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Strengthening of Structures with Carbon Fibre Laminates

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Werner Steiner, born 1943, received his civil engineering degree from the ETH in Zürich, He worked several years in South Africa disigning harbour structures in Durband and afterwards as project manager for a Swiss general contractor carrying out tunrkey projects. After joining the Sika Group he specialised in rehabilitation work, developing the new strenghtening method with CFRP-material from 1994.

Summary

Carbon fibre reinforced plastics (CFRP strips), are used ever more for the strengthening of concrete structures. The particular characteristics of CFRP strips, the most important properties of the epoxy adhesive as well as the application are described in this paper. Particular attention is given to quality assurance aspects. Application examples show that strengthening with CFRP strips is particularly well suitable for bridges.

1. Introduction

Maintenance, rehabilitation, transformation and extension of existing structures becomes ever more important in times when the number of new structures decreases. Investments for renovation of existing structural substance have kept increasing for the last 10 years. Intensive usage, manifold environmental influences and ageing affect the fitness for use and safety of structures. The main reasons that non-corroding CFRP strips have lately been used more and more often for strengthening work, are the ease of handling and the efficiency of application of the feather-light and flexible material.

2. CFRP strips

A CFRP strip, 50 mm wide and 1,2 mm thick, consists of 2,5 million carbon fibres with a diameter of one five thousandth of a millimetre. The fibres are aligned lengthways parallel by pulltrusion and bonded together with epoxy resin. The dispersion of the values of the tensile strength is small because of the large number of unidirectional fibres. Whenever a fibre in a strip breaks the remaining fibres remain intact and the rupture does not propagate as in a

homogeneous material. The embedding of the carbon fibres in the epoxy matrix assures that a broken fibre has full load bearing capacity again at few millimetres both sides of the rupture. CFRP strips behave linear-elastic up to the point of failure. Using different carbon fibres allows to manufacture CFRP strips with different modules of elasticity.
For the time being, three different types of CFRP strips are used. They are available in different widths between 50 mm to 120 mm and thickness of 1,2 mm and 1,4 mm.

	Sika CarboDur S	Sika CarboDur M	Sika CarboDur H
E-modulus	155'000 N/mm^2	210'000 N/mm^2	300'000 N/mm^2
Tensile strength	>2'400 N/mm^2	>2'000 N/mm^2	>1'400 N/mm^2
Elongation at break	>1,9%	>1,1%	>0,8%

The chemical resistance of CFRP strips against pollutants generally present in the environment of structures is very good. The carbon fibres and the epoxy matrix are long-time resistant against concrete pore water, de-icing salts and hydrous acid solutions.

3. Epoxy adhesive

Two component epoxy resin systems are particularly well suitable for the bonding of CFRP strips to concrete, steel wood or bricks. This type of adhesive has very high mechanical strengths as well a good chemical resistance against aggressive media. Good wetting properties on concrete, wood etc. assure good bond characteristics.
The function of the adhesive layers is above all to transfer the forces acting onto the joined elements. Of particular importance is the elimination resp. the reduction of stress peaks. The more a layer of adhesive is able to level such stress peaks, the greater the load transferring portion of the bonded area will be.
The following properties are important for high strength structural bonding:

- High bonding forces onto elements to be joined.
- High cohesive strength of the adhesive.
- Low tendency to creep under permanent load.
- Good resistance against humidity and alkalinity.

Epoxy resin adhesive layers, thanks to their dense cross linking, meet above listed criteria very well.
Only high-quality epoxy resin adhesives should be used for the bonding of CFRP strips.

4. Application of CFRP strips

The purpose of substrate preparation is to provide optimal conditions for maximum bond with the epoxy adhesive. The removal of foreign matter and laitance is above all important.
Preparation of the substrate can be carried out applying the following methods:

- Sand blasting (best method).
- Bush hammering.
- Grinding.
- High pressure water blasting (attention: moisture).

