INNOVATION OF STRUCTURAL MEMBERS BY APPLICATION OF FRC

A. Kohoutková [1], V. Brejcha[2]

Abstract: *Research and development of Steel and Synthetic Fibre Reinforced Concrete have generated a lot of information on the features of these composites, which are defined by higher ultimate tensile strength, higher impact resistance and more ductile behaviour than normal concrete. While the potential benefits of FRC on structural response and performance have been experimentally demonstrated, specific procedures for structural implementation of FRC in form of design guidelines, manufacturing processes, and evaluation and quality control tools are rarely available. Experience with practical implementation of innovative technologies in production of precast members used in transportation infrastructure is presented. Transfer of processes from laboratory into manufacturing of real structures is documented on practical examples. Practical results obtained from successful cooperation of academic sphere and construction industry during the activities in the project financed in a program of support for research and development by the Ministry of industry and trade of CR is discussed.*

Keywords: Fiber reinforced concrete, structural concrete members, precast elements, noice barriers, impact resistance, ductility of members.

1. Introduction

The expected range of use of FRC covers areas like new structural elements, maintenance, retroffitings etc. It is known that the durability of material often plays an important role within structures design and resolving process. The crack width limits for an aggressive environment are so strong that it is difficult to fulfill in practice using common steel reinforcement and normal concrete The combination of steel bars and fiber reinforcement opens a wide field of applications for aggressive environment. A practical significance of the project is therefore given by direct usability of the results in engineering design. Practical results serve as feed-back for research team from the university as well. In particular, reliable prediction of the overall response and durability of FRC will help structural engineers to design and produce more precise structures resulting in substantial savings. University guarantee that the project targets will be addressed adequately.Transition from an intention of an FRC application to the actual production of an element is very demanding process.

[1] Alena Kohoutková , CTU in Prague, Faculty of Civil Engineering, Thákurova 7, 16629 Prague 6, alena.kohoutkova@fsv.cvut.cz

[2] Vladimír Brejcha, SMP CZ, a.s., Evropska 1692/37; 16041 Prague 6, vladimir.brejcha@smp.cz

Therefore such elements were tipped for the first phase of production, where positive qualities were promising and highly expected. Operating conditions in a production plant are quite different from conducting laboratory studies. Harmonized components of concrete mixture had to be adjusted and technological process should be verified for corresponding type of concrete regarding workability, strength and other parameters of tested member. By concreting of plate elements real applicability of production for cornice plates in previous phase of collaboration was proved.

The procedure of production of fresh fiber concrete and casting concrete into the form was documented on the photos. The influence of steel fibre of variable types on SFRC beams was verified, the shear and bending load capacity and also type of failure of RC and SFRC beams were compared.

Fig.1.: Set up of the full-scale test in a laboratory

Knowledge of the mechanical properties of cement-based materials, especially their growing strength at any arbitrary time is fundamental for operations or cracking control. Such properties are conditioned by the suppression of evolution of damage, initiated in the early-age period, characterized autogenous material shrinkage, and activated later by external loads. The presence of fibre reinforcement of various types, as well as the early-age treatment, is able to modify this process substantially. The project covers both the design of a complex practical testing and numerical analysis, based on the proper motivated formulation, supported by experiments with modified materials under realistic conditions. Its output should be useful in the design of advanced building materials and structures with high and decreased cost.

2. Noise barrier concrete wall system

The experimental research verified precast members of noise barrier reinforced concrete wall system. The noise barrier system consists of columns fixed in the basement and of horizontally spanning panels. Since the early 1970s, it has become common practice in the industrialized countries to engineer noise barriers along major highways to protect adjacent residents from intruding roadway noise. The technology exists to predict accurately the optimum geometry for the noise barrier design. Noise barriers generally may be constructed of wood, masonry, concrete, earth or a combination thereof. In the case of concrete any improvement of the system should lead to decreasing cost, because of large amount of barriers produced.

