Flexural stiffness of the composite steel and fibre-reinforced concrete circular hollow section column

A Tretyakov [1], I Tkalenko [1], F Wald [1], J Novak [2], R Stefan [2] and A Kohoutková [2]

[1] Czech Technical University in Prague, Dept. of Steel and Timber Structures, Czech Republic
[2] Czech Technical University in Prague, Dept. of Concrete and Masonry Structures, Czech Republic

E-mail: alexey.tretyakov@fsv.cvut.cz

Abstract. The recent development in technology of production and transportation of steel fibre-reinforced concrete enables its utilization in composite steel-concrete structures. This work is a part of a project which focuses on development of mechanical behaviour of circular hollow section (CHS) composite steel and fibre-concrete (SFRC) columns at elevate temperature. Research includes two levels of accuracy/complexity, allowing simplified or advanced approach for design that follows upcoming changes in European standard for composite member design in fire EN1994-1-2 [1].
One part is dedicated to determination and description of flexural stiffness of the SFRC CHS columns. To determinate flexural stiffness were prepared series of pure bending tests at elevated and ambient temperature. Presented paper focuses on the results of the tests and determination of flexural stiffness at ambient temperature. Obtained outputs were compared to data of existing studies about concrete-filled tube members with plain concrete and values analytically calculated according to the existing European standard EN1994-1-1 [2].

1. Introduction

Concrete filled steel tube (CFST) members combine main advantages of both materials (concrete and steel) and provides better properties of the members in many aspects [3]. CFST gives more efficient construction process with no formwork needed rather than steel reinforced concrete composite. Infilling of the steel tube brings better mechanical properties of the members and increases fire resistance [4].

Numerous researches of CFST members' behaviour have been conducted in the last three decades. There is conventional set of questions in fire resistance assessment incorporated by their peculiar objects and characterized by principally similar ways of the solutions. Alberto, Romero and Espinos' latest researches were summarized in a proposal of a new method in EN1994-1-2 [1] for the fire design of concrete filled steel tubular columns [5]. This research is focused on investigating behaviour of CFST filled with plain and bar-reinforced concrete. Proposed approach aimed at developing European design solutions for CFST columns based on available test data, numerical and analytical simulations. However, EN1994-1-2:2005 [1] and most current proposition of standard development do not specify design solutions for composite steel and FRC columns in fire. Current practices of testing and modelling emphasize usage of higher strength materials [3], regardless of previous focuses on normal strength concrete infill. Since 1954 more than 150 circular hollow section steel to concrete composite (CFST) columns were tested in fire and less than 5% had SFRC infill.

Adding steel fibres to mixture increases ductility, compressive and tensile strength of concrete [6] and as a result flexural stiffness of the member, which is more efficient for subjecting to combined loads at ambient and elevated temperatures. Compared to the filling of CHS with plain concrete, SFRC's fiber plastic tension capacity to hold appearing cracks increases the volume of member's resistance to combined compression and bending [7]. Comparison of typical behaviour in tension of

