Strengthening of bridges with epoxy bonded steel plate

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Renforcement des ponts par des tôles d'acier collées

Verstärkung von Brücken mit angeklebten Stahllaschen

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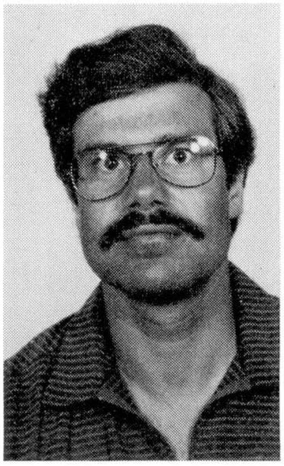

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SUMMARY
Numerous prestressed concrete bridges in the FRG, built by spanwise construction, show cracks in the working joints. For the remedy of these cracks the strengthening with epoxy bonded steel plate is a possible solution to reduce fatigue stresses of the prestressing steel and for crack control. After discussion of the efficiency the actual application of the method for a bridge is presented.

RESUME
De nombreux ponts en Rép. Féd. d'Allemagne, dont les travées ont été construites séparément, montrent des fissures dans les joints de construction. Des tôles d'acier collées représentent une bonne solution pour renforcer la construction. L'utilisation de ces tôles permet de réduire les contraintes de fatigue de l'acier de précontrainte et de contrôler les fissures. Après avoir discuté de l'efficacité du renforcement, un exemple d'application à un pont est décrit.

ZUSAMMENFASSUNG
Zahlreiche ältere Spannbetonbrücken in der BRD, die feldweise hergestellt worden waren, zeigen Risse in den Koppelfugen. Zur Sanierung dieser Risse eignen sich angeklebte Stahllaschen, mit denen die Ermüdungsbeanspruchung des Spannstahls und die Rissbreiten reduziert werden können. Nach Erläuterung der Wirksamkeit der Verstärkung wird deren Anwendung bei einem Brückenbauwerk beschrieben.

1. INTRODUCTION

During the past decades numerous prestressed concrete roadway bridges were built in the FRG employing the method of in-situ spanwise construction. These multi-span continuous bridges are mostly hollow-box beams. The working joints are in the points of contraflexure where usually all of the tendons are coupled. Many of the bridges exhibit more or less severe cracks at the joints. Usually, the bottom slab of the box girder is traversed by a crack of large width. This crack rises into the webs with diminishing width, thereby crossing the lower tendons and couplings. The main cause of these cracks is a temperature restraint, unaccounted for in previous designs [1]. In combination with other actions tensile stresses at the bottom arise and overcome the very low concrete tensile strength at the joint. As the reinforcement ratio of the bottom slab was often very low, yielding of the steel occurs and wide residual crack widths are formed. Due to transformation of the cross-section into the cracked state the durability of the reinforcement and of the tendons in connection with increased fatigue stresses is endangered. Thus, the necessity for repair arises, for which the strengthening with bonded steel plates, positioned in the interior of the box section, is a promising method and for which positive experiences were already gathered in several countries.

2. EFFICIENCY OF BONDED STEEL PLATE REINFORCEMENT

The repair of cracks in joints by epoxy resin injection alone is not a sufficient countermeasure because the highly probable repetition of thermal restraint may cause either new cracks or the opening of injected cracks. Therefore, besides crack injection also additional reinforcement - provided for by the bonded steel plates - is necessary to reduce the amplitude of fatigue stresses and the crack widths as well.

The efficiency of the bonded steel plate reinforcement with respect to fatigue stresses in the prestressing steel is shown by Fig. 1. The base moment M_o is superimposed by the moment M_{te} of the first high thermal restraint. Thereby, the cracking moment M_r is transgressed. The moments due to traffic loads cause a fatigue stress range $\Delta\sigma_p$ which exceeds the stress range in the uncracked section. After strengthening of the section the slope of the steel stress-moment-curve will be diminished. Thus, by choice of a suitable cross-section of steel plate the stress range may be reduced to the admissible value as predetermined by acceptance tests.

