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EFFECTS OF A TRAVELLING FIRE ON A CONCRETE COLUMN – TISOVA FIRE TEST

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Abstract

The Tisova Fire Test was a large fire test conducted in the Czech Republic in January 2015 inside of a 4-storey concrete frame building, with concrete and composite deck floors. The test compartment was on the ground floor and the fire compartment had a total area of ca. 230m^2 with a height of 4.4m. The fire compartment included four columns from the original 1958 concrete construction, one of which was instrumented for temperatures, chosen due to its higher likelihood of observable structural response both during and after the fire. This paper presents selected results of the test, concentrating on the thermal environment around the column showing the variability of temperatures through the compartment height. The paper also present the columns thermal response, as well as a post-fire assessments of the columns visual condition.

Keywords: concrete column, travelling fire, large scale structural fire test, Tisova Fire Test

1 INTRODUCTION

Current fire engineering design guidance (e.g. CEN, 2010), in general, assesses structures and their response to fire on a pass/fail assessment usually consisting of prescribed fire resistance criteria and times. This assessment is usually based on a standard fire (e.g. ISO-834 (CEN, 2009)) that represents only one fire out of a range of possible fires which may occur, and may not represent the most onerous (or more realistic) fire insult that a structure might experience (Gales, Maluk and Bisby, 2012). Also standard fire testing, from which the deign guidance is generally based, are, in general, limited to single elements rather than full structures and cannot capture the full complexities of the structural interactions of a building subject to a real fire. Current fire engineering design is also based almost entirely on life safety performance goals and, in general, has no means of quantifying property protection goals (i.e. damage level, reinstatement costs, business continuity, etc…), which are however becoming more popular with building owners and insurers alike, and are now becoming frequently considered as a design driver.

Property protection is rarely explicitly considered in fire engineering design due to a lack of credible data from which to assess/model full structures in fire - this is particularly true for concrete structures (Bisby, Mostafaei and Pimienta, 2014). Modelling of concrete elements and structures to non-standard fires has shown that long durations of some travelling fires (Law et al., 2011) or parametric fires (Rush et al., 2014) can have significant effects on the fire and post-fire damage and response of concrete structures. However the validity of these models remains in question due to the lack of experimental data, with very few tests conducted in large compartments with travelling fires (e.g. (Horová, Wald and Bouchair, 2013). The Tisova Fire Test aimed to generate experimental data on some of the modelling uncertainties namely; travelling fires; the thermal and structural response of composite slabs, concrete slabs, and concrete columns to real fires as an input to round robin studies; and a post-fire assessment of a structure after a quantified fire event. This paper considers one aspect of the Tisova Fire Test – the thermal response of columns to a travelling fire.

2 FIRE TEST

The Tisova Fire Test was carried out in January of 2015 by a team from SP, the University of Edinburgh, Imperial College London, Luleå Technical University, and Technical University Ostrava, Majaczech, CSTB and CERIB. The fire test was conducted inside of a real building, Figure 1, which was scheduled for demolition. The building was constructed in 1958 as a powdered coal boiler and comprised of a reinforced concrete frame and slab construction. In 1980 the buildings use was changed to a combination of workshops and offices and additional floors and slabs were added using composite slab construction tied in to the original frame. The aim of the test was to achieve a structurally challenging travelling fire.

Figure 1: Left – Southwest corner of test building, and Right – fire compartment

The test compartment shown in Figure 2 was on the ground floor and the fire compartment had a total area of approximately 230m^2 and was 4.4 m high from floor to slab soffit. The layout was generally open, with a series of large rooms enclosing one side as well as one corner. There was also a central lift shaft. Four columns were fully within the fire compartment. The smallest 30 x 30 cm column (C1) indicated in Figure 2 was chosen to be examined due to its slenderness and was therefore most likely to experience higher core temperatures and damage during the fire test.