CFRP strips should be applied at temperatures between +10°C and +35°C. The different application steps are as follows:

- Reprofiling of defective and uneven areas with epoxy mortar the previous day.
- Visual checking of the strips for mechanical damages.
- Checking the straightness of strips to be placed side by side.
- Checking the length of the CFRP strip against the length of the structural part to be strengthened.
- Cleaning of the strip's face to be bonded.
- Delimitation of the concrete surface to receive the adhesive with masking tape.
- Mixing of the epoxy adhesive.
- Application of a scrape coat of epoxy adhesive by steel trowel.
- Removal of the masking tape.
- Application of the epoxy adhesive in roof shape onto the CFRP strip.
- Placing of the strip onto the epoxy coated concrete and fixing by slight finger pressure.
- Pressing-on of the CFRP strip with a roller.
- Removal of excess adhesive.

The rigidity of the CFRP strips is such that they cannot be rolled-on onto excessively concave uneven areas. The thickness of the adhesive layer should in the average be 3 mm, minimum 1 mm, maximum 5 mm.

5. Strengthening of three bridges in Dresden

The three, almost 70 years old bridges near Dresden, suffered from heavy damages of the concrete cover and severe corrosion of the reinforcement steel. New structural analysis showed that, to recover full bearing capacity, structural strengthening was necessary besides extensive concrete repair and rehabilitation work.
To get the approval for the strengthening with CFRP strips for this particular case, tests have been carried out at the Technical University of Braunschweig with a steel reinforced concrete beam on a scale of 1 : 4. The main parameters, such as the shear and bending strengthening factors, elongation of the CFRP strip at the point of failure as well as the stresses in the inner reinforcement bars under dynamic load corresponded to the conditions existing in the real structure. The supposed 30% loss of steel-section of the reinforcements in the flexural tensile zone required a flexural tensile strengthening factor of $\eta_B = 1{,}98$.
After loading in steps up to a load F = 45 kN, the beam has been subjected to 2 million load alternations. After this, the loading was increased up to failure.
The calculated values and the values resulting from the tests are as follows:

calc. M_{u0} [kNm] . Ultimate bending moment calculated on the base of measured materials characteristics before strengthening.	req. M_{ud} [kNm] Bending moment under ultimate design load.	req. η_B Required bending strengthening factor.	exp. M_{uv}[kNm] Measured ultimate bending moment.	actual η_B Actual bending strengthening factor.
167	331	1,98	350	2,10

The test was able to prove that the method of strengthening with CFRP strips is suitable for the bridges in question. The stability and fitness for use for the intended usage of the three bridges can be restored in full. According to the tests, a sufficient ductility of the structure is assured.

6. Strengthening of the Rhine bridge Oberriet-Meiningen

Extensive rehabilitation work had to be carried out on the bridge, built in 1963, crossing the border between Switzerland and Austria. Thorough investigations, including structural analysis according to today's SIA standards, had shown that the bridge deck was in need of transversal strengthening. In order to assure structural safety for today's traffic loads, it was decided for one thing to increase the compression zone of the bridge deck and for another to strengthen the tension zone with CFRP strips.