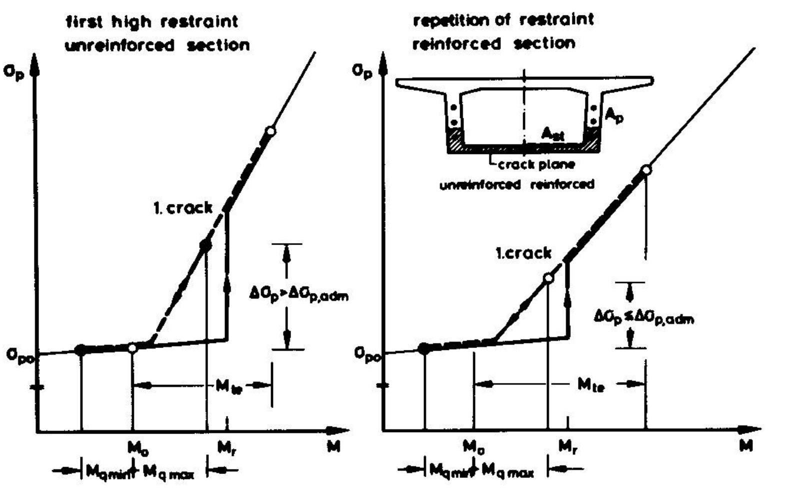

Fig. 1 Efficiency of bonded steel plate strengthening with respect to fatigue stresses in prestressing steel of joint

The efficiency of the additional reinforcement with respect to the steel stress of the regular reinforcement and to the crack width is depicted in Fig. 2. Due to the steel plate the steel stresses are relieved once a new crack is formed by repetition of restraint. After strengthening, both reinforcement and steel plate operate in the elastic range, thus, contracting the widths of possible new cracks without virtual residue.

3. RESEARCH WORK

Prior to application of this repair method extensive tests had to be carried out to assess the influence of the numerous parameters of strength and deformability of the composite steel plate - epoxy resin glue - reinforced concrete. The tests were financed by the Federal Ministry of Traffic [2],[3],[4].

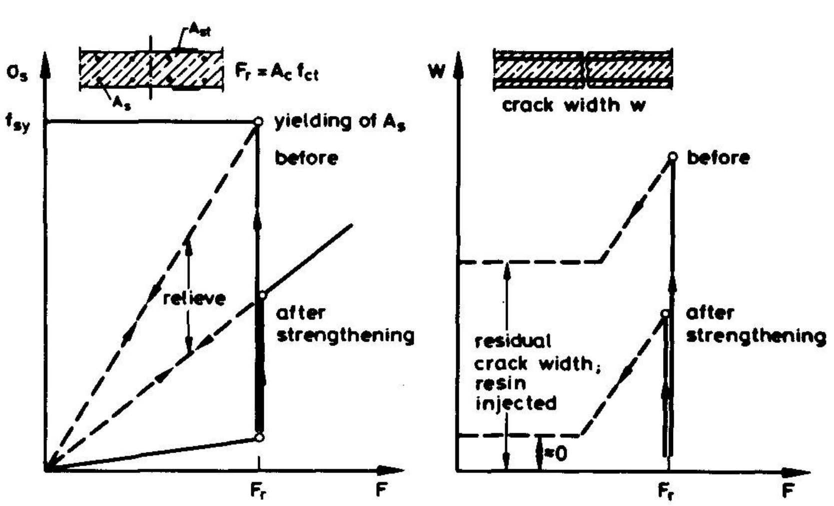

Fig. 2 Influence of strengthening on the steel stress of the reinforcement and on the crack width

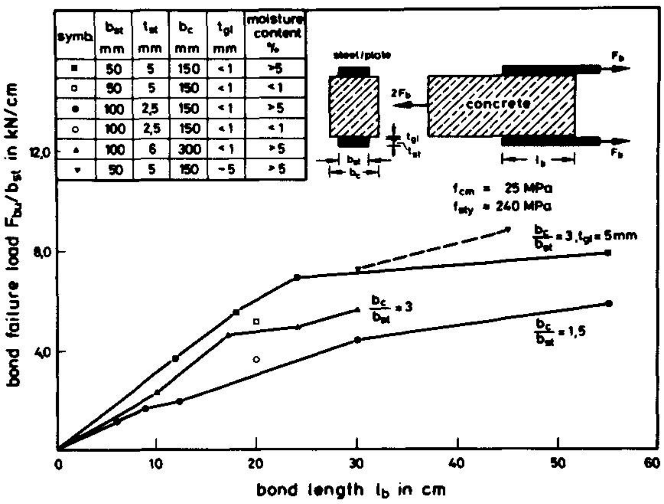

Fig. 3 Bond failure load as a function of bond length and of b_c/b_{st}

The research consisted two parts. In the first part basic experimental work was conducted to study the following parameters of bond strength:

a) concrete
   strength, carbonation moisture and planeness of surface

b) steel plate
   strength, planeness and surface condition

c) glue
   type, thickness of glued joint, ambient conditions during work and after

d) type of loading
   short-time, long-time or dynamic loading

e) climate
   humidity and temperature during service

f) geometry
   relation between dimensions of concrete and plate

Then, applied research followed in which the behaviour of reinforced concrete members of realistic size with and without strengthening was studied.

