COMPOSITE BRIDGES WITH PRECAST CONCRETE SLABS

P. SCHAUMANN
Univ.-Prof. Dr.-Ing.
J. UPMEYER
Dipl.-Ing.

University of Hanover
Institute for Steel Construction
Appelstraße 9A
30167 Hanover / Germany
Tel.: 01149-511-7623781
Fax.: 01149-511-7622991
E-Mail: schaumann@mbox.stahl.uni-hannover.de

Summary

This contribution introduces the research and development in composite road bridge superstructures in Germany in the short and medium span range. It starts with the report about a research program using hot-rolled steel sections. The investigations resulted in a modular design system comprising a multi-web composite section with precast partial depth concrete slabs. Further developments led to type design calculations with precast partial depth slabs for composite road bridges crossing highways. Currently initial design is carried out for composite road bridges using precast full depth reinforced concrete slabs. The significant details such as shear connection between slab and steel girder as well as in situ joints of the precast slabs have been worked out. Finally some completed composite bridges are introduced, where actual research results have been taken into account. At present German design standards are still based on the global safety factor concept. Composite road bridges represent an economic solution in the short and medium span range. Decisive for the success of these developments is the current low price of structural steel and the high rate of prefabrication concerning steel construction as well as precast concrete members.

1 INTRODUCTION

In Germany nearly 90% of the road bridges are reinforced or prestressed concrete bridges. In an European comparison the quota of composite bridges is very low. The reunification of Germany and the collapse of the Iron Curtain led to a massive expansion of the German highway net during the last decade. Therefore numerous short and medium span bridges are required. In view of this background simple, quickly erecting and competitive composite bridge systems for renovations, widenings and new bridge constructions have to be introduced.

At present German standards for design calculations of bridge superstructures are still based on the global safety factor concept. The following contribution covers bridges of the German bridge class 60/30. That means the highest level of traffic loads comprising a heavy lorry with a total weight of 600 kN and a one axe load of 200 kN. In future design calculations will be carried out according to the Eurocodes based on the partial safety factor concept.

This contribution describes the development of composite bridges with precast concrete slabs in Germany. At the beginning a research program with hot-rolled steel sections is introduced. Afterwards a type bridge design using precast partial depth slabs is presented. After that an initial design with full depth precast slabs is considered. At last some completed bridge projects are introduced.

2 RESEARCH PROGRAM WITH HOT-ROLLED SECTIONS

2.1 Purpose

On the symposium ”Taking Steel Constructions into the 20th Century” in May 1990 in Luxembourg *Roik* proposed the use of hot-rolled beams for composite road bridges in the range of short and medium spans. In particular *Roik* suggested a sequence of concreting according to Fig. 1 with concrete transverse girders at the supports and at the abutments. This sequence of concreting leads to a simplified steel construction and reduced hogging moments at the supports. Tolerances can be compensated easily during erection.

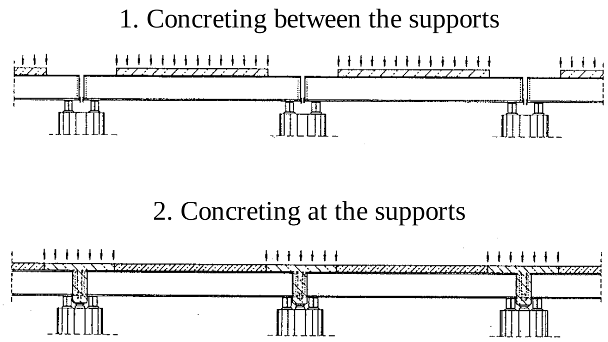

Figure 1. Sequence of concreting

Within the following years the author worked out a research program sponsored by *ARBED*, Luxembourg, one of Europe´s largest rolling mills, to optimise design and construction of composite bridges using hot-rolled steel girders [1,2,3]. *ARBED* intended to take advantage of the latest developments of hot-rolled steel sections (depth up to 1100 mm and yield strength up to 460 MPa) for bridge construction. The research program comprised an experimental and a theoretical part with the following items.

