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The Steel Construction Institute

REPORT TO CORUS CSD

SLIMFLOR COMPENDIUM

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EXECUTIVE SUMMARY

This Slimflor compendium reviews a substantial amount of data from standard fire resistance tests on Fabricated Slim Floor beams, Asymmetric Slim Floor beams and RHS edge beams. A total of 21 fire tests have been reported. Seven tests were carried out on fabricated Slimflor beams with pre-cast concrete units, three on fabricated Slimflor beams with deep decking, five on asymmetric beams with deep decking and three on RHS edge beams.

For each test, a summary description is provided covering the construction of the fire test specimen, the instrumentation fitted to the specimen and the results of the fire test in terms of the specimens' performance as assessed against the load bearing failure criteria. Data recorded during the fire test is also provided on a CD that accompanies this report. Data has been provided in Excel format for all of the tests included in this report. However, in some cases only summary data was available.

CONTENTS

Page No.

EXECUTIVE SUMMARY 3

1 INTRODUCTION 7

2 Fabricated Slimflor beams with precast units 9
2.1 Summary of available test data 9
2.2 Test WFRC 36438 11
2.3 Test WFRC 38185 12
2.4 Test WFRC 50521 14
2.5 Test WFRC 50522 19
2.6 Test WFRC 52896 23
2.7 Test WFRC 52897 28
2.8 Test WFRC 51883 33
2.9 Test WFRC 54278 38
2.10 Test WFRC 51884 43

3 Fabricated Slimflor beams with composite slabs 47
3.1 Summary of available test data 47
3.2 Test WFRC 56867 48
3.3 Test WFRC 60248 52
3.4 Test TNO 1995 58
3.5 Test WFRC 44174 67

4 Asymmetric Slimflor beams 70
4.1 Summary of available test data 70
4.2 Test WFRC 66162 71
4.3 Test WFRC 66163 76
4.4 Test WFRC 67756 92

5 RHS Slimflor edge beams 100
5.1 Summary of available test data 100
5.2 Test WFRC 65514 101
5.3 TNO 1996 105
5.4 Test WFRC 106891 108

6 References 117

1 INTRODUCTION

A significant volume of fire test data was generated during the development of the Slimflor and Slimdek systems. The aim of the Slimflor Compendium is to compile the standard test fire data available for:

- Fabricated Slim Floor beams
- Asymmetric Slim Floor beams
- RHS edge beams

For each test, a summary description of the fire test is provided including details of the test specimen construction, the applied loading, details of the instrumentation, and a summary of the results.

Where the measured data from the fire test is available this is provided in ASCI file format on the CD that accompanies this report. This data is also available in Excel format. Where the original data files where not available the most detailed version of the data that could be obtained has been provided as an Excel file. All of the tests reported have an electronic data file of some sort. Details of the electronic data files available are included in the summary table provided for each construction type.

The fire tests reported in this compendium were carried out between 1985 and 1996. Over the period from the start of testing to the present day a number of the standards for the specification of materials, structural design and fire testing have changed. In this report the steel grades have been related to the equivalent structural grade as specified by the current version of BS EN 10025-4(5). All of the fire tests reported in this compendium were carried out in furnaces where heating was controlled with bead thermocouples. The major of tests were conducted in accordance with BS 476-20(1) and BS 476-21(2) which are the UK national standard for fire resistance testing and the methodology for testing load bearing elements respectively. However, for a few tests carried out before 1987 the specification of the test was in accordance with BS476-8(3). The load applied to the specimen has been reported in all cases based on the load ratio as defined by BS5950-8(4). For some of the earlier tests the applied load was calculated based on the BS449-2(6) design standard for structural steel work and is report as such in some of the reports referenced by this document.

2 Fabricated Slimflor beams with precast units

2.1 Summary of available test data

The nine test specimens included in this section of the report have been tested as simple supported members with a span of 4500mm and a heated length of 4000mm. The majority of the tests were conducted between 1985 and 1992 and details of the test specimens and the availability of electronic data are summarised in Table 2.1. Additional information covering the measured material properties and measured section geometries are available from the original British Steel Reports. Summary datasheets for all of the tests in this section of the report are provided in an Excel a spreadsheet, ***'Fabricated Slimflor Summary.xls'***. For tests P1, P2 and P3 this is the only form of data available.

Table 2.1 *Summary of fire tests on fabricated Slimflor beams supporting pre-cast concrete slabs.*

	Section details	**Plate Dimension**	**Type**	**Test Reference**	**Electronic Data**		
					ASCI	**Excel**	**Summary**
P1	254 x 254 x 73	-		36438	NO	NO	YES
P2	254 x 254 x 89	-		38185	NO	NO	YES
P3	254x254x107	460 x 15	B	50521	NO	NO	YES
P4	203x203x86	425 x 15	D	50522	YES	YES	YES
P5	203x203x60	405 x 15	B	52896	YES	YES	YES
P6	254x254x73	405 x 15	C	52897	YES	YES	YES
P7a	152x152x30	355 x 15	B	51884	YES	YES	YES
P7b	152x152x30	355 x 15	B	54278	YES	YES	YES
P8	305x305x283	525 x 15	B	51883	YES	YES	YES

Beam Type:

A Deep decking with concrete above flange but no shear studs
B Precast flooring with partial filling of section
C Precast flooring with concrete filling up to top of section
D Precast flooring with composite slab over top of section
E Steel deck on concrete base

The results of the loaded fire tests are summarised in Table 2.2. In a number of tests the loading was increased at some point during the test. In accordance with the guidance given in the fire test standard BS476-21:1987[(2)] the formal fire resistance test is terminated at this point. However, useful data has continued to be recorded until load bearing failure was achieved.

Table 2.2 *Summary of Fire Test Results for fabricated Slimflor beams supporting pre-cast concrete units.*

Test	Section	Fire Resistance (mins)	Load Ratio	Plate Temperature(†) (°C)	Flange Temperature (†) (°C)
P1	254 x 254 x 73	44	0.56	-	746
P2	254 x 254 x 89	109	0.42	-	783
P3	254x254x107	60	0.55	799	661
P4	203x203x86	67	0.44	727	558
P5	203x203x60	83*	0.51	812	691
P6	254x254x73	83*	0.47	778	578
P7a	152x152x30	-	-	-	-
P7b	152x152x30	69*	0.48	788	731
P8	305x305x283	90*	0.17	728	411

Notes:

* Alterations to the load level meant that these tests were discontinued before failure.

† temperature measured at 60 minutes

2.2 Test WFRC 36438

This test was conducted by Warrington Fire Research Centre on 11 July 1985. No electronic data files are available for this test. However the results were summarised in British Steel reports[8][9] and the data sheet from this document is available in Excel format on the CD which accompanies this report.

Test Specimen

The test specimen consisted of a 254x254x73 universal column section simply support with a span of 4.5m and supporting pre-stressed hollow core concrete slabs on the bottom flange. The slabs were 1550mm long by 590mm wide and 200mm deep 'Spiroll' slabs, supplied by Richard Lees. The space between the flanges was filled with dry sand, which was also used to cover the top flange of the section. The construction of the test specimen is shown in Figure 2.1.

A total load of 328.6kN was applied to the concrete slabs at 4 locations along the span ($1/8$, $3/8$, $5/8$ and $7/8$) on both sides of the beam 500mm from the centre line of the steel section. The load ratio for this specimen was calculated as 0.56.

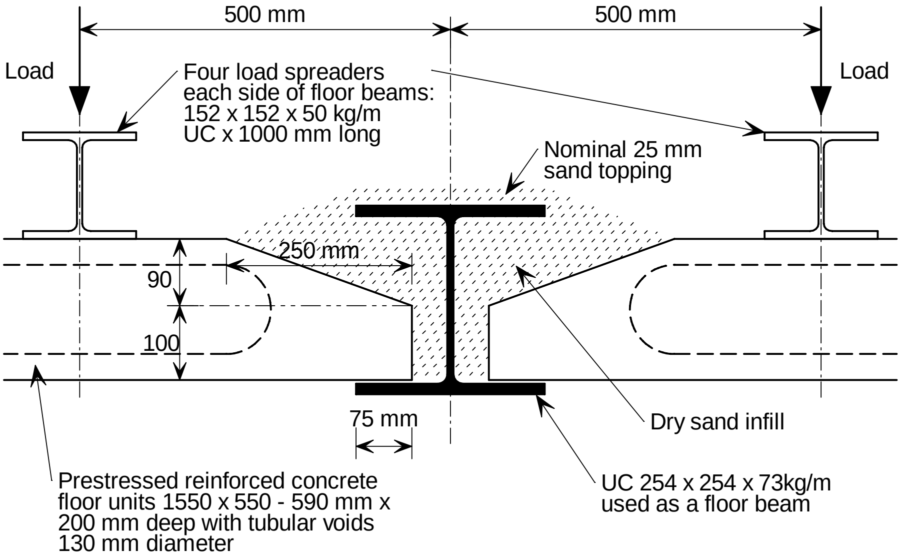


Figure 2.1 *Construction of the test specimen WFRC36438*

Instrumentation

The steel section was instrumented with a total of 15 thermocouples attached to the web the flanges and the lower flange web root radius, as shown in Figure 2.2. The deflection of the beam was measured using a LVDT located at mid span.

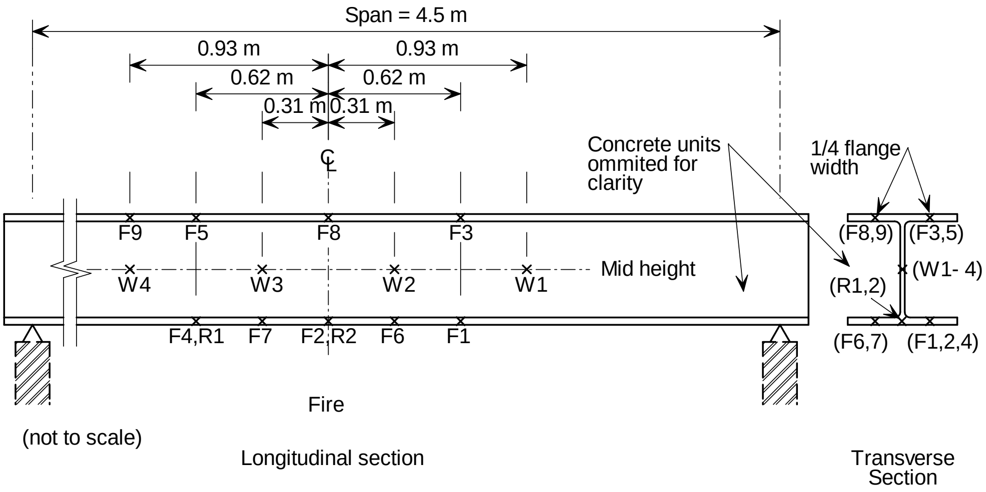


Figure 2.2 *Location of thermocouples WFRC36438*

Result

The test was discontinued after 44 minutes when a central deflection of 150mm was reached.

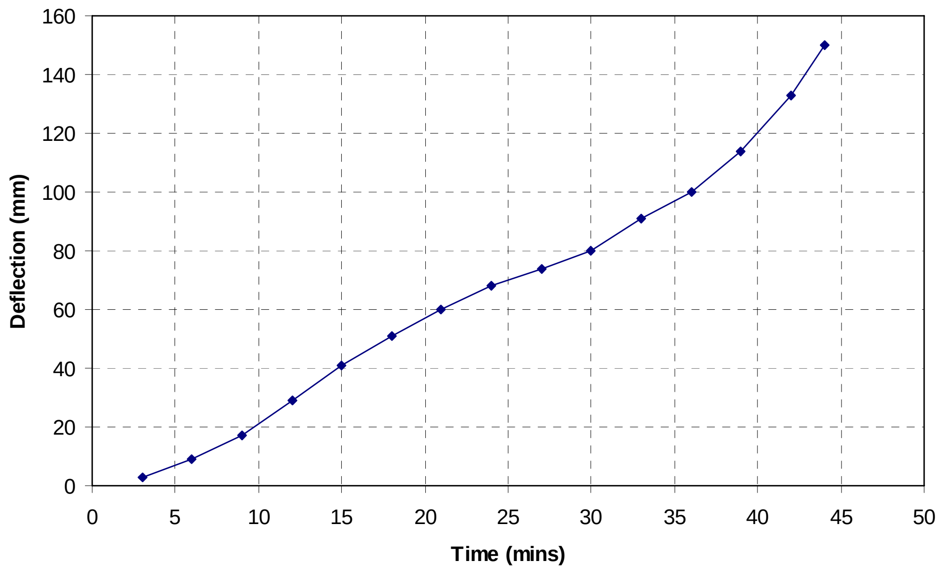


Figure 2.3 *Deflection of Test Specimen WFRC36438*

2.3 Test WFRC 38185

This test was conducted by Warrington Fire Research Centre on 29 April 1986. No electronic data files are available for this test. However the result were summarised in British Steel reports[(8),(11)] and the data sheet from this document is available in Excel format on the CD which accompanies this report.

Test Specimen

The test specimen consisted of a 254x254x89 universal column section spanning 4.5m between simple supports and supporting solid pre-cast concrete slabs on the bottom flange. The slabs were 1550mm long by 590mm wide and 200mm deep. The space between the flanges was filled with dry sand, as shown by Figure 2.4.

A total load of 342kN was applied to the concrete slabs at 4 locations along the span ($1/8$, $3/8$, $5/8$ and $7/8$) on both sides of the beam approximately 500mm from the centre line of the steel section. The load ratio for this specimen was calculated as 0.42.

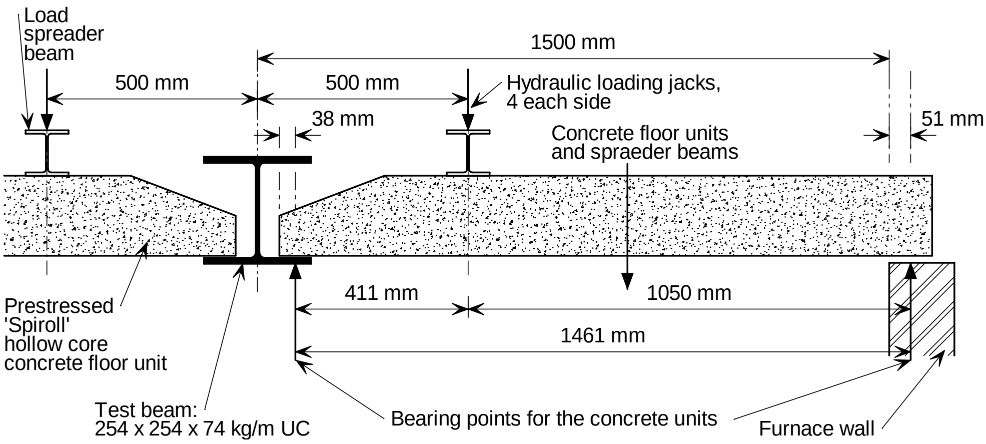


Figure 2.4 *Construction of the test specimen WFRC36438*

Instrumentation

The steel section was instrumented with a total of 15 thermocouples attached to the web the flanges and the lower flange web root radius, as shown in Figure 2.5. The deflection of the beam was measured using a LVDT located at mid span.

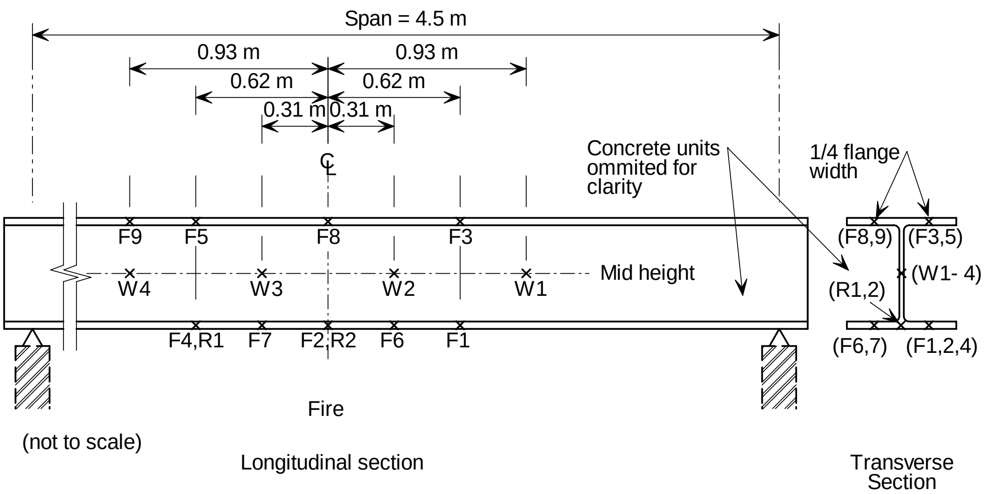


Figure 2.5 *Location of thermocouples WFRC36438*

Result

The test was discontinued after 109 minutes when a central deflection of 225mm was reached, equal to the L/20 limiting deflection. The deflection of the test specimen at mid span recorded during this fire test is shown in Figure 2.6.

