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COMPARISON OF THE BEHAVIOR OF GFRP REINFORCED CONCRETE BEAMS WITH CONVENTIONAL STEEL BARS

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Abstract: Concrete beams reinforced with glass fiber-reinforced polymer bars exhibit large deflections and crack widths compared with concrete members reinforced with conventional steel. In this work, the current design methods for predicting deflections under loading and crack widths are developed using the same theory with some additional parameters. Based on the research work presented in this paper and past studies, a theoretical correlation for predicting the crack width and deflection is proposed by testing six concrete beams; specifically two sets are reinforced with different glass fiber-reinforced polymer of reinforcement ratios and one set is used as the control beam. The research objective is to analyze the behavior of the beams under loading and obtain the differences in their behavior in terms of the following parameters: deflections; cracks, and general bearing capacity.

Keywords: Glass fiber-reinforced polymer bars, Deflections, Crack widths, Reinforced concrete

1. Introduction

Generally, concrete structures endure loads and other exposure conditions during their service life. The strength and behavior of these structures is different when other or new materials are used without prior experience or when the materials have non-standard parameters. It is a constant inner stimulus that drives engineers to search for new applied materials, and in this case, Fiber-Reinforced Polymers (FRPs) or similar products are being considered to extend or improve the service life of structures. Furthermore, a very influential factor is the type of exposure, which results in deterioration of the structure followed by corrosion or other degradation factors. Glass

Fiber-Reinforced Polymer (GFRP) bars are promising alternatives for reinforced steel bars for preventing corrosion and other effects. The cost of GFRPs is economical compared with Carbon Fiber-Reinforced Polymers (CFRPs) or Aramid Fiber-Reinforced Polymers (AFRPs), and the objective of this paper is to focus on the deflections and cracks occurring in these systems, and in fact to compare them with conventional reinforced steel.

In the last ten years, the use of FRP reinforcements in concrete structures has increased rapidly owing to their excellent corrosion resistance, high tensile strength, and good non-magnetization properties. However, the low modulus of elasticity of the FRP materials and their non-yielding characteristics result in large deflections and wide cracks in FRP-reinforced concrete members [1]. In various cases, the serviceability requirements may satisfy the design parameters of the members of a structure. GFRP bars have a low elastic modulus and behave elastically up to near failure; therefore, protection from corrosion in reinforced concrete structures actually leads to the development of more durable concrete, in which the risk of corrosion is high [2].

The results of the investigation can be summarized as follows:

- The deflections and strains of the concrete beams reinforced with GFRP rebar are generally larger than of those reinforced with steel bars;
- The strength of the concrete has a negligible effect on the crack spacing and crack width;
- The FRP-reinforced concrete beams examined in this study are safe for design in terms of their deformability.

2. Experimental investigations

2.1. Materials

GFRP rebar, as an alternative material, is used in the reinforcement of beams with different diameter. In this study, the diameter of the GFRP rebar was Ø6 mm and Ø10 mm in comparison with the conventional steel bars, Ø10 mm. In regard to investigate the detailed behavior of GFRPs, the samples were examined, and the properties of the materials are presented in *Table I* [1], [2], [3].

Table I

Properties of the examined samples

Sample	Type	Nominal diameter(mm)	Modulus of Elasticity (GPA)	Tensile Strength (N/mm^2)
'1' Ø6 mm	GFRP	6.05	47.55	1022.1
'2' Ø10 mm	GFRP	10.05	38.45	1194.3
'3' Ø10 mm	conventional	10.00	200	585.5

The examination methodology of the mechanical properties of these GFRPs is completely different in terms of their fabrication process and behavior under applied loads. Some of manufacturing details are presented in *Fig. 1*, and mechanical properties results are exhibited in *Fig. 2*, [4], [5], [6].

