New German guideline for strengthening concrete structures with adhesive bonded reinforcement

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ABSTRACT: In the Federal Republic of Germany, the strengthening of reinforced concrete structures with adhesive bonded reinforcement has only been governed so far through national technical approvals and approvals in individual cases. Since the strengthening of reinforced concrete structures with adhesive bonded reinforcement has become a standard construction method and due to the progress of the European harmonization it was resolved to create a guideline for the strengthening of reinforcement concrete structures with adhesive bonded reinforcement in Germany. For that purpose all groups, which are concerned about this topic were assembled in a guideline committee and created a guideline.

This guideline is divided into several parts and provides both general planning principles, the design and the execution. In the following a brief explanation of the contents and the backgrounds of this guideline is given. After that the background of the bond checks for externally bonded FRP reinforcement for strengthening in flexure is explained more accurately and some hints are given, on which research result the design rules are based on.

1 INTRODUCTION

1.1 Previous situation of the regulations for strengthening with adhesive bonded reinforcement

Currently, there are technical approvals for strengthening RC-structures in bending and in shear using externally bonded steel plates. Also approvals exist for flexural strengthening with externally bonded CFRP-strips DIBt (2008) and near surface mounted reinforcement with CFRP-strips DIBt (2010). A technical approval for flexural and shear strengthening with CFRP sheets was issued in 2000 DIBt (2000) but has not been extended after 2002. However, a large number of buildings were strengthened based on approvals in individual cases by using CFRP sheets. The national technical approvals are governing the materials, the design as well as the product and execution control of the strengthening. Currently there are only national approvals for the adhesive bonded reinforcement, but a switch to European approvals is currently in progress. Thanks to the increasing harmonization of standards within Europe, national standards and regulations were gradually adapted to the European standards. With these developments the national technical approvals also had to be adjusted step by step to the new generations of standards. Since such conversion is very time consuming because of the need for the consulting of all parties, the national technical approvals have always been behind the current standard approach. In Figure 1, the various references of the national technical approvals and the connections of them are shown schematically.

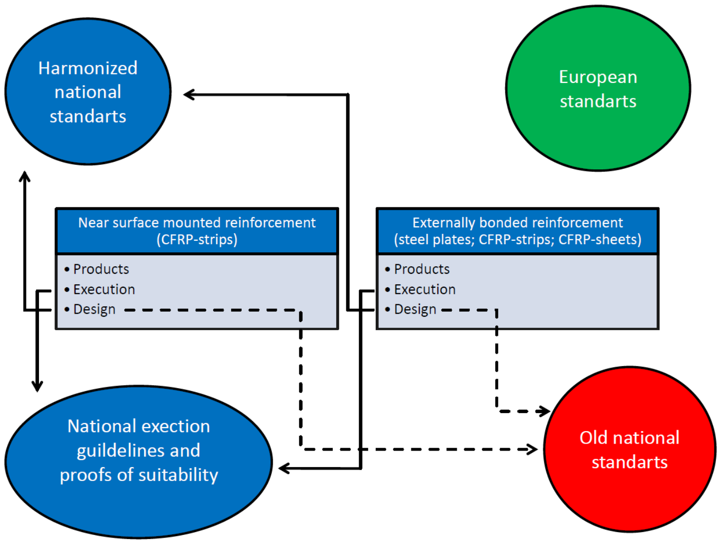

Figure 1. Previous situation with the national technical approvals

1.2 Need for action

By Date of Wirthdraw on 31/03/2010, all national standards, which regulate the same things as the euro codes have to be withdrawn. This implies that the approvals within the next few years must refer to the Eurocodes.

Furthermore, the findings from numerous research projects in recent years are only partially included in the national technical approvals, and therefore this approvals don't represent the current state of knowledge. Thus in the recent years the industry, the building authority and the German Research Foundation provided immense financial funds for research on adhesive bonded reinforcement. This results in the German-speaking countries is about 20 dissertations and numerous research reports and other publications.

