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CONSTRUCŢII. ARHITECTURĂ

PARTICULARITIES OF ANALYSIS AND BEHAVIOUR OF CONCRETE BEAMS REINFORCED WITH FIBROUS POLYMER COMPOSITE BARS

BY

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Traditional steel based reinforcement systems for concrete elements are facing with serious problems mainly caused by corrosion due to chemically aggressive environments and salts used in deicing procedures, especially in case of bridge steel reinforced concrete girders. Also in some cases special applications require structural members with magnetic transparency. An alternative to this major problem has recently become the use of fibre reinforced polymer (FPR) composite bars as internal reinforcement for concrete beams. The particularities of their mechanical properties are making the design process a difficult task for engineers, numerous research centers being involved in correcting this situation. The general aspects concerning the conceiving of FRP reinforced concrete beams are firstly analysed, compared to those reinforced with steel bars.

Some results of a Finite Element Analysis, as part of a complex program which also implies full scale testing of FRP reinforced beams subjected to bending, are given and discussed in the paper. The low elasticity modulus presented by glass fibre reinforced polymer (GFRP) bars does not justify its use from structural point of view when deflection is the limiting condition but for corrosive resistance reasons and special electromagnetic properties this system can be promoted.

1. General Aspects

1.1. Introduction

The problems raised by the corrosion of traditional internal steel reinforcement for concrete elements justify the continuous struggle for finding more durable alternatives. Although adopted as the ideal reinforcement for concrete elements and thus used as generally suitable solution, the exploitation of steel reinforced concrete in aggressive working environments and the development of new communication systems requiere new types of concrete reinforcements [1].

Until recently the recommended solution was to adapt the steel reinforcement based concrete systems to various working conditions and to protect and prevent steel from corrosion by different means. Solutions derived from this way of dealing problems often lead to very expensive, laborious and time consuming procedures.

Fibre-reinforced polymer (FRP) composite materials have developed into economically and structurally viable construction materials for load bearing elements in buildings and bridges over the last two decades. FRP reinforcements for structural elements in construction have raised the interest of structural engineers since the beginning of the fibre reinforced plastics industry and the use of FRP composite materials with various fiber reinforcement types has become an interesting alternative as reinforcement for various concrete members.

There is nowadays a wide range of available types of FRP composites (with polyester, epoxy or vinyl-ester matrices) reinforced with glass, carbon and aramid fibers, with suitable properties for different applications in civil and structural engineering. However the particularities of behavior of FRP bars and the insufficient experimental data on structural and long time behavior of concrete elements reinforced with internal FRP composite bars still require extensive theoretical studies and experimental programs to be able to fully exploit the potential of these new materials.

1.2. FRP Composites as Internal Reinforcement for Concrete Elements

Reduced own weight, high strength to specific weight ratios, electromagnetic transparency, increased resistance to corrosive agents, along with other structural and technologic aspects recommend these materials as suitable for structural applications. However high initial application costs, relatively high manufacturing costs, lack of specific national design codes are the main disadvantages in the extensive use of this class of materials. Nevertheless, the great potential these materials present fully justifies the research activities of numerous research centers worldwide.

The high tensile strengths of FRP composites may recommend them as an ideal alternative to longitudinal reinforcing elements (Fig. 1) for structural concrete members subjected mainly to flexure. These superior mechanical properties are yet parts of the general landscape of a problems free structural application of such elements.

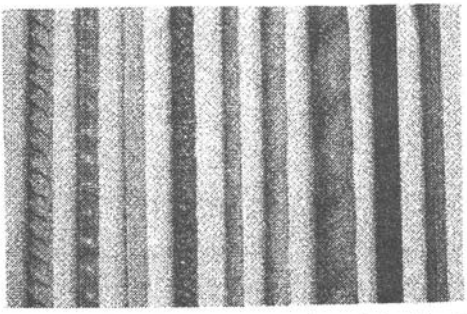

Fig. 1.- Types of FRP composite reinforcing bars for concrete elements.

The main and first approaches in introducing FRP as reinforcing elements try to adapt the existing steel reinforcement based design codes [2].

The anisotropic nature of FRP composites, as opposed to isotropic materials, leads to superior mechanical properties development only along the direction of reinforcing fibers but very weak in the transverse direction. This is the most important difference as related to steel. Deriving from this aspect, transversal properties and bond characteristics are directly affected. The various failure modes (from concrete – FRP bar interface to internal FRP failures) are having direct implications in selecting the best FRP based system for reinforcing of concrete elements.