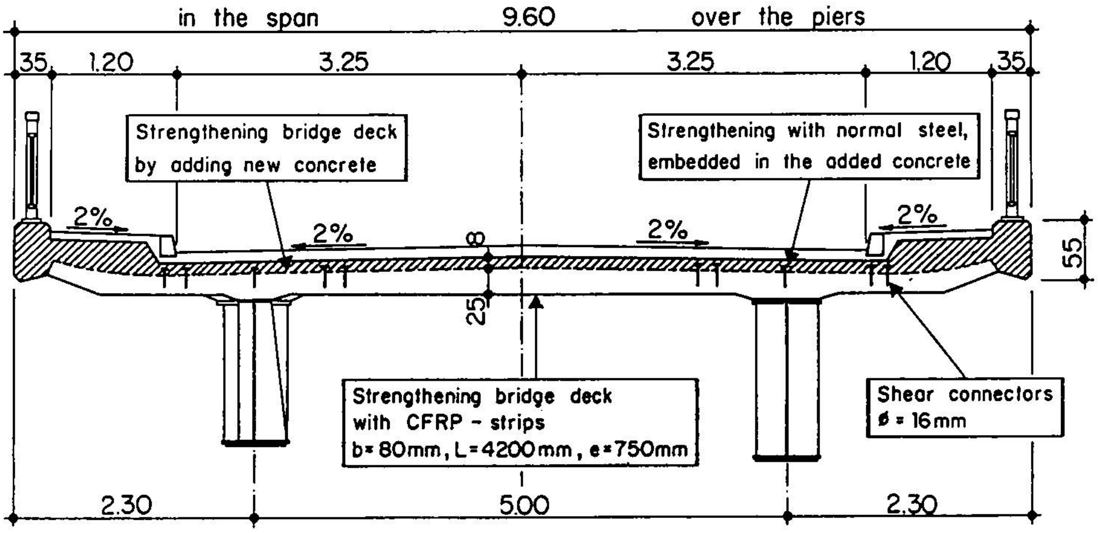

Fig. 1 Cross-section

By adding 8 cm height to the deck, it was possible to remove the chloride contaminated concrete layer by high pressure water blasting and replace it. The structural safety of the deck slab was insufficient, between as well as over the girders. The zones with negative bending moments have been strengthened with conventional steel S 500 embedded in the added concrete. The tension zone has been strengthened with CFRP strips 80 mm wide, 1,2 mm thick. A total of 160 strips, about 4,20 m long have been bonded at 75 cm intervals. The total strengthening factor of 2,4 is the result of added concrete (factor 1,4) and CFRP strips (factor 1,7).

