SAFE STRUCTURAL BEHAVIOUR OF BEAMS MADE OF DIFFERENT TYPES OF FIBRE CONCRETE AND LONGITUDINALLY REINFORCED WITH GFRP BARS

NAĎ Ľudovít [1], ĎURICA Tibor [2], ŠPAK Matej [3], ONDÍK Slavomír [4]

Abstract

The paper presents some results of a parametric experimental study of simply supported beams made of concrete with different types of fibres. Twelve beams in four series were tested : beams made of normal concrete - without fibres, with steel fibres, with glass fibres and with polypropylene fibres. GFRP bars are used as a main longitudinal reinforcement. Due to low modulus of elasticity of GFRP, the concrete beams with such main reinforcement are characterized by higher deflection and extensive cracking. Consequently larger and longer cracks cause the beam stiffness decrease and then the deformation increasing. This phenomenon is one of the main reasons why the GFRP reinforcement up to now is not routinely used in concrete structures. This disadvantage could be controlled by use of fibre concrete instead of ordinary concrete. The sample beams were statically progressively loaded up to their real load bearing capacity. Then, other sample beams were submitted to the load program ended with first cracks creation.

Keywords: GFRP reinforcement, fibre concrete, beam, cracking, deflection

1. Introduction

The intention of the research project realized by the authors consisted of the effective combination of the main advantages of non-metallic reinforcement and fibre concrete in the structural elements. Regarding the durability point of view, the most important feature of the Fibre Reinforced Polymer (FRP) reinforcement is its corrosion resistance. Mainly higher price do not allow their large use, even if Glass FRP could be economically fully acceptable. But there is another problem influencing structural behaviour of GFRP reinforced concrete structures. The bending stiffness of a concrete element is decreasing in correlation with the cracks extensive development (caused by low Young modulus of GFRP reinforcement). On the other hand, the fibre concrete is a material allowing some

[1] NAĎ Ľudovít, Prof. Civ.Eng., PhD., PE, University of Security Management in Košice, Jantárová 30, Košice, Slovak Republic, Email : ludovit.nad@vsbm.sk ///and Alfa 04 a.s. Bratislava, Dept. Košice

[2] ĎURICA Tibor, Prof. Civ.Eng., PhD., University of Security Management in Košice, Jantárová 30, Košice, Slovak Republic, Email : tibor.durica@vsbm.sk

[3] ŠPAK Matej, Civ.Eng., PhD.,

[4] ONDÍK Slavomír, Civ.Eng.,

"control" of cracking in the desirable manner and consequently the deformation as well. Structural safety as an essential factor of the reliability of the structure must be fulfilled for its each element. GFRP is a totally "elastic" material with the brittle failure. It is, why the concrete structures with GFRP as a main reinforcement are designed with an assumption of the concrete crashing at ULS. For normal concrete that means the sudden – brittle failure as well. So the use of fibre concrete instead of normal concrete can "help" not only in the tensioned but also in the compressive zone because of its ductile fracture at ULS.

2. Parametric study of GFRP reinforced fibre concrete beams

Twelve beams in total divided into four series were tested. From practical reasons, small samples were chosen for the experimental investigation. Real structural behaviour of these samples has been confronted with theoretical assumptions and reults.

2.1 Experimental program, material properties

The subject of the first stage of this research program has been focused on small scaled simply supported beams of rectangular cross section 90 x 115 mm and the span of 1,2 m.