With these efforts, the strengthening with adhesive bonded reinforcement is increasingly becoming a standard construction method. Hence, it was recognized by all concerned parties, that there is the need for creating a generally guideline for the adhesive bonded reinforcement.

1.3 Course of action

In order to create a generally guideline that reflects the current knowledge the German Committee for Structural Concrete (DAfStb) initiated a compilation of the current knowledge report Zilch et. al. (2010c). In this current knowledge report the national and international knowledge was collected and documented. Furthermore, a test database with nearly all international and national available experimental studies was created. With this experimental database the collected models and available international guidelines were evaluated.

By creating this current knowledge report it was noticed, that there were still some gaps in the current knowledge from the German point of view for creating a safe and economic guideline, which doesn't restrict the application possibilities too much. Therefore a research project was initiated under the leadership of the German Committee for Structural Concrete in which all parties were involved.

The research work was here done by two research institutes in Germany[1], who have been performing continuously in researching with adhesive bonded reinforcement for more than 20 years. The project was funded equally by industry[2] and the Federal Republic of Germany[3]. In particular questions about the project bond strength under static load Zilch et. al. (2010a), the bond resistance under dynamic loads Budelmann et. al (2010) and the shear behavior of strengthened reinforced concrete structures Zilch et. al. (2010b) have been solved successfully.

Already during the accomplishment of this project a guideline committee was created. This committee was composed according to DIN 820-1 (2009) of equal numbers of participants of each involved party (building authority, industry, researchers, building agencies and several interested associations).

2 CONTENT

The guideline "strengthening of reinforced concrete structures with adhesive bonded reinforcement" is divided into several parts. There is a part for the design, for the execution and an additional part for general planning hints.

The design part is structured as the Eurocode 2 EN 1992-1-1 and based on all assumptions and definitions of the EC2 and EC0. For each chapter of the EC2 there is a similar chapter in the guideline with additions and changes.

In the execution part of the guideline instructions and rules for the execution of the defined strengthening systems are given. Here, for example, the pretreatment of the structural element and the corresponding test, which have to be carried out on the structural elements are mentioned. Furthermore, the requirements for the contractor, which carries out the strengthening project, are defined.

The general planning part provides general planning advice. It addresses, among other things, on which strengthening systems and on which to strengthen structural elements the guideline can be applied. Furthermore the planning responsibilities of a strengthening project are defined and statements are given, how the planner has to take action and what he has to observe.

3 GUIDELINE IN CONTEXT TO OTHER STANDARDS

The created guideline must be seen in context with the European standards and all National standards, which consist of product, execution and design standards. In principle, the guideline refers to the Eurocode 2 EN 1992-1-1 (2002) with the National Annexes.

For the strengthening an approved system is necessary with protection and repair products according to EN 1504 (2005).

Furthermore the guideline „Protection and repair of concrete structures" DAfStb (2005) from the German Committee of structural concrete (DAfStb) must be considered on planning and

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[3] Das Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) (The Federal Institute for Research on Building, Urban Affairs and Spatial Development)

execution. Any company that performs a strengthening project must have a suitable qualification, what is provided in Germany by the proof of suitability, which is approved by state-licensed institutes.

An overview of the guideline in context to the other European and German standards and approvals is shown in Figure 2.