- Stability failure of rolled beam in composite sections in hogging moment regions
- Application of high strength structural steel (S 460, yield strength of 460 MPa) in bridge building
- Structural behaviour of the deck when using precast partial depth slabs as permanent formwork
- Detail solutions for main girders connection
- Demonstration of erection principles

2.2 Tests

The total test program consists of different tests on five test specimens. The specimens represent full scale parts of composite bridge sections. The essential features are summarised in figure 2.

The test program provides ultimate limit state tests on all test specimen under static loads. Special attention was paid to the cracking of the concrete slab. The rolled shapes were chosen to be HE-900A, steel grade S 460 (yield strength 460 MPa). The total thickness of the slab was 280 mm.

The rapid and easy erection with precast partial depth concrete elements with a thickness of 80 mm used as permanent formwork to the in situ deck slab was demonstrated in test 2. In tests 1, 2 and 5 hogging moment regions of length half of the span were used to create moment gradients more unfavourable for the stability problems than would occur in practice.

Tests 3, 4 and 5 deal with main girder connections. In tests 3 and 4 a connection near the supports with moderate bending moments and high shear forces is considered. In order to simulate the effect of alternating loads, two different test configurations of girders 3 and 4 are required. This is a configuration to simulate positive and negative moments and shear forces in the connection region. The connection has been made only with web cover plates and high strength bolts.