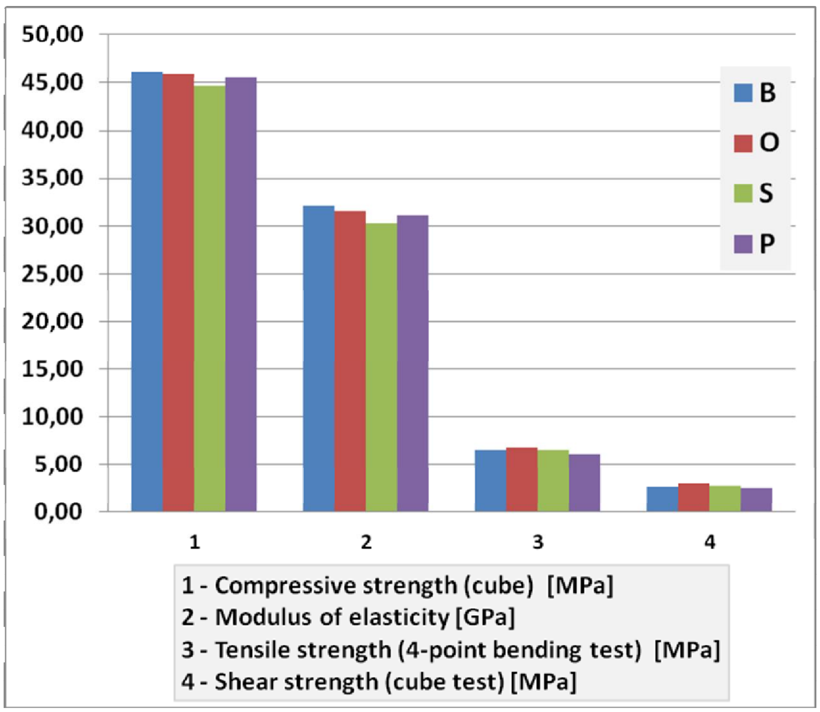


Fig. 1: Mechanical properties of all four types of concretes (B, O, S, P)

All beams were made of concrete designed for class C 30/37, with fine gravel of 0-4 mm only and were reinforced with two GFRP bars 5 mm diameter. The nominal strength of GFRP bars is 900 MPa and heir modulus of elasticity is 35 GPa. Fibre concrete has been based on the reference concrete C 30/37 by adding a moderate amount of fibres as follows:

B1, B2, B3 – normal concrete without fibres - reference beams
O1, O2, O3 – concrete with steel fibres DG 12,5/0,5 (25 kg/m^3)
S1, S2, S3 – concrete with glass fibres G 12/14 E (1,0 kg/m^3)

P1, P2, P3 – concrete with polypropylene fibres PM 12/18 (1,0 kg/m^3)
The beams were made in the testing laboratory of BetonRacio, Ltd. in Veľký Šariš. The basic mechanical properties of produced concretes were determined in BetonRacio and Building Testing and Research Institute, Branch Košice. They can be seen in Fig. 1.

2.2 Loading test

Twelve beams in total (three in each of four series) were investigated. Two types of loading arrangements were applied. First, the beams B3, O3, S3 and P3 were submitted to loading test in the laboratory of Building Testing and Research Institute, in Košice following the loading program, example of which is shown in Fig. 2. This short-term loading test is presented in Fig. 3 a).

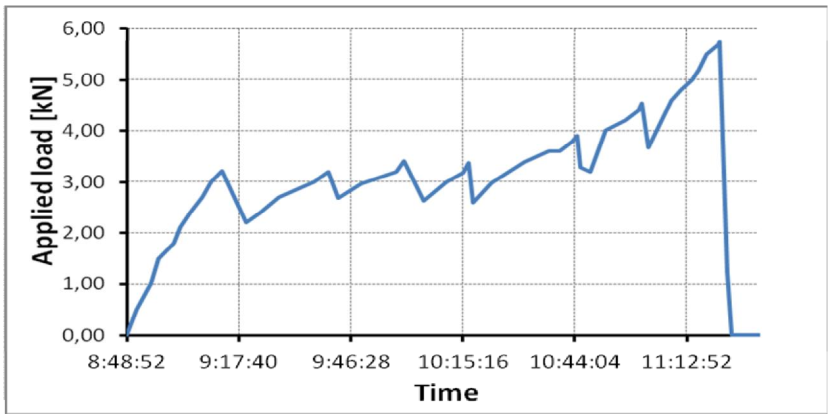
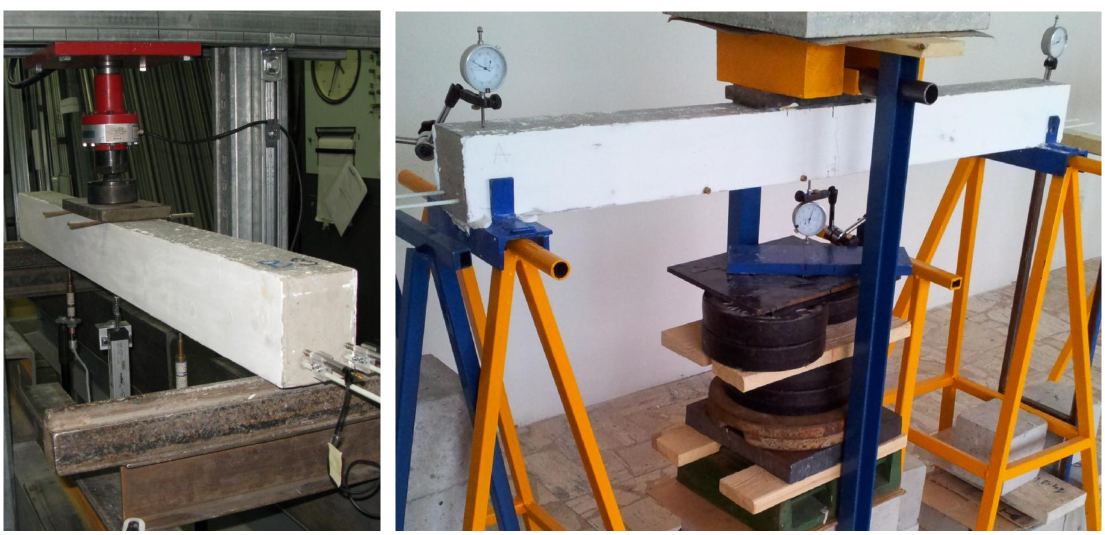


