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Design software for FRP strengthening of concrete elements

For many years fibre reinforced polymers (FRP) have been used as externally bonded reinforcement particularly for strengthening of concrete elements. At the beginning, the main application was flexural strengthening with manual laminated carbon sheets. Shortly afterwards, prefabricated CFRP strips of carbon fibres embedded in an epoxy resin matrix came on the market. Meanwhile a variety of different strengthening schemes has been developed and applied like FRP strips glued into slots in the concrete surface, end anchorage devices for FRP strips and prestressing systems.

FRP design software

While software for the design of traditional reinforced concrete members is available for a long time, structural engineers were until now vainly looking forusable design aids for strengthening measures. Such calculations were done by hand and were not precise enough to optimise the strengthening.

As the design of FRP strengthening measures is a very complex task, S&P Clever Reinforcement Company AG provides easy-to-use FRP design software developed by bow engineers since almost 10 years. Two different design programs are available: *FRP Lamella* for flexural and shear strengthening and *FRP Colonna* for strengthening of columns subjected to axial compression. Based on exact iterative procedures, this software enables structural engineers to design the additional FRP reinforcement with particular attention to economic issues. The software includes the complete range of S&P products for the above mentioned applications. It can be used for a quick preliminary design of strengthening measures as well as for complete calculations within the scope of structural analysis.

In addition both programs offer useful tools for the definition of the relevant national concrete strength, the reinforcing and prestressing steel grades and the selection of the existing rebar cross-sections. Every input window shows a graphic to illustrate the essential data. The results of the calculation can be printed in form of a detailed report.

The software *FRP Lamella* plays a decisive role in the worldwide spread of new technologies such as bending and shear strengthening of concrete structures with externally bonded fibre reinforced polymer. Meanwhile it has been adapted to different national concrete design standards and FRP guidelines like Eurocode 2 and European fib FRP guideline, German DIBt Approvals, British Standard and FRP guideline TR 55, American ACI codes, Dutch NEN code and FRP guideline CUR 91, Italian FRP guideline CNR 200 etc.

Today both design programs are used in over 15 countries worldwide for the design of various kinds of strengthening projects. They have been translated into many languages and provide user manuals as well as detailed explanations of the mechanical background.

FRP Lamella for flexural and shear strengthening

FRP Lamella is a design program (fig. 1) for FRP strengthening of reinforced and prestressed or post-tensioned concrete elements subjected to uniaxial flexure and shear as well as additional axial forces.

The software provides the required FRP cross-sectional area for the strengthened state and is performing the necessary verifications of the adhesive bond, required anchorage lengths and the shear capacity of the concrete member according to the selected national concrete design code and FRP guideline.

FRP Lamella supports four types of cross-section: slabs as well as rectangular beams, T-beams and I-beams.