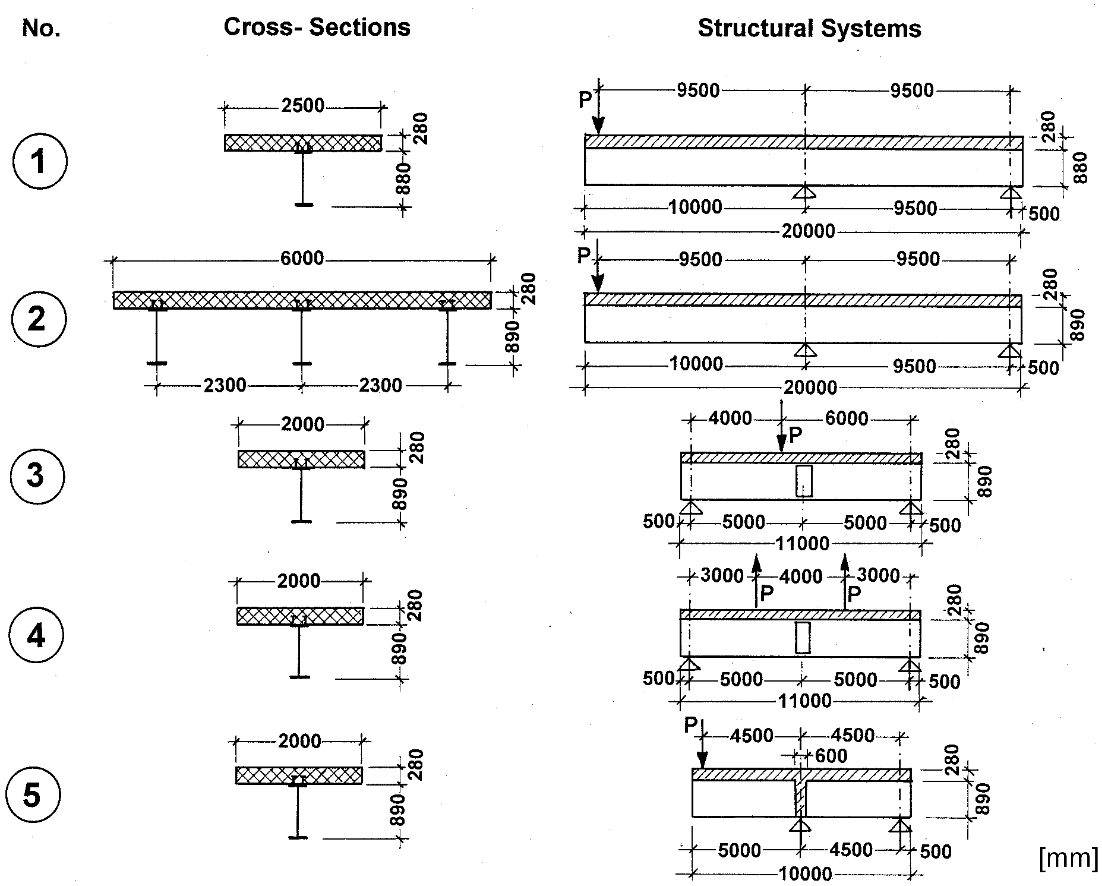

Figure 2. Parameters of the tests

At test 5 a main girder connection was carried out in the zone of high negative bending moments and high shear forces using a concrete transverse beam. In addition the concrete slab has been tested in the ultimate limit state.

2.3 Results

The experimental investigations demonstrated a ductile behaviour of the beams. Full plastic moment capacity predetermined by calculations could be verified by tests 1 and 2 (Fig. 3 and 4).

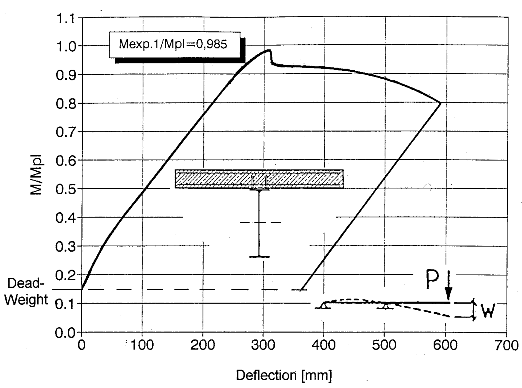

Figure 3. Deflection history of beam 1

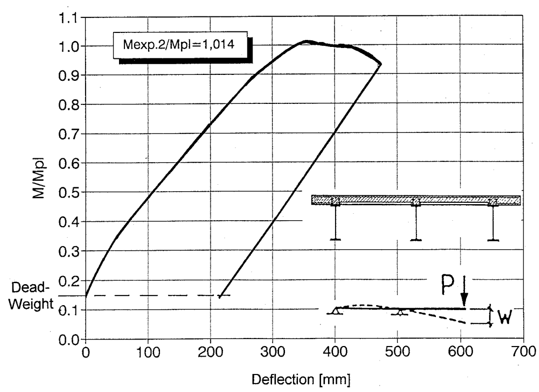

Figure 4. Deflection history of beam 2

The typical stability failure like plate buckling in the steel web and lateral-torsional buckling of the lower flange could be observed when reaching the plastic ultimate limit state. The tests proved that no transverse girders are required to guarantee the stability of hot-rolled steel sections at ultimate load levels with respect to internal supports of multi-span composite bridges. All given parameters and influences like vertical stiffeners at the support, restraint by the cracked concrete slab, the combined stressing due to shear and bending and the non-linear elasticity of the bottom flange have been taken into consideration when calculating the elastic critical moment with a recently developed computer program [4,5].

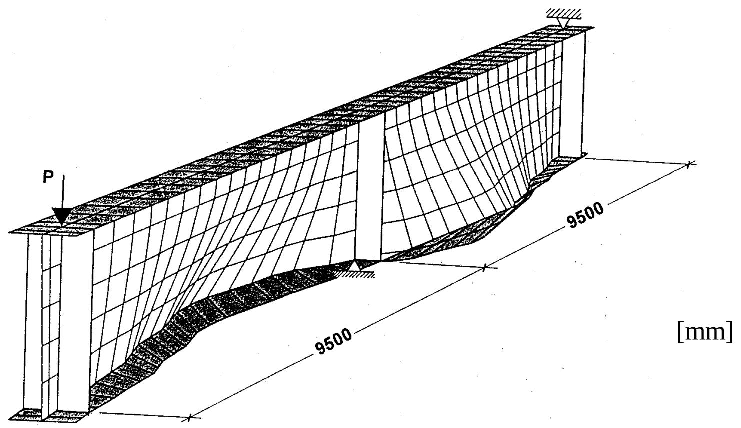

Figure 5. Natural form of the test specimen calculated by the program BDK2 [4]

The beam connections in tests 3 and 4 had been designed with the moments and forces of a continuous beam. The design of the connection is governed by the shear resistance of the high strength bolts (Fig. 6). The tests showed pure elastic behaviour at serviceability limit state. The ultimate load reached more than four times the service load. The crack widths in the concrete slab were in the permitted range.