Basic principle differences in mechanical properties and brittle linear-elastic behaviour of FRP reinforcements are the mostly influencing factors when trying to adapt steel based existing design regulations. A special *fib* Bulletin [2] will be published in the near future dealing with almost all particularities of FRP composite reinforced concrete structural members.

2. Analysis Program

2.1. FRP Composite Bars Reinforced Beams

The Faculty of Civil Engineering in Jassy is an active partner in national and international research and development programs concerned with establishing the FRP composites based reinforcement systems as applicable alternatives in situations where traditional steel reinforcement based systems are no longer suitable.

In this context a complex study program is now in progress. This program involves the study regarding the influences of Glass Fiber Reinforced Polymer (GFRP) Composite reinforcement bars upon the structural behaviour of bent concrete beams. Traditionally steel reinforced counterparts are used as basis for comparisons.

Fig. 2 presents the internal distribution of reinforcement as well as the position of applied loads and supports.

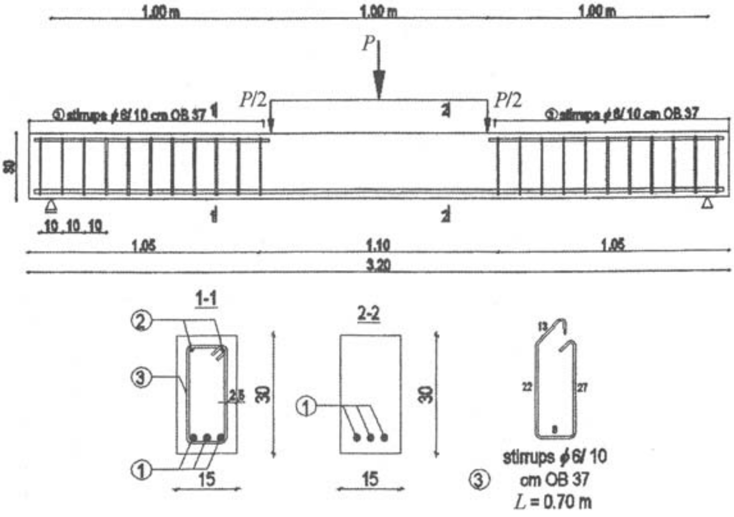

Fig. 2.– Beam internal reinforcement layout; application of forces; characteristic cross-sections.

The bars labeled with 1 are longitudinal steel bars, GFRP smooth and ribbed bars, respectively. For each type of reinforcement, three beams were constructed.

In parallel with this intended experimental program, a numerical simulation using the Finite Element Method based software LUSSAS was conducted in order to make comparisons. This paper gives only the Finite Element Analysis results; the experimentally obtained results are still under processing and comparisons with currently available similar testing data will be carried out. They are to be presented in a future paper.

Fig. 3 illustrates the testing set-up as well as detailing of FRP reinforcement.

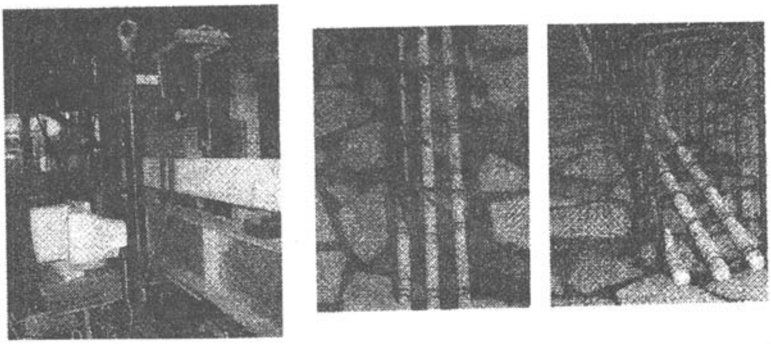

Fig. 3.– Experimental set-up; FRP reinforcement detailing.

2.2. LUSSAS Finite Element Analysis

After definition of all material parameters (for concrete, steel and GFRP reinforcement bars), the meshing of the reinforced concrete beam was performed using "quadrilateral" finite elements. As it was defined, the concrete exhibits a non-linear behaviour up to failure. The reinforcing bars were meshed into "bar" type finite elements, subjected only to axial loads and connected to the concrete meshing nodes.