Fig. 1. GFRP bars and their examination

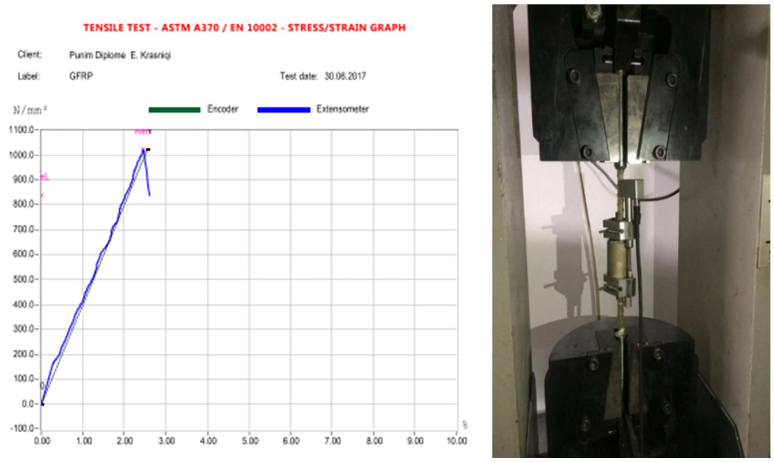

Fig. 2. Examination of the mechanical properties of the GFRP bars

2.2. Test specimens

In this research work, for testing the samples, three series of Reinforcement Concrete (RC) beams are prepared. For each series of concrete beams, there are three samples. The beams have a rectangular cross-section with geometrical parameters: length l=180 cm; span with l_0= 160 cm; and cross-section with dimensions b=15 cm and h=25 cm. All the beams were tested with the four-point loading test.

Series ‘A’ is reinforced with conventional steel bars of 2Ø10 mm; series ‘B’ is reinforced with GFRP bars of 2Ø6 mm; and series ‘C’ is reinforced with GFRP bars of 2Ø10 mm .The beams and control specimens are cured under similar conditions.

During the casting, instead of concrete, the samples are used the samples to determine the compressive strength of the concrete when the beams are tested (*Fig. 3*). Each series of beams is reinforced with different reinforcement ratios. Based on the reinforcement ratio, this research is conducted in two stages: low percent of reinforcement and near or close to balanced reinforcement. The geometric and reinforcement details of the test beams are shown in *Fig. 4* and listed in *Table II*, [7], [8], [9].

Fig. 3. Set of concrete beams and concrete cubes for examination

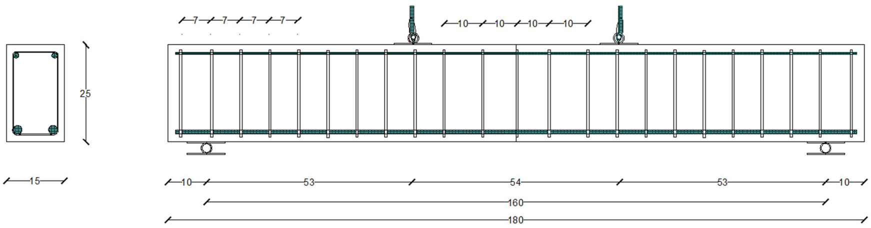

Fig. 4. Geometric and reinforcement details of the test beams

Table II

Series of RC beams

Series	Reinforcement	Type	Percent of reinforcement (%)	Percent of balanced reinforcement (%)
'A'-Etalon beams	Steel bars-conventional;	2 Ø10 mm Stirrups Ø5/7(10) cm	0.46	2.29
'B'	GFRP	2 Ø6 mm Stirrups Ø5/7(10) cm	0.19	0.253
'C'	GFRP	2 Ø10 mm Stirrups Ø5/7(10) cm	0.46	0.154

2.3. Test instrumentation and procedure

The load was applied centrally by a 150 kN hydraulic jack, Controls MCC8, and a spreader beam was used to distribute the load to the two third-span points (*Fig. 5*). Linear Variable Displacement Transducers (LVDTs) were used to measure the deflections at the supports. One LVDT (with an extended belt) was used to measure the average strain and the crack width at the level of the reinforcement. Another LVDT was placed predictably to measure a referent crack, and a third LVDT was placed in the mid-span of the beam to measure the main deflection.