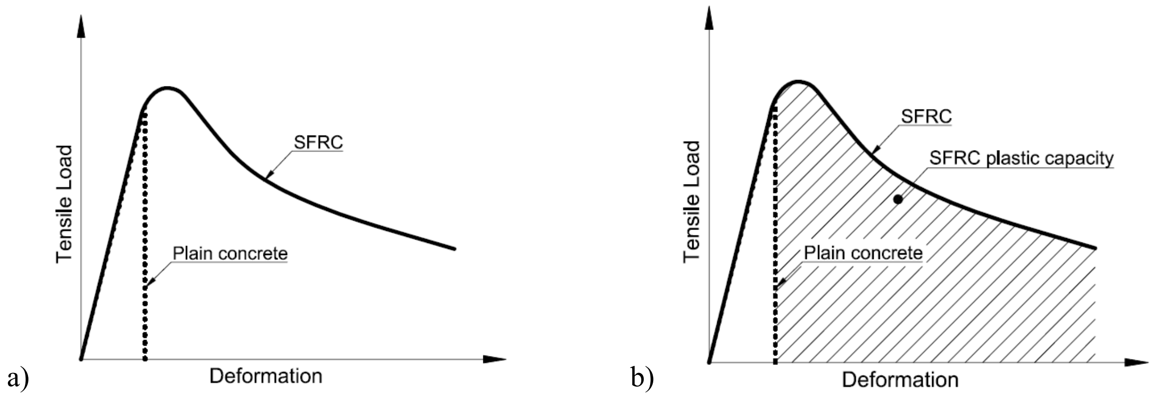

Figure 1.1 a) Behaviour in tension of plain and SFR concrete [7] **b)** Delineation of SFRC plastic capacity

plain and SFR concrete is shown on *Figure 1.1*.

From design rules of EN1994-1-1 [2] follows that improvement of flexural stiffness has negligible impact to buckling resistance. This demonstrates the importance of experimental and numerical investigation of flexural stiffness and determination of relevant design rules for CHS filled with SFRC.

Flexural behaviour of CHS sections filled with plain concrete was researched by many authors. Lin-Hai Han [8] [9] presented results from experimental studies on rectangular and circular CFST members and their comparison with different design approaches. Method used in his research was applied to compare flexural stiffness from current bending tests on CHS infilled by SFRC.

This paper shows the results obtained from the pure bending experiments at ambient temperature. Calculated values from tests are compared to EN1994-1-1 [2] design approach and to the selected results from Lin-Hai Han research [8] [9]. Received data is an inseparable part of further research focused on development of mechanical behaviour of circular hollow section (CHS) composite steel and fibre-concrete (SFRC) columns at elevated temperature.

2. Material properties

A welded circular hollow section with 323,9 mm diameter and 5 mm wall thickness made from steel S355, was chosen for the experiment.

The concrete composite is composed of easy available and widely used components which include Portland cement 42,5 R characterised by high early strength in accordance with CSN EN 197-1[10], water and siliceous aggregate. The workability of fresh concrete mass was maintained by using plasticizer Sika Visco Crete 1035 which also reduces the content of used mixing water. The chosen fibre reinforced concretes also contain two types of fibres. Single hook end steel fibres Dramix RC-80/60-BN with tensile strength 1225 MPa serve as reinforcement in the concrete composite. Whereas polypropylene fibres were added in concrete with an aim to reduce the risk of explosive concrete spalling which occurs at higher temperature at elevated temperature tests [11] [12].

3. Prue bending test

3.1. Specimens

For experiments were produced 3 m long specimens. To prove and prevent influence of friction between concrete and steel tube the specimens was produced in two types: with fully open ends (specimen B1) and with shear plate (specimen B2). List of the specimens is given in *Table 3.1.* Beams were stored for 28 days in the warmed-up warehouse. First test was carried out 29 days after specimens concreting.

Table 3.1. Specimen list

Specimen	Tube diameter, mm	Wall thickness, mm	Length, mm	End type	Quantity
B1	323,9	5	3000	Open ends	1
B2	323,9	5	3000	With shear plate	1

3.2. Test setup

Tests were performed at CTU in Prague laboratory. To reach a pure bending effect in specimen was chosen a four-point bending setup. During the test was measured deflection, tension and compression at steel tube, and displacement of the concrete beside the steel tube at the ends of the beam. Strain gauges were placed at the bottom and top surface of the steel tube at the distance 200 mm from the middle. Deflection was measured at 1/3 and 1/2 length of the beam. Setup of the test is shown on *Figure 3.1* and *Figure 3.2*.