Fig. 4 illustrates the Finite Element Modelling of the steel/FRP reinforced beam. The beam was subjected to constantly increasing load as presented above; the stress distribution and the crack development into the concrete volume were monitored. Load–displacement curves were obtained in case of both materials used as reinforcements.

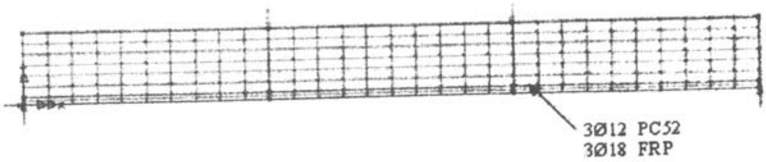

Fig. 4.– Finite element meshing of steel/GFRP reinforced concrete beams (LUSSAS).

Figs. 5,...,7 show the characteristic curves of the construction materials involved in the numerical modelling (concrete, steel, GFRP). It is noticeable t hat the FRP reinforcement and the concrete used have similar stiffness properties. This is also to be observed as influencing the structural behaviour of the FRP reinforced concrete beam.

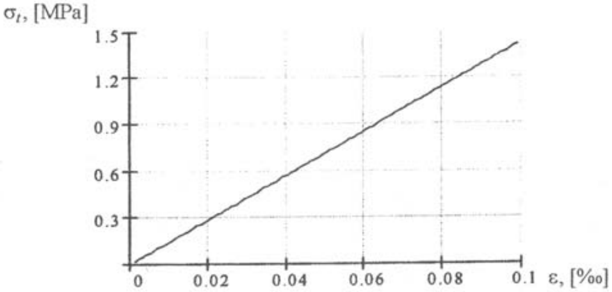

Fig. 5.- Characteristic curve of concrete in tension.

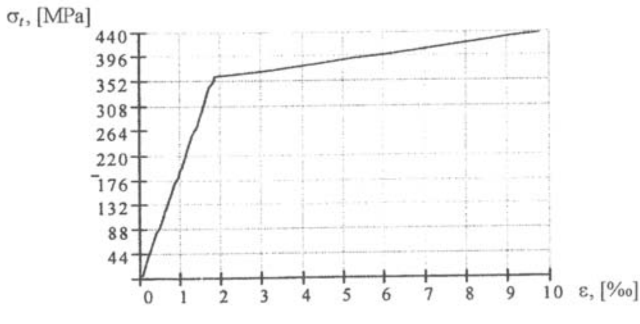

Fig. 6.- Characteristic curve of steel reinforcement.

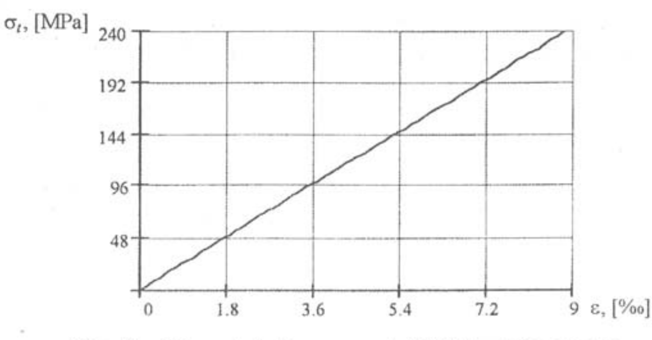

Fig. 7.- Characteristic curve of GFRP reinforcement.

Figs. 8,...,11 present stress distributions and crack development for both types of beams in initial and final loading stages.

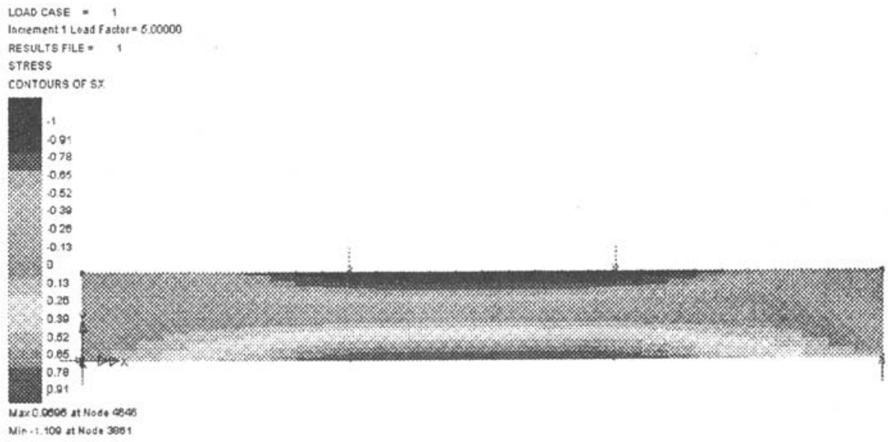

Fig. 8.– Normal stresses distribution after first loading step, [MPa] – (steel reinforced beam).