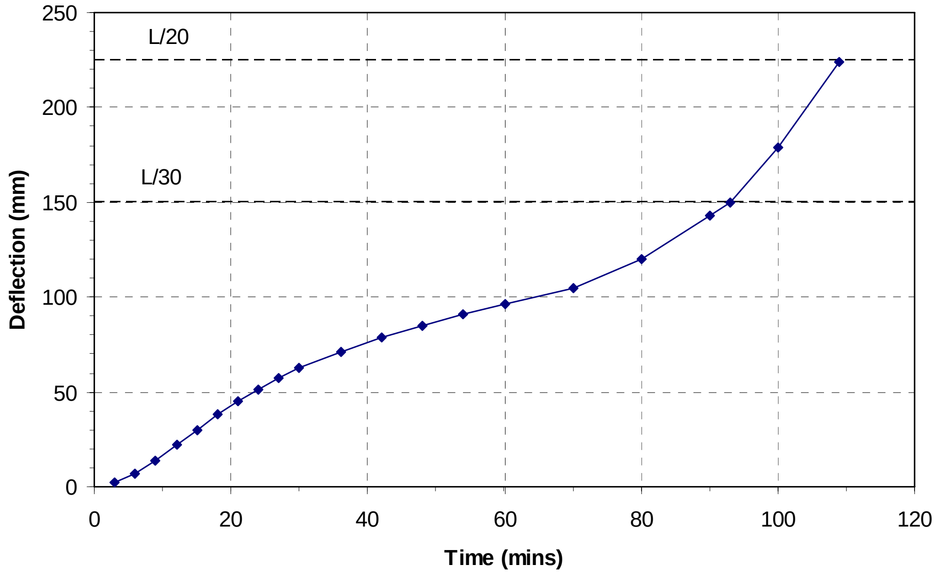


Figure 2.6 *Measured Deflection of test specimen WFRC36438*

2.4 Test WFRC 50521

This test was conducted at Warrington Fire Research Centre on 25th September 1990. The CD which accompanies this report contains data files recorded during this test that include all thermocouple data. Information on this test is also available from a British Steel Report(7) that includes additional data on the actual section geometry and measured material properties of the test specimen.

Test Specimen

This test was conducted on a non composite specimen consisting of a universal column of serial size 254x254x107 and a steel plate 460 mm wide x 15 mm thick. The steel grade of both the column and plate was Fe 430A, equivalent to S275. The bottom plate of the fabricated section was used to support pre-cast reinforced concrete slabs which covered the entire roof area of the furnace. These were standard hollow core "TEMBO" slabs manufactured by Richard Lees Ltd., and were nominally 600 mm wide x 200 mm deep x 1500 mm in length. The end 250mm of each pre-cast unit was solid concrete. The gap between the pre-cast units and the web of the steel section was filled with dry sand. The upper flange of the section was also covered with dry sand to a depth of 25mm, as shown in Figure 2.7.

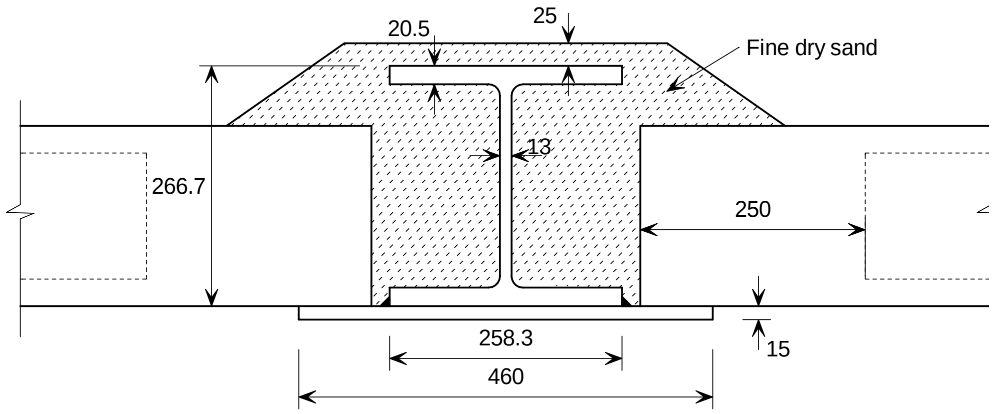


Figure 2.7 *Cross section of test specimen*

A total imposed load of 388kN was applied directly to the steel section at four points along its supported length and directly over the web. The rams were spaced at 875 mm intervals along the section length, as shown in Figure 2.8. The plastic moment resistance of the section was calculated as 511kNm and the applied moments due to dead loads and loading imposed by the hydraulic rams was 13kNm and 267kNm respectively, giving a load ratio of 0.55.

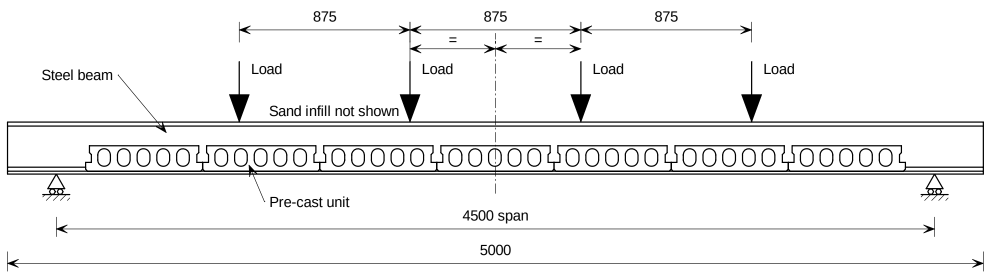


Figure 2.8 *Arrangement of loading positions*

Instrumentation

The load from the hydraulic rams was monitored during the test using a pressure gauge on the pump set. The deflection of the steel section with time was recorded using a LVDT located at mid-span.

Detailed measurements of the temperature of the steel section were made throughout the duration of the test. Thermocouples were located on 7 cross sections over a central 2m length of the span, as shown in Figure 2.9. The locations of thermocouples on each cross section are as shown in Figure 2.10 and Figure 2.11.

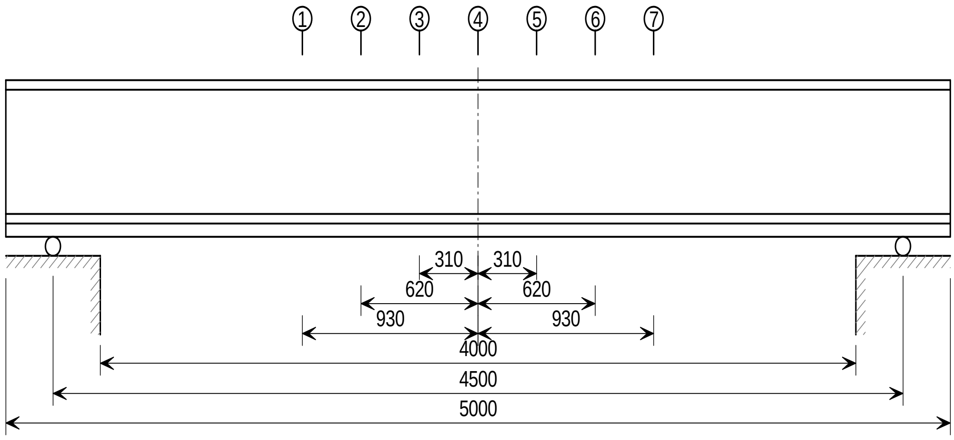


Figure 2.9 *Longitudinal arrangement – Position of thermocouple cross sections*

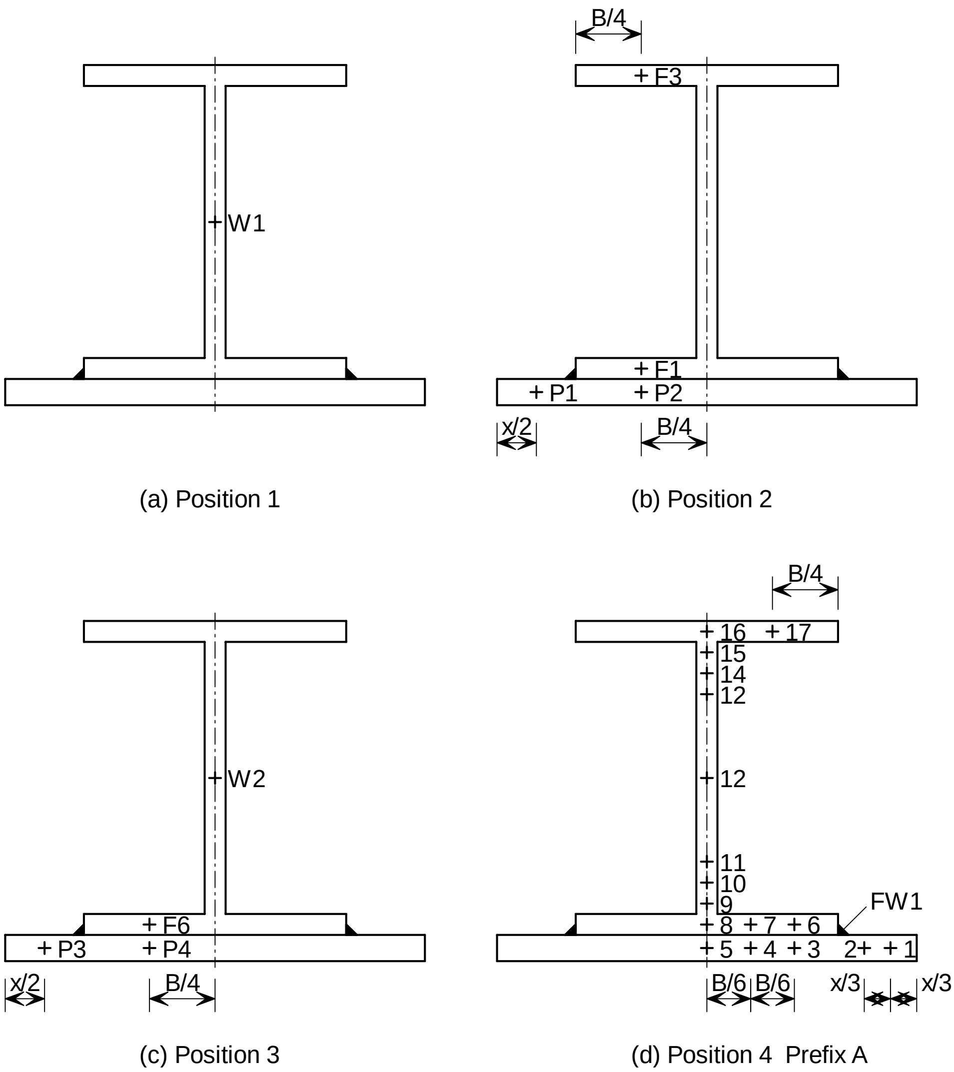
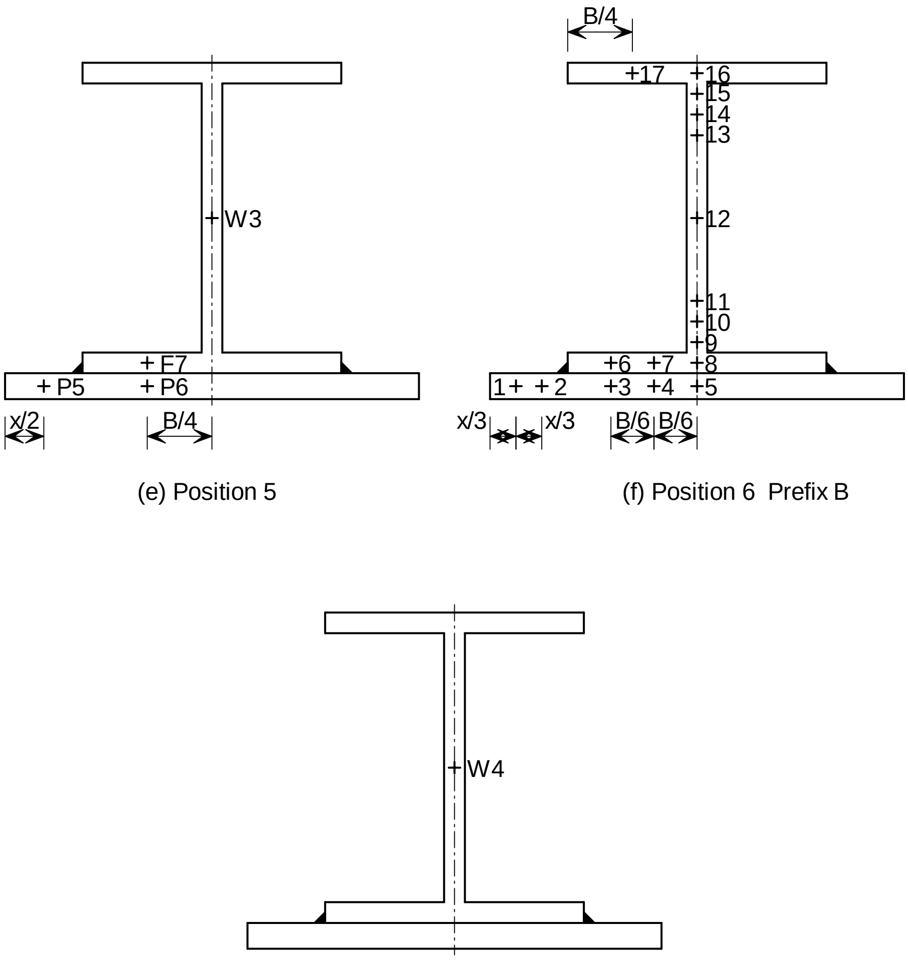


Figure 2.10 *Transverse arrangement at positions 1 - 4*



(g) Position 7

Figure 2.11 *Transverse arrangement at positions 5 - 7*

Results

The loaded fire test specimen achieved a fire resistance of 60 minutes in the test. At this time the mid span deflection reached L/30 (150mm) and the rate of deflection (12mm/min) exceeded the limiting rate of deflection as defined by BS476. The measured mid span deflections recorded during the test are shown in Figure 2.12.

The load was removed from the test specimen after 60 minutes but the test continued until 90 minutes to allow thermal data to be recorded.

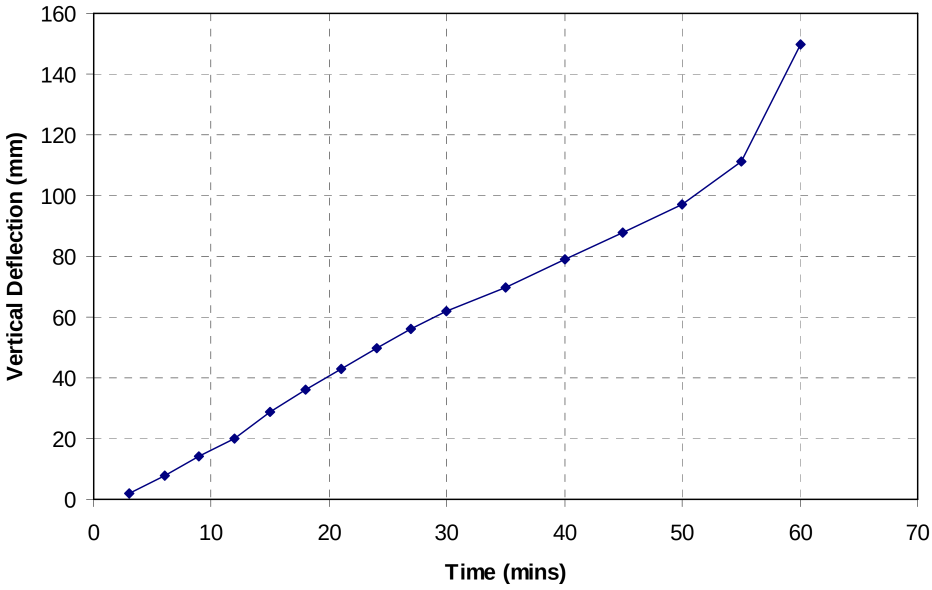


Figure 2.12 *Measured mid-span deflection for test specimen WFRC50521*

2.5 Test WFRC 50522

This test was conducted at Warrington Fire Research Centre on 14 November 1990. The CD which accompanies this report contains data files recorded during the test providing data measured from all the thermocouples. Summary data is also supplied which includes the deflections recorded during the test.

Test Specimen

The test specimen consisted of a Slimflor beam fabricated from a universal column of serial size 203x203x86 and a steel plate 425 mm wide x 15 mm thick. The steel grade of both the column and plate was Fe 430A, equivalent to S275. The fabricated Slimflor beam was designed to act compositely with a concrete slab. Shear connection was provided by two rows of shear connectors (19 mm diameter x 100 mm long) fixed at the quarter flange width and spaced at 200 mm centres along the full length of the section. Details of the measured geometrical properties of the steel cross section and material properties of the steel are also available[(7)].

The composite cross section is shown in Figure 2.13. The concrete floor slab was constructed from normal weight concrete with a value of 35 N/mm^2 for nominal cube strength. The slab contained A193 crack control mesh and T12 bars at 150mm centres as transverse reinforcement.

Two 20mm deep x 6mm wide grooves were cut into the surface of the concrete slab approximately 60mm from the tips of the column flange. The purpose of these grooves was to weaken the concrete and thereby ensure that the fillet weld between the section and the plate was sufficiently stressed [(7)].

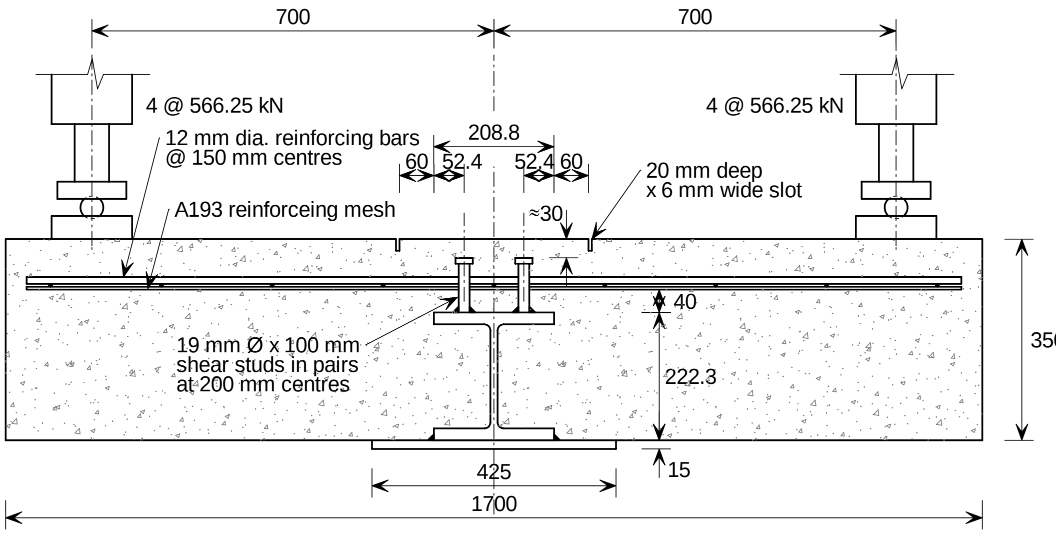


Figure 2.13 *Details of the composite cross section, showing the transverse location of the loading rams.*

A total imposed load of 450 kN was applied to the system at eight positions on the concrete floor slab. The rams were spaced at 530 mm intervals along the section length as shown in Figure 2.14 and at a distance of 700 mm from the centre line of the steel section as shown in Figure 2.13. The moment applied by the hydraulic rams and the moment due to self weight were calculated as 427kNm and 40kNm respectively. The plastic moment of resistance of the composite section was calculated as 799kNm giving a load ratio of 0.58.