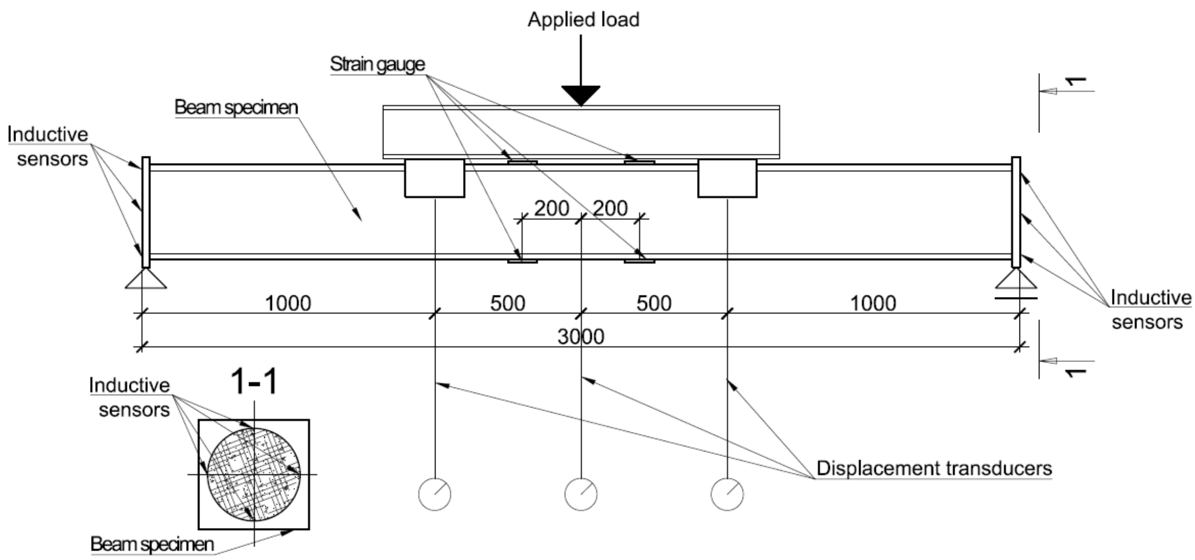

Figure 3.1 Bending test setup scheme.

a)  b) 

Figure 3.2 Bending test setup photo a) Full view b) Inductive sensors setup.

3.3. Results

Dependence of vertical deflection in the middle of the specimen length curves is apparent on *Figure 3.3*. Behaviour of CFHS with SFRC member in bending can be divided into four stages: cracking linear, post-cracked linear, post-cracked non-linear and failure.