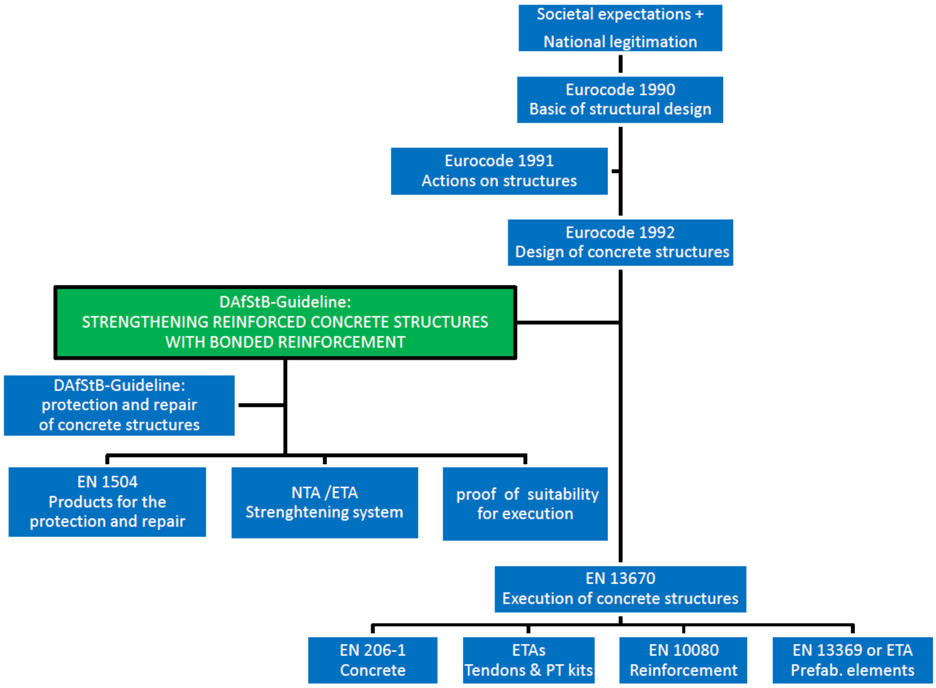

Figure 2. Guideline in context to National and European product, design and execution standards

4 REGULATIONS FOR EXTRENALLY BONDED FRP REINFORCEMNET

4.1 General

In the following the bond checks for externally bonded FRP-Reinforcement for flexural strengthening are presented. The flexural strengthening with externally bonded FRP-reinforcement is the most common use of adhesive bonded reinforcement and in the recent years many research was done on this topic.

In common the bond of the externally bonded reinforcement is the controlling point of the design. The researches in recent years have shown, that a sole consideration of the end anchorage as it is done in conventional reinforce concrete design isn't sufficient. The forces must be transferred continuously to the structural element. Because of this for the design of the bond a verification of the end anchorage as well as a bond force transfer verification in the other parts of the structural elements is necessary. The end anchorage verification has to be done in the uncracked part of the structural element and the verification of the bond force transfer must be done on elements between the cracks. In the following the several calculation steps as well as their source and its background is presented.

4.2 Calculation of the crack pattern

The following approaches of the bond force transfer are depended on the distance between the cracks. The crack development in a strengthened reinforced concrete element is controlled by various effects and has a high variation. Because of that reason the crack distance can only be calculated approximately on the safe side. The crack distance can be assumed on average calculated approximately with one and a half times the transmission length of the reinforcing steel:

$$s_r = 1.5 \cdot l_{e,0} \tag{1}$$

The transmission length can be calculated with equation (2) by dividing the cracking moment of equation (3) through the internal lever arm and the bond force of the reinforcing steel:

$$l_{e,0} = \frac{M_{cr}}{z_s \cdot F_{bsm}} \tag{2}$$

The cracking moment of the RC can be calculated using the simplified equation (3) by multiplying the section moment with 1.4 times the axial tensile strength, since the flexural strength is about 40% higher than the axial tensile strength of concrete:

$$M_{cr} = 1.4 \cdot f_{ctm,surf} \cdot W_{c,o} \tag{3}$$

The bond force per length can be calculated using equation (4) by taking the circumference of the rebars and their average bond stress. The latter can be calculated depending on the bond performance of the existing rebar using equation (5). In this equation k_{vb}= 1 and k_{vb} = 0.7 should be used for good bond conditions:

$$F_{bsm} = \sum_{i=1}^{n} = n_{s,i} \cdot d_{s,i} \cdot \pi \cdot f_{bSm} \tag{4}$$

$$f_{bSm} = \begin{cases} k_{vb} \cdot 0.43 \cdot f_{cm}^{2/3} & for \quad ripped \quad rebars \\ k_{vb} \cdot 0.28 \cdot \sqrt{f_{cm}} & for \quad smooth \quad rebars \\ k_{vb} \cdot 0.21 \cdot f_{cm}^{0,7} & for \quad indented \quad rebars \end{cases} \tag{5}$$

In Zilch et al. (2010b) it was found out, that a sole consideration of the internal reinforcing for the crack distance leads to a small over estimation of the crack distances, because the externally bonded FRP influence the crack development caused by their bond behavior. But larger crack distance in the design calculation lead to results on the safe side.