From the first part of research, Fig. 3 shows the influence of the bond length on the bond failure load per unit width of the steel plate (short time tests). The most important influence is exercised by the bond length. Up to a bond length of 30 cm the bond failure load shows an approximately linear increase. Beyond this length the increase becomes small with the tendency to approach a limit value of the bond strength. A thickness of steel plate of 5 to 10 mm and a geometry ratio $b_c/b_{st} \simeq 3$ seem to be optimal. Several epoxy glues, especially formulated for this application, were tested without showing significant differences in strength. With a suitable glue and adequate preparation and fabrication of the bonding joint, bond failure always occurs in the concrete several millimeter below the joint. Moisture and carbonation of the concrete surface region are of little influence. Up to a thickness of the glue of 5 mm the thickness exercises no significant influence. The dynamic strength proved to be satisfactory.

In the second part of the research work the composite action of reinforced concrete members strengthened with bonded steel plates was studied. At the onset of cracking the bottom slab of a box girder will be approximately subjected to axial tension. Thus, the specimens with a cross-section of 15 cm/50 cm and the length of 3,40 m had to simulate this situation. They were reinforced with 4 deformed bars of 10 mm diameter (grade 420/500). The cross-section of the steel plate was chosen to be twice and four times of the reinforcement's cross-section. The tests showed that the combined yield force of the two steel materials could be activated prior to bond failure. Up to failure the deformation and cracking of the strengthened specimens corresponded to r/c-specimens reinforced with same total steel area but as deformed bars. Fig. 4 shows typical results [2]. On basis of the test results rules for design and for the practical execution of the strengthening with bonded steel plate were developed. An alternating force during the hardening of the glue does not harm bond provided certain limits are not exceeded. This finding is of great practical consequence for the repair of bridges whose traffic flow must be kept up during repair.

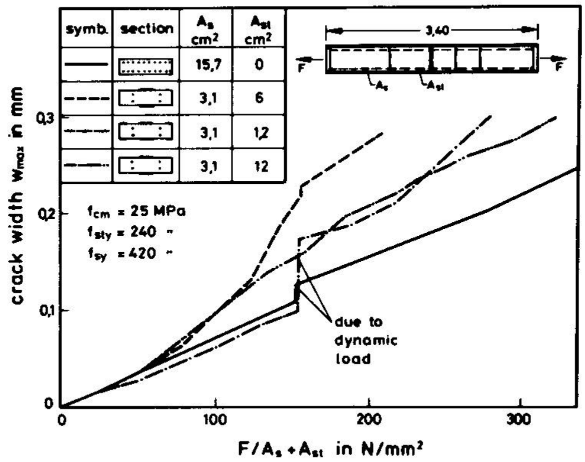

Fig. 4 Width of largest crack, depending on load and strengthening ratio

4. PRACTICAL APPLICATION

In order to gain practical experience with this method of strengthening its application was decided on for the Sterbecke Bridge near Hagen in 1980. This motorway-

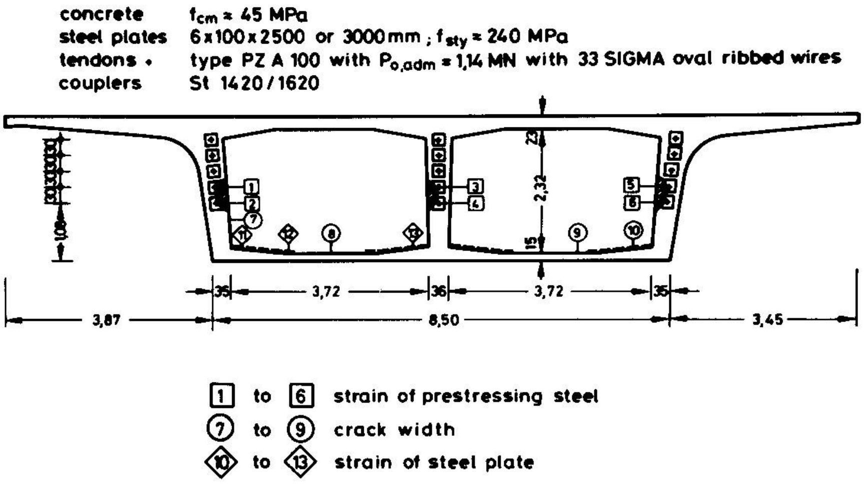

Fig. 5 Cross-section of bridge and other data

bridge consists of two separate superstructures with box sections as shown by Fig. 5. It is continuous over 7 spans of 40 m each. It was built spanwise with all of the 15 tendons being coupled at the joint near the points of contraflexure. In all working joints the bottom slab was cracked; the crack plane extended into the webs, passing the lower couplings. The necessary cross-section of the bonded steel plate reinforcement was chosen to reduce the calculated stress-range of the prestressing steel in the coupling to the admissible value of the prestressing system. The arrangement of the plates is depicted in Fig. 5. The length of the plates was chosen to cover the region of possible concrete tensile stresses at the bottom due to repeated restraint and other actions.