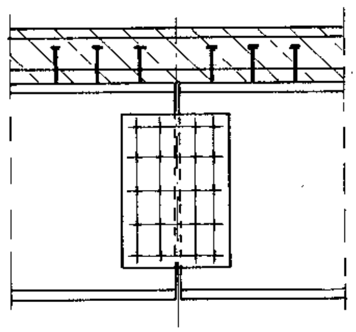

Figure 6. Main girder connection

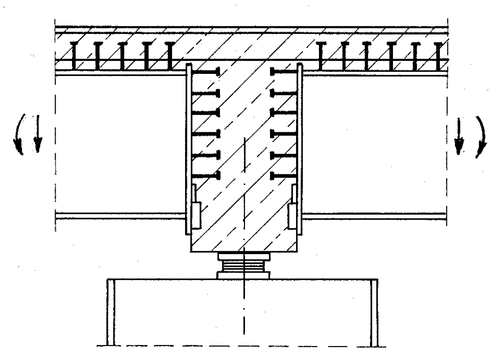

Figure 7. Concrete transverse beam

The main girder connection in test 5 was subjected to hogging moments and shear (Fig. 7). The negative bending moment causes a couple of forces with a tension force in the slab and a compression force at the lower flange of the steel beam. The tension force is transmitted by the longitudinal reinforcements in the concrete slab. Compressive forces are introduced into the concrete by a load-spreading plate. Shear forces are transferred into the concrete by the horizontal studs. In serviceability limit state no crack between cap plate and transverse concrete beam and no cracks in the slab occurred. The ultimate load reached more than twice the service load.

3 TYPE DESIGN WITH PRECAST PARTIAL DEPTH SLABS

In the year 1997 type design calculations have been worked out for composite bridges crossing highways normally comprising six traffic lanes [6]. In this case bridge superstructures vary only insignificantly regarding spans, static system and cross section1. The axis of the overpass is assumed to go at a right angle to the highway. Under these conditions design results in two-span bridges of 54.0 m length (Fig. 8). In these cases the German bridge class 30/30 has been taken into account.

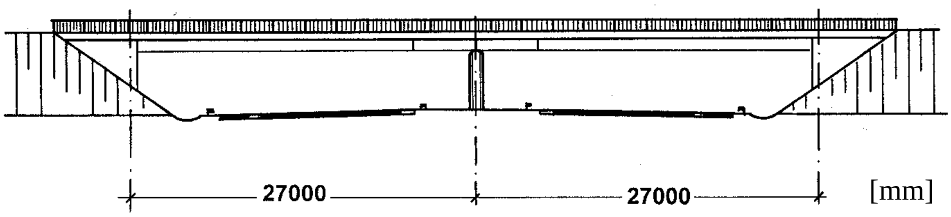

Figure 8. Elevation

The following bridge sections have been analysed:

