrete bridge decks and composite bridge decks lead to economical solutions. Two applications are given:

The new Isarbridge in Dingolfing/Bavaria shows the combination of prestressed concrete bridge decks in the approaches and composite bridge decks in the river area. In the approach-parts the decks are constructed with prefabricated pc-beams and the plate structure is cast in place. The longer spans are built as composite constructions. For the plate structure of the composite part semi-prefabricated concrete elements are used.

While the Isarbridge is a beam bridge in both parts of the decks the river Donaubridge in Vilshofen/Bavaria connects prestressed concrete bridge decks with an arch bridge deck in the middle span.

The topics of this article are the special problems in the connection zone.

1. Introduction

Trend setting constructioning is increasingly ruled by the optimised choice of materials according to the structural necessities. Moreover, the designing engineer has the advantage to use the achievements of research and development of recent years. This gives the opportunity to assemble new materials, improved material properties, and optimised connectors to newly formed structural elements. This is helped by the growing together of German and also European code regulations for the different materials. In the following, "hybrid structures" are explained by applications in the field of bridge construc-
tions using different materials and systems. Besides the description of the general applicabilities in bridge construction, examples of constructions are given.

2. Intensions and effects of hybrid constructions

The basic idea of hybrid constructions is the appropriation of occurring stresses to suitable structural material. Hence, the conventional approach in engineering applies cheap concrete for compressive stresses, whereas for tensile stresses steel is used. The composite steel-concrete is the best example in this context. In particular for the development of the double composite the stress distribution is obvious.

Extending this approach to the whole structure suggests a combination of different structural systems. Especially in bridge constructioning the design is chosen to build the whole superstructure with the same system. So, for short and medium spans the reinforced or prestressed concrete is preferred, whereas for long spans steel constructions or composite steel-concrete is used. In the case of largely varying spans or because of other limiting conditions, such as river crossings and approaches, or for distribution of loads the combination of reinforced and prestressed concrete with steel or composite structures is conceivable. Some structures even become practicable only by applying hybrid systems. Furthermore, due to the optimisation process these structures are highly cost efficient.

3. Choice of applications in bridge constructioning

The commonly used connectors between steel and concrete are headed studs. They are, in particular for bridge constructioning, used to transmit shear forces only. This way of stress transmission is used for the linking of steel and concrete.

Figure 1 shows one example of such a connecting part. Here, top and bottom flange, and web of the steel beam are equipped with headed studs in a way that load transmission is possible for the appropriate forces (tension, compression, shear). Special treatment is necessary to transfer the stresses within the concrete. Therefore appropriate reinforcement is required. This demands for a careful spatial reinforcement design, since the high reinforcement ratio for different kinds of reinforcement in different directions needs tight fitting.

New developments in composite construction - like the connectors given in Eurocode 4 and e. g. perfobond strips - may yield better solutions for design details of this kind.

Another question by joining several elements is the choice of coupling points. Generally, there are two main possibilities, first the coupling with cross beams at the support points and second in the zone of zero bending moments. The coupling by transverse beams gives the opportunity to use nearly any kind of structural elements and cross sections.
Most suitable are open cross sections and plate structures as well as prefabricated concrete elements. The coupling at the zones of zero bending moments is suggested for prestressed box girders. Thereby, longitudinal tensional forces are taken over by prestressing tendons. Especially with unbonded external post-tensioning this construction is advantageous because no cross sectional areas are intersected.

4. Examples of applications

The application of hybrid structures in the way of combining prestressed concrete with concrete-steel composite is explained by examples of the bridge over the river Isar in Dingolfing and the Donau crossing in Vilshofen.

4.1 Isarbridge Dingolfing

The bridge was built in 1999 and 2000 as a part of the newly planed eastern by-pass of the small city of Dingolfing over the meadows of the river Isar and the river itself. The road has a standard 11.5 m wide two-lane cross-section (RQ 11,5). The height over the terrain is relatively low and the outline is mostly straight with a slight curvature to the right at the southern end. The structure is a nine-span continuous beam designed as deck bridge with the length of 296 m.
The specified design in the invitation to bid suggested spans between 25 m and 46 m with a box girder at a constant depth of 2.30 m. This should have been longitudinal prestressed either by post-tensioned internal tendons or alternatively by external tendons. The substructure was conceived as piled panels and shallow founded box piers.

Figures 2 and 3: Views of the Isarbridge Dingolfing

During the tender preparation, the design concept with its rigid superstructure, governed by only one span length of 46 m, was considered to be uneconomical. In addition, the superstructure would have been built on false work in sections with a large number of coupling points. Thereby, the crossing of the river would have been most complicated. The search for a together economic and pleasing design lead to a combination of two multiple side spans made of prefabricated prestressed girders supported by pairs of round columns and steel composite beams used for the two spans over the river. All sections were connected to assure a continuous spanning beam. The different surface and colour design of the two river spans emphasise their technical and geometrical characteristics.

The special location of the middle pier is especially outlined by the increasing construction height to 2.30 m from 1.70 m at standard cross section. This greater depth is beneficial for structural purpose too, after all during construction as it functions as a two-span beam. Further, the installation of the concrete bottom plate over the middle pier (double composite) was another advantageous application of hybrid design. The choice of steel in sectional change with prestressed concrete made it possible to extend the structure harmonically over the river, even though the length of the spans enlarged to 42 m.

Moreover, the assembly of the girders was possible with cranes located at the riverbanks. The economical usage of steel composite structures - especially in exchange with conventional cross sections of reinforced and prestressed concrete - is met by the permissibility of prefabricated form plates according to the "Allgemeines Rundschreiben Straßenbau Nr. 42/1998" (ARS 42/1998, German circular for road constructioning), because it avoids expensive formwork systems or formwork carriers. Here, the 10 cm thick form plates overhang on both sides and are statically efficient with its full cross section in transverse direction. To resist the compression stress in longitudinal direction
mainly the 23 cm thick in-situ concrete is supplemented. The bonding results from headed studs of 175 mm length and a diameter of 22 mm, which are concentrated in gaps of the form plates.