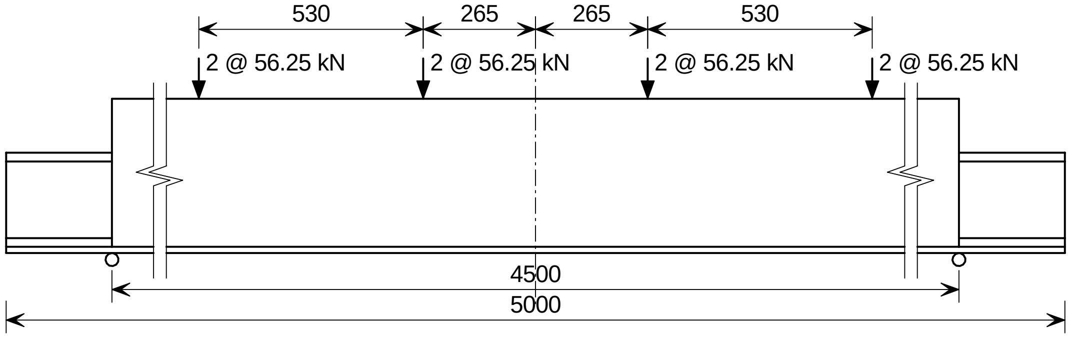


Figure 2.14 *Longitudinal arrangement of hydraulic loading rams*

Instrumentation

The thermocouple positions in the steelwork were identical to those used for Test WFRC 50521 and are shown by Figure 2.9 to Figure 2.11. For this test specimen additional thermocouples were used to monitor the temperatures in the shear connectors, steel reinforcement and concrete slab. The location of the 10 thermocouples used to record the temperature of shear studs are shown by Figure 2.16. The locations of the thermocouples embedded in the concrete slab are shown by Figure 2.15. This cross section is at the mid span of the specimen (Section 4 in Figure 2.9).

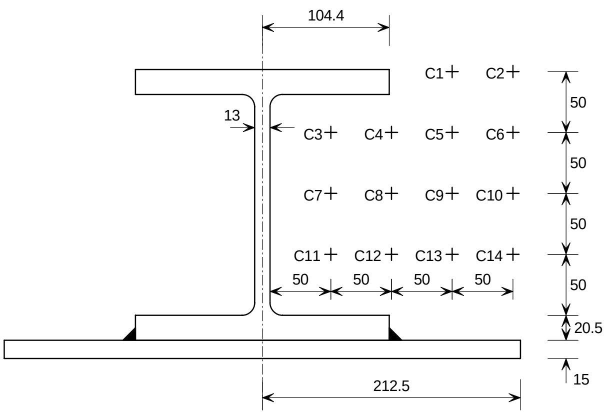


Figure 2.15 *Transverse arrangement at position 4*

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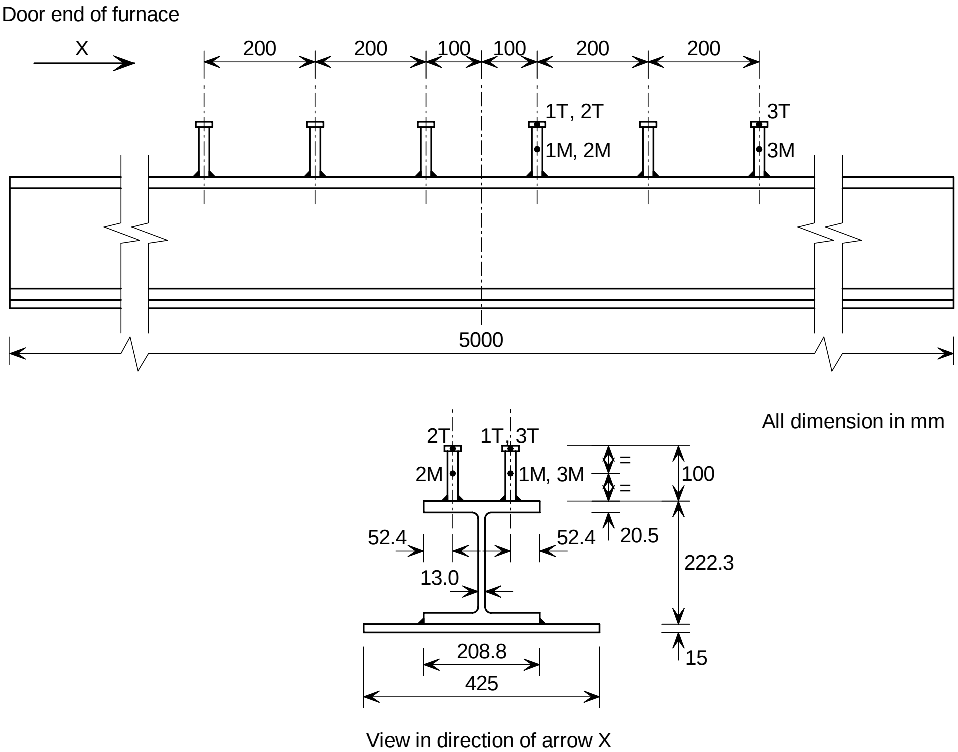


Figure 2.16 *Location of thermocouples on shear studs*

Results

During the fire test the specimen retained its load carrying capacity for 67 minutes. At this time the deflection of the section reached a value equivalent to L/30 and the rate of deflection at this time exceeded the limiting rate specified by BS476-20:1987. The measured deflection of the specimen is shown in Figure 2.17.

The load was removed at this time and the fire test continued until 90minutes providing additional temperature data. This data is contained on the CD supplied with this report. The file reference is WFRC 50522.

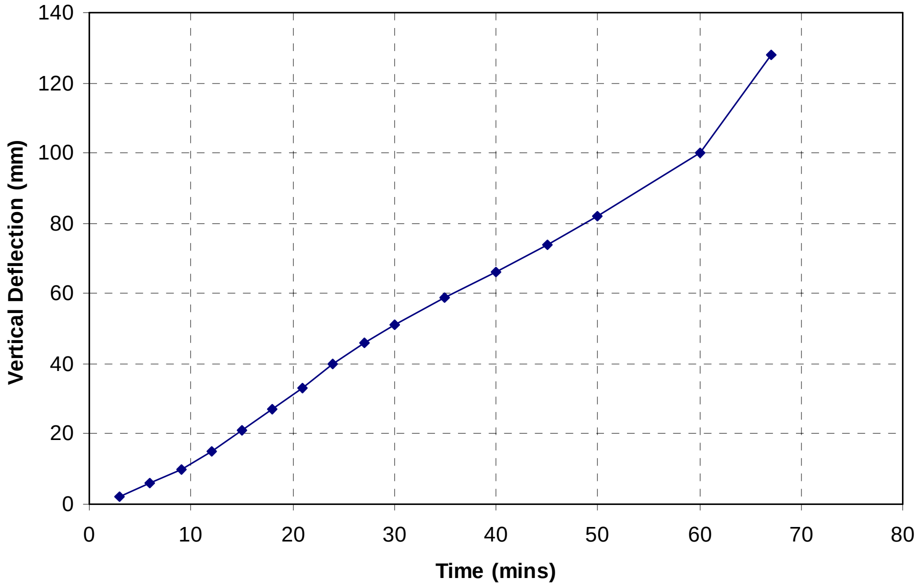


Figure 2.17 *Measured mid span deflection*

2.6 Test WFRC 52896

This test was conducted at Warrington Fire Research Centre on 8 February 1991. The CD which accompanies this report contains data files recorded during the test providing data measured from all the thermocouples. Summary data is also supplied which includes the deflections recorded during the test.

Test specimen

The test specimen consisted of a non composite Slimflor beam fabricated from a 203x203x60 universal column section with a 405mm x 15mm thick steel plate welded to the bottom flange. Both the column and plate were grade Fe 430A material (equivalent of Grade S275)[(5)]. Web stiffeners formed from 15 mm thick plate (also Fe 430 A) were welded on both sides of the section at mid span and roller support positions. The presents of a concrete floor slab was simulated using pre-cast dense concrete blocks each 440 mm long x 140 mm wide x 215 mm deep supported on the bottom plate and the space between the flanges was infill with fine dry sand up to half the depth of the section, as shown by Figure 2.18. The moisture content of the sand and the precast concrete blocks were measured on the day of the test and found to be 1.5% and 1.9% respectively. The measured density of the concrete blocks was 1870kg/m^3.

The load was applied to both the steel section and the concrete blockwork. A total imposed load of 123.88kN was applied directly to the steel section at two points situated 970 mm either side of the mid span position and directly over the web. In addition a total imposed load of 44.88kN was applied at four positions on each side of the section (see Figure 2.19). Assuming that the loading positions offer lateral restraint to the beam the plastic resistance of the non-composite steel section at room temperature was calculated as 245.1kNm. The moment due to the self weight of the steel section, concrete blocks and sand infill was calculated as 6.75kNm. The applied loading resulted in a moment of 119.9kNm given a total applied moment of 126.7kNm. This resulted in a load ratio of 0.52. If the beam is assumed to be unrestrained the buckling moment of resistance is 137.6kNm resulting in a much higher load ratio of 0.92.

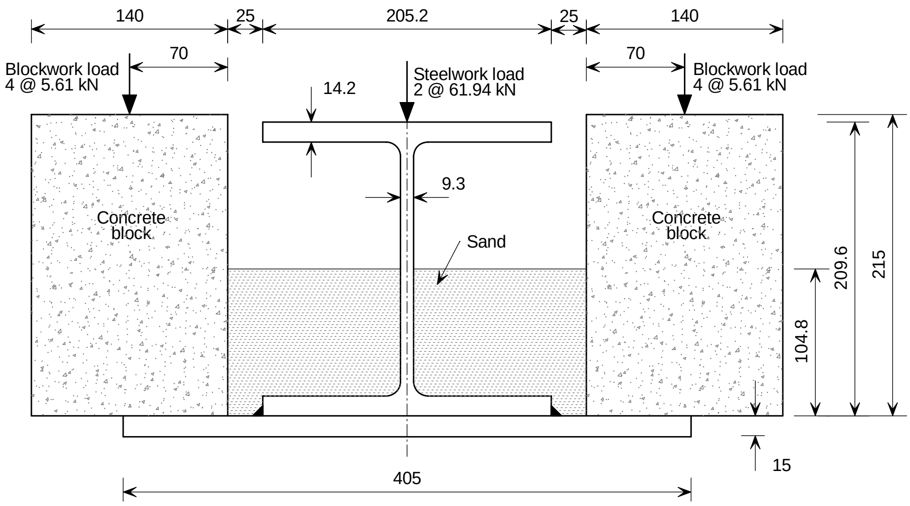


Figure 2.18 *Schematic arrangement of components*

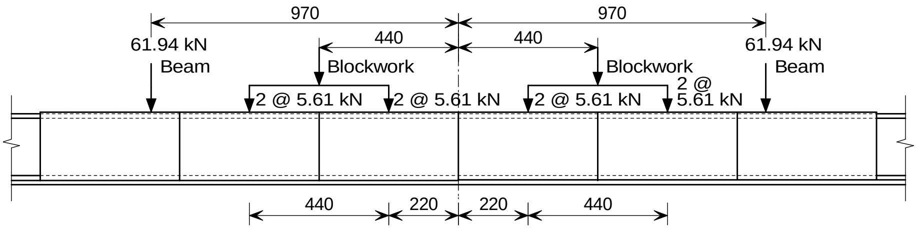


Figure 2.19 *Applied load positions – Longitudinal arrangement*

Electronic temperature data for this test specimen is provided on a CD which accompanies this report. The file reference is: WFRC 52896.

Instrumentation

The locations of thermocouples on the steelwork were as shown in Figure 2.20 to Figure 2.22. One additional thermocouple was placed in the sand infill at the mid depth and mid width position at mid span. A reference to a prefix (A or B) means that thermocouples will be preceded by the prefix in computer data files.

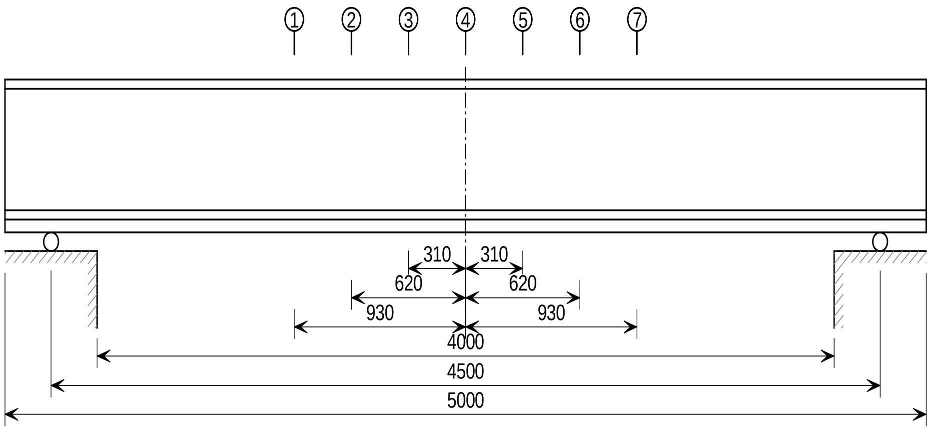
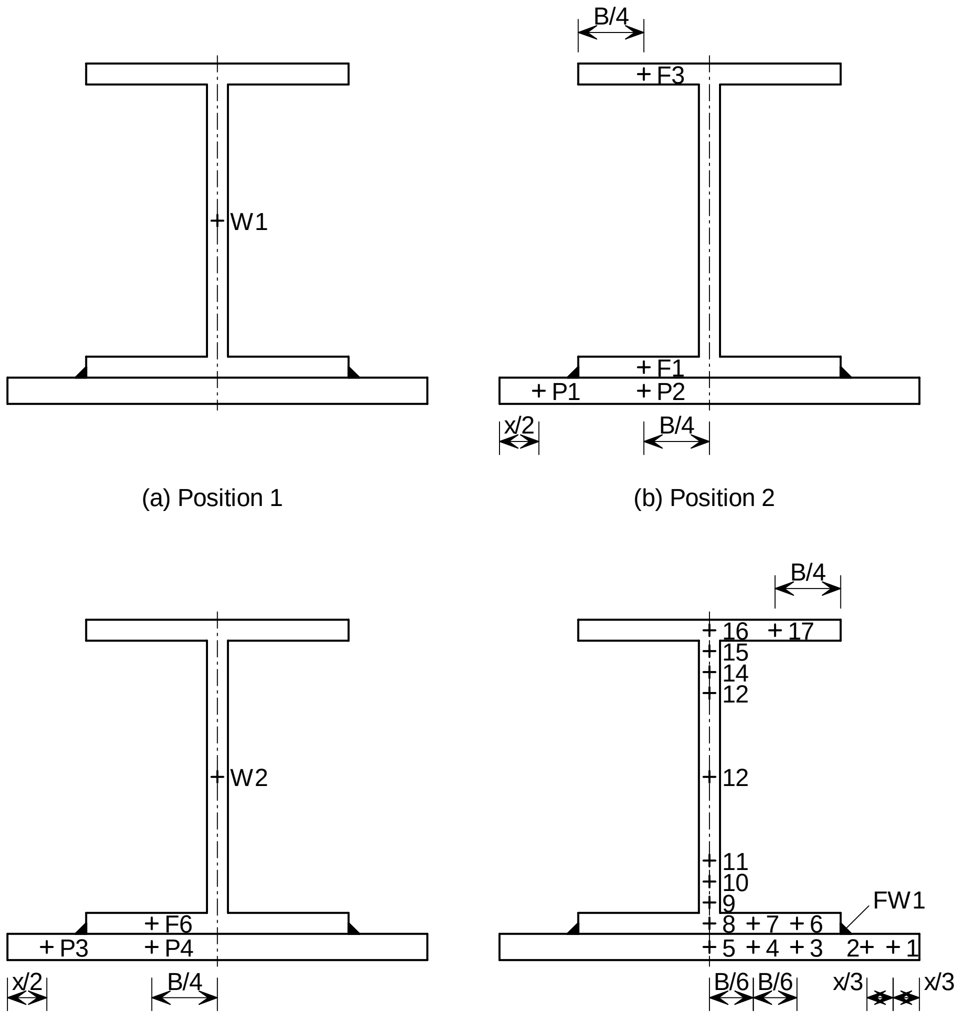


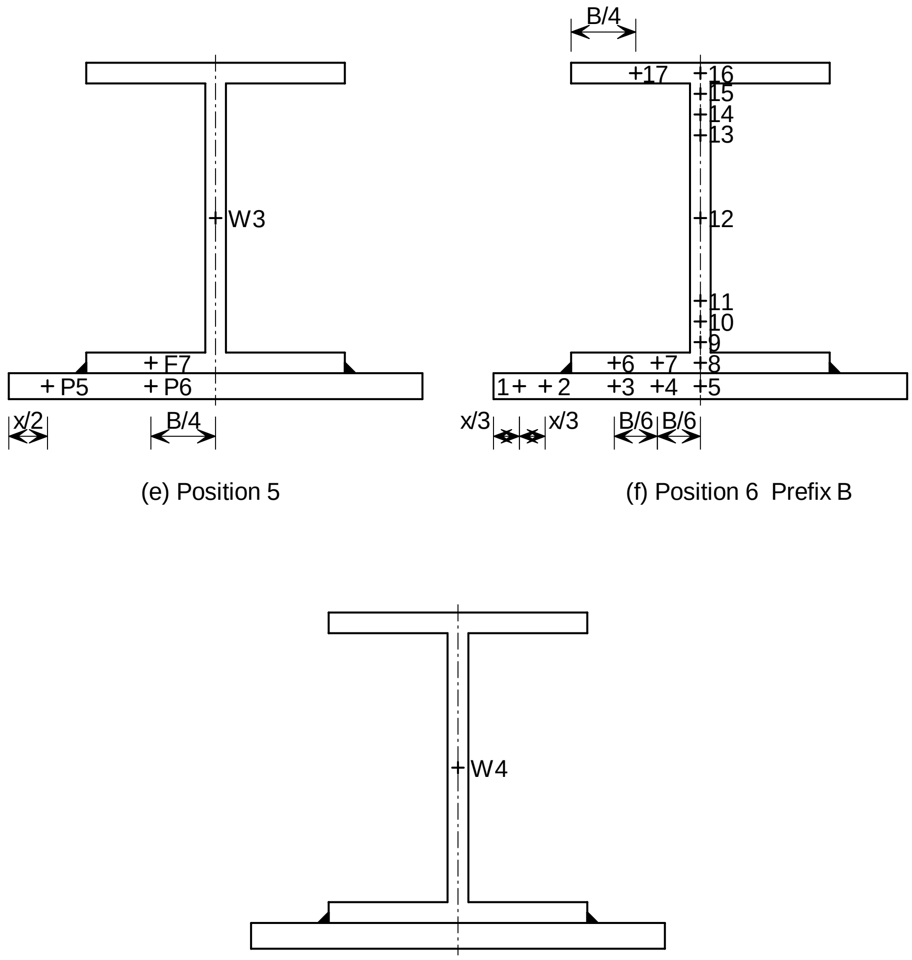
Figure 2.20 *Longitudinal arrangement – Position of thermocouple cross sections*



(a) Position 1 (b) Position 2

(c) Position 3 (d) Position 4 Prefix A

Figure 2.21 *Transverse arrangement at positions 1 - 4*



(g) Position 7

Figure 2.22 *Transverse arrangement at positions 5 - 7*

The load on the specimen was maintained at a constant value until 83minutes after which time the load applied to the beam and the block work were increased. For this reason the fire resistance of the specimen is reported as 83 minutes. However the maximum deflection recorded during this time was 129mm which is less than the limiting deflection of L/20 specified by the load bearing criteria of BS476-20:1987. The measured deflection of the specimen is shown in Figure 2.23.

