

DEVELOPING OF NEW NON-METALLIC CONCRETE REINFORCEMENT



**David
Horák**

**Petr
Štěpánek**

**Pavel
Krůpa**

Summary

An own reinforcement based on glass or carbon fiber reinforced polymers in frame a Czech ministry of industry and trade research task was developed. A set of experiments was made for reinforcing of concrete structures with this FRP internal reinforcement. The developed reinforcement was used for reinforcing of several concrete elements. These elements were exposed to different types of loading. Their behavior was monitored to verify the functionality of new reinforcement. This reinforcement was also used to additionally strengthen the masonry vaults loaded with static and dynamic loads. Obtained results are compared with theoretic results of nonlinear numerical analysis of constructions. Finally a set of optimizing calculations was performed to determine the financial influence and impact for the construction reinforced with this special kind of the reinforcement.

Keywords: Longitudinal and shear GFRP reinforcement, reinforced concrete structures, strengthened masonry vaults, optimization

1 Introduction

At present non-metallic reinforcement is used very frequently (because of their resistibility) in constructions that are exposed to aggressive environment's influence. It makes possible to reduce costs needed for special arrangements for protection the common reinforcement and eventually consecutive repairs.

However the price of the non-metallic reinforcements is quite high (see **Fig. 1**). And because this reinforcement form the significant part of the final costs of the cross-section price, it is very advisable to (next to economical optimizing of the cross-section [1]) use local non-imported (i.e. probably cheaper) materials.

The economic aspect mentioned above isn't in the Czech Republic so strong, because there isn't any native producer of this kind of reinforcement. While using it is necessary to import the reinforcement from abroad which makes construction sometimes more expensive.

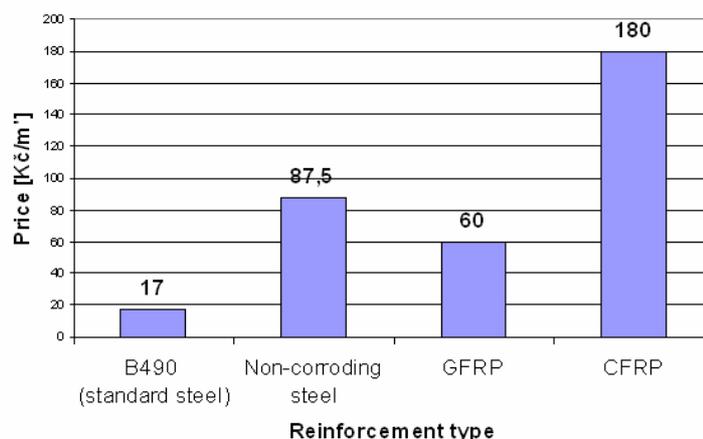


Fig. 1 Comparison of the average prices in the Czech Republic (approximately prices for the reinforcement of diameter 12 mm; the price of the non-metallic reinforcements vary in dependence on diameter of the reinforcement bars)

In terms of research in frame of the Czech Ministry of Industry and Trade, development of “home” reinforcement based on glass and carbon fibers has begun. It is of course necessary to check out functionality of this system – i.e. functionality of interaction of reinforcing bar and surrounding concrete.

But not only new concrete structures are in the centre of interest. Masonry continues to be popular because of its relative simplicity of application in the technical practice. Indeed, for a new use of structural masonry reasonable constructional rules are required, because conventional approach based on the experience is unacceptable nowadays. In addition, most methods of carrying capacity assessment and of strengthening for the existing masonry construction are increasingly based on analyses of mathematical simulation and appropriate (linear and nonlinear) computational models. One method of load-bearing elements strengthening is application of additional external non-prestressed reinforcement into chases in masonry on intrados of vaults, which will provide stiffening and increasing of load carrying capacity of the individual load-bearing elements.

The existing and especially historical masonry structures are nowadays considerably monitored. Many of them are in need of some retrofitting or strengthening. In such cases the non-metallic with minimal requirements for reinforcement cover even in aggressive environment could be the best solution. Therefore some tests were undertaken to learn about behavior of masonry vaults additionally strengthened with GFRP bars. These test logically followed previous research of the additionally strengthened masonry structures.

To achieve good usable results it is necessary to provide also statistical evaluation and theoretical backgrounds for further designs of such structures. Therefore all data obtained from the tests are used to create and verify the numerical model of FRP reinforcement material used in calculations. This model should allow to predict as accurate as possible the behavior of concrete and masonry structures reinforced with FRP bars. Comparison of the real and numerical results shows very good correspondence (some results are shown in the text below and in [2] and [3]).

2 Concrete reinforcement

Tests were performed in several partial fields:

- obtaining physical-mechanical characteristics of reinforcement,
- obtaining cohesion between reinforcement and concrete,
- monitoring behavior of specimens reinforced with non-metallic reinforcement (i.e. real function of reinforcement in loaded construction).