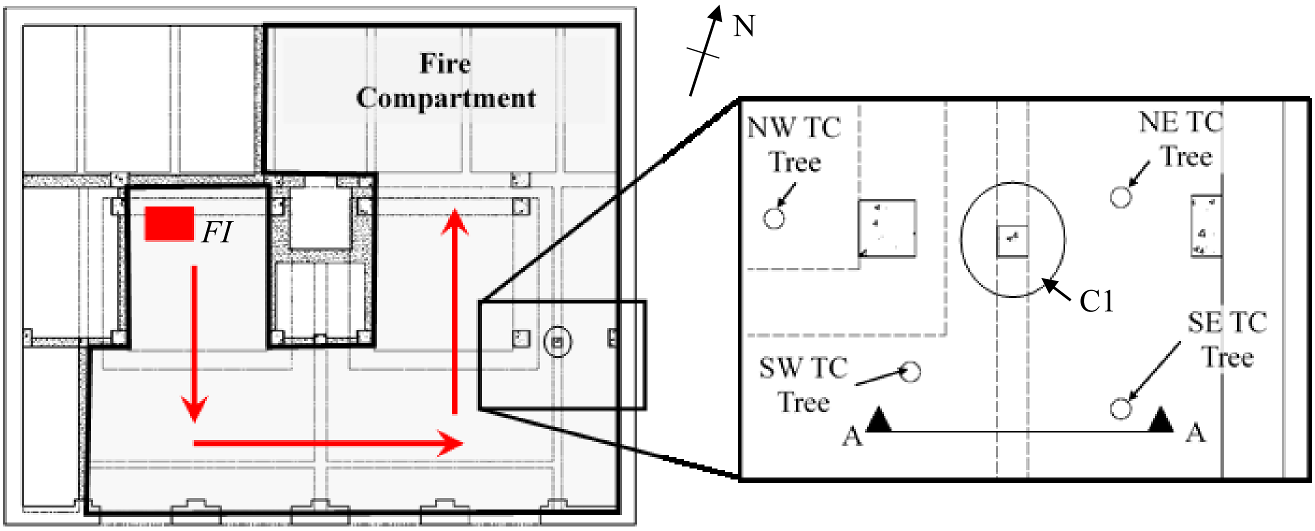

Figure 2: Fire compartment showing fire ignition point (*FI*) and path of travel (arrows), and column C1 and associated TC tree locations

The size and layout of the compartment meant that it was ideal for testing the travelling fires methodology developed by Stern-Gottfried & Rein (2012). The fuel was laid out as a uniform single fuel bed across the whole floor, apart from a 0.5 – 1 m path around the perimeter of the floor area. Fuel covered approximately 170 m^2 of the floor area as shown in Figure 2. The arrangement of the fuel bed was 5.5 layers/m^2 of 8 x 1m x 0.06m x 0.04m sticks per layer of spruce timber conditioned to a targeted 11% moisture content. The 44 sticks per layer which gives a fuel load of approximately 40kg/m^2 within the fuel bed, or approximately 680MJ/m^2. The fire was well ventilated to ensure that fire was fuel load controlled and not controlled by ventilation, and the fire was ignited at location *FI* in Figure 2 using organic fuel soaked in lighter fuel within the crib.

Fire temperatures within the compartment were recorded using 56 thermocouple (TC) trees incorporating Type-K Inconel sheathed thermocouples hung from the ceiling at approximately 2.5m spacing's. Figure 2 shows the four thermocouple trees within a 2.5m radius of the column C1, named NE, NW, SE, and SW TC trees, respectively. Each thermocouple tree had 6 thermocouples at heights below the soffit of the slab of: 5cm, 65cm, 140cm, 205cm, 260cm, and 370cm, respectively. The top of the fuel bed was approximately 40cm off the floor. The SW and SE TC trees are shown in Figure 3: Section A-A.