Fig. 2: Loading program of the first part of the experiment



a) b)

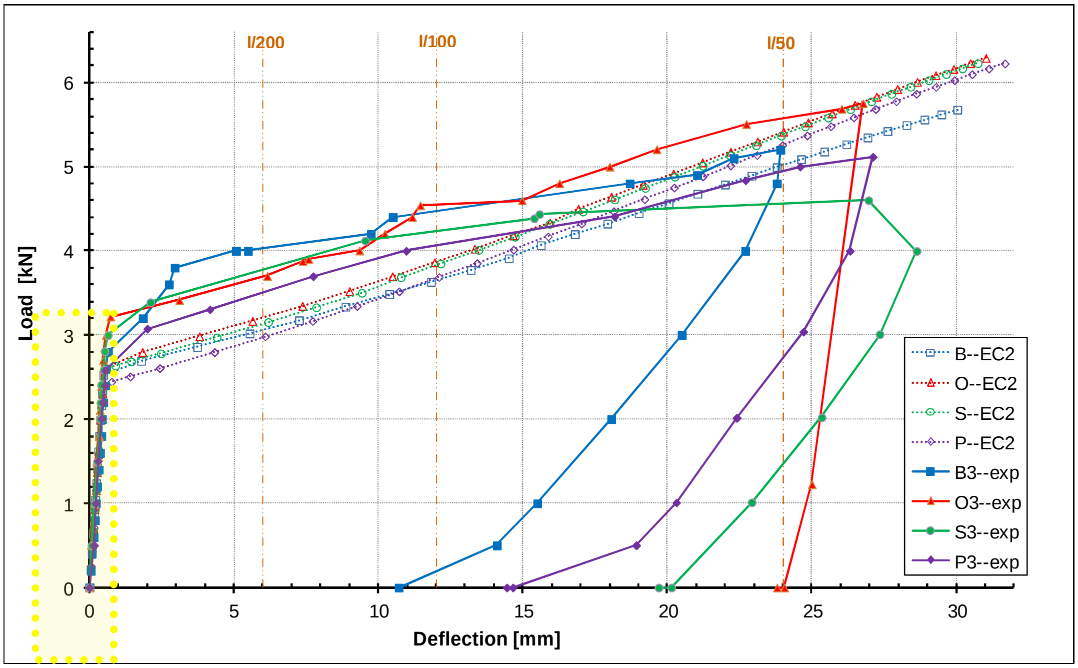
Fig. 3: Two types of loading test arrangement : a) applied for beams denoted 3 of each series; b) applied for beams denoted 1 and 2 of each series

The second part of experimental investigation has been done in the laboratory of the University of Security Management in Košice, Institute of Security Technology (IST) (Fig. 3 b)). In both cases the progressive loading in appropriate steps was applied. In the first part, the beams B3, O3, S3 and P3 were loaded by means of hydraulic jack up to their load bearing capacity. In the second part, the beams B1, O1, S1, P1 and B2, O2, S2, P2 were placed in the laboratory of IST with an initial intention of long-time loading and observation. This loading arrangement can be seen in Fig. 4. The load is applied by means of central hangers and transmitted into two acting forces in a distance of 200 mm.

