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Resistance of the component 'lateral faces of RHS' at high temperature

Carlos López-Colina *, Miguel A. Serrano-López, Fernando L. Gayarre, Francisco J. Suárez

Department of Construction and Manufacturing Engineering, EPSIG, University of Oviedo, Campus de Gijón, 33203, Gijón (Asturias), Spain

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ABSTRACT

The component method is the most important theoretical approach for the evaluation of the properties of joints. The present paper tries to extend this method to new fields of application. For this purpose, two subjects that have been traditionally excluded from the application of the component approach were considered: structural hollow sections and fire conditions. For this purpose, the lateral faces under compression of rectangular hollow sections (RHS) were chosen as one of the most important components in joints between hollow sections or between hollow and open sections. To study the resistance behaviour of this constitutive part of the joints under high temperature conditions, experimental and numerical research was carried out to check the validity of some analytical equations. The experimental tests, at ambient and high temperatures, are used to validate the finite element modelling, which allows for a more extensive analysis of the parameters included in the analytical formulation.

1. Introduction

The good performance provided by the structural hollow sections submitted to compression forces has spread their use as columns in steel framed buildings. Moreover, architects and structural engineers are encouraged to utilise hollow sections in structural steel frames for their aesthetic qualities, and even leaving them without any coating except for some protective paint. In addition, two important issues related to steel structures have been deeply studied in recent decades: connections and behaviour under fire conditions. One of the main tools to calculate the response of joints, taking into account their strength and stiffness, is the component method. It has been developed as a simplified design tool to be included in the design codes [1] for practitioners and allows the evaluation of a wide range of joint configurations and connection types.

Despite the advance provided by the component method, the design rules for joints between hollow sections have been traditionally based on simple theoretical models and they are usually restricted to specific configurations of joints in which the rules have been validated. Normally, these formulae give an estimation of the resistance of the joint as a whole for special loading cases and configurations. The limited field of application of this method makes it difficult to change the joint geometry. Another restriction of this kind of formulation is that there are no methods to evaluate the stiffness of joints involving hollow sections. The most practical way to study the behaviour of structural joints between rectangular hollow sections under high temperature conditions must be the extension of component method to hollow sections and to elevated-temperature situations. However, the component method described in the standards is limited to joints between H or I sections and it does not mention its applicability in high temperature situations.

To reach the proposed objective it is necessary to improve knowledge in the following three main fields: interaction between bending moment and axial force; behaviour of joints under high temperature conditions; and development of new specific components for joints involving RHS profiles. The first two subjects have been studied by some important research groups [2–4], mainly for I and H sections, and some of their results can be extended to hollow sections.

The extension of design formulae for new specific components to joints with RHS profiles has advanced in recent years thanks to the work of some researchers with the support of CIDECT. Despite the useful recompilation that has been done in the last report of the CIDECT project [5], many of its presented components still need an experimental validation or even a complete characterisation since they are not supported on laboratory tests or finite element modelling.

Following the path opened by CIDECT, the lateral faces under compression of rectangular hollow sections were chosen as one of the most important components in joints between

* Corresponding author. Tel.: +34 985181988; fax: +34 985182433.
E-mail address: lopezpcarlos@uniovi.es (C. López-Colina).

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Nomenclature

EC3	Eurocode 3. EN-1993
F	Force
f_{y0}	yield strength of the steel of the hollow section
h_0	depth of the hollow section
l_x	Length between the external and the internal plastic hinges
M_p	Plastic moment on the front face of the hollow section
RHS	Rectangular hollow section
$R_{p0.2}$	0.2% proof stress. Stress at which the material undergoes a 0.2% non-proportional (permanent) extension during a tensile test.
$R_{t2.0}$	2.0% total stress. Stress at 2.0% strain during a tensile test.
SHS	Squared hollow section
t_1	Width of the load (thickness of the loading plate)
t_0	Thickness of the hollow section
δ	Displacement of the force's application point
χ	Buckling coefficient according to EC3 formulation

RHS profiles or between hollow and open sections. To study the resistance behaviour of this constitutive part of the joints under fire conditions, experimental and numerical research was completed to check the validity of some analytical equations. The experimental test results, at ambient and high temperatures, are used to validate the finite element modelling, which permits a wider study of the parameters that appear in the analytical formulation.

The final result of this paper is an analytical proposal that could be used as a design equation for the resistance of the mentioned component at ambient and high temperatures.