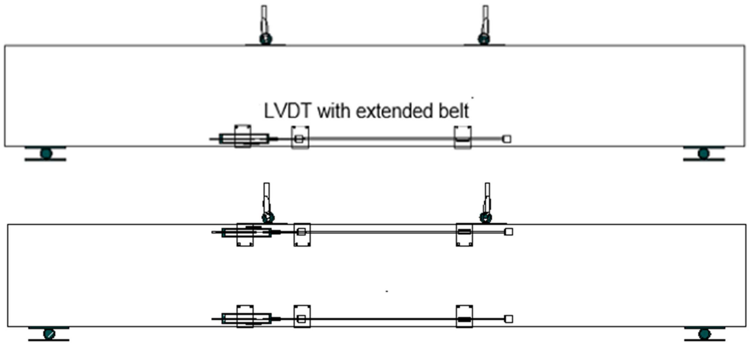

Fig. 5. Schematic view of the LVDT with an extended belt placed to measure the compressive and tensile zones

All the data were collected by a data acquisition system and downloaded to a Personal Computer (PC) at 1-s intervals, [10], [11], [12], [13], [14]. The measurements on the typical points and behavior under the applied loads are presented in *Fig. 5* and *Fig. 6*, respectively.

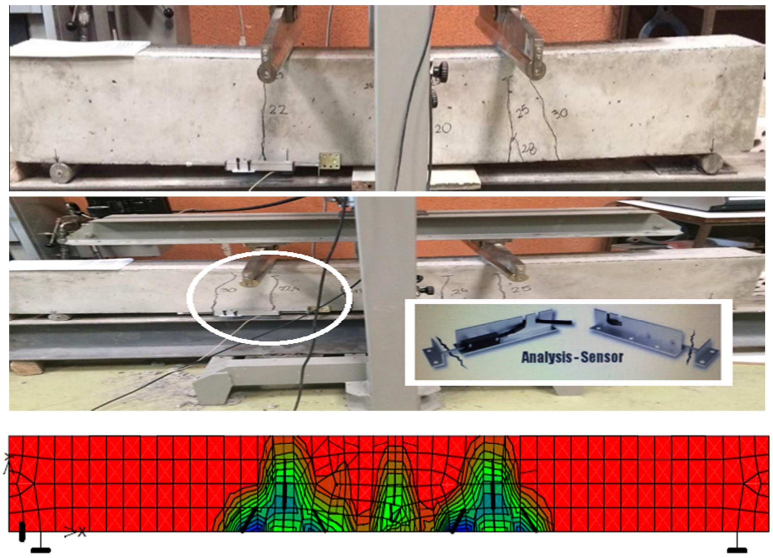

Fig. 6. Typical beam test setup and the deflections and cracks from the experimental and analytical analysis

3. Test results and discussion

For the examination process and understanding the behavior of the beams, in the calculations on the set of beams, first an analytical model and software 'ATENA' are used. Following the analysis of the experimental set up for all the three series, the following two parameters are compared: deflections and cracks.

3.1. Analytical and experimental calculations of cracks under loading process

The prepared series of concrete beams are analyzed after the hardening of concrete, and the research is focused on the comparison of the behavior of the three series formed with different reinforcements and types of reinforced bars.

- Series 'A' with conventional steel bars -2Ø 10 mm;
- Series 'B' with GFRP-2Ø 6 mm;
- Series 'C' with GFRP-2Ø 10 mm.

FRP-reinforced bars have a low elastic modulus and relatively poor binding to concrete as compared with steel bars. A direct result of these characteristics is larger crack widths and larger deflections under service loads as compared with beams reinforced with conventional steel bars, [12]. Set A of beams, reinforced with conventional steel bars, is considered as the relation control beam, which has relatively the same flexural capacity as set B and same reinforcement area as set C, [6], [7].

The crack widths are calculated using different methods with the objective to compare with the experimental results, which are listed in *Table III*.