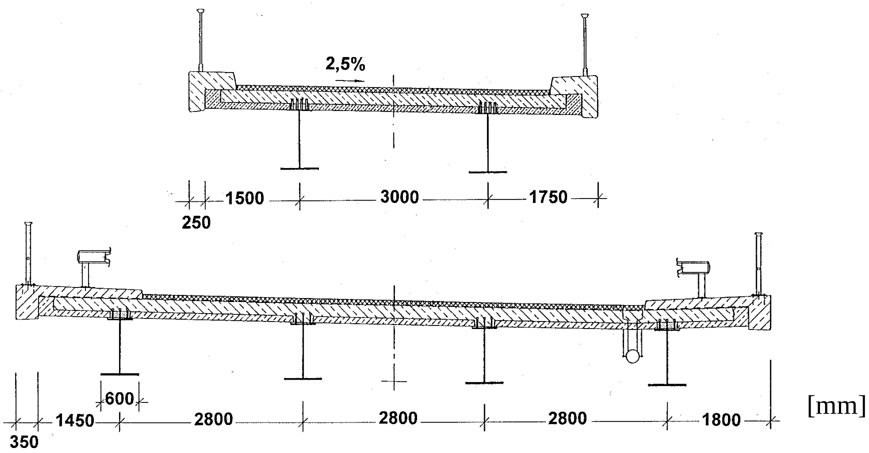

Figure 9. Type design sections [6]

Furthermore cross sections with box girders were assessed. For these types of bridges design calculation, formwork drawings and reinforcement drawings for the concrete slab and steel construction drawings including steelwork sketch details are available. Notes are given for erection. Building specifications are given and estimated costs are calculated [6].

4 DESIGN WITH PRECAST FULL DEPTH SLABS

4.1 General

For bridge superstructures passing across highways a composite bridge design was worked out with precast full depth sections for the concrete slab [7]. Design conditions considering spans have been taken as in chapter 3 (see. Fig. 8).

The superstructure of the bridge construction comprises two main girders in order to create a statically determinate system in transverse direction for the prefabricated slab. Hence, imposed deformations during erection are largely reduced. The optimisation of the slab led to a main girder distance of 7.30 m. The main girders are welded steel sections, steel grade S 355 (yield strength 355 MPa). The transverse girders and stiffeners are fabricated from S 235 (yield strength 235 MPa). In the calculation a concrete strength class of C 30 (cylinder strength 30 MPa) has been taken into account on the safe side. In the precasting works a concrete strength class of C 45 (compressive cylinder strength 45 MPa) or even a higher quality is obtainable.

Design has been carried out based on German standards assuming the bridge class 60/30. It could be demonstrated, that this type of composite bridge with precast full depth concrete slabs can be designed in full accord with German standards.

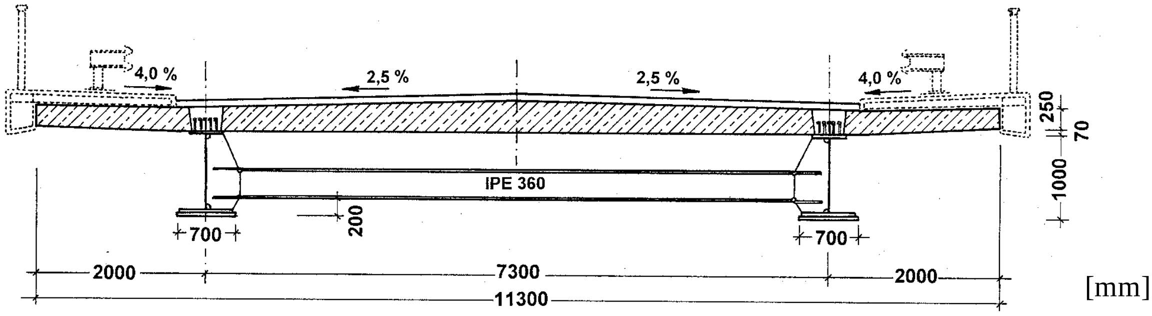

Figure 10. Section

4.2 Precast concrete slab

The bridge slab comprises 21 reinforced precast concrete sections with a length of 2.50 m, a width of 11.30 m and a thickness varying in transverse direction from 280 mm at the main girders up to 380 mm at midspan. Each piece weighs 18.2 tons.