4.3 Bond check at the intermediate crack element

4.3.1 Exact approach

In the exact approach of the bond force transfer at the intermediate crack element, it must be checked for every intermediate crack element, which is illustrated in figure 3, that the force increase of the FRP, according to equation (6) is smaller than the force which can be transferred by bond by the element according to equation (7).

$$\Delta F_{LEd} = F_{LEd}(x + s_r) - F_{LEd}(x) \tag{6}$$

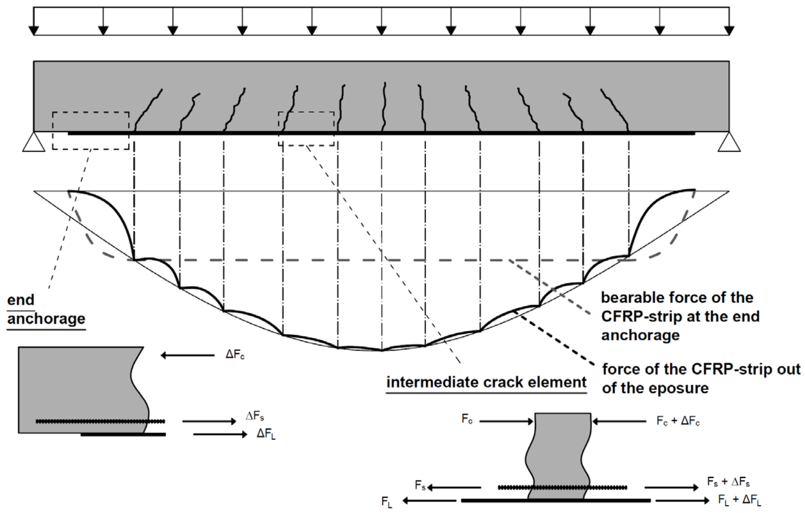

Figure 3. Principle of the bond force transfer of externally bonded FRP

The force, which can be transferred by bond by each intermediate crack element, can be calculated with equation (7) and consists of three parts, one part which is caused by the basic of the bilinear bond approach, a second part caused by bond friction as well as third part caused by the curvature of the structural element. The foundation of the different part is lead back to Zilch et al. (2010)

$$\Delta F_{LRd} = \frac{\Delta F_{Lk,BL} + \Delta F_{Lk,BF} + \Delta F_{Lk,KF}}{\gamma_{BA}} \tag{7}$$

The part of the basic of the bilinear bond approach can be calculated by using equation (8), which is depended on the force of the FRP at lower stressed crack and the values of the bilinear bond approach, which is very detected on bond test at end anchorage specimens.

$$\Delta F_{Lk,BL} = \sqrt{b_L^{\;2} \cdot \tau_{L1k} \cdot s_{L0k} \cdot E_L \cdot t_L + F_L^2} - F_L \tag{8}$$

The part of the bond friction can be calculated by using equation (9) which is depended on the force of the FRP at lower stressed crack, the crack distance and the bond friction stress. In this equation is the back part of the equation which subtracted from the crack distance, the effective bond zone of the intermediate crack element. The bond friction stress t_{LF} was detected of tests on the idealized intermediate crack element by Zilch et. al (2010a)

$$\Delta F_{Lk,BF} = \tau_{LRk} \cdot b_L \cdot \left(s_r - \frac{2 \cdot t_L \cdot E_L}{\tau_{L1k}} \cdot \left(\sqrt{\frac{\tau_{L1k} \cdot s_{L0k}}{t_L \cdot E_L} + \frac{F_L^2}{b_L^{\;2} \cdot t_L^{\;2} \cdot E_L^2}} - \frac{F_L}{b_L \cdot t_L \cdot E_L} \right) \right) \tag{9}$$