The load was increased at this time and the fire test continued until 116minutes although temperature data is available no further reporting of deflection was made after the load was increased. This data is contained on the CD supplied with this report. The file reference is 52896.

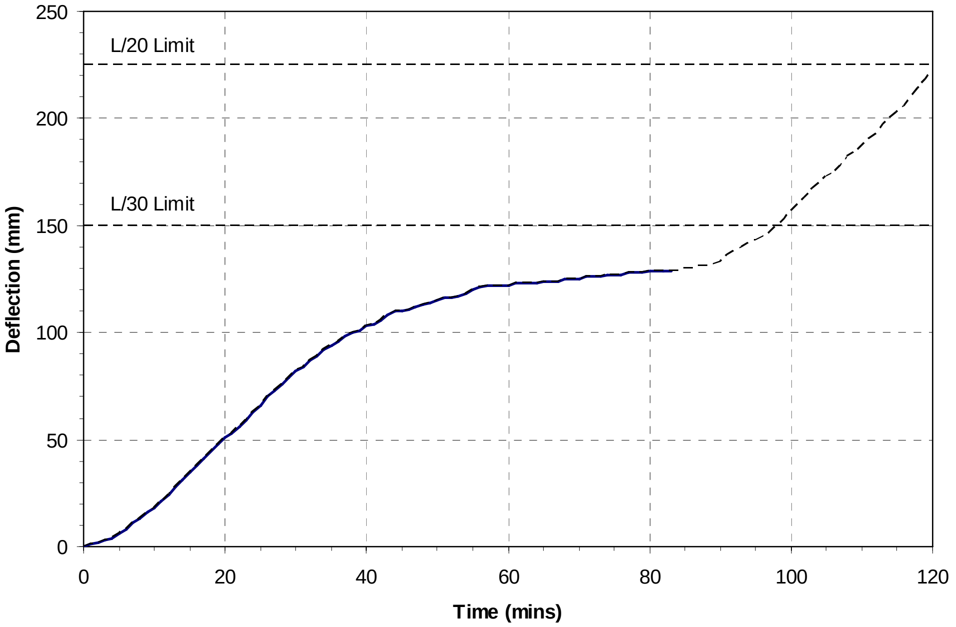


Figure 2.23 *Measured mid span deflection*

2.7 Test WFRC 52897

This test was conducted at Warrington Fire Research Centre on 14 February 1991. The CD which accompanies this report contains data files recorded during this test that include all thermocouple and deflection data. Information on this test is also available from a British Steel Report(7) that includes additional data on the actual section geometry and measured material properties of the test specimen.

Test Specimen

The test specimen consisted of a non-composite fabricated Slimflor beam supporting a concrete floor slab simulated using concrete blocks. The Slimflor section was fabricated from a 254x254x73 universal column with a 405 mm wide x 15 mm thick steel plate welded to the bottom flange. Both the column and plate were grade Fe 430A material (equivalent of S275 grade). The web of the section was totally encased in normal weight concrete with a value of 30 N/mm^2 for nominal cube strength. A concrete floor slabs was formed using pre-cast dense concrete blocks each 440 mm long x 140 mm wide x 215 mm deep supported on the protruding section of the bottom plate, as shown by Figure 2.24.

The load was applied to both the steel section and the concrete blockwork. A total imposed load of 174 kN was applied directly to the steel section at two points situated 1000 mm either side of the mid span position and directly over the web. In addition a total imposed load of 70 kN was applied at four positions on each side of the section (see Figure 2.25). Load ratio for this system was 0.46.

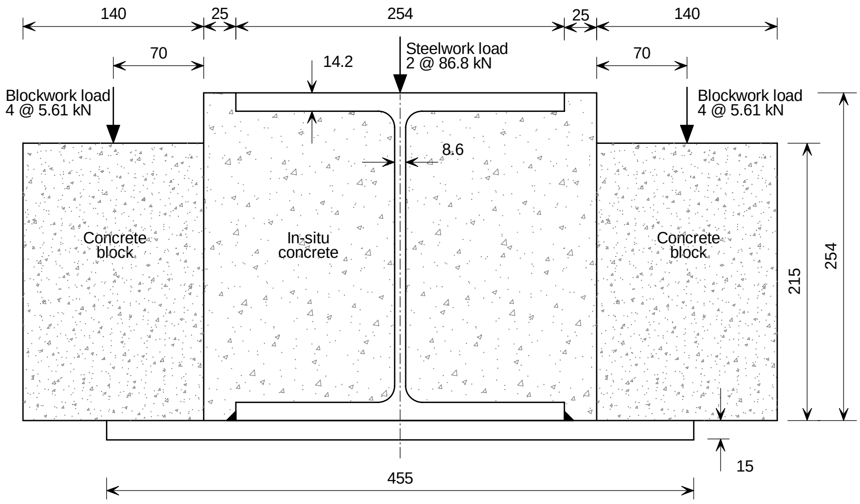


Figure 2.24 *Schematic arrangement of components*

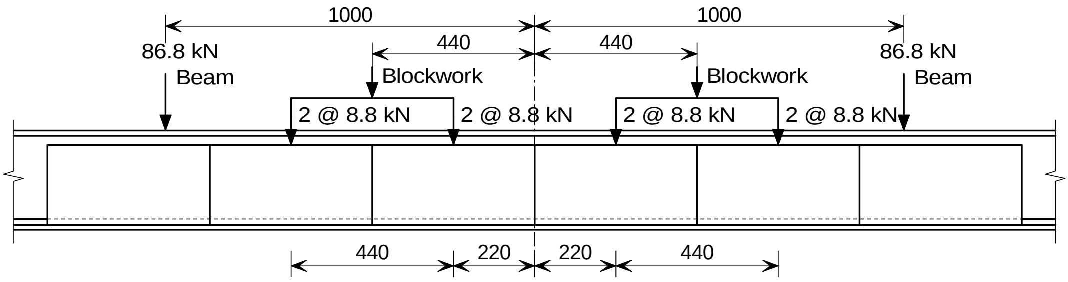


Figure 2.25 *Applied load positions – Longitudinal arrangement*

Instrumentation

The thermocouple positions in the steelwork were as shown in Figure 2.26 to Figure 2.28. A reference to a prefix (A or B) means that thermocouples will be preceded by the prefix in computer data files.

The deflection of the loaded test specimen was measured during the fire test using an LVDT located at mid-span.

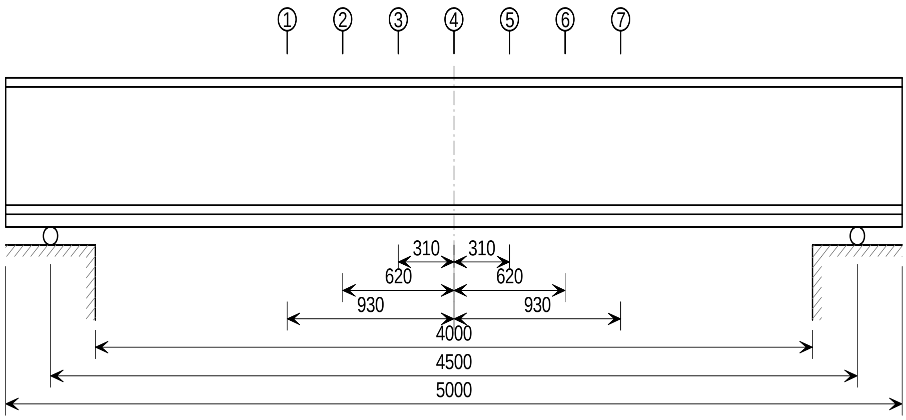


Figure 2.26 *Longitudinal arrangement – Position of thermocouple cross sections*

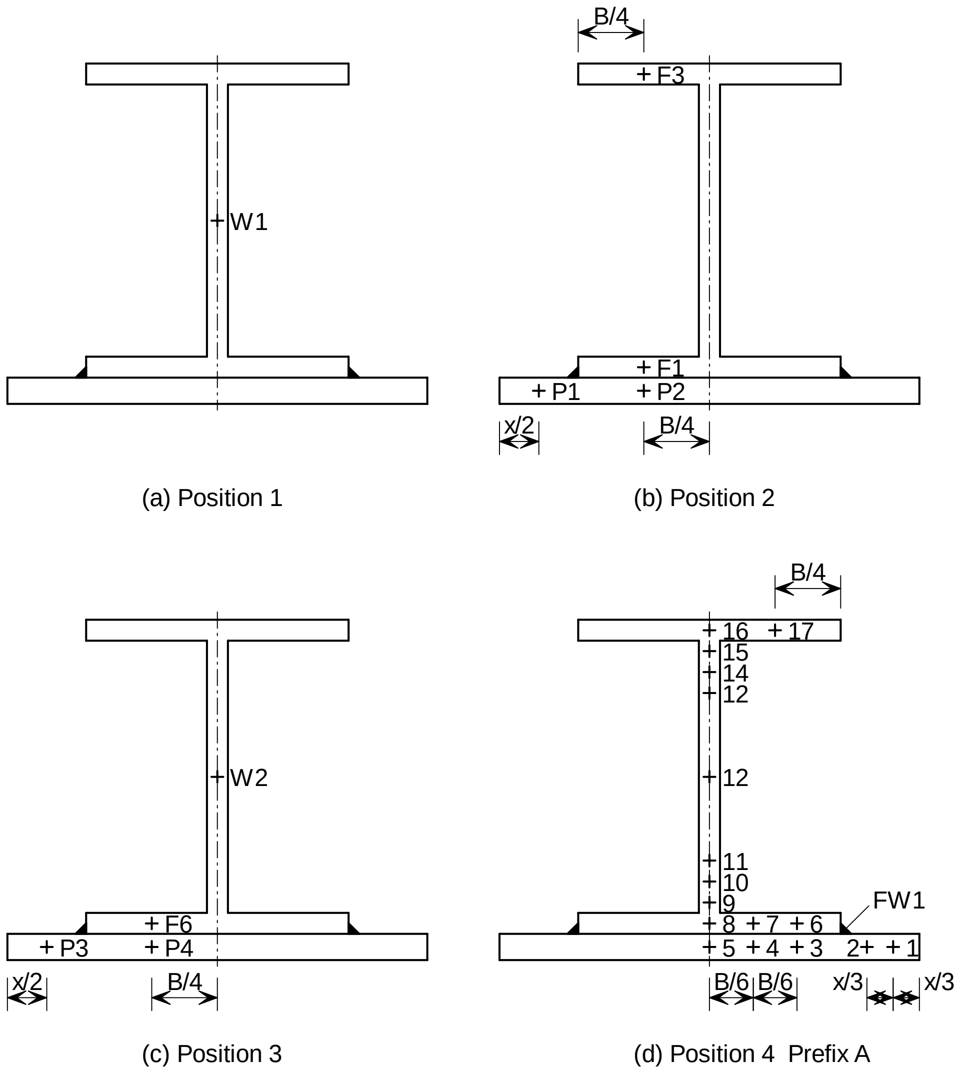
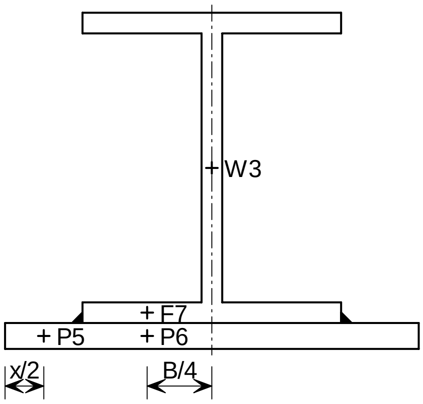
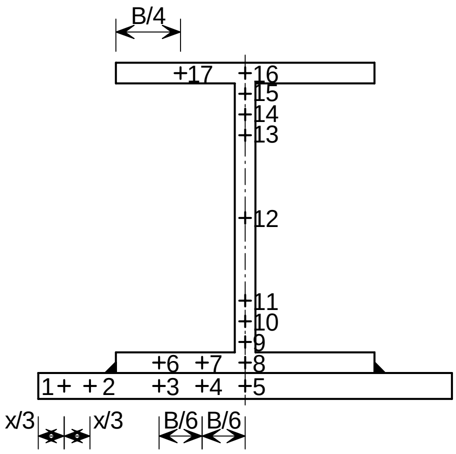


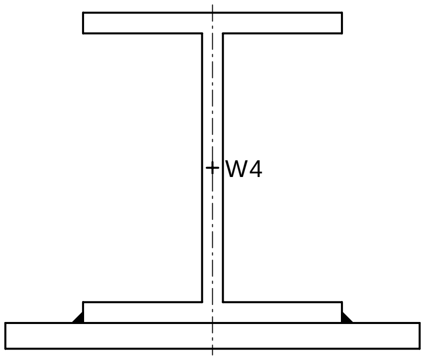
Figure 2.27 *Transverse arrangement at positions 1 - 4*



(e) Position 5



(f) Position 6 Prefix B



(g) Position 7

Figure 2.28 *Transverse arrangement at positions 5 - 7*

Results

The deflection of the test specimen measured during the fire test is plotted with respect to time in Figure 2.29. The specimen attained a deflection equal to the L/30 limit after 79minutes and after 83 minutes the load level was modified effectively ending the fire resistance test. The fire resistance is reported as 83minutes although the test was continued until 110 minutes. No deflection data was reported after 83minutes and the final load level is not known. The measured deflection after 83 minutes was 170mm and the rate of deflection was 4mm/min. The section at this point had not reached achieved the failure criteria of BS476.

The specimen achieved a fire resistance of 83 minutes when evaluated against the load bearing criteria of BS476.

Electronic temperature data for this test specimen is provided on a CD which accompanies this report. The file reference is: WFRC 52897.

Deflection data available up to 109 minutes

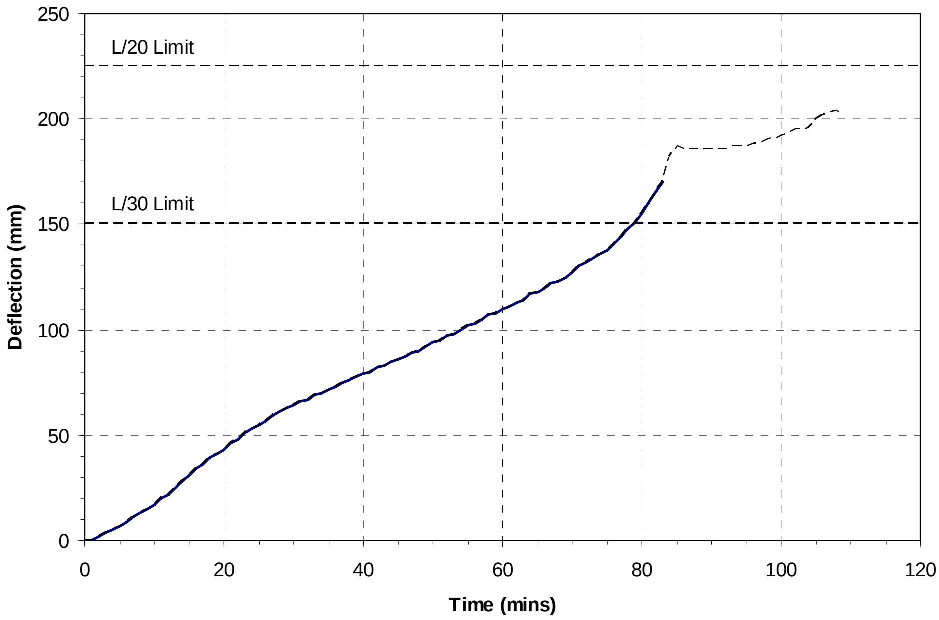


Figure 2.29 *Mid span deflections recorded during fire test WFRC 52897*

2.8 Test WFRC 51883

This test was carried out by Warrington Fire research centre on 7 August 1991. The CD which accompanies this report contains data files recorded during this test that include all thermocouple data. Information on this test is also available from a British Steel Report(7) that includes additional data on the actual section geometry and measured material properties of the test specimen.