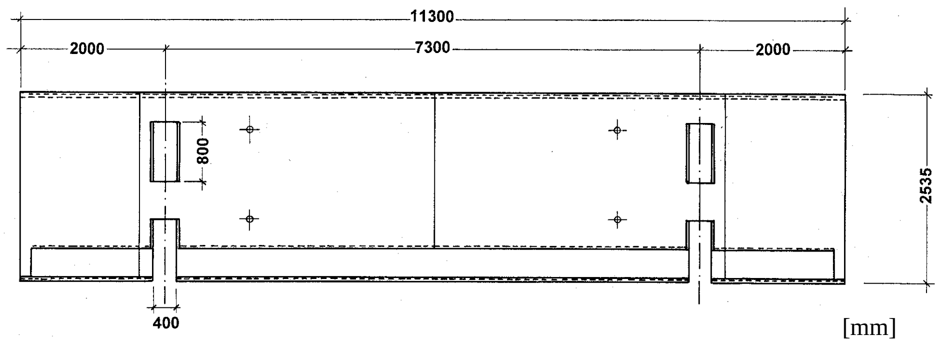

Figure 11. Precast slab (horizontal projection)

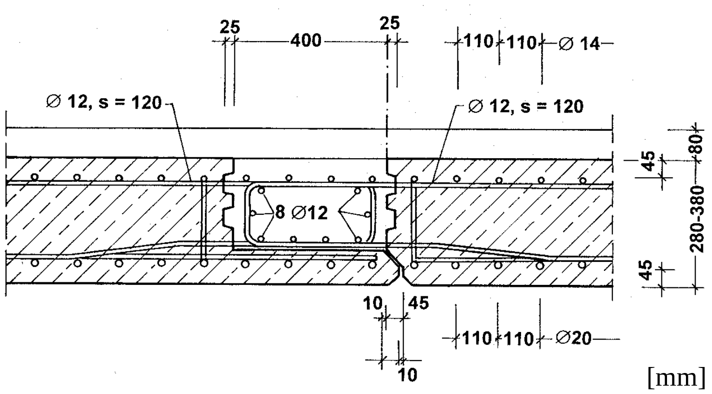

Figure 12. Joint configuration of precast slabs

Rectangular pockets for the shear studs are opened up conically formed (Figure 13 and 14). At the final state shear forces are transmitted into the concrete slab by the concentrated stud groups. The shrinkage of the infilled concrete is decreased by applying special non-shrinking concrete.

For the structural analysis the precast slab has been assumed to be continuous in both the transverse and the longitudinal direction. The design of the joint having a profiled concrete surface (Figure 12) has been carried out considering the corresponding forces and moments. When calculating the resistance to vertical shear at the joint only the shear reinforcement but not the concrete is taken into account. The cracking of concrete is controlled according to [8]. The longitudinal reinforcement splice of the slab in the joint is executed as a full strength connection with loops (Fig. 12). The required anchorage lengths have to be considered. In order to fulfil the high requirements of precision reinforcement work in the precasting works has to be carried out using templates.

4.3 Main girders

The main girders have been designed under the following assumptions. Dead weight and erection loads act on the steel section whereas surfacing loads, traffic loads and secondary loads act on the composite section. The result is a welded plate girder with a height of 1.28 m including 280 mm slab thickness. To guarantee stability against lateral torsional buckling of the main girders during erection cross girders are required at a distance of 5.40 m from the pile. In order to use identical precast slab elements over the whole bridge length a settlement of the middle support is necessary. The settlement is 220 mm under the given geometrical conditions.