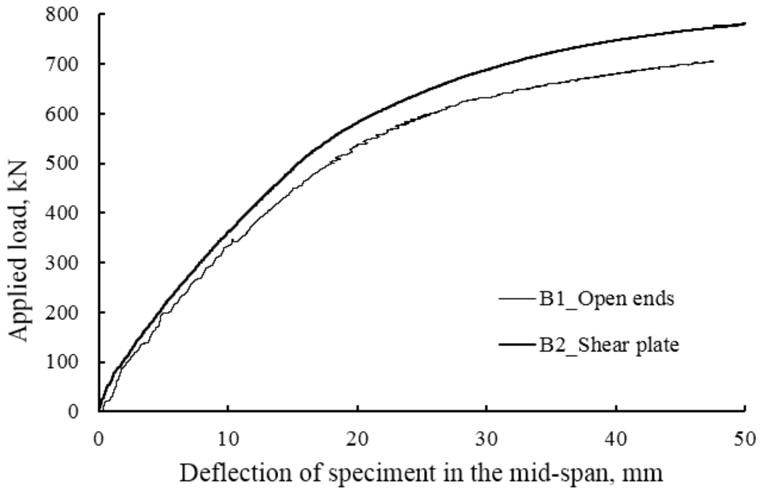

Figure 3.3 Vertical deflection in the 1/2 of specimen's length

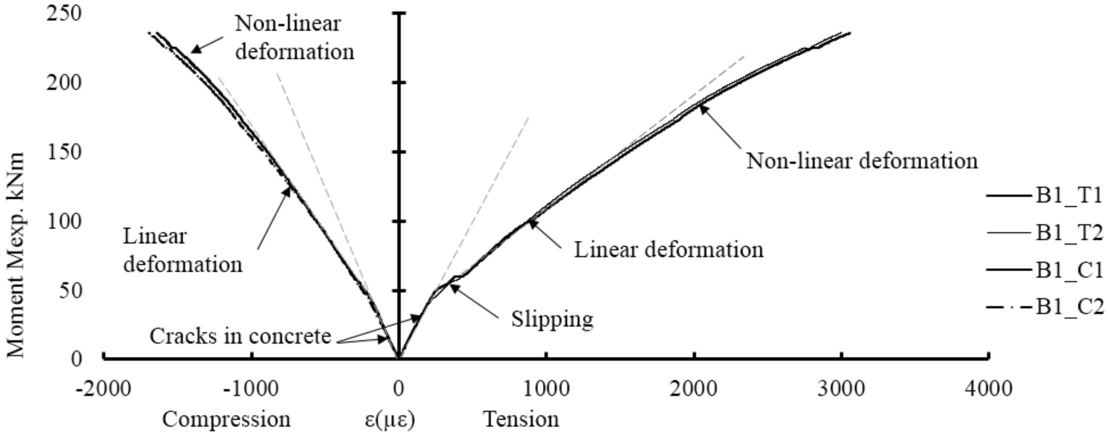

Figure 3.4 Moment-strain curves for specimen B1

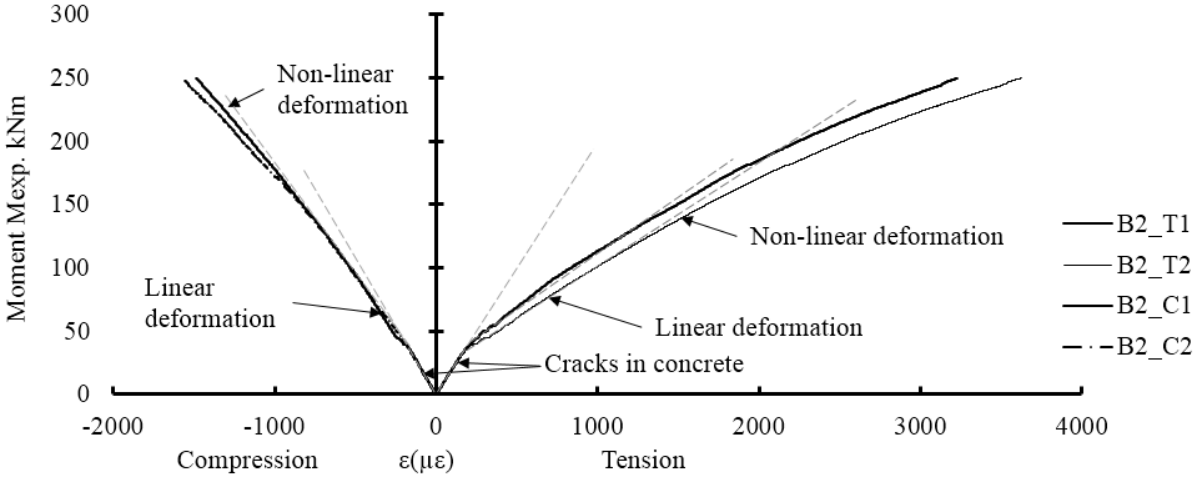

Figure 3.5 Moment-strain curves for specimen B2

Cracking linear stage ends with initial cracking of SFRC in tension area of composite section, post-cracked linear stage takes place until steel tube is yields, post-cracked non-linear stage is characterized by increasing of plastic deformation until failure. Typical moment-strain curve with determination of stages is shown on *Figure 3.4* and *Figure 3.5.* From the curve of specimen B1 on *Figure 3.4* could be seen the concrete core slipping influence, which was verified from the inductive sensors data.

From the moment-curvature diagram given on *Figure 3.6* it is apparent, that flexural stiffness decrease after cracks in concrete core growth. Flexural stiffness in first linear stage could be assumed as initial flexural stiffness of the section $EI_{exp.}$.