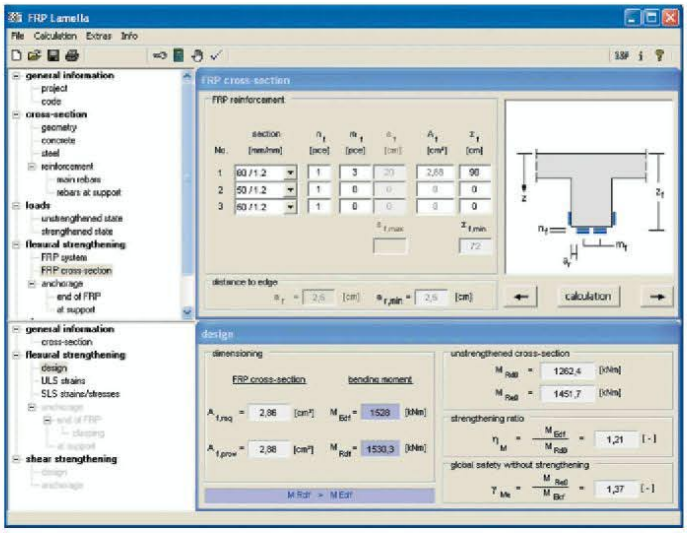

Fig. 1. Design software FRP Lamella for flexural and shear strengthening

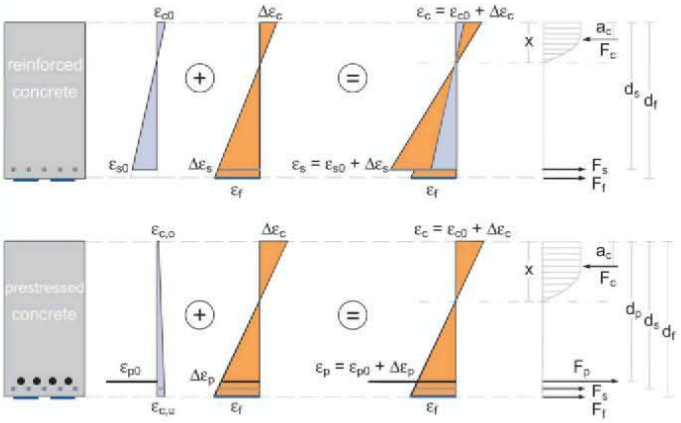

Fig. 2. Superposition of the strain profiles and internal forces

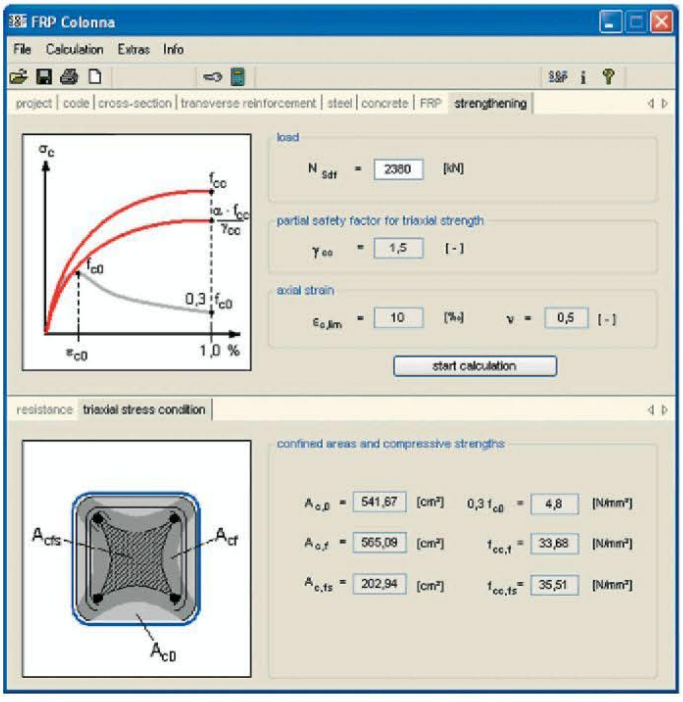

Fig. 3. Design software FRP Colonna for confinement of columns
(Figures: bow ingenieure gmbh)

bow ingenieure gmbh · breite straße 15 · D-38100 braunschweig · fon 05 31 / 2 43 59 -0 · fax 05 31 / 2 43 59 -51

These options cover almost all reinforced or prestressed concrete elements subjected to bending which will appear in practice.
The following FRP systems for flexural strengthening are available:
- externally bonded carbon sheets (unidirectional fabric),
- externally bonded prefabricated CFRP strips,
- near surface mounted (slot-in) CFRP strips,
- prestressed CFRP strips.

For structures to be strengthened the geometry, internal reinforcement, steel grades, concrete compressive strength and internal forces and bending moments in ultimate limit state and service state have to be given. This information can be derived from existing as-built documents or has to be established by on-site testing and structural analysis.
FRP Lamella is developed as a cross-sectional design program, performing different checks at relevant locations along the span.
The required cross-sectional area of FRP strengthening is determined by variation and superposition of the strain profile (fig. 2) within the limits defined in the regulations. The implementation of non-linear stress-strain relations for concrete as well as for reinforcing and prestressing steel and the iterative solution procedure lead to precise results. Compared with hand calculations the software provides particularly economic amounts of FRP strengthening. Additionally the strain and stress distributions can be controlled.
Depending on the selected code and FRP guideline, the design includes addional checks like interfacial bond stress, the verification of end anchorage of the internal rebars as well as minimum clasping of the anchorage zone or anchorage check of the FRP shear strengthening.