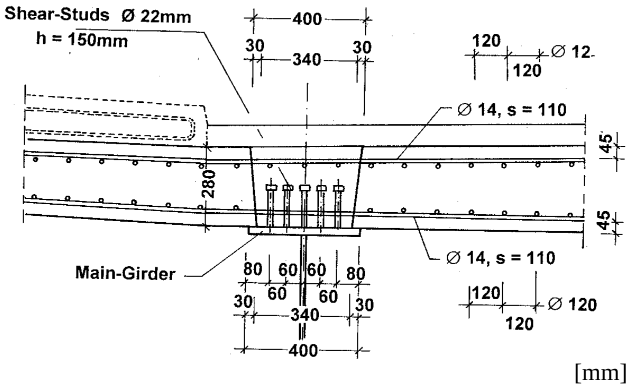

Figure 13. Shear connection

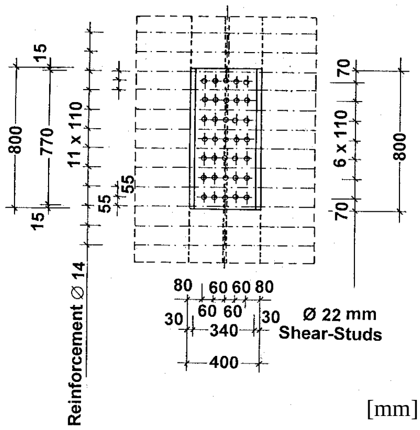

Figure 14. Arrangement of connectors

4.4 Crack control

The concrete slab may be designed without prestressing, because cracking control could be proved based on German standards, which are identical to the European regulations in [9].

The assessment of crack control comprises:

- Requirement of minimum reinforcement on the basis of the crack forces to limit single cracks in the stage of single cracking
- Limiting the maximum diameter and the maximum spacing of the reinforcing bars in the stage of stabilized cracking

4.5 Fatigue resistance

Currently fatigue design according to valid German standards is not relevant for composite road bridges. In future fatique resistance has to be determined according to the design concepts of the Eurocodes. The load models for fatigue design are different from the load concept for the stress analysis. According to Eurocode 4 part 2 fatigue strength design is carried out on the basis of a heavy single lorry with four axles, one axe load 120 kN, and the total weight of the lorry 480 kN. The basis of the previous design of the cyclical loading with reference to the traffic loads used in German standards is given up.

In view of future developments fatigue design has been carried out according to Eurocode 4 Part 2, 4.12.6 (simplified method) for the bridge presented here. For this every component of the bridge is treated separately such as the concrete slab, considering concrete as well as reinforcing, and the structural steel members. Simplified assessment according to Eurocode 4 Part 2 [9] is given by:

$$\gamma_{Ff} \cdot \Delta\sigma_E \leq \frac{\Delta\sigma_{Rk}(N^*)}{\gamma_{Mf}}$$

with

γ_{Ff}	partial safety factor for the fatigue loads
γ_{Mf}	partial safety factor for the fatigue resistance of the material
$\Delta\sigma_E$	damage equivalent stress range
$\Delta\sigma_{Rk}(N^*)$	characteristic stress range at N* cycles from the appropriate S-N-line
N*	$= 10^6$ for the reinforcement and the concrete in the compressive stress area
	$= 2 \cdot 10^6$ for the structural steel and shear studs

The result of the calculations was that fatigue design is only relevant for the main steel girders.

5 COMPLETED BRIDGE PROJECTS

In the last years about 50 composite bridges with precast partial depth slabs have been erected in Germany. In the following three of these projects are introduced briefly.

The bridge over the river *Nahe* near *Niederhausen* is a four span composite bridge with spans of 25.87 m (Figure 15) [10]. The cross section comprises five hot-rolled main girders (HL 1000x554, S 355) spaced 1.65 m with a precast partial depth slab (d=80+220=300 mm, cylinder strength 35 MPa). The transverse beams have been executed as reinforced concrete sections at the supports. To be able to transmit the compressive forces in the lower flanges of the main girders through the concrete transverse beam a continuous steel plate was arranged. The sequence of concreting is described in figure 1. Design has been carried out based on German standards with the highest level of traffic loads, bridge class BK 60/30. In addition an abnormal heavy lorry with total weight of 4358.0 kN was taken into account.

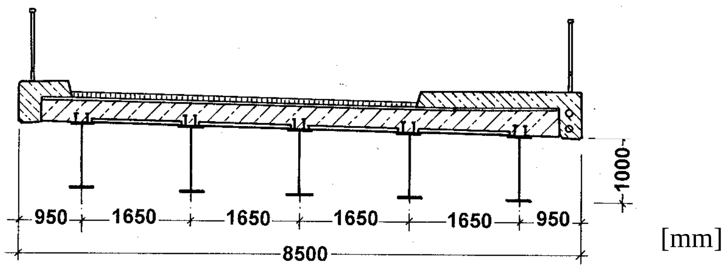

Figure 15. Bridge over the river *Nahe* near *Niederhausen* - cross section

The bridge across the river *Emscher* in *Oberhausen* is a single span composite bridge with 40 m length for public traffic lanes. Hot-rolled beams HL-1100 M, steel grade S 460, spaced 2,20 m are used. The transverse beams at the abutments have been designed in reinforced concrete. Design has also been carried out based on German standards, bridge class 60/30, additionally a tramway has been considered. The slenderness of the bridge with a construction depth of 1,28 m is very high (L/29).