Test Specimen

The test specimen consisted of a Slimflor beam fabricated from a 305x305x283 universal column and a steel plate 525 mm wide x 15 mm thick. Both the column and plate were grade Fe 430A (equivalent of S275 grade). Pre-cast dense concrete blocks each 440 mm long x 140 mm wide x 215 mm deep were supported on the bottom plate of the Slimflor beam to simulate a floor slab, see Figure 2.30. The space between the column flanges was partial in-filled with normal weight concrete with a nominal cube strength of 30 N/mm^2.

Hydraulic rams were used to applied load to the steel section and the pre-cast concrete blocks. A total imposed load of 170kN was applied directly to the steel section at two points situated 970 mm either side of the mid span position and directly over the web. In addition a total imposed load of 221 kN was applied to the pre-cast concrete blocks on each side of the section at four locations along the span, see Figure 2.30 & Figure 2.31.

The self weight of the beam and the concrete was 14.7kNm. The hydraulic rams imposed a further moment of 308.9kNm. The plastic moment of resistance of the section was calculated as 1722.7kNm resulting in a load ratio of 0.19.

The moisture content was measured on the day of the test and found to be 4.0% and 3.2% respectively. The measured density of the pre-cast concrete blocks was 1920kg/m^3.

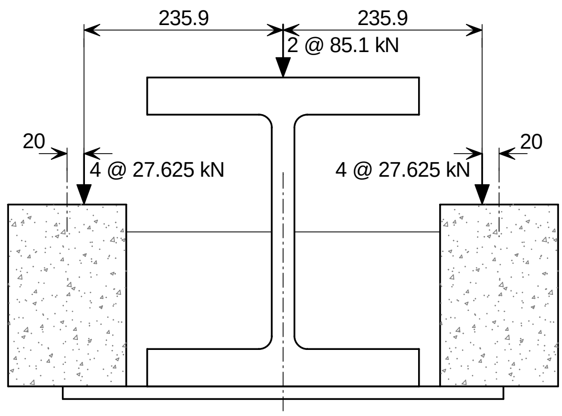


Figure 2.30 *Schematic arrangement of components*

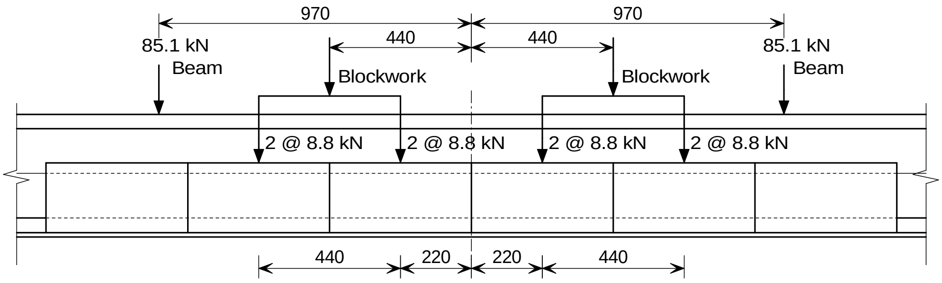


Figure 2.31 *Longitudinal arrangement of loading positions*

Instrumentation

Thermocouples were located on the steel section at 9 cross sections along the length of the beam as shown by Figure 2.32. The location of thermocouples on each of these cross sections is shown by Figure 2.34 to Figure 2.36. The locations of thermocouples on the web are shown in more detail by Figure 2.33. Thermocouples were also located in the insitu concrete infill between the flanges of the UC section and in the cavity above the concrete infill on cross sections 5 and 7, as shown by Figure 2.37.

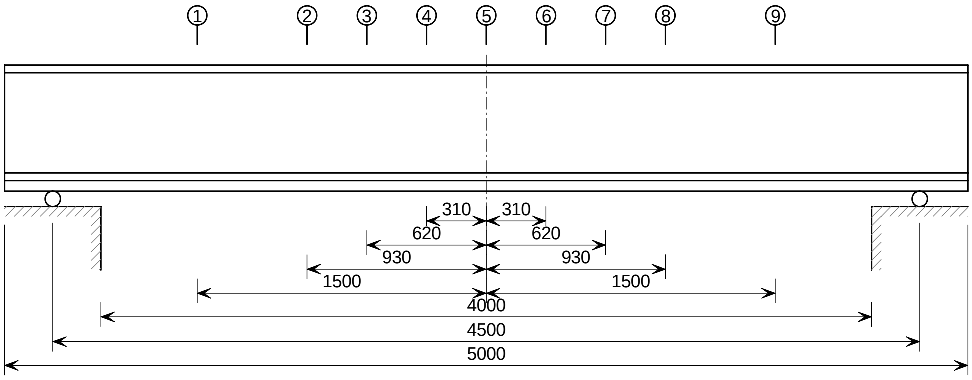


Figure 2.32 *Longitudinal arrangement – Position of thermocouple cross sections*

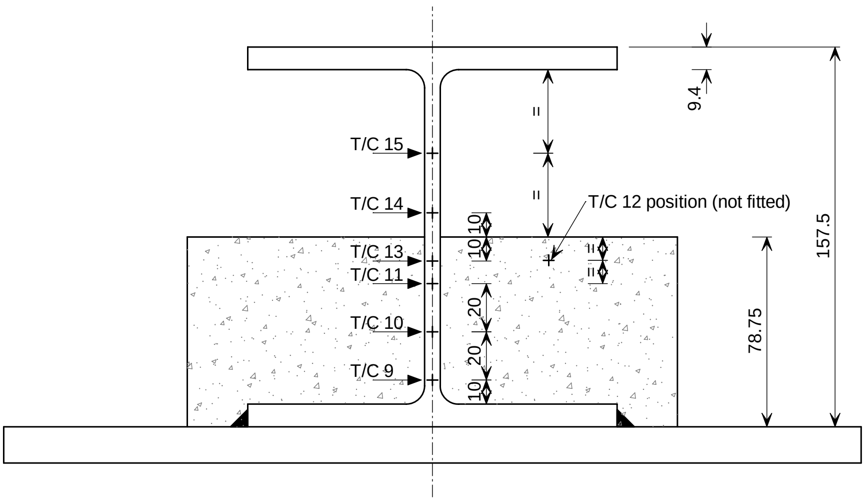
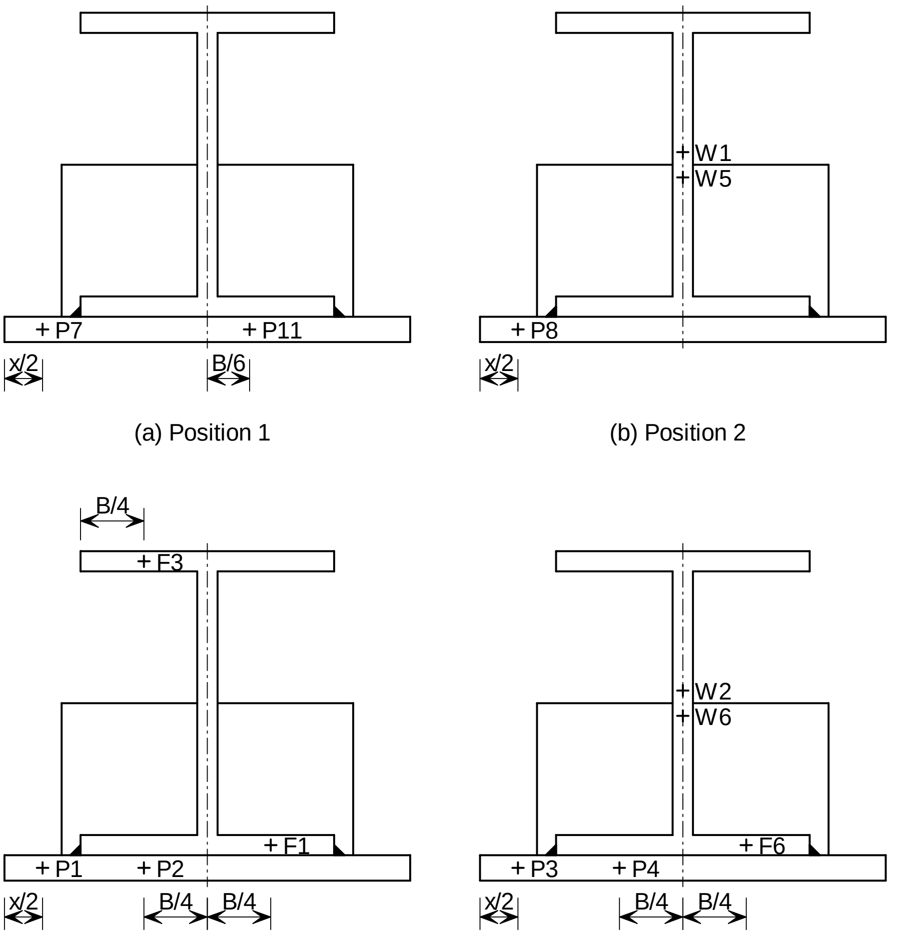


Figure 2.33 *Detailed location of thermocouples on the web of the steel section*



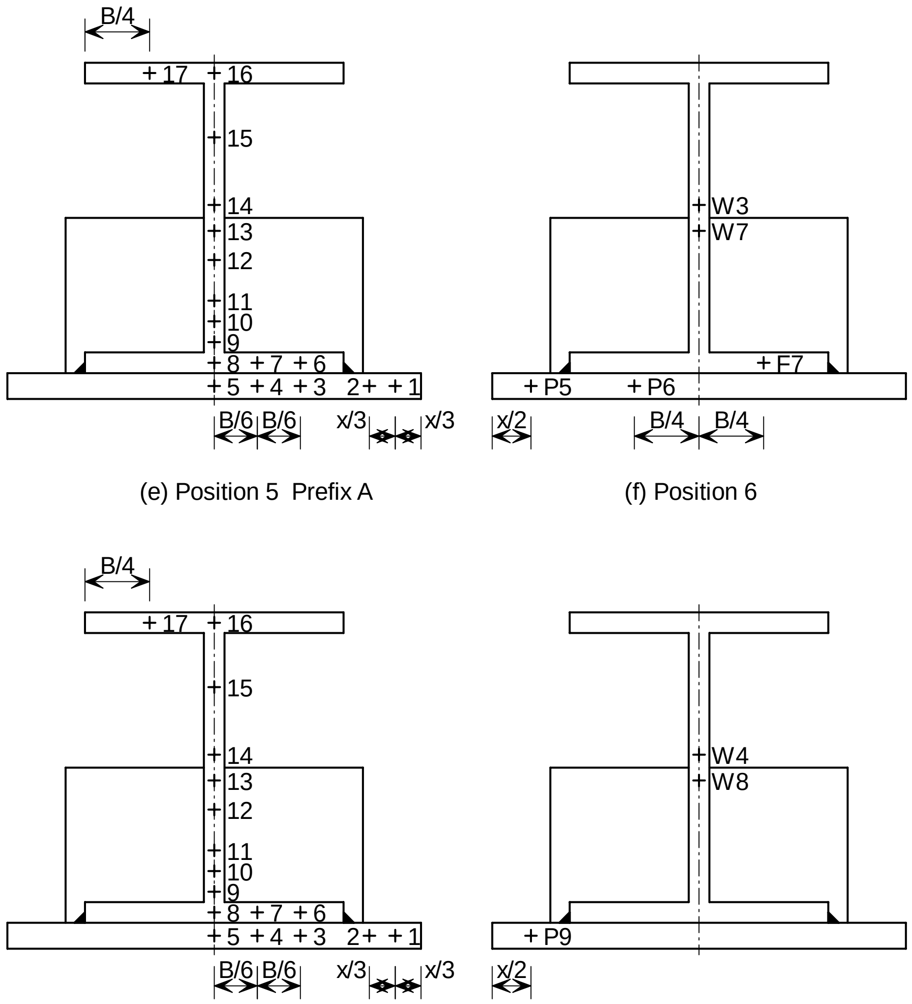
(a) Position 1

(b) Position 2

(c) Position 3

(d) Position 4

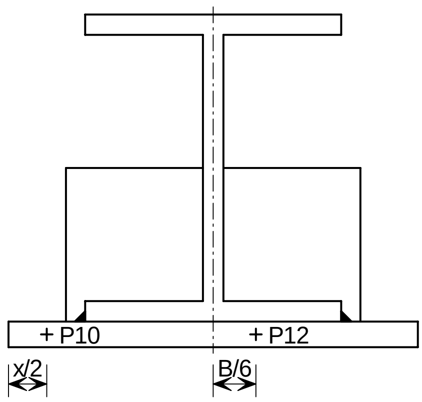
Figure 2.34 *Transverse arrangement at positions 1 - 4*



(e) Position 5 Prefix A (f) Position 6

(g) Position 7 Prefix B (h) Position 8

Figure 2.35 *Transverse arrangement at positions 5 - 8*



(i) Position 9

Figure 2.36 *Transverse arrangement at position 9*

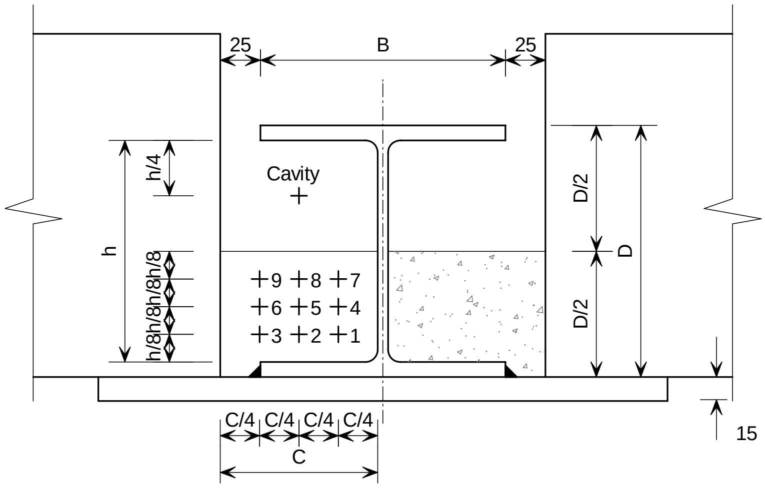


Figure 2.37 *Transverse arrangement at positions 5 and 7*

Results

The temperatures and deflections recorded during the tests are included on the CD which accompanies this report. The file reference is: WFRC 51883.

The load applied to the pre-cast concrete blocks was removed after 90 minutes. Technically the fire test ended at this time. However the test was continued until 120 minutes. The measured deflection is plotted against time in Figure 2.38.

The specimen did not reach the limiting deflection imposed by the load bearing criteria of BS476 before the loading was altered. The measured deflection after 90 minutes was 58mm and rate of deflection 1mm/minute.

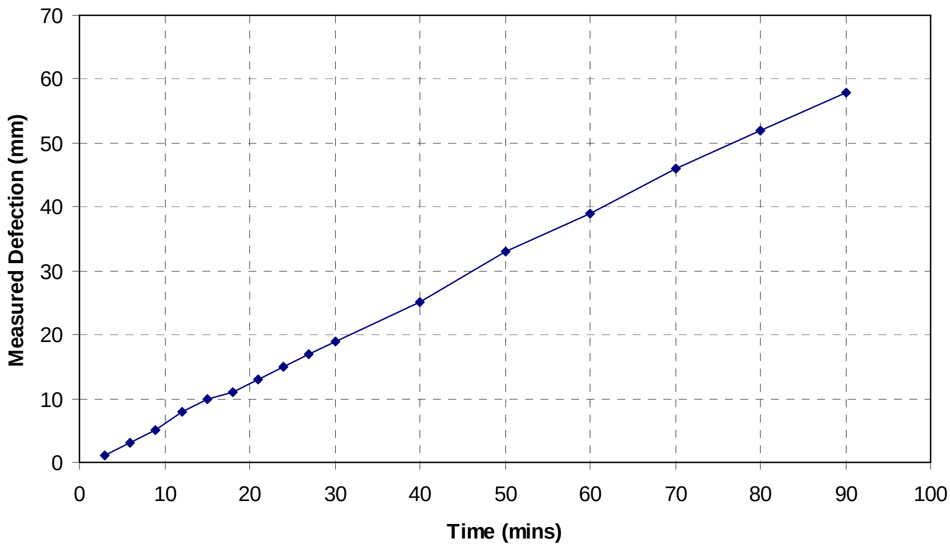


Figure 2.38 *Measured deflection at mid span of the test specimen (WFRC 51883)*

2.9 Test WFRC 54278

This test was carried out by Warrington Fire research centre on 30 October 1991. The CD which accompanies this report contains data files recorded during this test that include all thermocouple data. Information on this test is also available from a British Steel Report(7) that includes additional data on the actual section geometry and measured material properties of the test specimen

Test Specimen

The test specimen was a non composite construction consisting of a Slimflor beam fabricated from a 152x152x30 universal column section and a steel plate 355 mm wide x 15 mm thick. Both the column and plate were grade Fe 510B (equivalent of S355 grade). The bottom plate of the section was used to support pre-cast dense concrete blocks each 440 mm long x 140 mm wide x 215 mm deep and the space between the flanges of the beam were in-filled with concrete which had a value of 30N/mm^2 for nominal cube strength, as shown by Figure 2.39.

The load was applied to both the steel section and the concrete blocks on either side. A total imposed load of 37kN was applied directly to the steel section at two points situated 970mm either side of the mid span position and directly over the web. In addition a total imposed load of 40kN was applied at four positions on each side of the section, as shown in Figure 2.40. The moment on the cross section due to the self weight of the beam and concrete was calculated as 5.52kNm. The applied loads result in a moment of 59.8kNm. The plastic resistance of the section was calculated as 150.3kNm giving a load ratio of 0.43.