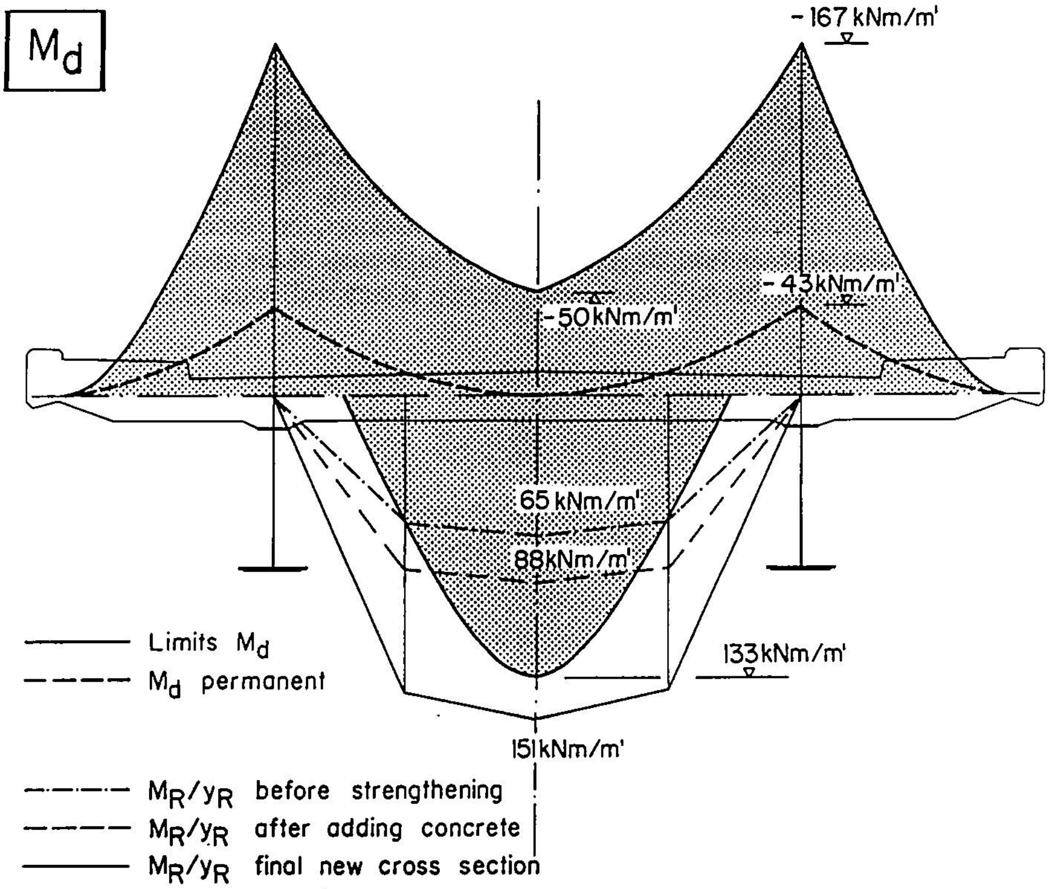

Fig 2. Transversal bending moment in bridge deck

7. Quality assurance

After preparation of the substrate, the surface is inspected visually for weak areas, inclusions in the concrete and cracks. The evenness of the concrete surface is checked with a metal batten and unevenness should not exceed 10 mm on a length of two metres.
Tensile bond strength of the concrete surface is measured by pulling off glued-on steel disks.
Before starting bonding operations, ambient temperature, relative humidity of the air, dew point, temperature of concrete and CFRP strips as well as humidity of the concrete have to be measured in order to prevent imperfect bond of the adhesive due to humidity.
During bonding operations, at least 2 prisms 40 x 40 x 160 mm of the epoxy adhesive used have to be prepared per day for later testing of compressive and tensile bending strength. For each different batch of adhesive used within one day, two additional prisms have to be prepared and tested.
The quality of the bond of the applied CFRP strips is of utmost importance. Therefore, for testing purposes, some CFRP strips, longer than required by the design, are applied. Tensile bond strength tests can then be performed on this additional length. This method allows to spread the testing over a period of years.
All CFRP strips have to be checked for hollow spots by careful tapping. Concave bends may not exceed 10 mm on a length of two metres. There is no objection to convex bends pressing the strip under traction against the concrete.

8. Conclusions

Intensive usage, manifold environmental influences and ageing affect the fitness for use of structures and their structural safety. CFRP strips, because of their outstanding properties, are used more and more for strengthening work. Their excellent long-time resistance, high corrosion resistance and light weight are particularly worth mentioning. These properties as well as the efficient way of application, the ease of executing crossings, the absence of construction joints are advantages outweighing the relatively high costs of the material. The two reported examples show that this method of strengthening is very well suitable for the strengthening of bridges.

References

1. Habennicht G. ,1990: Bonding
   Basics, Technology, Applications
   2 nd edition, Springer publishers, Berlin

2. Deuring M., 1994: CFRP strips in the construction industry
   Strengthening of concrete structures.
   SI+A, no 26, June 26 th 1994

3. Meier U.,1994: Strengthening of structures with fibre reinforced composite materials.
   VDI - Report no 1080, 1994, pages 587 - 594.

4. Steiner W., 1995: Application practice by roll-on method, quality assurance.
   SIA Documentation no D 0128

5. Meier U., 1995: Properties of unidirectional CFRP strips.
   SIA Documentation no D 0128

6. Steiner W.,1996: Strengthening of structures with CFRP strips,
   Advanced Composite Materials in Bridges and Structures, Montreal, Quebec, 1996

7. Walser R., Steiner W., 1996: Strengthening of the Rhine bridge Oberriet - Meiningen
   SI+A no 4, October 24 th 1996

8. Neubauer U., Rostasy F. S., 1996:
   Subsequent strengthening of concrete structural parts with bonded strip of carbon fibre reinforced plastics.
   Materials Science and Restoration, volume III, Aedificativ Publishers.