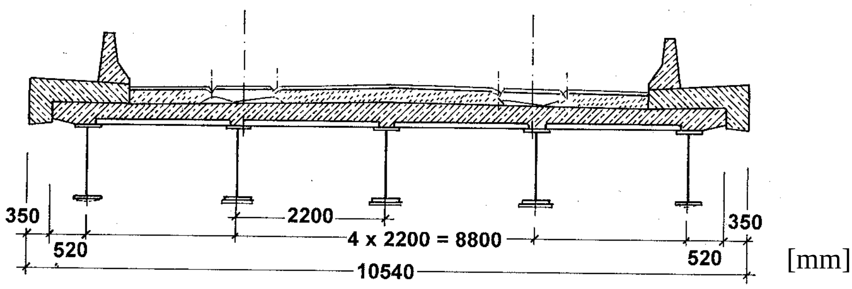

Figure 16. Bridge crossing the river *Emscher*

The composite bridge crossing the highway Berlin-Dresden near *Schwarzheide* is a 2-span bridge with spans of 31.14 m comprising 6 welded plate girders (steel grade S 355) spaced 2.23 m and a precast partial depth slab (d=80+200=280 mm, cylinder strength 35 MPa). The transverse beams at the abutments have been executed as reinforced concrete sections, the transverse beam at the pile is a welded steel section.

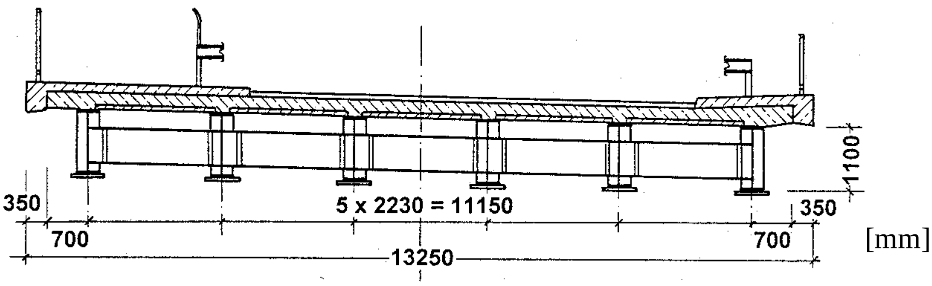

Figure 17. Bridge crossing the highway near *Schwarzheide*

6 CONCLUSION

In this contribution the development of composite road bridges with precast concrete slabs in Germany during the last decade is introduced. Research, design and practical execution are considered.

The general attitude of German authorities concerning solutions with prefabricated concrete members in bridge building is very conservative. The main counter-arguments are doubts concerning the long-term corrosion resistance in the joints under the action of frost and deicing salt. Therefore structural detailing has to be carried out very carefully particularly in the interface between steel girder and concrete slab and at the joints of the slab. In this context much work has to be done for convincing the clients.

The total bridge construction mainly comprises concrete members like abutments, piers, slabs and caps. Therefore the construction must be adapted to the features of the main contractor. That requires a high rate of prefabrication for the steel construction. The use of precast concrete slabs contrary to in-situ slabs is favourable for composite construction.

Other advantages such as short construction time and decreased traffic delay are not considered in this paper, so that the price is normally decisive for the composite construction. At the moment in Germany the price level of welded steel construction is very low, because competitive steel contractors from Eastern Europe are pressing on the market. Therefore hot-rolled beams are increasingly substituted by welded sections. From today's view composite road bridges become an economic alternative to prestressed concrete bridges in short and medium span range from 20 to 45 m.

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