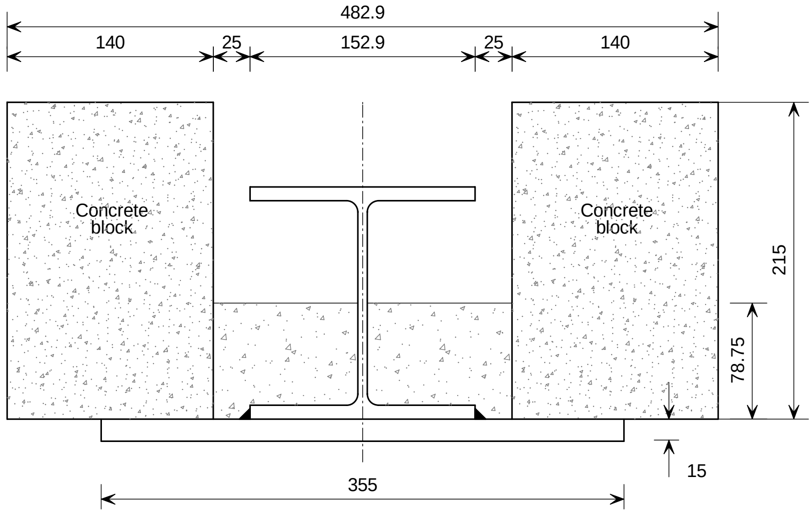


Figure 2.39 *Schematic arrangement of components*

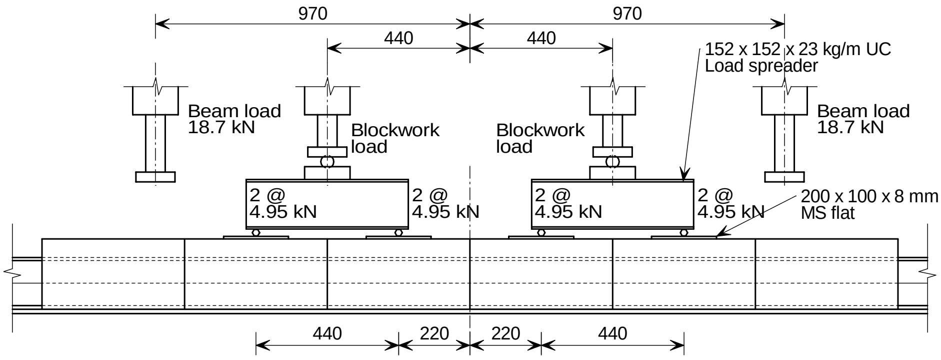


Figure 2.40 *Applied load positions – Longitudinal arrangement*

Instrumentation

The thermocouple positions in the steelwork were as shown in Figure 2.41 to Figure 2.44. A reference to a prefix (A or B) means that thermocouples will be preceded by the prefix in computer data files. An additional eighteen thermocouples were embedded in the concrete at the time of casting. Further thermocouples were embedded in the fillet weld, between the bottom flange and bottom plate, 750mm on either side of the mid span location.

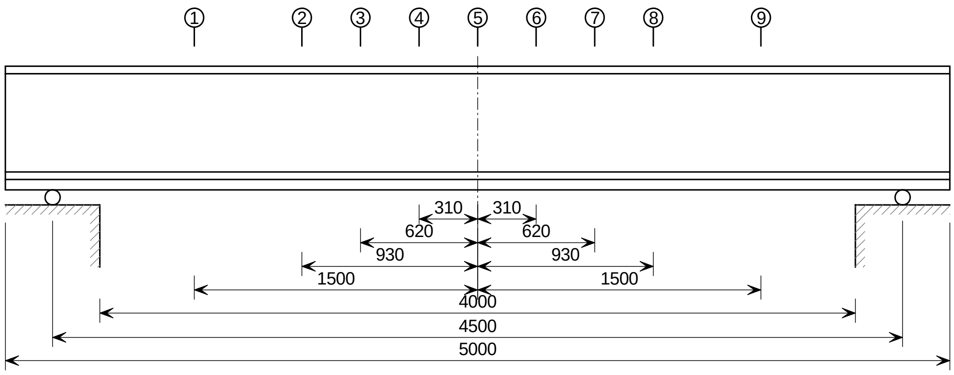


Figure 2.41 *Longitudinal arrangement – Position of thermocouple cross sections*

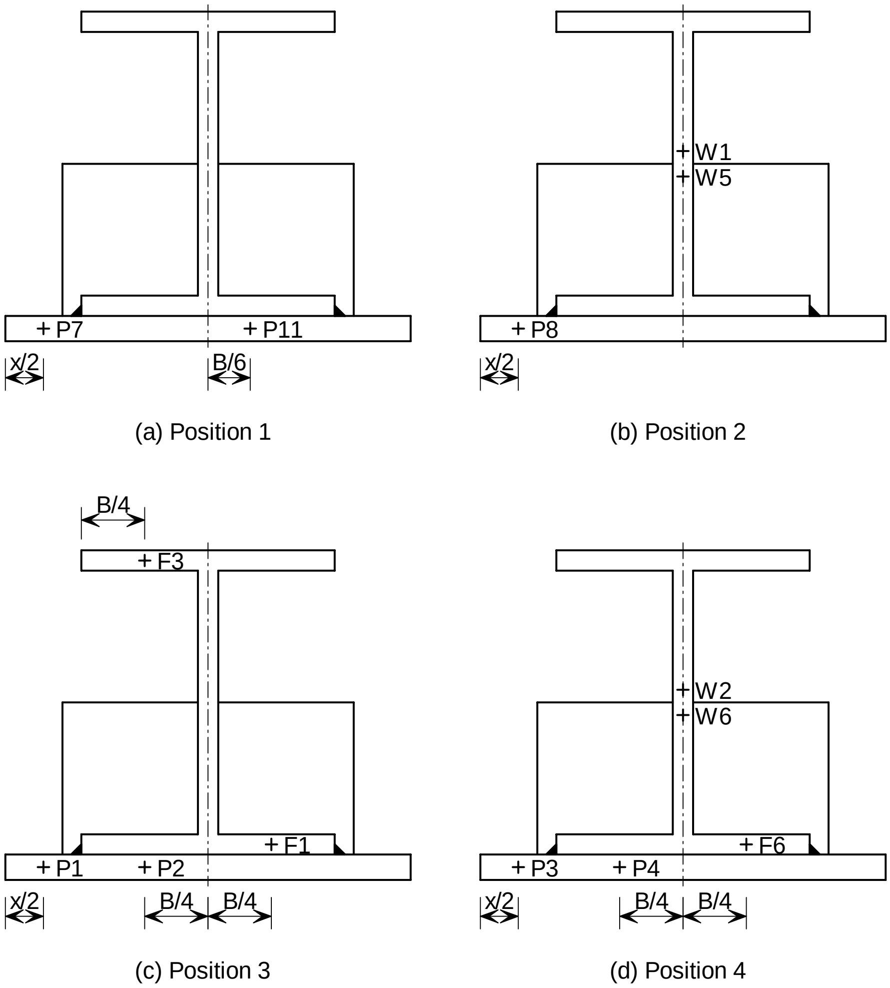


Figure 2.42 *Transverse arrangement at positions 1 – 4*

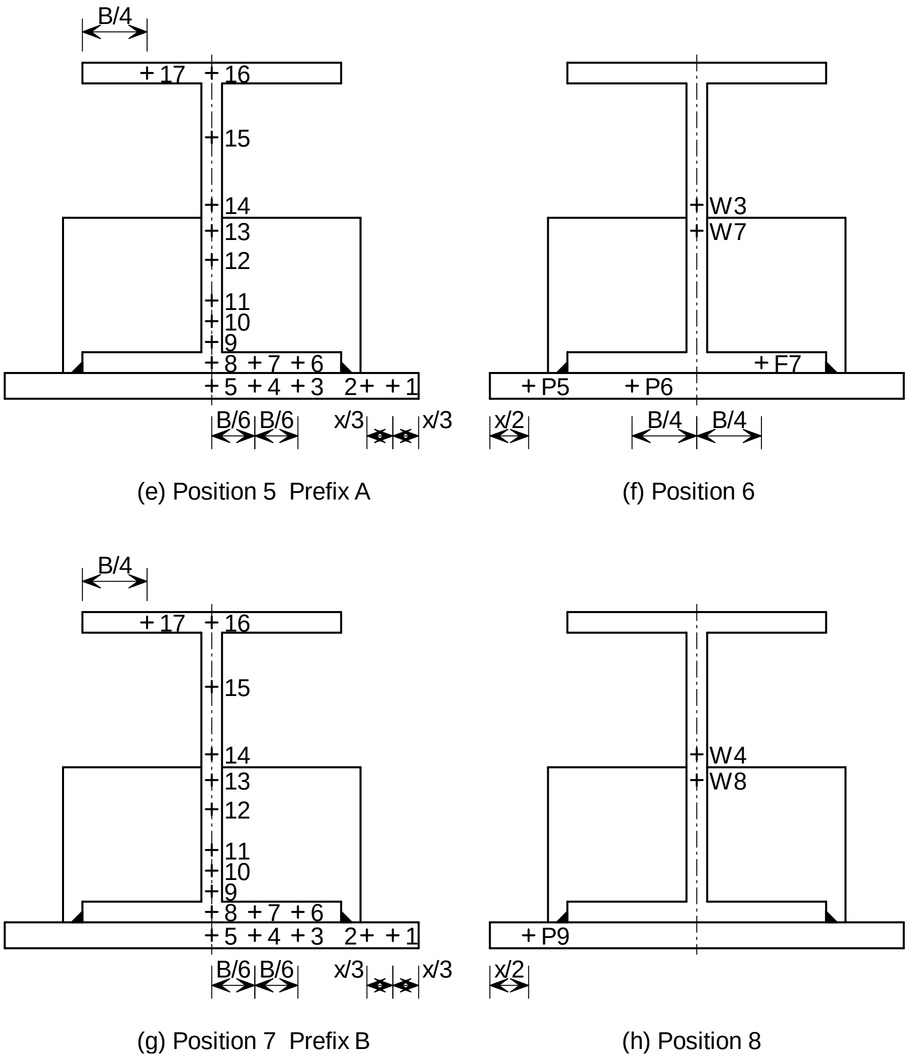


Figure 2.43 *Transverse arrangement at positions 5 – 8*

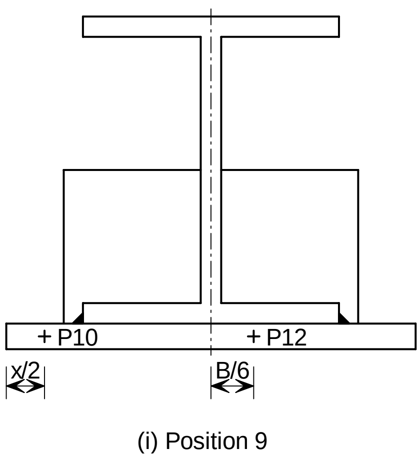


Figure 2.44 *Transverse arrangement at position 9*

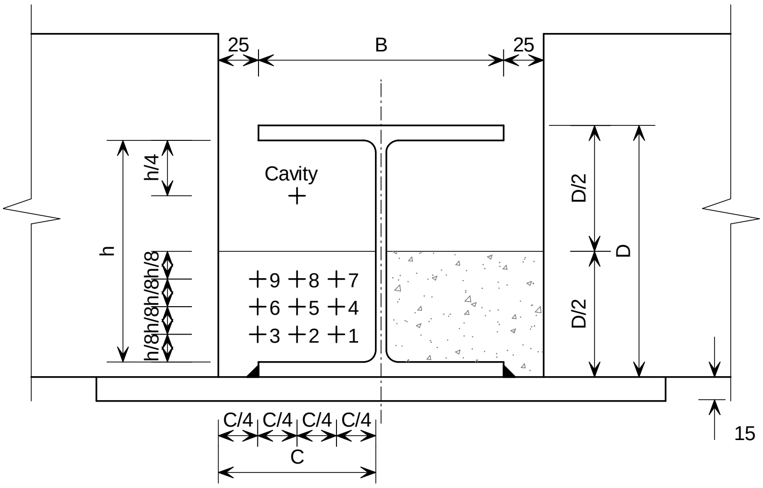


Figure 2.45 *Transverse arrangement at positions 5 and 7*

Results

In accordance with BS476 the deflection limit for this test specimen is 225mm and the limiting rate of deflection is 13mm/min. This limiting rate of deflection criteria is applied once a deflection of L/30 has been attained.

The measured deflection of the test specimen is plotted against time in . A deflection of L/30 is reached after 59 minutes. However before the specimen attained a limiting temperature of L/20 the applied loading was altered effectively ending the fire resistance test. The loading on the beam and the concrete blocks was increased after 69 minutes. The final magnitude of load applied to the beam is not known and the beam deflection beyond 69 minutes is not reported.

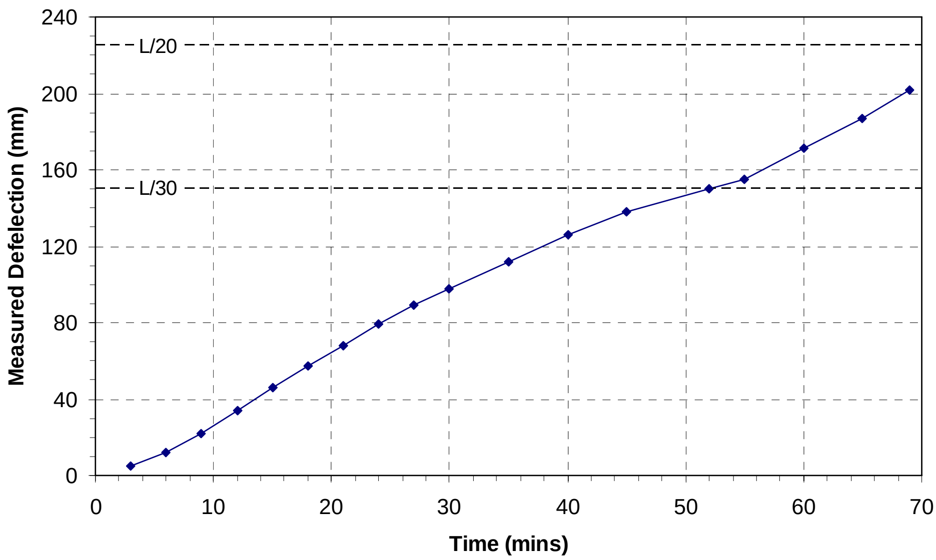


Figure 2.46 *Measured deflections at mid span of test specimen (WFRC55278)*

2.10 Test WFRC 51884

This test was conducted at Warrington Fire Research on 31 July 1991[7].

Test Specimen

The construction of the test specimen was identical in all respects to test WFRC 54278. This test specimen was initially loaded but due to unspecified difficulties during the test only thermal data has been reported.

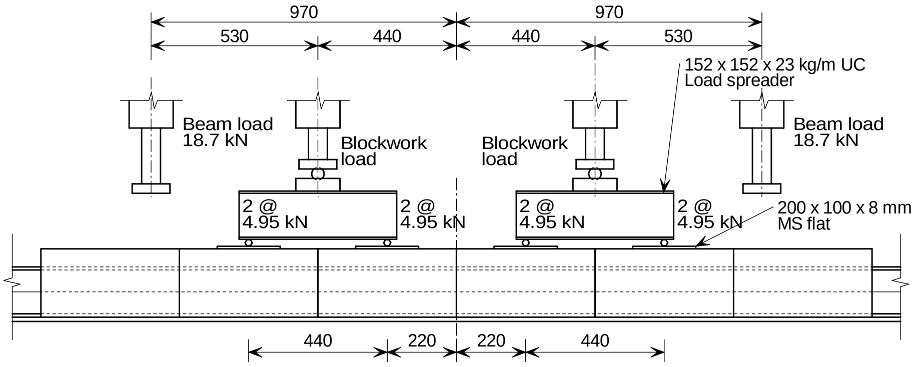


Figure 2.47 *Applied load positions – Longitudinal arrangement*

Instrumentation

The steel section was instrumented with thermocouples on 9 cross sections as shown by Figure 2.48. The locations of thermocouples at each cross section are shown in Figure 2.49 to Figure 2.51. At cross sections 5 and 7 additional thermocouples were embedded in the insitu concrete infill around the steel section, as shown in Figure 2.52. A LVDT was also located at mid span in order to record the deflection of the specimen during the test.