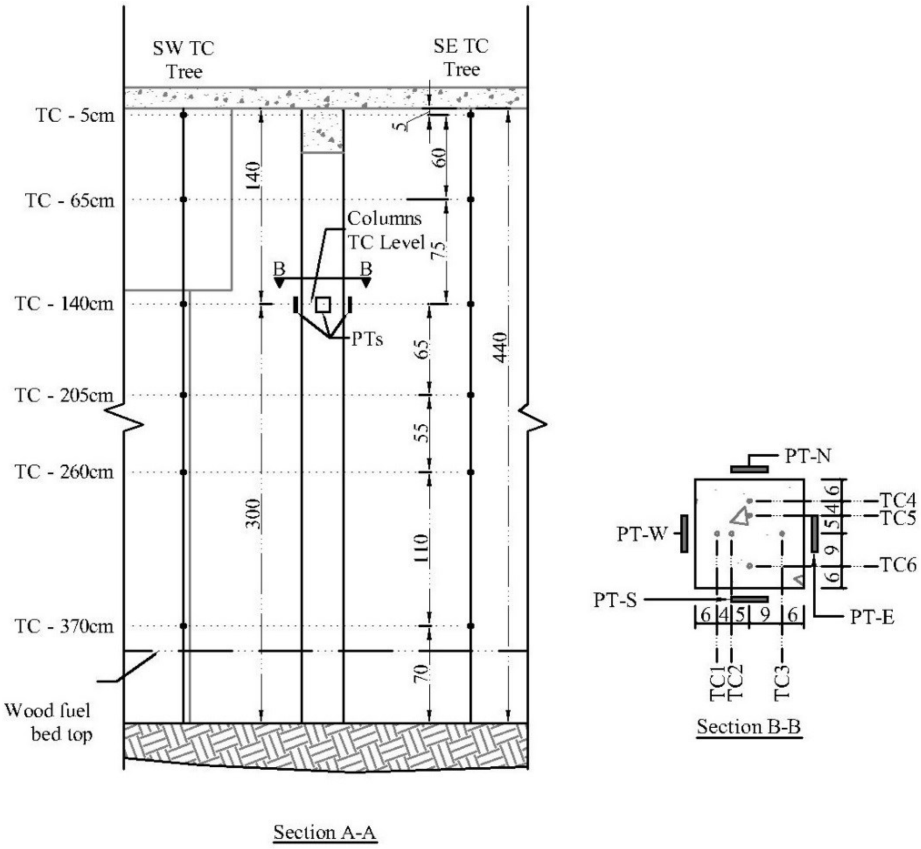

Figure 3: Section A-A: TC tree thermocouple layout, and column TC and PT height, and Section B-B: Column cross-section showing TC and PT placement

Column C1 was instrumented with 6 thermocouples at two heights, 1.5m above the floor and 3m above the floor, unfortunately the thermocouples 1.5m above the floor suffered from a failure early on in the test and all data was corrupted and will not be discussed any further in this paper. Figure 3 b) shows the locations of the thermocouples at the 3m height of the column. Figure 3 shows four TCs which were placed 6 cm from each of the four faces, and two TCs which were placed 10 cm from the North and West faces. Holes were drilled at an angle of 45° from above to mid-depth of the columns and TCs were then temporarily held in position and re-cast into the column using quick setting mortar. A plate thermometer (PT) was placed 10 cm from each of the North (N), East (E), South (S), and West (W) column faces with their centres at the same height from the floor as the thermocouple ends as an indication of the fire exposure to the column at the 3m height.

3 RESULTS

The fire was successfully ignited as planned however it soon became evident that fire spread rate was very slow with the flame length along the path (shown in Figure 2) of approximately 1 m with a flame height between 1.5 – 2 m. The resulting temperatures in the compartment, especially near the ceiling, were not high enough for a structurally challenging fire, i.e. well below 100^{o}C. To encourage fire growth during the test the ventilation was reduced and a 10 litre mixture of gasoline and diesel at a ratio of 1:1 was poured over the fuel bed along the southern perimeter 2.5 hrs into the test. This resulted in a more severe fire covering cribs in the west and south ends of the building. However, as the fire started to move north (Figure 2), the intensity of the fire reduced and the fire spread further into the compartment slowed significantly. The reason for the poor severity of the fire was mainly due to the moisture content of the wood, which when controlled specimens were tested after the fire, showed a moisture content between 18-22% rather than 11%. Higher moisture contents results in more energy being absorbed in the evaporation of water rather than into the fire environment, and reduces the rate of flame spread (Fons, Clements and George, 1963)

