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Beams with corrugated web at elevated temperature, experimental results

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ABSTRACT

The paper is focused on presenting the thermal and mechanical response of sinusoidal corrugated web beams subjected to high temperatures. Two tests were performed to monitor the behavior of isolated elements and composite slabs designed with corrugated web beams. Different aspect ratio beams exposed to standard fire temperatures and one beam subjected also to mechanical load were tested in the first experiment. The second study was conducted on a real-scale building compartment designed using corrugated web beams–concrete slab composite floor. The results obtained from experimental works reveal the real temperature distribution in the steel profile and the fire performance of sinusoidal corrugated web beams.

1. Introduction

Fire resistance design of elements has been highly improved and studied in structural analysis for the last two decades. A large credit is owned by the increasing number of experimental tests on individual elements and especially real scale buildings. Behavior of isolated elements subjected to high temperatures and mechanical load are commonly performed to establish the fire resistance. The deficiencies of these tests are presented from the structural engineering aspect in [1,2] and they refer to the distinct boundary conditions and lack of interaction with other elements in real situations. Full large-scale experimental tests eliminate these shortcomings and through detailed monitoring the response of structure can be observed. Large scale tests considering natural fires like the experimental program in Cardington or standard fire tests performed in a European project, MACS+ [3], show the performance enhancement of structural elements. All these tests accommodated commonly used structural elements. A distinct category of bearing capacity elements are the beams with corrugated web.

Although known for the improved performance to shear force both trapezoidal and sinusoidal corrugated web beams are mostly used in bridge engineering and less used in administrative or industrial structural buildings. Their behavior at ambient temperature has been studied by many authors, [4–9], considering different assembly layout. Few numerical studies were made on response of corrugated web beams at elevated temperatures [10] and even less experimental tests [11]. Although the fire experiment performed in a furnace, in Linz, Austria [11] was carried out in order to monitor temperature development in beams and evaluate their performance under mechanical load supplementary data would still be needed for verification and validation.

This paper is focused on two large scale fire tests with sinusoidal corrugated web beams. One test is performed in a furnace on isolated elements having the main purpose to evaluate the temperature development on the beam cross-section. The second test will present the response of a real scale building fire test in Mokrsko. Both test involved staff of Czech Technical University in Prague supervising the experimental process. The data presented in the paper precedes the work regarding an analytical model for temperature development in corrugated web beam cross-sections and the numerical validation of the model.

2. Isolated element tests

Temperatures in steel profiles can be determined based on fire design part of Eurocode 3 [12] which offers prescriptive relations based on the section factor A_m/V. The Eurocode methodology leads to similar results between analytical and experimental determined values for flat web beams. Owing the considerable greater ratio between flange and web thickness corrugated web beams exhibit a different temperature evolution and distribution over the cross-section. In order to determine the particular response of sinusoidal corrugated web beams a fire test was conducted in two stages at

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fire testing laboratory VESELÍ NAD LUŽNICÍ as presented in [13]. The aim of the first part of the test was to determine temperature distribution for several beam aspect ratios while structural response was also monitored for the second stage.

2.1. Structural setup of experiment

An experimental enclosure was set to 3.5 × 5.8 m as presented in Fig. 1a. A larger group of elements were monitored in the test but the paper designated specimens are listed in Table 1. The elements tested in Veseli were manufactured by Zekon Sp. Z.o.o, Poland a part of Zeman Gmbh group and provided by Kovové profily s.r.o. Eight corrugated web beams of 1 m long were monitored by 15 thermocouples each for the first stage of the test while the second stage included also the mechanical response of a 6 m long beam under two point loads.

For the first test the specimens were suspended on two threaded rods, half of them in contact with the top trapezoidal steel sheet, TR 150/280/0.75, while the rest were suspended 300 mm under the ceiling. The dimensions of beam cross-sections and the position of the specimens in the furnace are presented in Table 1 and Fig. 1, respectively.

Second part of experiment involved a 6 m long beam with the dimensions presented in Table 1 for specimen 9. The support conditions for the beam ends follow the restraints of pin and roller support, respectively. On the top flange the beam was covered with a trapezoidal TR150/280/0.75 steel sheet which served as a support for the thermal insulation. The assembly of thermal insulation had no interaction with the furnace structure and was able to ensure a flexible behavior to vertical and horizontal displacements of 200 mm and 100 mm, respectively. Also, due to its trapezoidal shape, it is considered to have no contribution to the bearing capacity of the beam.

The beam carrying mechanical load was stiffened by full web height steel plates 25 × 100 in the two supports and in the load application points. For the support sections lateral restraints were provided for the upper part of the beam. The requested material for specimens was steel of class S235JRG2 for the flanges and St37-2G for the web.