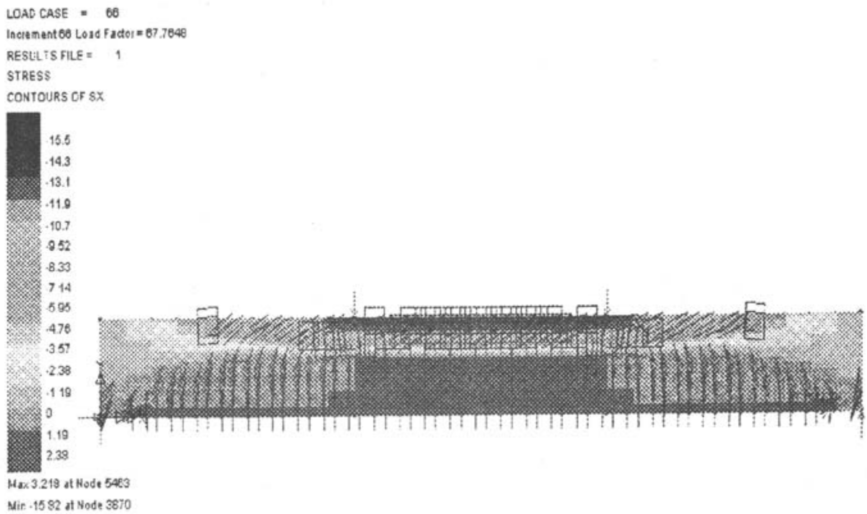

Fig. 9.– Normal stresses distribution after the last loading step, [MPa] – (steel reinforced beam). Note the distribution of cracks at the bottom part of the beam and the crushed concrete at the upper part.

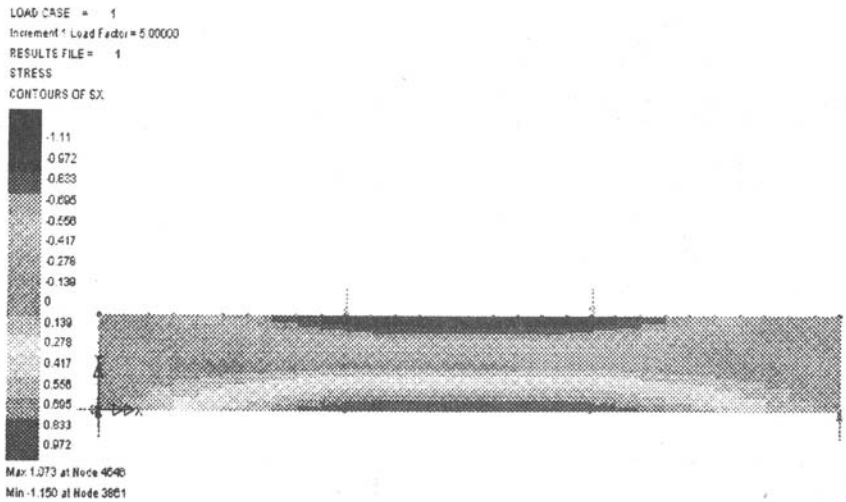

Fig. 10.– Normal stresses distribution after the first loading step, [MPa] – (FRP reinforced beam).