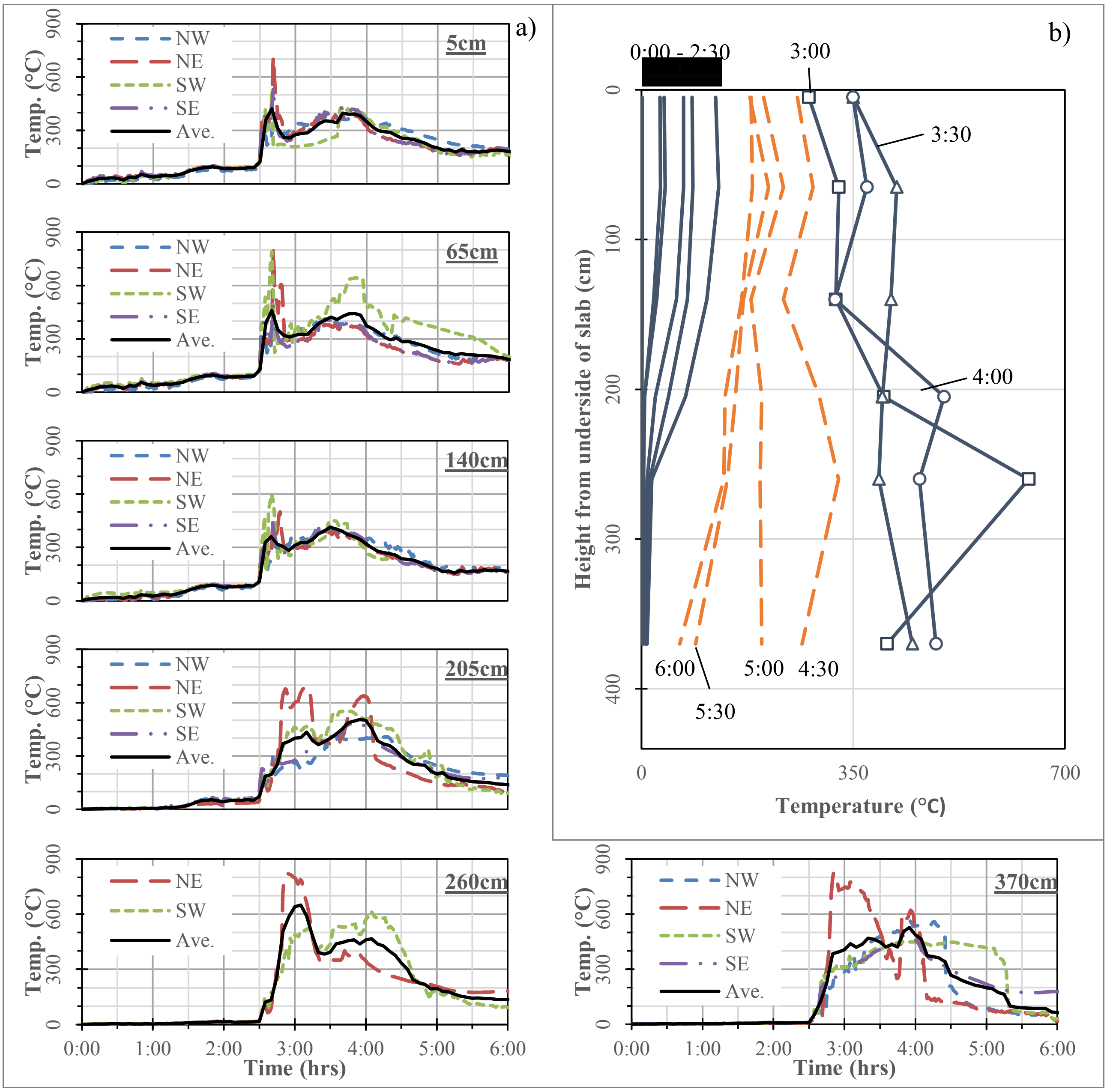

Figure 4: a) Time-temperature curves at each of the 6 TC heights below the soffit of 5cm, 65cm, 140cm, 205cm, 260cm, and 370cm; and b) variation in temperature over the height of the compartment at 30 minute intervals

3.1 Gas phase temperatures in region of column

Figure 4 a) shows the recorded temperatures during the fire test with respect to the height below the soffit, and shows the clear jump in temperatures after 2:30 hrs due to the addition of gasoline to the fire compartment to encourage the growth of the fire. It can also be seen from Figure 4 a) that the temperatures nearer the ceiling (5cm, 65cm, and 140cm) are fairly consistent across all four TC trees (NW, NE, SW, and SE). Maximum average temperatures experienced in the top 140cm of the fire compartment were in the region of 400-450°C. In contrast the temperatures further away from the ceiling were more varied but in general hotter than those near the ceiling, with average temperatures peaking at 500°C, 635°C, and 510°C, at 205cm, 260cm, and 370cm from the ceiling, respectively. This is clearly shown in Figure 4 b) which shows the variation in temperature over the height of the compartment at 30 minute intervals, with the maximum temperatures, after the gasoline was added at 2:30 hrs, consistently observed within the lower half of the compartment for over two hours.

3.2 Plate thermocouple data

Figure 4 shows that there is a great deal of variation within the fire environment through the height of the compartment. However the temperature measurements were at a not insignificant distance from the column C1 which is being investigated. To understand the thermal boundary for the column at 3m above the floor, four plate thermometers (PT) were installed around the perimeter of the column (Figure 3: Section B-B). Figure 5 shows the recorded PT temperatures for the individual PTs and compares the average temperatures from the PTs to the average TC-140cm temperature data, showing a very good correlation between the two averages. Any future modelling of the heat transfer to the column can be confident of the thermal boundary present in the tests.