![Figure 4: Coupling point of steel girder](image)

![Figure 5: View into the cross beam](image)

The rigid connection of the two-span steel composite structure to the side spans formed from prestressed concrete was desired out of the following reasons:

- statical relieving of the long spans
- avoiding of additional joint constructions
- horizontal connection of the whole superstructure whose longitudinal fixed bearings are located at the middle piers.

The cross beams on top of the bank piers are the transition zones between the different structural systems. These beams are design purely of reinforced concrete and consist of a 35 cm thick prefabricated base whereon the prestressed prefabricated beams as well as the longitudinal steel girders during the construction process were placed. The webs of the cross beams where the load is mostly transmitted were filled with concrete afterwards. Parallel to the hardening of the concrete the statical connection is established continuously. This makes the time of concreting become most relevant. For this construction the cross beams were formed when the deck slab of the side spans had nearly reached the coupling cross beams, whereas on top of the formwork girders only formwork panels where placed. The connection of the structural elements before pouring the
in-situ concrete in the river spans lead to a release of the steel beams due to partially fixed-ends. Therefore, smaller cross sections could be used. For compensation of the fixed-end moments the resistance to the tensional forces needed to be assured structurally.

Figures 6 and 7: Coupling of cross beam with load transmission plate

The tensional forces were transferred via horizontal blades with headed studs to the cross beams on the level of the top flange. There, reinforcement loops take the load within the deck slab. To take effect early, not only the webs of the cross beams were filled with concrete, but also a 2 m long slab strip with included support reinforcement was concreted. The compressional forces were treated alike with bottom blades and headed studs. Shear was taken by vertical plates in extension of the webs. The additional in-situ concrete affects the nine-span continuous beam structure without composite action, whereas service loads, live loads, and compulsion act on the final composite structure.

4.2 Donaucrossing in Vilshofen

Another example for the combination of post-tensioning and composite action is the newly built bridge over the river Donau near Vilshofen, Germany.

After the expansion of the clearance width for ships from now 49 m to 90 m, a renewal of the existing eight-span road bridge including the demolition of two piers in the river (reduced number of spans) was announced. According to the design concept provided by the client the existing deck bridge, an orthotrope steel structure built in 1978, was apriori slided transversely to auxiliary supports. This enabled a continuous traffic crossing over the river during construction time. The design suggested a steel arch structure for the large span with a length of 116 m. It was further intended to rigidly connect the new composite steel superstructure to the south approach with two short spans of 25,80 m.
To the north of the steel arch an existing part, despite of its smaller width, was meant to be redesigned as a three-span structure and connected by an expansion joint. It should have been moved back to almost its initial location. And again, an alternative tender proposal, introduced by Bilfinger+Berger Bauaktiengesellschaft, with hybrid constructions was less costly and finally built.

Starting with the new large middle span with its 15° inclined double steel arch and a hanging composite steel roadway, the northern as well as the southern post-tensioned concrete parts were rigidly joint to the roadway slab of the arch. Despite of the abandonment of 800 m² of existing bridge area with its restricted width and the instead newly built 1100 m² area bridge deck, the design of the structure outside the arch with precast prestressed girders proofed to be very economical. The advantages of the hybrid solution of coupling prestressed girders with the arch structure are for this example:

- minimisation of costs
- uniform roadway geometry for the whole length of the bridge
- no reduction of the roadway from 3 to 2 lanes due to restrictions of the existing structure
- no expansion joint at the end of the arch
- reduction of road closing time due to the left out of the sliding back of the existing bridge part.

The arch structure is connected to the adjacent parts at the end of the arches near the cross girders. These are primarily the end cross connectors of the arch and therefore steel composite elements on deck level. Secondary, a massive in-situ concrete part is added to mainly transfer the forces from the three longitudinal deck girders of the arch structure to the five webs of the prestressed girders. The sectional optimisation of the longitudinal structural elements leads, as a matter of course, to additional stresses in the joints such as torsional moments and splitting tensional stresses due to change of force direction.
Here, the cross beam between the main span and the approach have a width of 1.80 m with 40 cm designed as torsional rigid steel box and the rest executed with B 55 concrete. The normal and shear forces are again transferred by studs. The normal forces in the top and bottom flanges may alter from tension to compression and vice versa due to changing traffic load moments. Negative moments at support are usually absorbed by reinforcement within the deck slab. The structural analysis showed that, because of the stiffness ratio of the arch and the adjacent parts, larger positive moments at support occurred for traffic loads on half of the arch. These moments had to be transferred to the prefabricated longitudinal girders within the cross beams.

Therefore, in the bottom zone additional threaded bars (Gewi Ø 32 mm) were placed to connect tensional reinforcement (see figure 11). The design of the steel parts of the cross girder with the required diaphragms and studs can be seen figure 10. For this combination it becomes obvious that a unification of the standards for concrete construction on one hand, and for steel construction and steel-concrete composite construction on the other hand is desperately needed. According to the current German standards the question arises whether the concrete encased end cross girder of the arch span is treated as a concrete structure (factor of safety is 1.75) or treated as a steel composite structure (factor of safety is 1.4)? With the introduction of the new generation of standards this contradiction would be solved.

5. **Final statement**

This report shows how the combinations of reinforced and prestressed concrete, as well as steel and composite elements yield hybrid structures for bridge constructioning. These structures are characterised by its robust load bearing behaviour, low maintenance demand, and its high efficiency. The use of similar structures will increase in the future.

6. **References**