Table III

Different methods for the analysis of cracks

Series	Reinforcement percent (%)	ULS Mr [kN m]	EC-2 function [cracks, M/Mu]	Gergely-Lutz-SLS function [cracks, M/Mu]
'A' 'B' 'C'	0.46 0.19 0.46	13.22 11.09 20.56	0.201 mm, 75% 2.88 mm, 75% 1.967 mm, 75%	0.180 mm, 75% 1.49 mm, 75% 1.41 mm, 75%
Series	Modified Gergely-Lutz [cracks, M/Mu]	ATENA Software, function[cracks, M/Mu]		Experimental results-function[cracks, M/Mu]
'A' 'B' 'C	0.098 mm, 75% 0.652 mm, 75% 1.014 mm, 75%	0.192 mm, 75% 1.42 mm, 75% 1.531 mm, 75%		0.1803 mm, 75% 2.08 mm, 75% 1.739 mm, 75%

The comparison objective is focused on beams reinforced with GFRP-2Ø 10 mm - series 'C' and beams reinforced with steel bars 2Ø 10 mm - series 'A', and the results are presented in *Fig. 7* and *Fig. 8*, [14], [15].

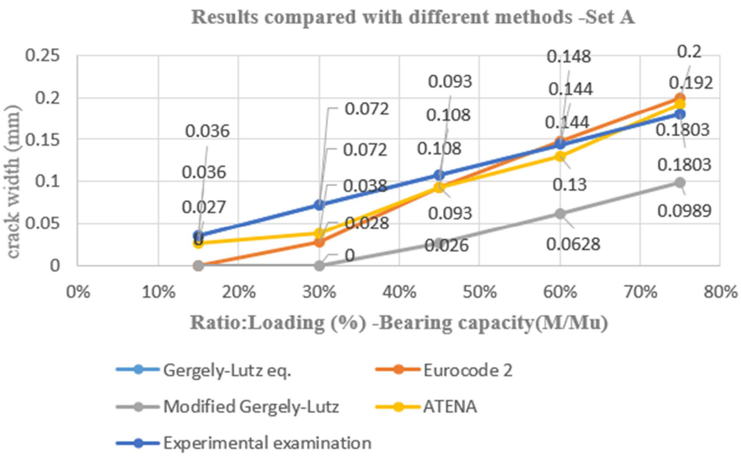

Fig. 7. Behavior of the beams - set 'A' in crack development under loading

The same approach is also used for the GFRP- reinforced beams for comparing with conventional steel beam, usually referred as the relation control beam.

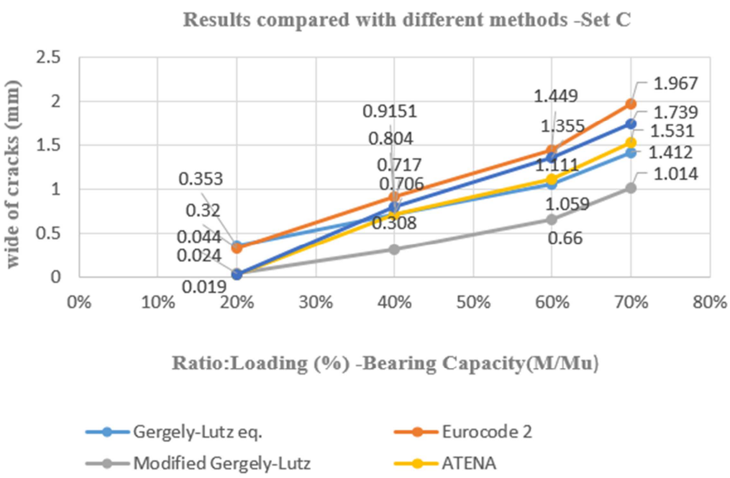

Fig. 8. Behavior of the beams - set 'C' in crack development under loading

3.2. Analytical and experimental calculations of deflections under loading process

For the evaluation of the behavior of the concrete beams, the deflections are calculated with different methods and compared with the experimental results. The results are presented in *Table IV* and *Fig. 9* and *Fig. 10*, [16], [17], [18].