2.2. Mechanical and thermal load

The test furnace is heated with a set of oil burners capable of increasing the temperatures according to the standard ISO834 curve. For the first test, upon request, the temperature was maintained constant after 31st minute at a value of 850 °C.

The second test was stopped after 31 min when the temperature in the furnace was 859 °C. Two point loads of 60 kN were applied at 2 m apart from each support through plates of 150 × 150 mm before the temperature increase in the furnace. The load was maintained constant for 15 min, reduced to 45 kN in the 16th minute and by 19th minute the structure was totally unloaded.

2.3. Measured material properties

Material tests for structural properties of flange and web steel were performed for further use of test results. The obtained values for material properties are presented in Table 2. All the tests were performed at a 20 °C ambient temperature.

2.4. Experimental results

The resulted data regard the temperature development for the first test and temperature and deformation development for the second test. In both cases temperatures were monitored using

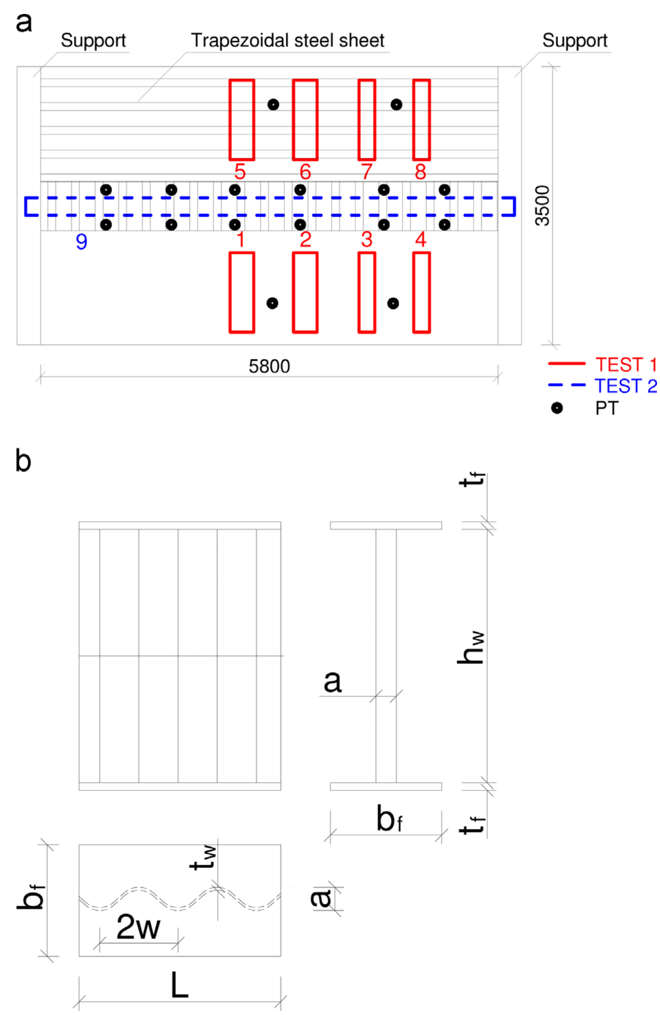

Fig. 1. Test setup: (a) top view, (b) geometric notations.

K-type thermocouples (TC), sheathed thermocouples and plate thermometers (PT) with STC Ø 3 mm. Vertical deflection was measured by cable sensor positioned in the beam mid span.

Average gas temperature for both tests is comparatively presented in Fig. 2 with Standard fire curve. Plate-thermometers (PT) were distributed in the furnace according to Fig. 1, at web mid height level and 100 mm from the specimen 9 ground plan projection.

The short specimens were monitored separately using 9 thermocouples on the web and 3 thermocouples on each flange. The TCs represented inside a circle in Fig. 3 were fixed on opposite face of the web.

Average temperatures recorded by thermocouples are calculated for the following parts of cross-section: top flange, bottom flange, upper part of the web, web mid height and lower part of the web. The results are depicted in Fig. 4(a)–(h).

Temperatures of the second test were recorded in five sections along the web, three sections along the flange, three and seven points on flange width and web height, respectively. The exact temperature measurement positions are presented in Fig. 5.

Temperatures recorded in the Veseli mechanical test are presented in Fig. 6 for flanges and web comparatively to the average recorded gas temperature. It must be mentioned that TCs installed on flanges recorded similar temperatures for each part, therefore, average values are given for the top and bottom flanges.

For the transient procedure adopted for beam testing the mid span deflection was set to 0 after loading the structure with the