The first two research points were completed and all the results were analysed [2]. Choice of the most suitable type of reinforcement was achieved based on obtained results. The best cohesion with the concrete, material properties and demand factor of the production of the reinforcement and the surface preparation were confronted. All these parameters influence the price and the efficiency of the developed reinforcement.

2.1 Concrete Members with Longitudinal GFRP Reinforcement

These tests are related to concrete beams reinforced only with longitudinal GFRP reinforcement. This test was classical four-point bending test. Beams were designed to obtain failure caused by a bending moment. During the experiment following input data were monitored – force load, deflection on several points and strain of the reinforcing bars (monitoring units build into the reinforcement [2]).

Three specimens with the longitudinal reinforcement were exposed to load forces. Also three specimens without the reinforcement were loaded to provide reference data and to make possible the comparison of effects of the reinforcement. Results of specimens without reinforcement allowed also validating the input data (i.e. material model of the concrete) used in FEM numerical model.

All three reinforced beams collapsed because of exceeding the tensile strength of the GFRP bars. Two of them collapsed under the load force, one beam collapsed in the middle. Maximal average load carrying capacity of this beam improved from total 6.11 kN (calculation presumption 6.09 kN) to 17.19 kN (calculation presumption 16.38 kN – according to ACI 440.1R-03 without any safety factors). The tests results demonstrated the functionality of the developed non-metallic reinforcement.

2.2 Concrete Members with Longitudinal and shear GFRP Reinforcement

The non-metallic reinforcement was tested also as shear reinforcement. The longitudinal reinforcement in these beams were the GFRP bars. The shear reinforcement was created from one GFRP bar shaped into spiral looped around all longitudinal reinforcement bars.

All beams were loaded by the same way as the beams with longitudinal reinforcement only. Supposed failure mode was exceeding the shear capacity in the area near supports. Again the test set was made from three test specimens with shear reinforcement and from three “reference” specimens without shear reinforcement. The shear capacity improved from 54.7 kN (reference specimens without shear reinforcement) to 82.2 kN (reinforced specimens).

3 Strengthening of the masonry structures

The method of additionally inserted non-prestressed reinforcement allows additional strengthening of masonry structures without a necessity of large intervention into vaults especially in case of external application. This system is capable redistributing newly originated stresses from load that act on a strengthened construction. The aim of reinforcement is to restrict the development of existing cracks and eliminate possibly an origin of the new ones, and to improve load-bearing capacity of vaulted masonry constructions.

From the static viewpoint, unreinforced masonry structure is unable to transfer tensile forces that can originate on existing structure from following action:

- action of the higher imposed load against the designed one,
- action of either identical or the lower load against the designed one.

Another consequence of the retrofit reinforcement application into masonry structures is the rigidity improvement. The effect is evident especially at the structures cracked by the previous traffic utilisation. Nevertheless, from the practical viewpoint this consequence could be smaller for railway bridges.

For reinforcing the masonry structures two types of reinforcing materials were used (shape of this reinforcement bars can be seen in **Fig. 2**):



Fig. 2 Helibar reinforcement



Fig. 3 Wrapped and sandblasted surface of the GFRP reinforcement

As a binding (transferring) medium between reinforcement and origin masonry was used special mortar (grouting substance). It is important to mention that it is essential the reinforcing bars compose with grouting substance and with origin masonry the reliable and durable system.

Within experimental parts of the project three sets of masonry vaults with for various loading types were manufactured. The exact description and results can be found in [4]. In a word the vaults were loaded symmetrically in $\frac{1}{2}$ of the span, asymmetrically in $\frac{1}{4}$ of the span and symmetrically in both quarters of the span.

From the comparison of the load-bearing capacity of the individual vaults in the series results that essential growth of the load-bearing capacity was achieved especially in the case of 1st series and 2nd series of the vaults, namely more than eight multiple growth. This growing of carrying-capacity can be watch for both cases of reinforcement – helical metallic and non-metallic. It was related to the vaults stressed by either concentrated or one-sided load, at which the vaults were loaded by the interaction of normal forces and bending moments.

In the case of non-strengthened vaults of 1st and 2nd series the failure was acute, main crack was opened and the vault ruptured. In the case of the strengthened vaults of 1st and 2nd series came to the gradual opening of separate cracks until the failure, which was accompanied by the rapture of the metallic reinforcement from the chases. All glass reinforcing bars were in the ultimate limit state ruptured.

4 Optimization of the concrete cross-section with non-metallic reinforcement

The price of the FRP reinforcement is one of the essential factors decisive to decision about the use of the non-metallic reinforcement. This price is significantly higher than common steel reinforcement and therefore it highly influences the total amount of the cost of purchase of such reinforced concrete structures. Should the financial means be used economically the different parameters (bearing capacity, resistibility, price...) of the reinforcement have to affect the optimal proportion of the needed amount of the reinforcement and concrete.