First of all the investigations focused on columns. The columns have I-shaped cross-section what enable supporting of horizontal panels. The columns are manufactured in lengths from two to six meters according to local conditions on the final position and other requirements. Current precast columns are made from reinforced concrete with classical steel bar reinforcement. The investigations enquired after possibilities of the reduction of rebar reinforcement in the element with combined (rebar – dispersed) reinforcement and if it would be cost-effective. The feasibility of production of prestressed columns with and without dispersed fibre reinforcement was verified too.

Several types of concrete classes with various fibres were investigated.

Within the project precast elements are nominated (proposed) suitable for modification and change of technology.

The first element chosen for the research program was a column with I-shaped section. The column is a part of noise-barriers.

The noise barrier consists of columns fixed in the basement and horizontally spanning panels. The I-shaped section of columns enables supporting of horizontal panels.

Some precast columns from the current production show defects after transport to the site; the edges and corners are spalled out. Other columns exhibit defects after assembling. These defects are claimed by the contractor and the producer must repair them or replace the damaged element.

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2.1 Choice of materials

In the decision-making process a suitable fibre concrete must be determined. Many points of view had to be considered. The question is which steel fibres shall be used for the mixture; if more profitable is using of SFRC (Steel Fibre Reinforced Concrete) with outstanding tensile strength or SFRC with high ductility. The length of fibres is an important aspect as the dimensions of section are relatively low and long fibres may cause non-homogeneities and balling of fibres. Last not least decision affecting factor is the price of fibres offered by the producer.

The dispersed reinforcement was assumed in two variants – steel fibres and synthetic fibres. SFRC (Steel Fibre Reinforced Concrete) was chosen in cases where the increase of tensile strength and residual tensile strength were demanded, synthetic fibres were chosen for the increase of toughness and resistance to stroke damage.

Mixtures that would not complicate the production and would not affect the traditional technology of production were designed. Workability was tested, standard laboratory tests performed and strengths determined.

2.2 Experimental program

Full-scale tests and numerical simulations of the precast columns were performed within the research project.

The tested specimens were 2.75 m long; I-shaped section had web 110 mm thick and haunched flanges. The prestressing tendons are placed in the vertical axis of symmetry.

The problem of the testing is modelling of supporting of the element. In real conditions the element is fixed to the spread footing and acts as a cantilever. Modelling of a fixed support in laboratory conditions was discussed and resulted in a verdict that simple and cheep solution must be chosen. That's why the fixed support for laboratory loading is simulated by two pinned supports in a short distance and the member is loaded on the farer end; the span is 1.95 m. Lay-out of the test is depicted in the Fig.1.

Deformations, crack widths, and load are measured in tests. For the prestressed members pull-in of prestressing tendons is measured to verify the transfer length of prestressing tendons and needed length of fixing in support

3. Discussion of tests results

Columns of I shaped cross section with (see Fig. 2) concreted of C35/45 and C 55/67 concrete, reinforced concrete columns with steel B505B, prestressed concrete columns with prestressing strands 1770S7 Y - 15.7 – A. Steel fibres were Fibrex and synthetic fibres wre of polypropylene. Prestressing stress was 1375 Mpa. Footings for all types of columns were from C30/37 concrete and steel B505B. Footing reinforcement consists of longitudinal bars and transverse shear stirrups both profile 10 mm.

Columns were fixed at the various length 600mm, 800 mm and 1000 mm. In the Fig. 3 load – deflection diagram of prestressed column (Tab.1) made of concrete C 55/67 XF4 with synthetic fibres can be seen. Maximum load and load at the cracking with crack width less than 0.02 of value 36,5 kN is promising result from point of view of real performance of chosen material.

From the overall results can be seen that prestressing and a higher class of concrete led to increased resistance of prestressed concrete columns compared to the reinforced concrete column. Load at the first crack of prestressed concrete columns is much higher than that of reinforced concrete column. Differences between columns with different lengths of restraint are not decisive. The first crack in prestressed concrete columns with a fixed length of restraint 600, 800 and 1000 mm occurred at the acting forces of value 42,9, 42,9 and 43,6 kN respectively.