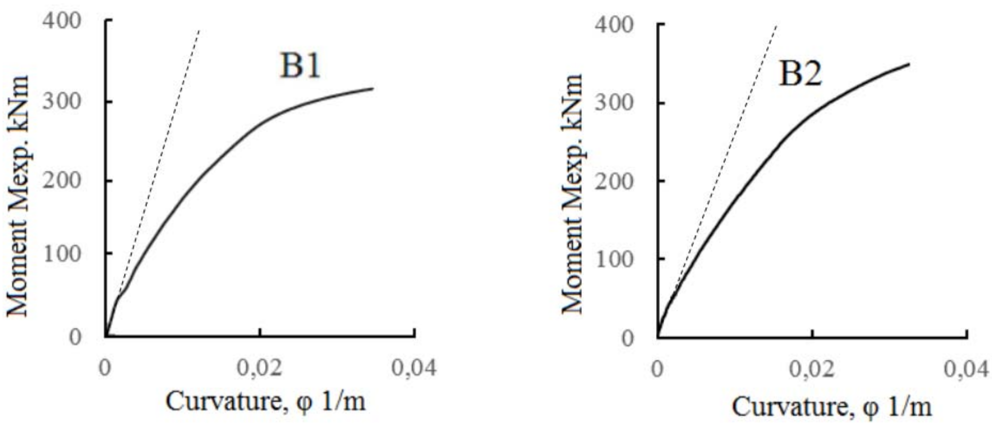

Figure 3.6 Moment-curvature diagrams

4. Determination of flexural stiffness and comparison

Determination of flexural stiffness for steel tubes filled with concrete without fibres is based on the effective member stiffness which could be assumed as addition of flexural stiffness of steel CHS and flexural stiffness of concrete core adjusted by correction factor [2]. According to EN1994-1-1[2] effective flexural stiffness of the member in comparison is defined as:

$$(EI)_{eff} = E_a I_a + 0{,}6 E_{cm} I_c \tag{4.1}$$

where E_a is the modulus of elasticity for the steel tube, E_{cm} is the modulus of elasticity for concrete, I_a and I_c are moments of inertia of the steel tube and concrete core without cracks. Modulus of elasticity for SFRC infill was taken from the experimental and numerical studies of mechanical properties and was adjusted as E_{cm}=36 GPa. Modulus of elasticity for the steel tube was adjusted as E_a=210 GPa. Values of flexural stiffness $(EI)_{eff}$ taken from the Lin-Hai Han research papers [8] [9] were changed according to adjusted E_a value. Results of the analytical calculation, together with selected values from Lin-Hai Han research, are given in *Table 4.1*. Comparison of the initial flexural stiffness $(EI)_{eff}$ / $EI_{exp.}$ ratio for members with SFRC and plain concrete infill [9] is shown on the *Figure 4.1*.

Table 4.1. Analytical flexural stiffness calculation results

Specimen	Dimension D x t x L	$(EI)_{eff}$ [kNm²]	$EI_{exp.}$ [kNm²]	$(EI)_{eff}$ / $EI_{exp.}$	Note
B1	323,9x5x3000	23700	31479	0,75	Current
B2	323,9x5x3000	23700	31555	0,75	
CVB-1	200x1,9x1400	2891	3414	0,85	Han *et al* (2006)
CVB-2	200x1,9x1400	2891	3216	0,90	
CB5-1	180x3x1800	2305	2383	0,97	
CB6-1	180x3x1800	2305	2371	0,97	
CB6-2	180x3x1800	2305	2321	0,99	

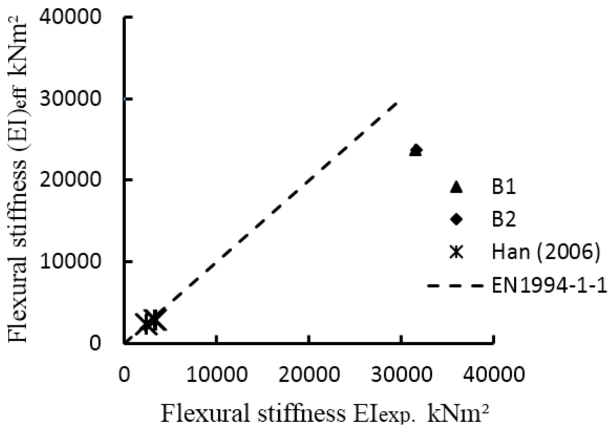

Figure 4.1 Comparison of the initial flexural stiffness values

Value of the flexural stiffness $(EI)_{eff}$ for all examined members is lower than obtained from the tests. From the presented comparison could be seen that, current specimens with SFRC infill have lower $(EI)_{eff}$ / $EI_{exp.}$ initial stiffness ratio than that with plain concrete core.