By way of illustration a case of optimization of simple rectangular concrete cross-section was performed. The influence of the type of used reinforcement was verified. Main goal was to achieve the minimal possible price. Limit criterion was the carrying capacity of the cross-section (acting forces were bending moment and normal force).

The input data were taken from [5]. Reinforcement materials used in calculations were steel (standard and non-corrosive) and non-metallic reinforcement (GFRP and CFRP). Design variable were the height of the cross-section and the amount of reinforcement.

After the evaluation of the results it is possible to make some summary. The total cost of the cross-section increased (in comparison to concrete reinforcement B490) on average for non-corrosive reinforcement by 191 %, for CFRP by 54 % and for GFRP for 50 % (Fig. 4). However, gained results are highly dependent on the standard used for design the cross-section. Some standards require significant reduction of the material properties of the FRP reinforcement (typically ACI standards) and therefore the cost increase. Still these requirements do not cause the increase of the total cost to reach the costs of the non-corrosive reinforcement.

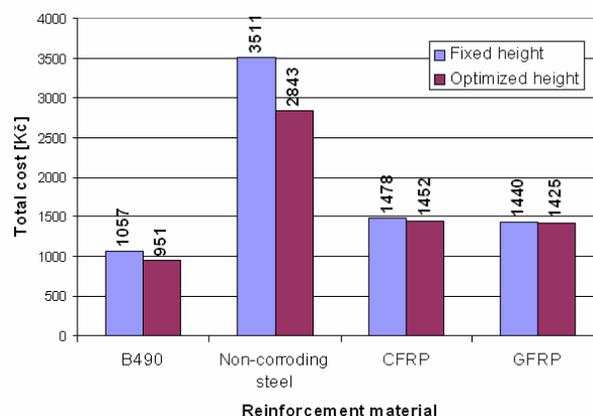


Fig. 4 Total price of the cross-section with fixed height and optimized height of the section

5 Conclusions

The tests showed that the developed system is functional. The reinforcement bars can work as concrete reinforcement and they are capable to transfer the load forces generated in the construction during the loading.

There is also very positive benefit for the strengthening of the masonry vaults. This system can be used to repair the historical structures with minimal impact to the structure

itself (thanks to low requirements for cover – there is no need to provide additional layers of cover materials).

Based on the optimization calculations it is obvious that the costs for reinforcing are almost equivalent for carbon based materials as well for glass fibers based materials. Also the construction with non-metallic reinforcement is cheaper than with non-corrosive metallic reinforcement (on average by 48 %).

This results show that the new developed materials are a good possibility to create cheaper and yet durable and safe constructions.

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References

- [1] PLŠEK, J., ŠTĚPÁNEK, P. *Optomisation of design of cross-section in concrete structures*. Proceeding of the 4th International Conference Concrete and Concrete Structures, 2005.
- [2] ŠTĚPÁNEK, P., FOJTL, J., HORÁK, D., *Pull-out test of non-metallic FRP reinforcement for concrete structures*. Proceedings of the 4th International Specialty Conference on Fiber Reinforced Materials, Hong Kong, 2006.
- [3] HORÁK, D., KRŮPA, P., ŠTĚPÁNEK, P., PROKEŠ, J. *Development of the new methods of measurement of the strain in GFRP concrete reinforcement*, Brno, 2006.
- [4] ŠTĚPÁNEK, P., ZLÁMAL, M. *Additional strengthening of masonry vaults with non-prestressed additional reinforcement*, Proceedings Structural Faults + Repair-2006, Edinburgh, 2006.
- [5] PLŠEK, J., ŠTĚPÁNEK, P. *Optimisation of reinforced concrete cross-section subjected to spatial load*, Proceedings Reliability, Safety and Diagnostics of Transport Structures and Means, Pardubice, 2005.

Ing. David Horák

✉ VUT Brno, FAST
Veveří 331/95
602 00 Brno, Czech Republic
☎ +420 541 147 872
📠 +420 549 250 218
😊 horak.d@fce.vutbr.cz
URL www.fce.vutbr.cz/

Prof. RNDr. Ing. Petr Štěpánek, CSc.

✉ VUT Brno, FAST
Veveří 331/95
602 00 Brno, Czech Republic
☎ +420 541 147 848
📠 +420 549 250 218
😊 stepanek.p@fce.vutbr.cz
URL www.fce.vutbr.cz/

Ing. Pavel Krůpa

✉ VUT Brno, FAST
Veveří 331/95
602 00 Brno, Czech Republic
☎ +420 541 147 871
📠 +420 549 250 218
😊 krupa.p@fce.vutbr.cz
URL www.fce.vutbr.cz/