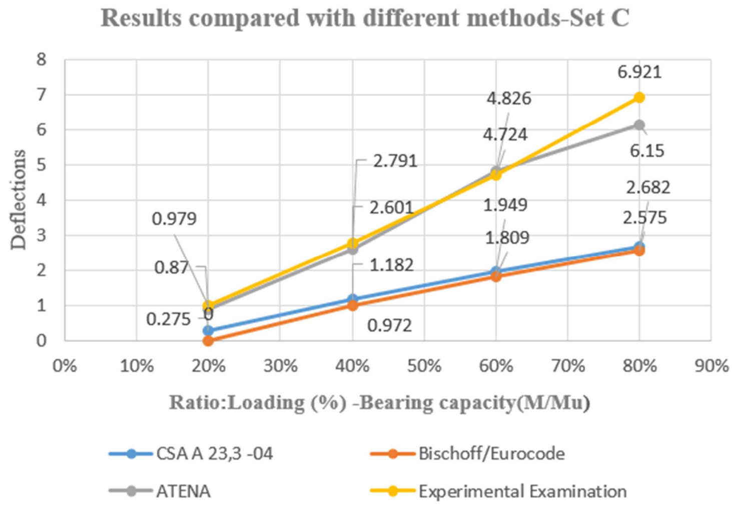

Fig. 9. Behavior of the beams - set 'C' - deflection development under loading

The same approach of comparison is used also for the beams reinforced with conventional steel, i.e., set 'A'.

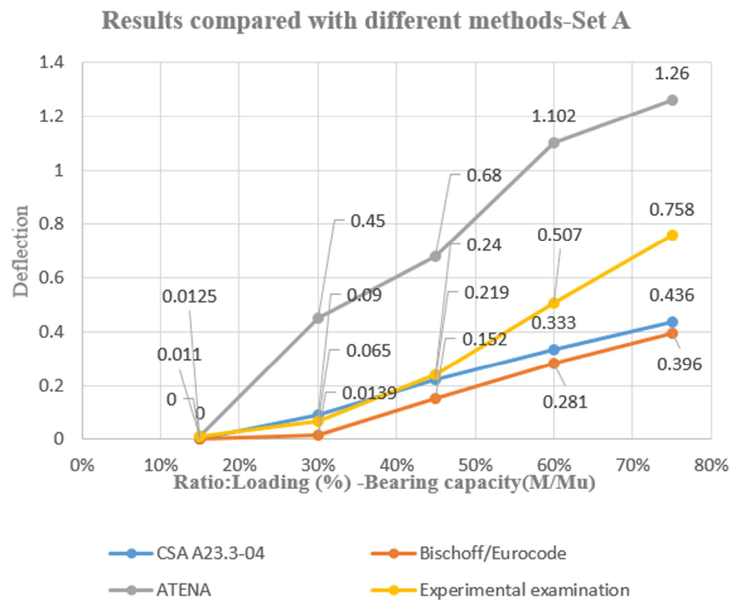

Fig. 10. Behavior of the beams - set 'A' - deflection development under loading

Table IV

Deflection analysis with different methods

Series	Reinforcement	Reinforcement percent (%)	ATENA [Deflection, M/Mu]	ACI 318-EC2 [Deflection, M/Mu]	Experimental examinations [Deflection, M/Mu]
'A'	Steel -2Ø 10	0.46	1.26 mm, 75%	0.436 mm, 75%	0.758 mm, 75%
'B'	GFRP-2Ø 6	0.19	6.88 mm, 70%	2.55 mm, 70%	6.59 mm, 75%
'C'	GFRP -2Ø 10	0.46	6.15 mm, 80%	2.681 mm, 80%	6.921 mm, 80%

4. Conclusions

From the experimental and analytical work presented in this paper, the following parameters are concluded:

- The effect of the low modulus of elasticity of the GFRP bars was evident in an early crack initiation in the beams reinforced with the GFRP compared with conventional reinforcement;
- The crack width is related to the ratio: load-bearing of 36% - starts from value of deformations 0.015 mm - 0.804 mm and then linearly increases to reach the maximum value of 0.473 mm - 1.581 mm at the ratio of 72%;
- The average deflection increases as a function of the ratio: load-bearing starting to deflection from the 0.758 mm steel bars to 6.333 mm GFRPs for a ratio 72%. This is a result of the modulus of elasticity and bonding parameters in concrete;
- A non-linear finite element analysis with software ATENA yields results for the ratio similar to the experimental examinations in comparison with other methods;
- The failure of the GFRP-reinforced concrete beams is mainly due to its reduced post cracking stiffness and the slip between the rebar and concrete matrix.

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