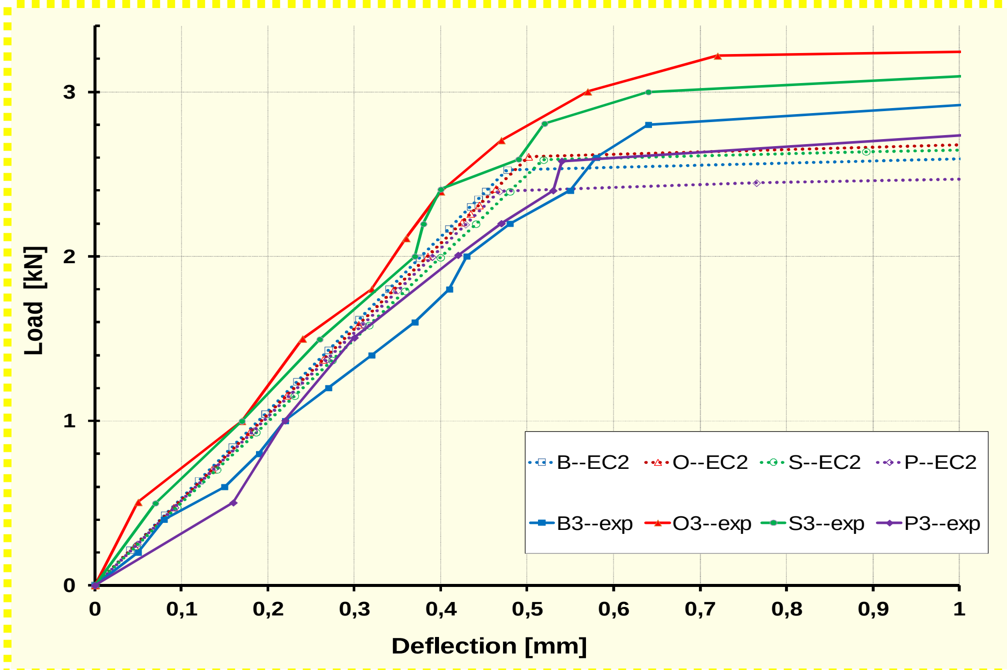
Fig. 4: Four beams (one of each series) installed for long-time loading

3. Results and discussion

For all beams, the ULS was achieved by crashing of concrete in compressive zone, when the GFRP reinforcing bars were stressed at about 800 MPa (their nominal strength is 900 MPa). Fig 5 shows the Load-Deflection diagram calculated and experimental too.



a)



b)

Fig. 5: Load-Deflection diagram, values calculated according to EC2 versus those experimentally obtained.

a) the whole range of loading tests - up to rupture

b) yellow rectangle represents the first phase of loading – slightly exceeding the cracking limit

Load-Deflection diagram presents the basic information about the beams structural behaviour at the age of 28 days. The theoretical L-D diagram (a)) was calculated with real mechanical parameters of each concrete according to EU standard (EC2) and the real properties of GFRP reinforcing bars (with totally elastic – linear behaviour up to rupture) as well. Although the beams were tested at their age of 28 days, which is the age on which the theoretical calculation is based too, there are some evident differences. Real initial cracking phase is higher than calculated and the beams are generally stiffer under the load corresponding to service (deflection less than 1/400 of span which is 3mm). The theoretical cracking load is approx. 2,670 kN, during the first part of load test (at the age of 28 days) this value was generally exceeded by 15 %, during the second part of loading (at the beam age of about 70 days in average), the cracking load varied between 3,2 and 4,2 kN.

The crack development is highly influenced by the fact of low modulus of elasticity of the reinforcement, which value is very close to this of the concrete (E_{GFRP} = 35 GPa and E_c = 30 ~32 GPa). The crack width is increasing then very quickly. At this phase (Fig. 5 b)) the most suitable is the beam made of steel FC, which shows the highest capacity of load bearing. However the differences are small and not so evident. These minor differences in the cracking and the whole structural behaviour is mainly caused by the fact that for this stage of research a specific case of FC was chosen – with moderate amount of fibre content in each of three series of FC beams.

4. Conclusion

The beams made of steel FC presented the best behaviour regarding the first cracks formation, deflection and the highest load bearing capacity. As expected, the beams made of PP fibres represent the most wicked properties comparing to other series of beams, even reference beams made of normal concrete without any fibres. Because of several reasons, the results obtained in this first stage of research cannot be generalized. The next stage will be focused on the FC with higher content of fibres, but the small scale samples will be maintained (with fine aggregate concrete and small diameter of GFRP reinforcement and short fibres as well).

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