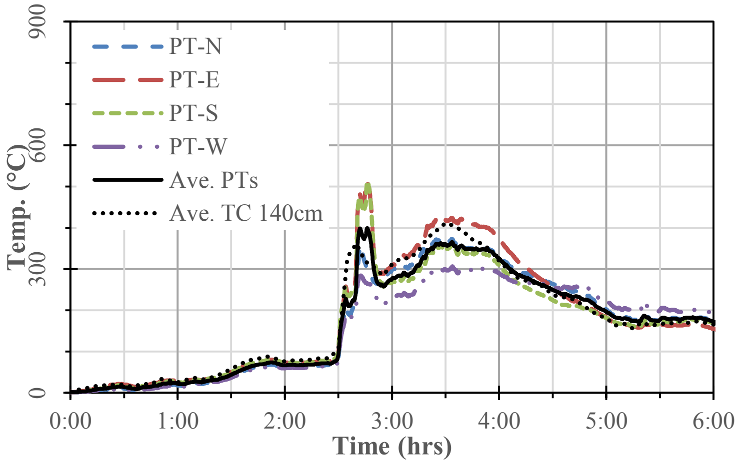

Figure 5: Comparison of PT and TC tree recorded temperatures at 140cm below ceiling soffit

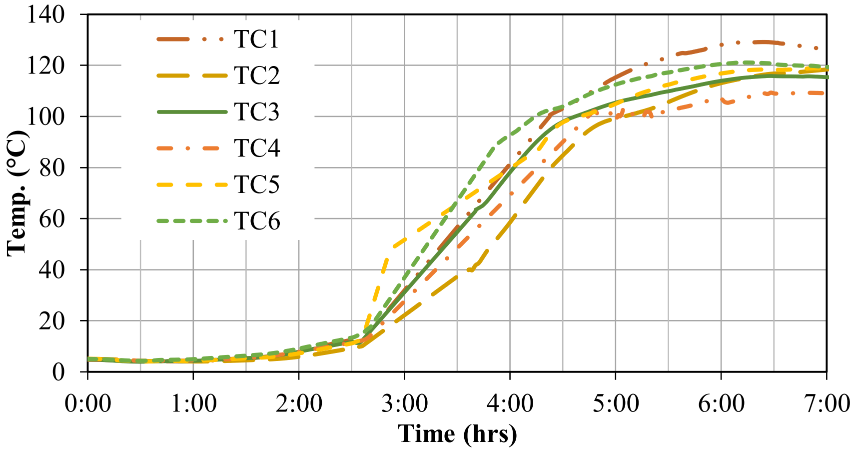

Figure 6: Recorded temperatures within concrete column C1

3.3 Column temperature data

As previously stated, unfortunately temperatures at 1.5m above the floor failed to be recorded, so comparisons of the heat transfer to the column from the more severe temperatures recorded within the lower half of the compartment to the cooler upper half cannot be made. However, Figure 6 shows the data recorded at 3m above the floor (1.4m below the ceiling), and shows an increase in structural temperatures at around 2:40 which increase relatively linearly until 4:30 at approximately 1°C/min.

The very slow heating rate causes very similar temperatures to be observed within the cross-section. As the maximum observed temperatures are well below those that would be considered structurally significant, little to no damage would have been experienced by the concrete material and a visual inspection of the column showed no signs of damage apart from aesthetic smoke damage.

4 CONCLUSIONS

This paper has presented selected results from the large scale Tisova Fire Test conducted in the Czech Republic in January 2015, from which we can conclude:

- The moisture content of wood severely retarded the fire severity and flame spread rate, and even after a gasoline/diesel mix was introduced to promote fire growth, temperatures struggled to get above 500°C for any prolonged amount of time within the compartment.
- Temperatures within compartment were found to be hotter in the lower half of the compartment (i.e. nearer the flames) rather than near the ceiling. If this were true for all large compartment travelling fires, this could have implications for the design of columns within such compartments.
- With temperatures being on average less than 500°C in the lower half of the compartment and less than 400°C in the upper half for approximately 2 hrs, recorded concrete temperatures within the column instrumented did not rise above 140°C, and as such the column experienced very little if any damage.
- More analytical and experimental research into the structural consequences of realistic and travelling fires is required so that performance based designs, where property protection is an additional driver to life safety, can be rationally and defensible conducted.

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