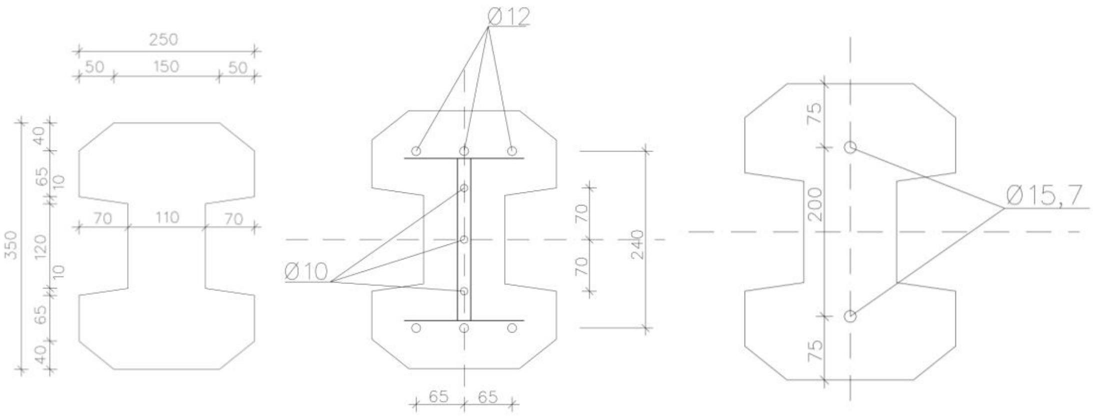

Fig. 2: Cross-sections: a) dimensions, b) position of longitudinal bars and shear reinforcement in reinforced column c) position of reinforcement in prestressed concrete column

Maximum loads was for restraint of 600, 800 and 1000 mm with are comparable and can be seen in Tab.1. Also in the behaviour in bending of prestressed steel fibre reinforced concrete columns were not big differences. The first crack was at the length of the restraint 600 and 800 mm at 22,1 mm deflection and at acting forces 32 a 33 KN. Maximum force was at the length of the restraint 600 and 800 mm 43 and 44 KN and deflection at 27.5 and 35.6 mm. While compare prestressed concrete and steel fibre reinforced concrete columns, the values of deflection and force applied during formation of the first cracks are still of similar values.

All these bending tests were also simulated by FEM numerical modelling in ATENa software. The results and their comparison with measured values are subject matter of other contribution, where the types of failure are discussed.

Moreover, health and environmental aspects must not be ignored. Extensive research activities in this area were summarized. Further investigation will be necessary to define safety limits for exposure and their life cycle in the nature. Infrastructure maintenance has traditionally been governed by optimization of economical, serviceability and safety issues. In last decades additional issues are born from recognized needs of sustainable development and life cycle analysis.

The prediction of a realistic life cycle and the prolongation of the service life is an important task to reduce costs of bridge structures in the future. The precise assessment of the life cycle will become an important challenge. Assessing the state of the structure must precede every life cycle determination. The actual and future trend in safety assessment is the use of reliability-based methods for bridge assessment. This will be the objective in the future.

The laboratory tests showed higher resistance than the theoretical analysis. In the analysis of executed tests several reasons of the differences were pronounced.

4. Conclusions

Performed tests, calculations and simulations show that prestressed columns have higher resistance than the reinforced concrete columns; at the same time the failure mode is acceptable and safe. For the tested length of columns are the prestressed columns reliable even without additional shear reinforcement or dispersed reinforcement. Yet the fibre reinforcement is assumed to enhance toughness, reliability and resistance to damage during transport and manipulation and also durability in severe conditions. Results of tested columns in bending are summarized in Tab 1.