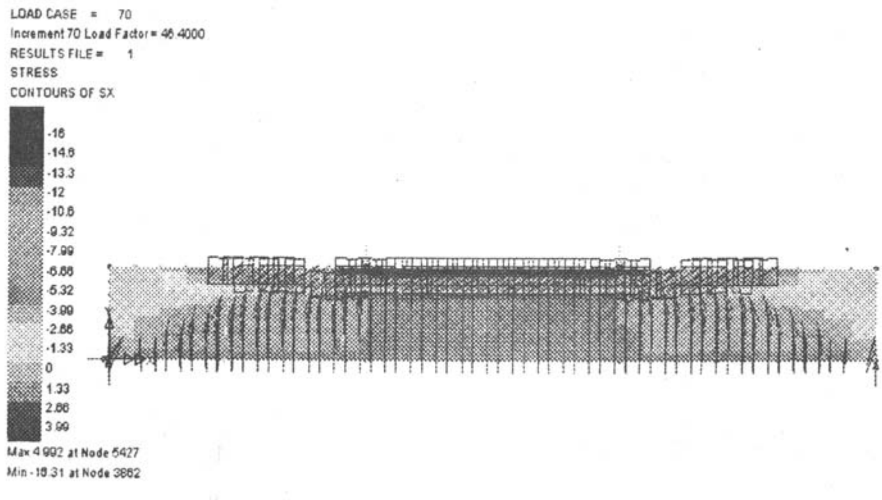

Fig. 11.– Normal stresses distribution after the last loading step, [MPa] – (FRP reinforced beam).

It has been found that in case of the steel reinforcement, the beam failed at 67.76 kN as long as for the FRP reinforced beams, the failure load was only of 46.4 kN. It was also found that the FRP bars reached only 35% of their strength capacity, the failure of the beam was due to premature crushing failure of the upper part concrete.

Fig. 12 gives the comparison between the two obtained force – displacement curves.

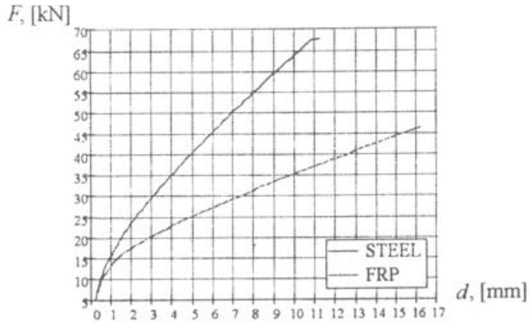

Fig. 12.– Force *vs.* displacement curves in case of steel and FRP reinforcements.

3. Conclusions

As direct conclusions, drawn from the finite element analysis, we may state the following:

1. Due to the low elasticity modulus of the GFRP reinforcement bars (comparable to the one presented by concrete), the crack development is more rapid than in the case of steel reinforcement, leading to a lower bearing capacity of the beam.

2. The structural stiffness of the GFRP reinforced beam is much lower than its steel reinforced counterpart.

3. The main advantage of the GFRP reinforcement as opposed to steel is its superior corrosion resistance.

4. The use of GFRP instead of steel reinforcement is mainly recommended in case of elements working in severely chemically aggressive environments and in special environments with particular electromagnetic requirements.

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2. * * * *Design and Use of Fibre Reinforced Polymer Reinforcement (FRP) for Reinforced Concrete Structures.* Fib Tg 9.3, Technical Report of the Task Group 9.3, Fédération Internationale du Béton, 2006, 8.1-8.14.

PARTICULARITĂŢI PRIVIND ANALIZA ŞI COMPORTAREA GRINZILOR DIN BETON ARMATE CU BARE DIN COMPOZITE POLIMERICE ARMATE CU FIBRE

(Rezumat)

Metodele tradiţionale de armare a elementelor din beton prin utilizarea barelor de oţel se confruntă in prezent cu probleme majore cauzate în special de fenomenul de coroziune favorizat de existenţa unor medii de lucru cu agresivitate chimică sau utilizarea sării pentru topirea gheţii (cazul grinzilor din beton armat de la poduri). În ultimul timp, utilizarea elementelor din materiale compozite polimerice armate cu fibre (CPAF) se impune ca o alternativă viabilă în cazul armării interne a grinzilor din beton. Particularităţile pe care le prezintă proprietăţile mecanice ale acestor materiale determină un proces de calcul dificil, fapt care justifică volumul mare de resurse implicate în rezolvarea acestei situaţii.

Se prezintă rezultatele unei simulări numerice (bazate pe Metoda Elementului Finit), componentă a unui program experimental ce are în vedere şi încercarea la încovoiere a unor epruvete la scară naturală, grinzi din beton armat cu bare CPAF. Valorile reduse pe care le prezintă modulul de elasticitate al materialelor CPAF nu justifică utilizarea lor din punct de vedere structural; totuşi, din considerente anticorozive şi pentru obţinerea unor proprietăţi electromagnetice speciale, aceste sisteme trebuie promovate.