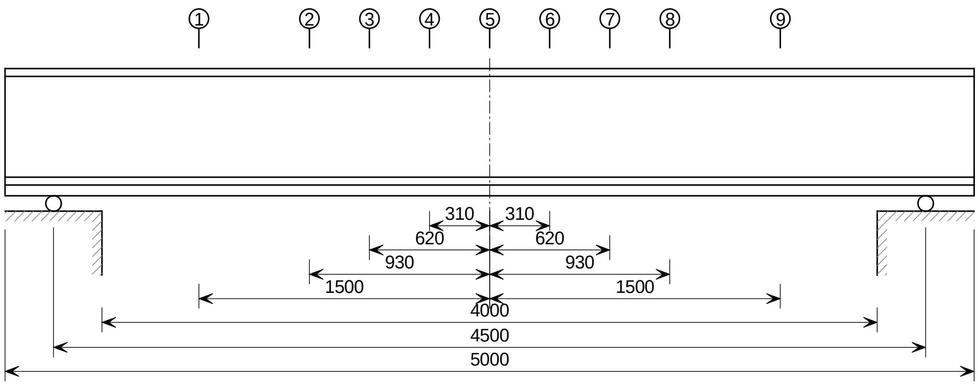


Figure 2.48 *Longitudinal arrangement – Position of thermocouple cross sections*

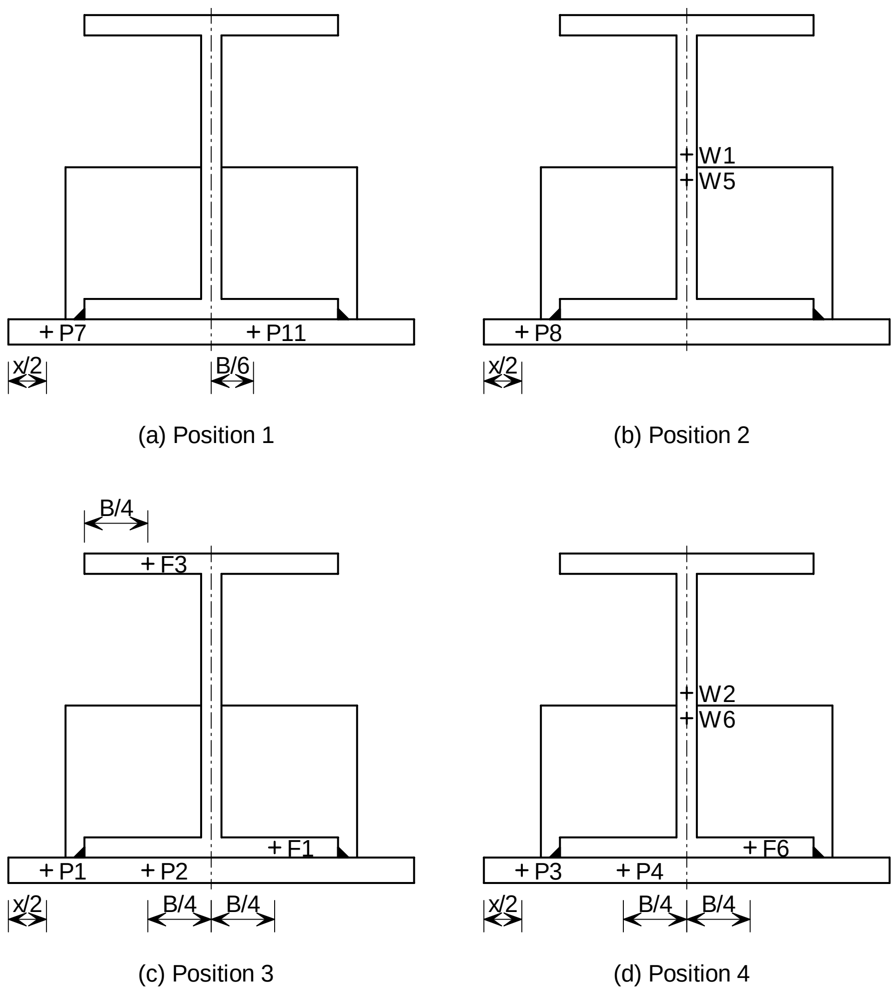
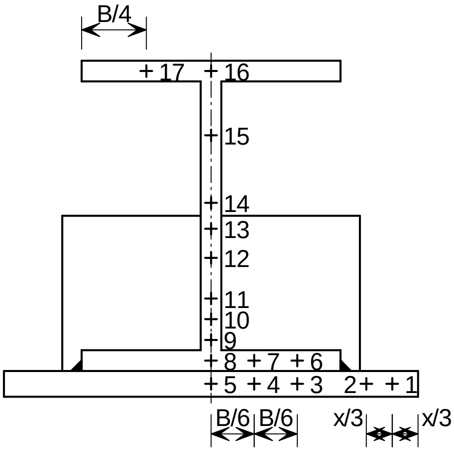
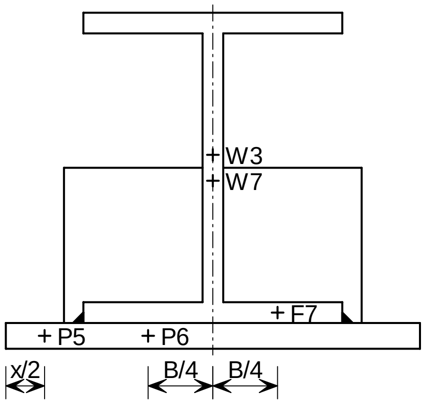


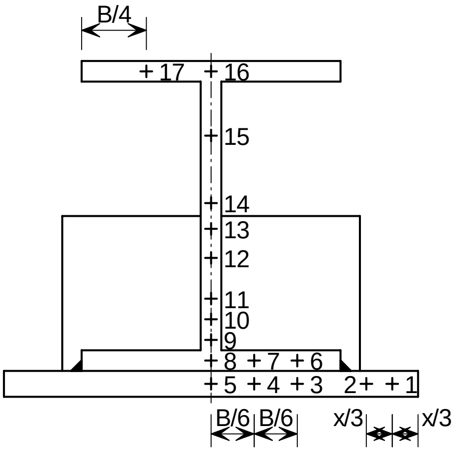
Figure 2.49 *Transverse arrangement at positions 1 - 4*



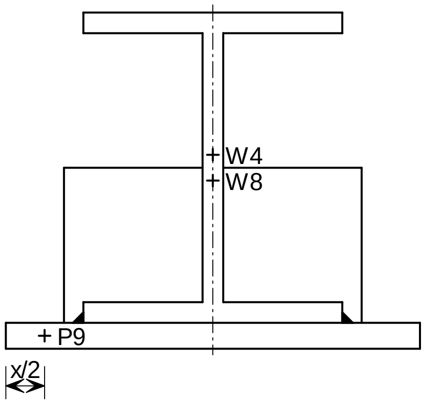
(e) Position 5 Prefix A



(f) Position 6

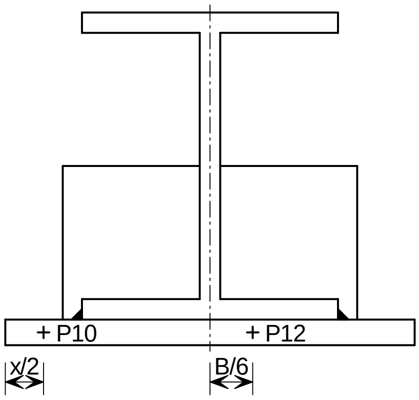


(g) Position 7 Prefix B



(h) Position 8

Figure 2.50 *Transverse arrangement at positions 5 - 8*



(i) Position 9

Figure 2.51 *Transverse arrangement at position 9*

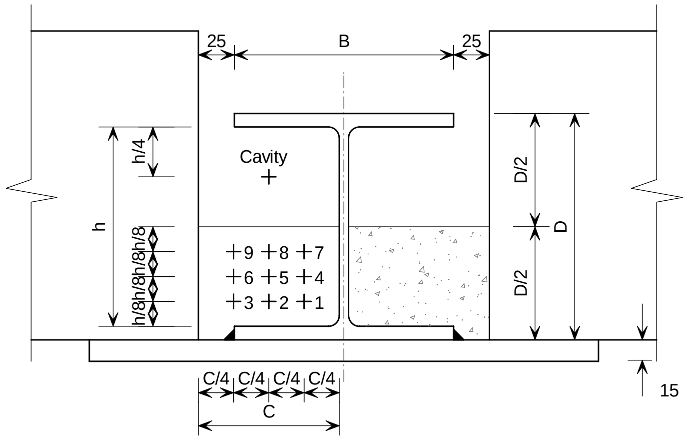


Figure 2.52 *Transverse arrangement at position 5 and 7 (concrete thermocouples)*

Results

Thermal data recorded during the test is included on the CD that accompanies this report.

3 Fabricated Slimflor beams with composite slabs

3.1 Summary of available test data

The fire tests conducted on fabricated Slimflor beams with composite slabs are summarised in Table 3.1. Three of the test specimens D1, D2 and D4 supported composite slabs constructed with deep decking. These beams were simple supported members with a span of 4500mm and a heated length of 4000mm. The three beams labelled D3 were part of a two span slab specimen that was tested at TNO, the beam spans in this case are 4.6m. Only the central supporting beam was tested to failure. The specimen used for test D4 also had a composite slab although in this case the concrete was case on a shallow re-entrant deck supported on partial concrete infill cast between the beam flanges. Additional information covering the measured material properties and measured section geometries are available from the original British Steel Reports were available.

Table 3.1 *Summary of fire test data for fabricated Slimflor beams with composite slabs.*

	Section details	Plate Dimension	Type	Test Reference	Electronic Data		
					ASCI	**Excel**	**Summary**
D1	254x254x73	455 x 15	A	56867	NO	NO	YES
D2	305 x 305 x 97	506 x 15	A	60284	NO	YES	NO
D3	HEB 240	440 x 15	A	TNO 95	YES	YES	NO
	HEB 200	330 x 15	A	TNO 95	YES	YES	NO
	HEB 200	330 x 15	A	TNO 95	YES	YES	NO
D4	254x254x89 encased	-	E	44174	NO	NO	YES

Beam Type:

A Deep decking with concrete above flange but no shear studs

E Steel deck on concrete base

The results of the loaded fire tests are summarised in Table 3.2. All of the specimens tested with composite slabs cast on deep decking achieved fire resistance periods in excess of 60 minutes.

Table 3.2 *Loaded fire resistance tests on fabricated Slimflor beams with composite slabs.*

Test	Section	Type	Fire Resistance	Load Ratio	Plate Temperature(†)	Flange Temperature(†)
D1	254x254x73	A	63	0.52	820	732
D2	305x305x97	A	71	0.40	818	643
D3	HEB 240	A	94	0.45	804	576
	HEB 200	edge	-	0.34	804	-
	HEB 200	edge	-	0.34	804	-
D4	254x254x89 encased	E	52	0.55	-	813

Notes:

† temperature measured at 60 minutes

3.2 Test WFRC 56867

This test was carried out by Warrington Fire Research on 4 November 1992. The test details are reported in a British Steel Report(7). This report includes additional information of measured material properties and steel geometry not reproduced in this report.

Test Specimen

The test specimen consisted of a fabricated Slimflor beam supporting a composite slab constructed using CF210 steel decking. The Slimflor beam was fabricated from a 254x254x73 universal column and a steel plate 460 mm wide x 15 mm thick, both grade Fe 430A (equivalent of S275 grade). The bottom plate was used to support a 210 mm deep metal deck profile produced by Precision Metal Forming Ltd. The composite slab was cast using normal weight concrete with 30N/mm^2 cube strength and reinforced with A142 mesh. The steel grade for the reinforcement is not specified but the nominal design strength would have been 460N/mm^2. The dimensions of the slab were nominally 1 metre wide with 90 mm cover over the steel deck. A special feature of the assembly was the inclusion of four 160 mm diameter ducts passing through the web of the section as shown by Figure 3.2.

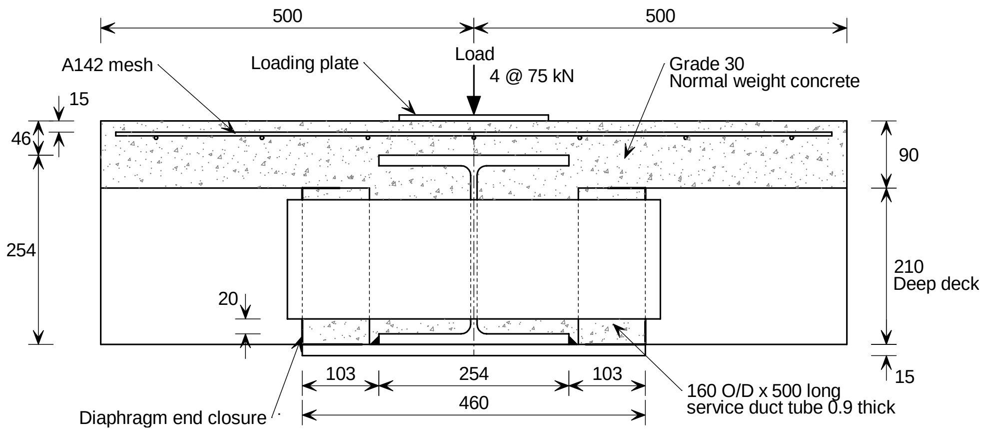


Figure 3.1 *Schematic arrangement of components*

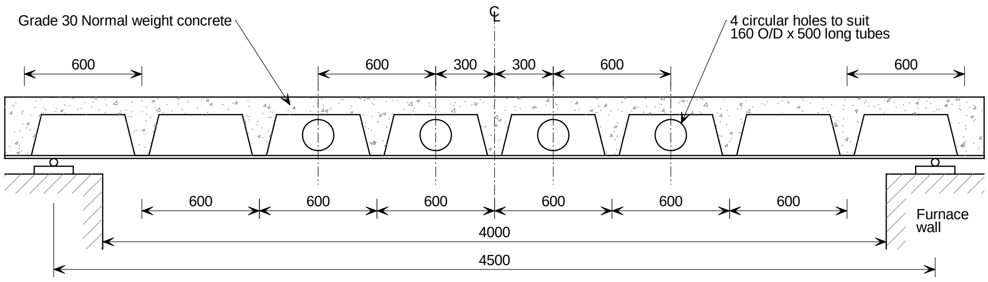


Figure 3.2 *Longitudinal arrangement of test specimen*

The assembly was designed and loaded on the basis that there would be no composite action between the steel and concrete components. It was appreciated however, that in practise a significant (but uncertain) degree of longitudinal shear transfer would occur.

A total load of 300 kN was applied directly to the steel section at four points along its supported length and directly over the web. The rams were spaced at 1125 mm intervals along the section length, as shown by Figure 3.3. The plastic moment of resistance of the section ignoring composite action was calculated as 358kNm. The moment due to self weight of the beam and the concrete was calculated as 15.8kNm and the moment due to the applied loading was 168.9kNm giving a load ratio of 0.52.

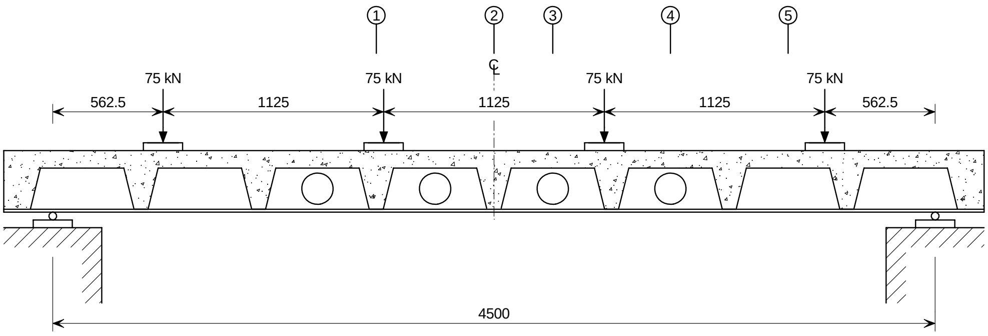


Figure 3.3 *Longitudinal arrangement showing location of hydraulic rams and cross sections instrumented with thermocouples.*

Instrumentation

The steel section was instrumented with thermocouples at five cross sections as shown in Figure 3.3. The positions of the thermocouples on each of these cross sections were as shown in Figure 3.4. A further twelve thermocouples were located in the web and lower flange of the section, in the region between the two central service ducts and at the geometric centres of both of these ducts as shown by Figure 3.5. Thermocouples were also embedded in the concrete infill around the steel section and in the rib of the slab at the mid span position (Position 2), as shown in Figure 3.6. The deflections of the test specimen were recorded with an LVDT located on the steel section at mid span.

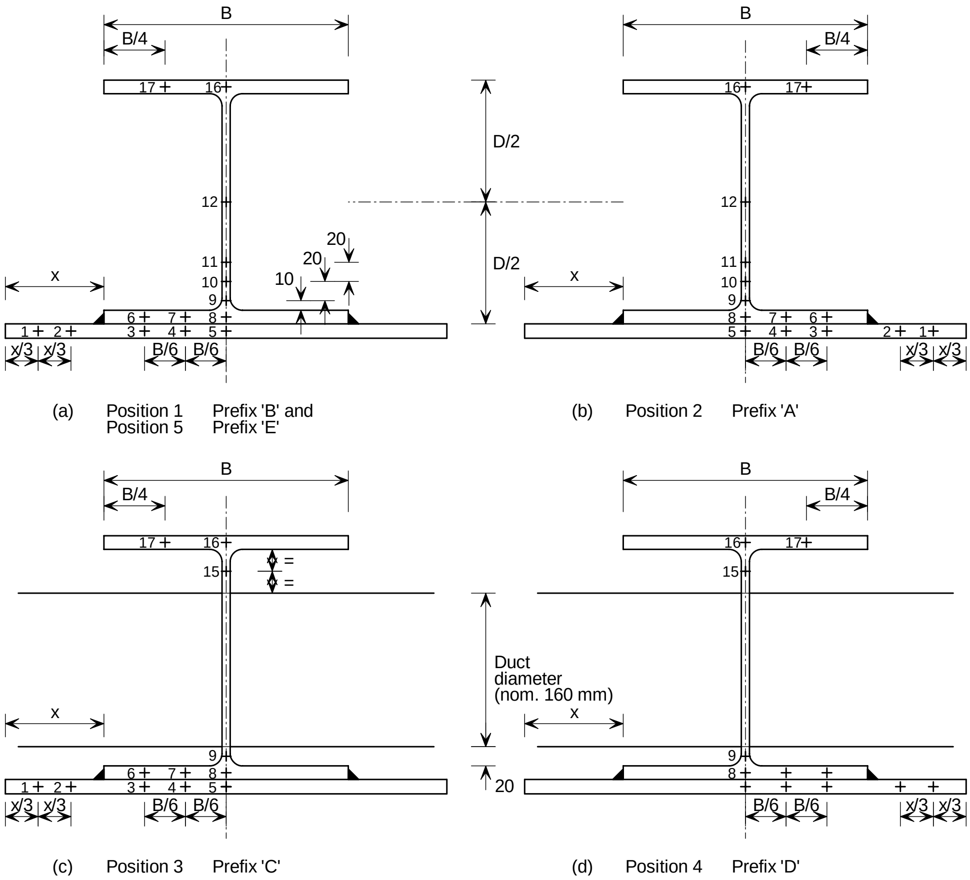


Figure 3.4 *Transverse arrangement at positions 1 - 5*

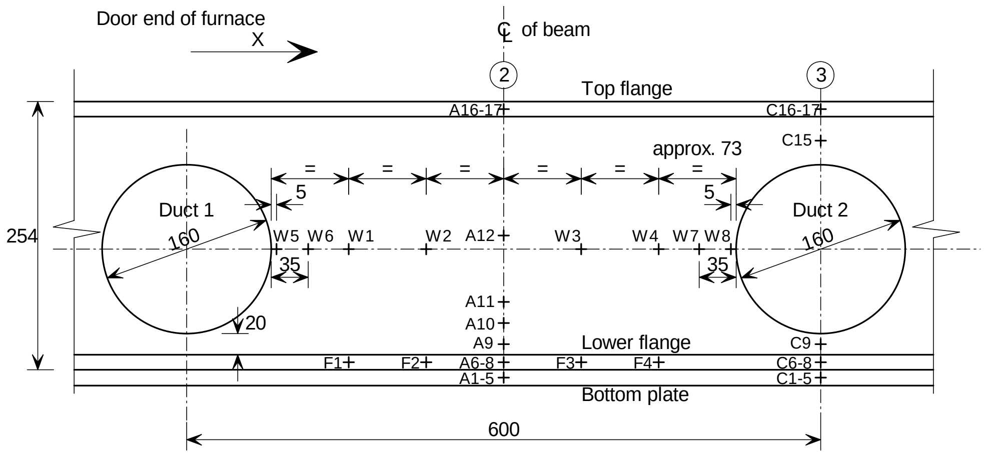


Figure 3.5 *Longitudinal arrangement of thermocouples positions between web openings at mid span (Position 2).*