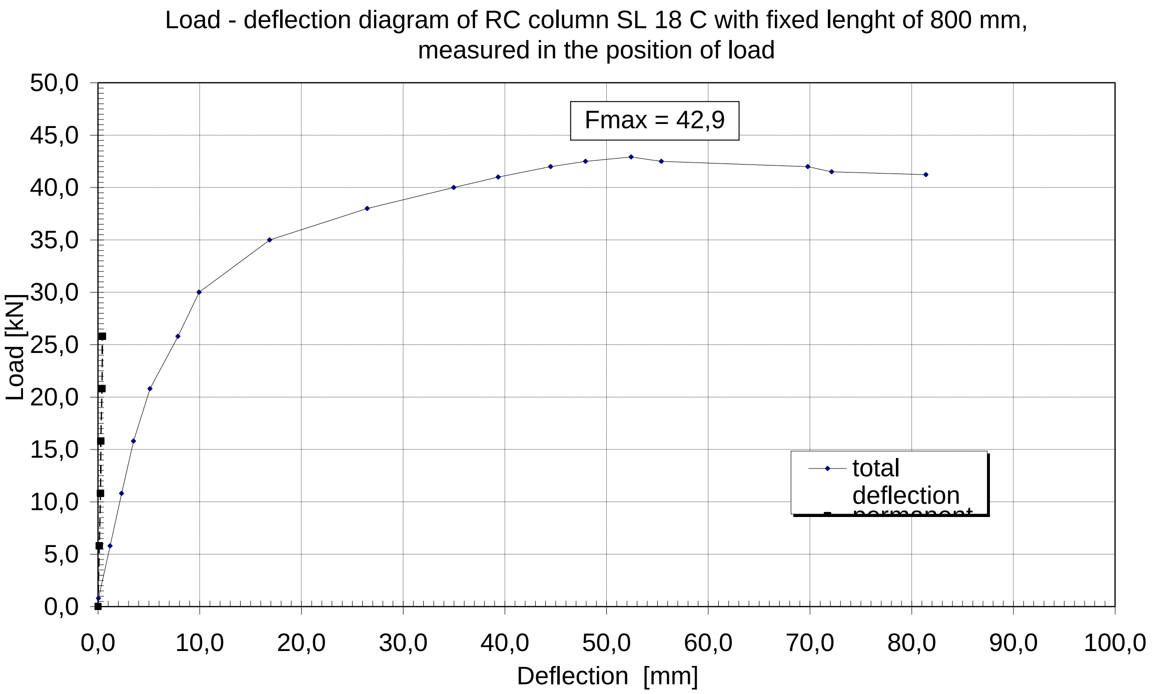

Fig.3: Load – deflection diagram of prestressed column SL 18 C , FC with synthetic fibers

Tab. 1 Results from bending tests of concrete columns

Spec.	Denom.	Concrete	Fibres	Length in mm	Crack load	Max. load in kN
SL11	A	RC	no fibres	600	9,8	36,1
					12,8	36,7
					14,5	36,1
SL12	B	prestress	no fibres	600	30	44,2
					24	41,3
					30	42,6
SL13	B	prestress	no fibres	800	30	42
					32,5	42,9
					28	40,2
SL14	B	prestress	no fibres	1000	28,5	44,5
					30,3	43,6
					30	42,4
SL15	DF	prestress	steel fibres	800	34	43,5
					33	43,4
					34	43,5
SL16	DF	prestress	steel fibres	600	36,5	44
					32,4	43
					30	40,2
SL17	C	prestress	synthetic f.	800	34,7	42,2
					33,7	42
					36,5	42,9

The object of further investigations will be feasibility of columns with higher lengths. Utilisation of numerical simulation is anticipated for verification of resistance, reliability and failure mode.

Innovation consisted in a transition from current concrete to fiber concrete when an optimization procedure is necessary: starting from selection of proper type of fiber concrete, adjusting shape and dimensions of the member and experimental verification of structural behaviour of the new member.

The procedure included optimization of amount of fibers so that it was ensured that the member would not fail or be damaged during function or transport under conditions prescribed for precast elements of common type and common reinforcement.

Program of applied research and experimental investigations is still at its first stage, so far obtained results are in accordance with expectations.

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