5. Conclusion

Two pure bending tests at ambient temperature were performed. Outputs from the experimental studies were analysed and presented. Experimental and design initial flexural stiffness of CHS with SFRC core were determined and compared to that for CHS with plain concrete infill. From the comparison is apparent that compared to analytical method in EN1994-1-1[2], initial stiffness for members with plain concrete infill is lower. Stiffness ratio $(EI)_{eff}$ / $EI_{exp.}$ for specimens with plain concrete core was determined in range of 0,85-0,99. Flexural stiffness ratio for current specimens B1 and B2 was determined as 0,75. Therefore experimental initial flexural stiffness from current tests is 25% higher than at EN1994-1-1[2] design approach and up to 24% higher compared to that for CHS with plain concrete infill. For the both current specimens, effective flexural stiffness obtained from EN1994-1-1[2] design approach could be assumed as conservative.

IOP Conf. Series: Materials Science and Engineering **246** (2017) 012021 doi:10.1088/1757-899X/246/1/012021

Given conclusion leads to the further numerical and experimental analyses. As a next step for the studies of CHS with SFRC core at ambient temperature, could be specified influence of the shear plates, determined and compared moment capacity and serviceability-level of section flexural stiffness [8][9].

Obtained data would be used for the research of steel CHS with SFRC infill behaviour at elevated temperature.

Acknowledgment
The authors would like to express their sincere gratitude to the Czech Science Foundation for the help provided through the project “Models of steel and fibre concrete composite columns exposed to fire”, carried out with a financial grant GAČR 15-19073S.

References

[1] CEN. EN 1994-1-2, *Eurocode 4: Design of composite steel and concrete structures. Part 1-2: General rules – Structural fire design*. 2005,Brussels, CEN
[2] CEN. EN 1994-1-1, *Eurocode 4: Design of composite steel and concrete structures. Part 1-1: General rules and rules for buildings*. 2004, Brussels, CEN
[3] Liew J.Y.R., Xiong M.X., Xiong D.X. 2015 *Design guide for concrete filled tubular members with high strength materials to Eurocode 4*, Research Publishing, Singapore
[4] Zhao X., Han H. and Lu H. 2010 *Concrete-filled tubular members and connections*. New York: Spon Press
[5] Albero V., Espinos A., Romero M.L., Hospitaler A., Bihina G., Renaud C. 2016 *Proposal of a new method in EN1994-1-2 for the fire design of concrete filled steel tubular columns*. Engineering Structures vol. 128, pp. 237–255
[6] ACI Committee 544, 1988 *Design Considerations for Steel Fiber Reinforced Concrete,* ACI 544,4 R American Concrete Institute, Farmington Hills, MI
[7] Adhikari S., Patnaik A. 2012 *Potential applications of steel fibre reinforced concrete to improve seismic response of frame structures* NED University Journal of Research, pp. 113-128
[8] HAN, L.-H. 2004 *Flexural behaviour of concrete-filled steel tubes* Journal of Constructional Steel Research vol. 60(2), pp. 313-337
[9] HAN L.-H., Hui LU, Guo-Huang YAO and Fei-Yu LIAO 2006 *Further study on the flexural behaviour of concrete-filled steel tubes* Journal of Constructional Steel Research 62(6) pp.554-565
[10] The Czech Standard ČSN EN 197-1 *Cement - Part 1: Composition, specifications and conformity criteria for common cements,* ČNI, 2002, (in Czech)
[11] Novák J. and Kohoutková A. 2017 *Fire response of Hybrid Fiber Reinforced Concrete to High Temperature. In: Procedia Engineering* Lausanne: Elsevier, Modern Building Materials, Structures and Techniques, vol. 172, pp. 784-790
[12] Goremikins, V., Blesak, L., Novak, J. & Wald, F. 2016 *Experimental method on investigation of fibre reinforced concrete at elevated temperatures*, Acta Polytechnica, vol. 56, no. 4, pp. 258-264