Fire Safety Journal 92 (2017) 64–76

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

A round robin study on modelling the fire resistance of a loaded steel beam

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ARTICLE INFO

Keywords:
Structural fire engineering
Round robin
Calculations
Testing

ABSTRACT

This paper details a round robin study of the calculated response of structures in fire. In this instance, the study is based on one of two fire tests which were conducted on steel beams in a horizontal fire resistance furnace. The two specimens in the tests were identical having come from the same cast flow. The tests were conducted according to EN 1365-3 and the steel beams had a total length 5.4 m, spanning 5.2 m. These tests also formed a part of a testing round robin, reported elsewhere.

The calculations were conducted by round robin participants in two stages. In the first instance a prediction of the response was made without knowledge of the measured temperatures of the steel beam and with only the grade of steel and details of the test setup. In the second instance the participants were also given the measured elastic limit of the steel, which differed significantly from the elastic limit implied by the grade, as well as measured temperatures from the steel beam and the plate thermometers from the furnace and asked to refine their model. Statistical analysis of the round robin results are presented to illustrate the variation which arises in the results of calculations. The results of the round robin study serve to illustrate the fire research and testing community's capability for modelling this simple case as well as the uncertainty in the calculation results. The results of the calculation round robin are also compared with the testing round robin to illustrate the comparative certainty between testing and calculations.

1. Introduction

1.1. Background

Structural fire design has taken a huge step forward in the past two decades. Enabled by the results of large scale testing and the lessons learned from the analysis of, for example, the Cardington tests [1] amongst others, fire engineers now employ sophisticated analysis tools in order to evaluate the structural response of a building to fire. This has led to significant cost savings as a result of optimisation of the design of structures for fire using these tools.

The Cardington tests were designed to represent a typical type of construction which was used in the UK in the 1990's – a braced composite steel framed building [2]. The beams were designed as simply supported, acting in composite with a concrete slab of maximum thickness 130 mm. Connection details were one of either of two types (beam to beam connections were comprised of fin-plates and beam to column connections were comprised of flexible end plates) and no other connection type was studied. Subsequent work included the modelling of these tests in order to further understand the underlying mechanisms which governed their behaviour in fire.

Based on the analysis of these and a few other tests, researchers identified and explained some of the fundamental mechanisms which govern the response of structures to fire. Now the fire engineering industry confidently applies complex tools to determine the impact of fires on structures.

As a result, calculations or simulations are now often used as an alternative means of evaluation of structures exposed to fire compared with testing. For building elements and structures in Europe the Eurocodes are the basis for design, and these allow calculations in simple or advanced design methods. For certification of certain building products calculations have the same credibility as testing. However, while for testing there are requirements on accreditation of the test laboratory as well as follow up inspections, this is not the case for calculations. In other words, when evaluating building products for certification based on testing there is a formal control system that must be followed. This type of control does not exist when doing the same job based on calculations. Therefore it is important that the calculation methods and software used are reliable, and that the results from calculations are both conservative and, importantly, consistent.

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http://dx.doi.org/10.1016/j.firesaf.2017.05.013
Received 10 November 2015; Received in revised form 22 March 2017; Accepted 22 May 2017

1.2. Round robins in fire science

A round robin study is a study conducted by a group of experts commencing from a common starting point, for example a collection of data or test specimens. The participants proceed to predict independently the response of a system; or perform and compare actual experiments. The purpose behind round robin studies is to evaluate the scatter of results across a discipline or between different laboratories.

Over the past decade there has been some renewed interest in round robin studies in fire science and modelling in particular. Notably, in fire dynamics, the round robin studies of the Dalmarnock tests which were coordinated by the University of Edinburgh [3] highlighted the considerable dependency of modelling results on the underlying assumptions and approach taken. The reports from this work show that while the tools which were used have been successfully validated against existing test results their use in prediction is extremely dependent upon the way that the model is set up.

In structural fire engineering, a small round robin study was undertaken to predict the temperature exposure of a single steel beam exposed to a pool fire. This was also coordinated by the University of Edinburgh [4]. The principal conclusion from this study was that design tools for estimating temperatures of elements of structure in pool fires are very conservative and that they are very dependent on the scenario.

In the report from the Dalmarnock tests [3], the lack of historical round robins was highlighted. It is stated that relatively few examples exist, for example one unpublished round robin conducted by the CIB and one carried out by Emmons [5]. Emmons's work highlighted the discrepancy between different fire testing laboratories throughout the world – something which the European Group of Laboratories for Fire testing (EGOLF) has made significant movements to address.