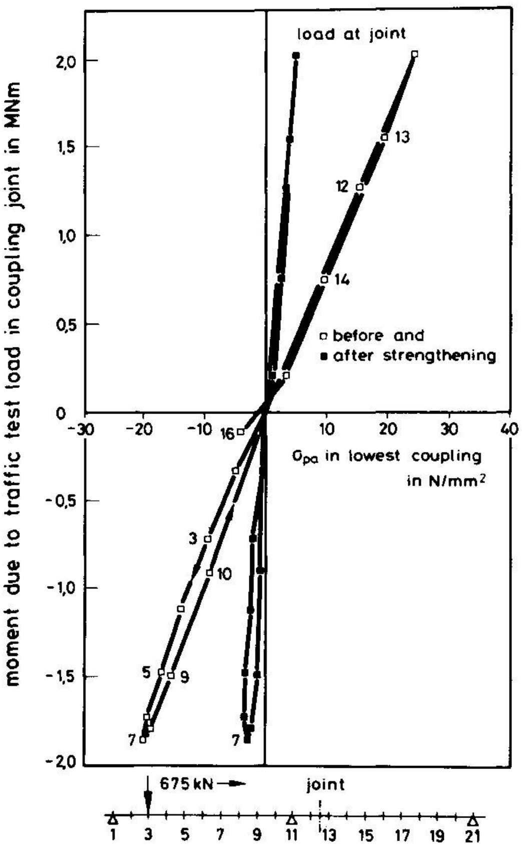

Fig. 6 Stress amplitude of prestressing steel of the lowest coupling, depending on test load moment

In order to assess the efficiency of the strengthening extensive on-site tests were performed prior and after strengthening. The test loading was executed with three 22,5 tons lorries which travelled along the bridge in different patterns. Fig. 6 shows the stress amplitude of the prestressing steel at one of the lowest couplings as a function of the moment at the joint due to the lorries travelling side by side. The stress amplitude is dramatically reduced proving the desired efficiency of the chosen strengthening method. The design loads will cause greater moment amplitudes, however, the admissible stress range of $\Delta\sigma_p$ = 55 N/mm^2 will not be transgressed. The complete results will be published soon.

The work on site consisted of several steps. Firstly, the cracks were injected with an approved epoxy resin. Then, the top surface of the bottom slab had to be prepared by vacuum grit blasting and by a shaper to the desired planeness. The grit blasted steel plates were glued to the concrete piecewise and pressed down by plane and stiff wooden distributing beams for the first 24 hours. Local deviations from the desired planeness of the concrete surface can be tolerated: they can be evened-out with thicker layers of glue ($\leq$ 10 to 15 mm). It is very important that the steel plates remain straight; tests have shown that transverse tension normal to the glued joint reduces bond strength. The glue must comply with the climatic conditions on site. During hardening of the glue the regular traffic prevailed. The gluing of 26 plates per box was performed within one day.

5. ACKNOWLEDEMENTS

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REFERENCES

1. IVÁNYI G. and KORDINA K., Defects in the region of construction joints of prestressed concrete bridges. German Technical Contribution to the 8. Congress of FIP, London 1978.

2. ROSTÁSY F. S., RANISCH E. H. and ALDA W., Strengthening of prestressed concrete bridges in the region of working joints with coupled tendons by bonded steel plates, part 1 (in German). Forschung Straßenbau und Straßenverkehrstechnik, Heft 326, Bonn 1980.

3. ROSTÁSY F. S. and RANISCH E. H., Strengthening of prestressed concrete bridges in the region of working joints with coupled tendons by bondes steel plates, part 2 (in German). BMV-Forschungsbericht No. 15,099, Bonn/Braunschweig, 1981.

4. ROSTÁSY F. S. and RANISCH E. H., Strengthening of reinforced concrete structural members by means of bonded-on reinforcement. Betonwerk + Fertigteil-Technik 1981, p. 6-11, 82-86.