In this guideline also the effect of a self induced contact pressure, caused by the curvature of the structural element is considered. This effect was also detected by Zilch et. al (2010a) based on tests. The part of the curvature is calculated as a constant increase of the bond strength by the curvature over the length of the intermediate crack element. In equation (10) the calculation of the force increase is presented. In this equation the curvature is calculated simplified by the strain of the FRP and the concrete divided through the height of the structural element.

$$\Delta F_{Lk,KF} = s_r \cdot 24.3 \cdot \frac{\varepsilon_{L1} - \varepsilon_{c1}}{h} \cdot b_L \tag{10}$$

4.3.2 Simplified approach

A more simple approach is the verification with a limitation of the force increase of the CFRP-strip through a constant value. The concept of a fixed constant force plate change has the advantage that it is both very clear and easy to understand, and limits the computational effort. The concept is illustrated in figure 4. In this figure it is evidence, that the slope of the force of the strip may not exceed a certain value.

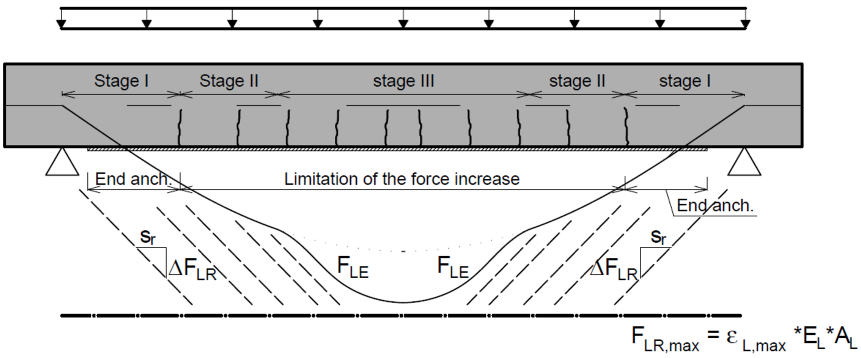

Figure 4. Concept of the simplified approach

The constant bearable FRP force increase can be calculated with equation (11), which is based on an analysis of the exact approach by Zilch et al. (2010a)

$$\Delta F_{LRd} = \frac{\tau_{L1,k} \cdot 2.3 \cdot \sqrt{s_r} + \tau_{LR,k} \cdot 0.098 \cdot s_r^{4/3} + \frac{2000}{h} \cdot s_r^{1/3}}{\gamma_{BA}} \cdot b_L \tag{11}$$

Because of the constant bearable FRP force increase the exact point of the crack isn't so important. The crack distance is more used as an examination length and as an input value for equation (11).

4.4 End anchorage check

For the end anchorage verification the concept of Zehetmaier and Zilch (2003) was adopted. This concept assumes an interaction between the FRP reinforcement and the internal reinforcement and the concept is verified on numerous experiments. The verification must be done at the outermost bending crack by consideration of the shifting rule according to EN 1992-1-1. In addition the bond force can be increased by the enclosure with externally bonded stirrups. This increase can be calculated according to Husemann and Budelmann (2008).

5 CONCLUSION AND OUTLOOK

The finished guideline of the German Committee for Structural Concrete "strengthening reinforced concrete structures with adhesive bonded reinforcement" DAfStb (2010) covers the planning, design and execution of strengthening projects. The guideline contains mechanically based models which correspond to the current knowledge. With this guideline, it is possible to perform strengthening projects with externally bonded steel plates, CFRP-strips, CFRP-sheets and near surface mounted CFRP-strips safe and economic. Thereby also strengthening in flexure and shear as well as strengthening columns with confinement can be performed.

The Guideline is expected to be published in the end of 2010 in German. There is also an introduction of this Guideline into the list of acknowledged technical rules for works aimed, even though this would not be needed, since the technical approvals may also point with-out introducing to this guideline. A translation into English is intended.

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