Round robin studies in fire engineering serve to highlight issues within the discipline, however very few of them are undertaken. They pool the collective knowledge of experts in the field and help to focus directions for future research. A need for more round robins within the field was one of the conclusions of the recent international R&D roadmap for fire resistance of structures compiled by NIST [6].

1.3. Overview

This paper summarises a two stage round robin study on calculations which has been performed along with a benchmarking test on the same object for study. The scope of the reported round robin is to determine the reproducibility of calculations on a fire exposed, unprotected, simply supported steel beam.

The test which the round robin study is based upon was carried out as part of an experimental round robin carried out by EGOLF on an unprotected simply supported steel beam [7]. This is, in the opinion of the authors of this paper, one of the most simple fire resistance tests on load bearing elements. This round robin will give a good estimation of the load bearing capacity of this element type, and thus a comparison between the calculated load bearing capacity and any uncertainties arising from the round robin modelling can be compared with the "true" behaviour and the uncertainties arising from the testing.

This paper details the first modelling stage, to which 19 different submissions were received. For this stage of the round robin the participants were only given a description of the test setup and the specimen. We then describe the results of one of the tests, which was to serve as the benchmark for the round robin, before describing the second stage round robin results, where the participants were given additional information made available from the benchmark test in order to refine their calculation results.

2. Selection of participants

An invitation to this round robin was sent out to numerous research institutes, laboratories, universities, consultants and other possible participants representing a cross section of the fire engineering community who are involved in research, certification, and consultancy and may be considered to be among experts in the field. Invitations for participation were sent initially to personal contacts of the authors based on their reputations in the field of structural fire engineering and attendance and participation in various conferences, including the Structures in Fire and the Applications of Structural Fire Engineering series of events. Future round robins could also use such conferences to advertise the studies in advance.

Of those invited, 12 participants agreed to contribute to the study, with some of them submitting more than one solution to the problem using different calculation tools. The participating organisations are approximately evenly split between academic or research institutions and commercial bodies. These additional solutions are treated as further participants in the overview of the data. In total 19 submissions were made to the first stage. One of the participants, however, contributed with only the thermal analysis to the first stage.

One of the participants declined to contribute to the second stage, however one of the participants contributed with an additional submission, meaning that in total we received at least one submission from 10 different groups and in total 18 different submissions to the second stage.

For anonymity the submissions were all assigned an identification number and the identities of the participants have been kept secret from one another. This information will not be published as part of this study.

3. Stage 1 round robin

3.1. Information provided to the participants

The test object was an HEB 300 steel beam, grade S355. In the benchmark test which was performed, and from which additional data for stage 2 was taken, the beam had a total length of 5400 mm, and a span of 5200 mm between the supports. Loading is applied at two points, 1400 mm from either support. At both the supports and the points of loading application web stiffeners were welded to the steel beam. The stiffeners had a thickness of 15 mm. The configuration of the beam is shown in Fig. 1. Applied loads, P, created a uniform bending moment of 140 kNm between the loading points.

During the testing the deflection was measured at mid span, as well as 700 mm from either of the supports, and the temperature of the beam was measured at 11 locations: in the middle of each of the flanges and in the middle of the web at the mid-span of the beam; and in the middle of one each of the top and bottom flanges and the web at 1200 mm from the supports.

The beam was unprotected and exposed to fire in a horizontal fire resistance furnace on 3 sides (bottom and the two sides – the top was not exposed to fire and continuity of the top of the furnace was ensured by covering the top of the beam with light weight concrete blocks). The test was carried out in accordance with EN 1365-3 [8] and the fire was an EN 1363-1 (ISO 834) standard fire [9].

3.2. Information requested from the participants

Prior to the fire test being carried out, all participants were asked to

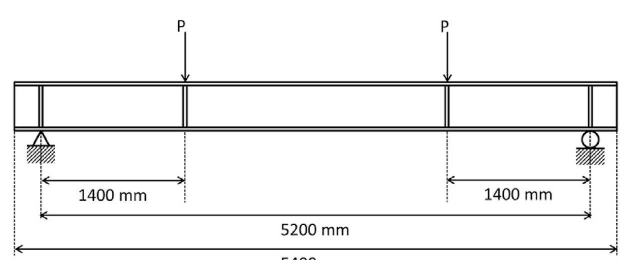

Fig. 1. Geometry of the test specimen.