FRP Colonna for confinement of columns

FRP Colonna is a design program (fig. 3) for the strengthening of axial loaded concrete columns by wrapping with FRP materials. The confinement is achieved by anchoring the end of the fibres through overlapping. It hinders the transverse expansion of the column, which generates a triaxial stress condition in the concrete. This leads to a considerably higher concrete compressive strength and therefor increases the load bearing capacity of the column.
The cross-section geometry, the amount and position of internal longitudinal and transverse reinforcement, and for rectangular columns the edge radius are relevant parameters.
The software supports circular and rectangular cross-sections and includes strengthening with glass, aramid or carbon fibres.
The design may be carried out according to the design model of Wang [1]. as well as the procedure of fib bulletin 14 [2].
FRP Colonna determines the required number of FRP layers for the confinement and the corresponding load bearing capacity in strengthened state.
According to the selected design model additional information like confined and anconfined areas, design and ultimate axial strain and resulting concrete compressive strength is given.

New FRP systems

Conventional FRP strips are simply bonded to the concrete surface. In this case debonding becomes critical not only at the strip ends but also at other locations of high bond stresses due to concentrated loads, yielding of the internal rebars etc. To prevent debonding, a limitation of the maximum FRP strain was introduced in most FRP design guidelines. As carbon fibres are linear elastic, consequently the exploitation of the material is reduced to only 40 - 60 % of the tensile strength.
To improve the anchorage capacity of externally bonded prefabricated FRP strips, the S&P end anchorage system may be used. Pull-out tests showed that the anchorage capacity is increased to at least the double compared to simple end bonding.
Prefabricated FRP strips can also be glued into slots which are cut into the concrete surface. Compared to externally bonded FRP strips, these near surface mounted (NSM) strips have a higher anchorage capacity, therefore they can almost be stressed up to their tensile strength.
A new prestressing system for prefabricated CFRP strips has recently been developed by S&P Clever Reinforcement Company and successfully applied. It consists of a conventional prefabricated CFRP strip and steel anchor plates glued over the strip and bolted to the concrete. In this case, the end anchorage is ensured by a combination of dowel action and adhesive bond.
Main objective besides the strengthening effect is to improve the serviceability of the strengthened member by introducing forces counteracting the external loads. Additionally the applied prestress increases the efficiency of the expensive material.
In contrast to unstressed FRP strengthening, which has only minimal influence on the deflections due to the small FRP cross-section, crack width and deflections can be significantly reduced by introducing prestress to the concrete element.
bow engineers recently upgraded the design software *FRP Lamella* to include these new FRP systems.

Order the design software

The FRP design software developed by bow engineers allows an easy introduction to the complex task of strengthening design. The presented design programs are being distributed directly by S&P Clever Reinforcement Company. You can order the latest software versions at the address listed below. The software is continuously improved and adjusted to the latest research and guideline modifications as well as new strengthening concepts.

Wiebke vom Berg, Dirk Grunewald

Literature

[1] Wang, Yung Chih: Retrofit of reinforced concrete members using advanced composite materials, University of Canterbury, Christchurch, New Zealand, 1999.

[2] fib technical report bulletin 14: Externally bonded FRP reinforcement for RC structures, chapter 6: Confinement, Fédération Internationale du Béton, Lausanne, 2001.

Further information:

S&P Clever Reinforcement GmbH,
Beyerbachstrasse 5, D-65830 Kriftel, Germany
phone +49 6192 961 28-30, fax +49 6192 961 28-29,
info@sp-reinforcement.de, www.sp-reinforcement.de

bow ingenieure gmbh,
Breite Strasse 15, D-38100 Braunschweig, Germany
phone +49 531 243 59-0, fax +49 531 243 59-51,
mail@bow-engineers.de, www.bow-engineers.de