2. Experimental work

To obtain successful test results at high temperatures, a review of the previous experimental work on the compression zone in columns was necessary. In that previous research some tests had been conducted at elevated temperatures, but all of them were carried out using open sections as specimens [6,7]. Only a few references were found for lateral faces of RHS under compression, and they were mainly about concrete-filled columns at ambient temperature [8].

The aim of the experiment presented in this paper – carried out in the Laboratory of Strength of Materials at the University of Oviedo – was to produce validation cases for finite element studies and simplified models, describing the ambient and high-temperature behaviour of the RHS lateral faces in compression. In order to simulate the necessary conditions, a specially adapted furnace and a universal testing machine were the main tools for this purpose.

The furnace is an electrically heated device of 1100 × 270 × 270 mm, that has two removable panels at both ends acting as isolation caps. It has 6 heating elements with a total power output of 8 kW, and two slots of about 170 × 30 mm on the top and the bottom that allow access for the acting tools specially manufactured for the testing machine. This furnace was initially built in the Civil and Structural Engineering Department of the University of Sheffield for testing UC profiles under transverse compression and axial load in a special loading frame. It was necessary to adapt the furnace to be used for testing RHS profiles in a standard testing machine.

For the test carried out in the University of Oviedo, it was necessary to use (see Fig. 1):

- A MTS test machine with a loading capacity of 250 kN including its own control system and software.
- A purpose-built trolley to support the furnace.
- The 8 kW electric furnace previously mentioned with the necessary adaptations, like isolation caps and wheels adapted for the slide on the trolley.
- Two loading plates that were made of S355 steel with a thickness of 20 mm.
- Four K-thermocouples to measure the temperature of the sample and the inside temperature in the furnace, with the corresponding thermometer.
- A steel rod acting as a brace in one of the ends of the profile to avoid the specimen rotation when it is loaded.
- Some cooling devices like fans and compressed air tools to avoid the temperature transmission to the test machine.

Since the furnace had a manual control, it was necessary to test the stabilisation of temperatures and the heating curves that could be obtained. The results for these tests were satisfactory when the chamber was adequately closed, but the tests of RHS under transverse compression at high temperatures required the entrance of the cold loading plates into the furnace and this caused an undesired cooling of the sample when the loading phase started. Due to the temperature limitations of the clamps of the testing machine, it was impossible to avoid this by heating the loading plates before the contact.

As the loading plates cannot be perfectly aligned, due to slight faults in the flatness of the base material or due to the fabrication process, we must assume a little deviation between them. This difference can introduce a small moment in the load area, forcing the specimen to rotate and, as a consequence, cause important lateral deformations and the buckling of the plates. In order to avoid rotation of the specimen, a brace has been necessary at one of its ends. A steel rod with nominally pinned ends was used.

The specimen length was 900 mm. One of the ends was joined to the brace and the other was far enough from the load introduction area to not be affected by any deformation. One of the removable panels acted as a cap and had a hole shaped and sized to allow the specimen end to reach the brace out of the furnace without any important heat release.

The loading plates that compressed the specimen transversally were 160 mm width since they had to be wider than all the tested profiles. By following this requirement, it was assured that the failure mode of the RHS would be the buckling or yielding of lateral faces under compression, otherwise the failure of front faces could be relevant. A plan and side view of the position and size of the loading plates is showed in Fig. 2.

The tests used squared hollow sections of S275 steel and three different sizes: SHS100 × 4, SHS120 × 4 and SHS140 × 4. These tests were isothermal displacement-controlled for a range from 400 to 650 °C, so it was necessary to take into account that the results can be affected by the strain-rate: the higher the displacement rate is used, the lower reduction of material strength at elevated temperatures and strain-hardening is present up to higher temperatures. However, available experimental data on the structural steel behaviour of steel under different strain-rates at high temperature are limited [9], and more research is necessary in this area. Therefore a medium-low displacement-rate was chosen for the tests, noting that the loading phase cannot be very long due to harmful effects of heat in the loading device. The effect of this displacement-rate was not important in the final results, as it could be seen in a further comparison with a numerical simulation.

Force–displacement curves of the lateral faces under compression at elevated temperatures were objectives of the tests. They were used to validate the numerical analysis that allows a more extensive study of all the parameters. To obtain the actual force–displacement behaviour of the specimen under transverse