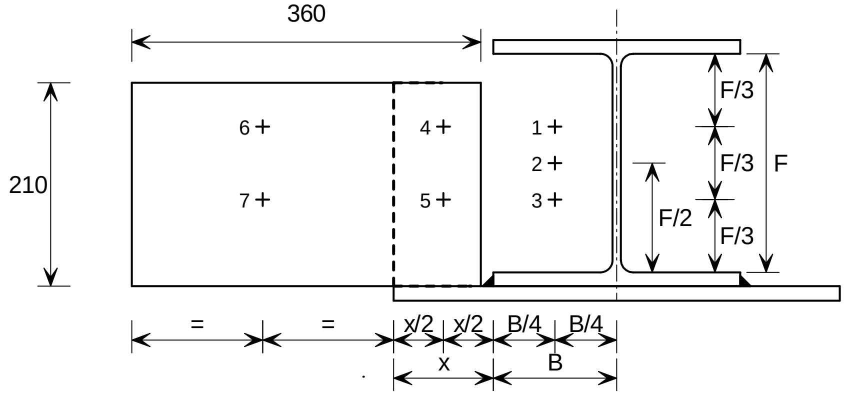


Figure 3.6 *Thermocouples located in the ribs of the composite slab and in the concrete encasement around the steel section at Position 2.*

Results

Although no electronic data files were available for this test specimen a second British Steel Technical Note[9] provides detailed information on measured temperatures and deflection. This information has been scanned and is supplied as an Excel file on the CD that accompanies this report. The data from this test is also summarised by a British Steel Report[7]. The data sheet from this report is available in Excel format on the CD that accompanies this report.

In accordance with load bearing criteria set out in BS476-21 the limiting deflection for this specimen was 225mm and the limiting rate of deflection 8.36 mm/min applied after the deflection exceeds span/30, 150mm in this case. Load bearing failure of the test specimen was deemed to have occurred after 62 minutes as the rate of deflection exceeded the maximum permissible rate of deflection between 62 and 63 minutes. The maximum deflection recorded was 205mm at 63 minutes. The measured deflection of the test specimen is shown in Figure 3.7.

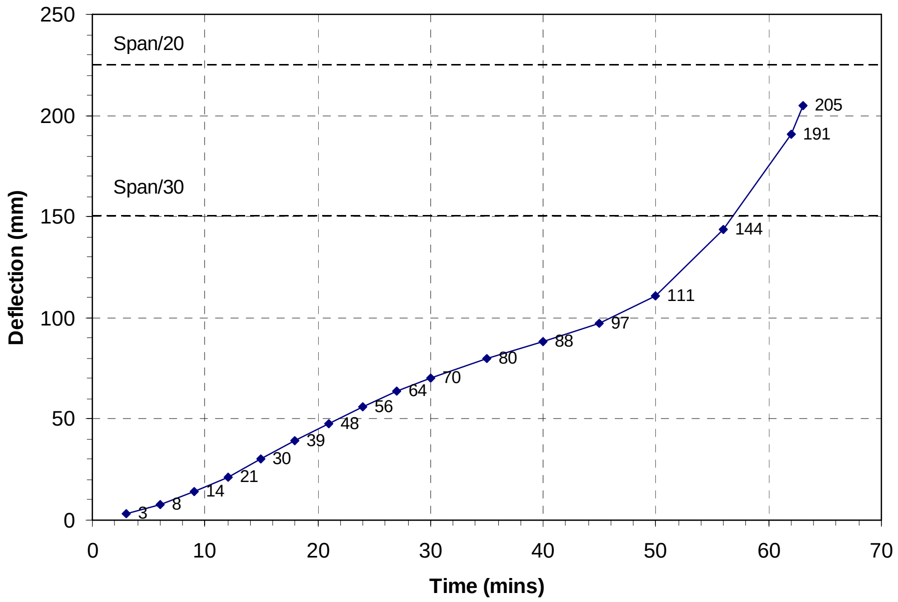


Figure 3.7 *Measured deflection of the test specimen during the fire test.*

3.3 Test WFRC 60248

This standard fire resistance test was carried out on a loaded fabricated Slimflor beam and composite slab construction. The test was carried out on 16th March 1994 at Warrington Fire Research centre, test reference number WFRC 60248. Details of the test specimen and the results of the test are reported in P248[10] and a Technical Note[13] published by British Steel Technical.

Test Specimen

The steel section used for the test specimen was fabricated from a 305x305x97 universal column with a 505mm wide 15mm thick steel plate welded to the bottom flange. Both the column section and the plate were manufactured from Grade S275 steel. The bottom plate of the fabricated section supported 210mm deep steel decking used to form the composite slab. The composite slab was nominally 1m wide and the concrete was finished flush with the top surface of the steel section giving 100mm concrete cover to the top of the steel deck profile. The cube strength of the lightweight concrete topping was nominally 30 N/mm^2 and the concrete was reinforced with A142 steel mesh and six 16mm diameter bars that passed over the top flange of the Slimflor beam, as shown in Figure 3.15. The assembly also included seven 160mm diameter service ducts that passed through the web of the steel section as shown in Figure 3.8 and Figure 3.9.

Loading in addition to the self weight of the specimen was applied using 4 hydraulic rams positioned along the centre line of the web of the profile and located at 1/8, 3/8, 5/8 and 7/8 of the span, as shown in Figure 3.8. The load from each hydraulic ram was spread over four application points using a system of spreader beams as shown in Figure 3.10. Each hydraulic ram was used to apply a load of 84kN which was calculated to result in a load ratio of 0.4 based on the non-composite resistance of the steel section.

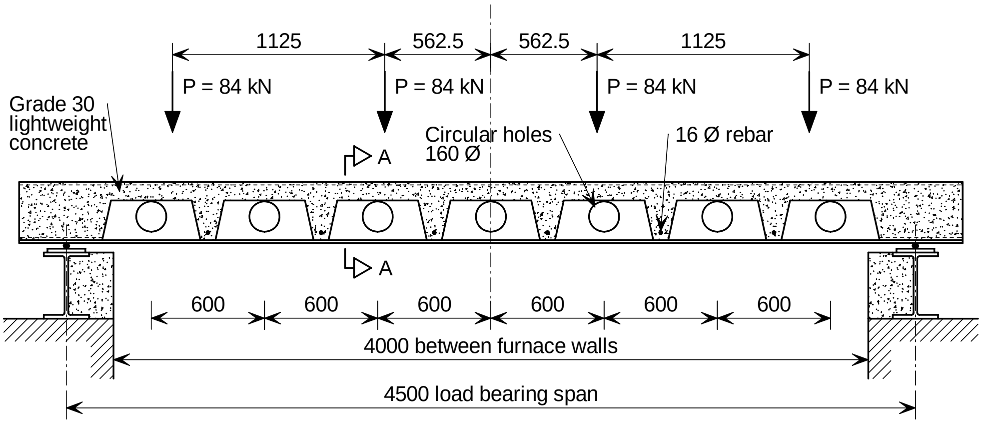


Figure 3.8 *Longitudinal arrangement of test specimen*

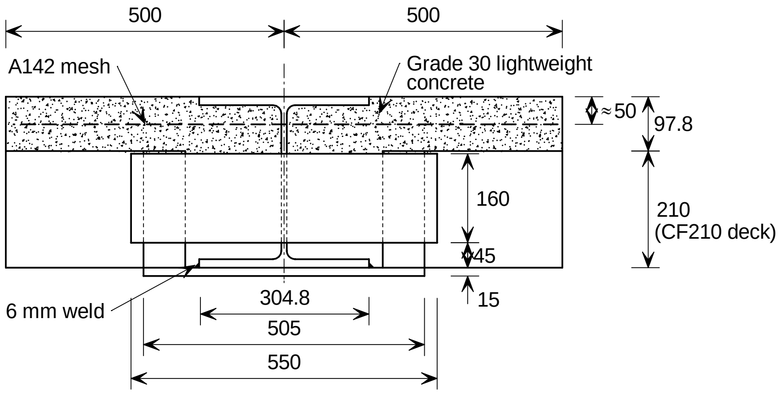


Figure 3.9 *Cross section A-A*

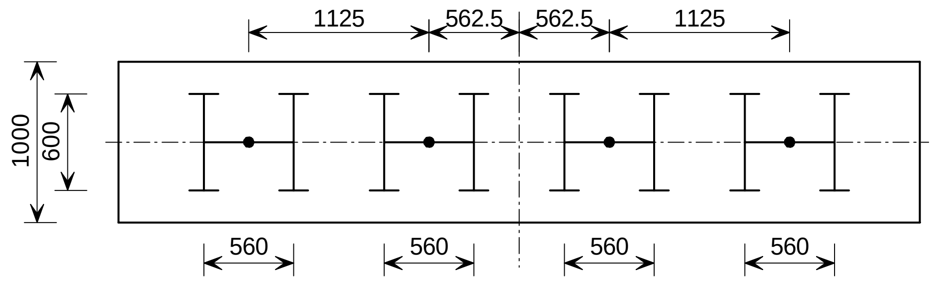


Figure 3.10 *Plan view of specimen showing loading application positions*

Instrumentation

The test specimen was instrumented with a total of 99 thermocouples. The cross sections instrumented are shown in Figure 3.11. The location of the thermocouples on each cross section are shown in Figure 3.12 and Figure 3.13. Positions A to D are most heavily instrumented and at positions C & D thermocouples have also been embedded in the concrete and reinforcement, as shown in Figure 3.15. Further thermocouples were also included on the weld between the bottom plate and the bottom flange of the universal column section between Positions C & D as shown in Figure 3.14.

The deflection of the beam was also measured during the test with a displacement transducer located at the mid-span of the test specimen.

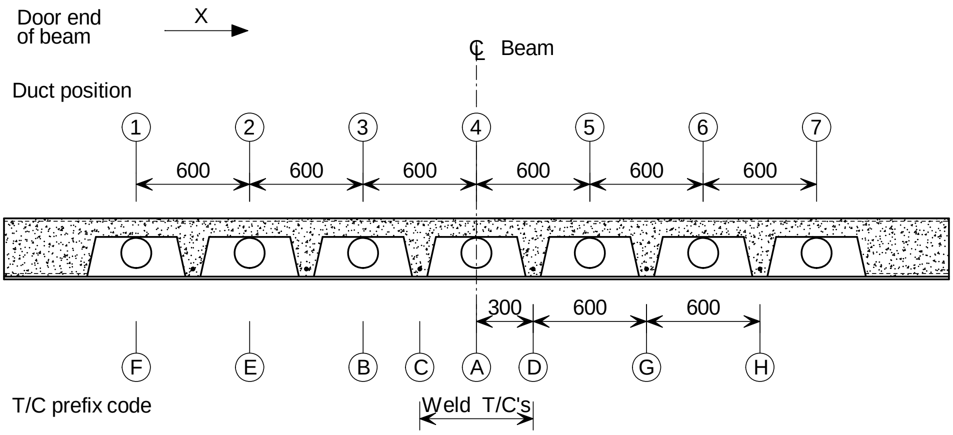


Figure 3.11 *Cross sections instrumented with thermocouples*

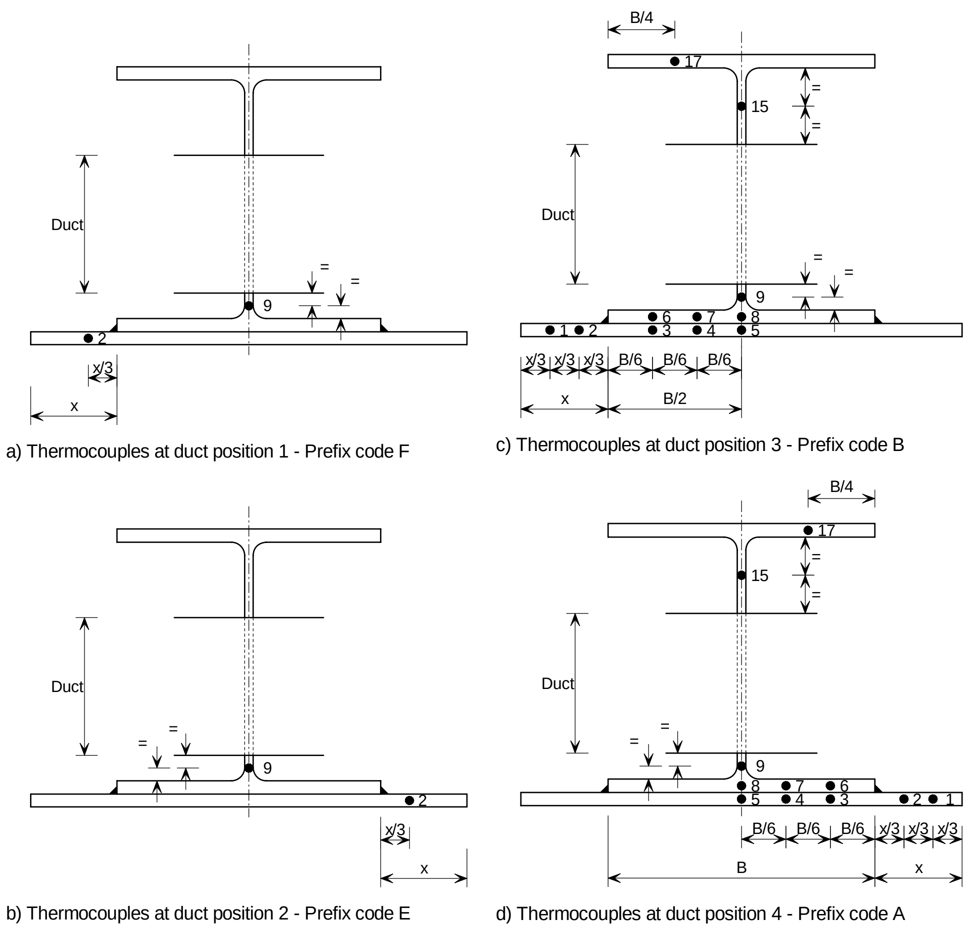
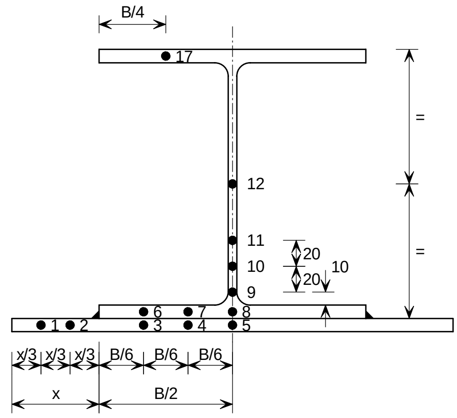
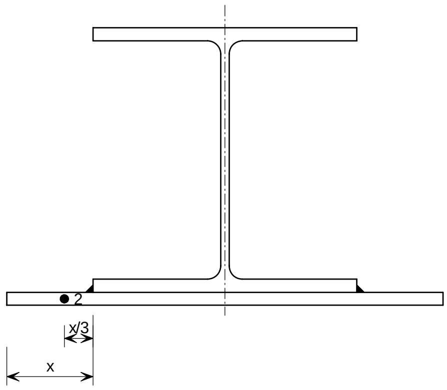


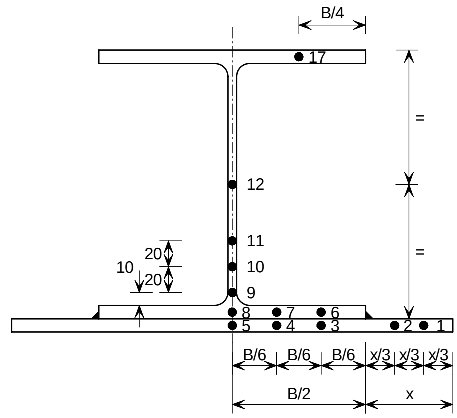
Figure 3.12 *Location of thermocouples on instrumented cross sections F, E, B & A*



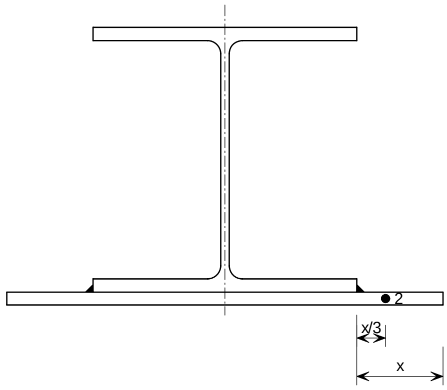
e) Thermocouples at duct position 3/4 - Prefix code C



g) Thermocouples at duct position 5/6 - Prefix code G



f) Thermocouples at duct position 4/5 - Prefix code D



h) Thermocouples at duct position 6/7 - Prefix code H

Figure 3.13 *Location of thermocouples on instrumented cross sections C, D, G & H.*

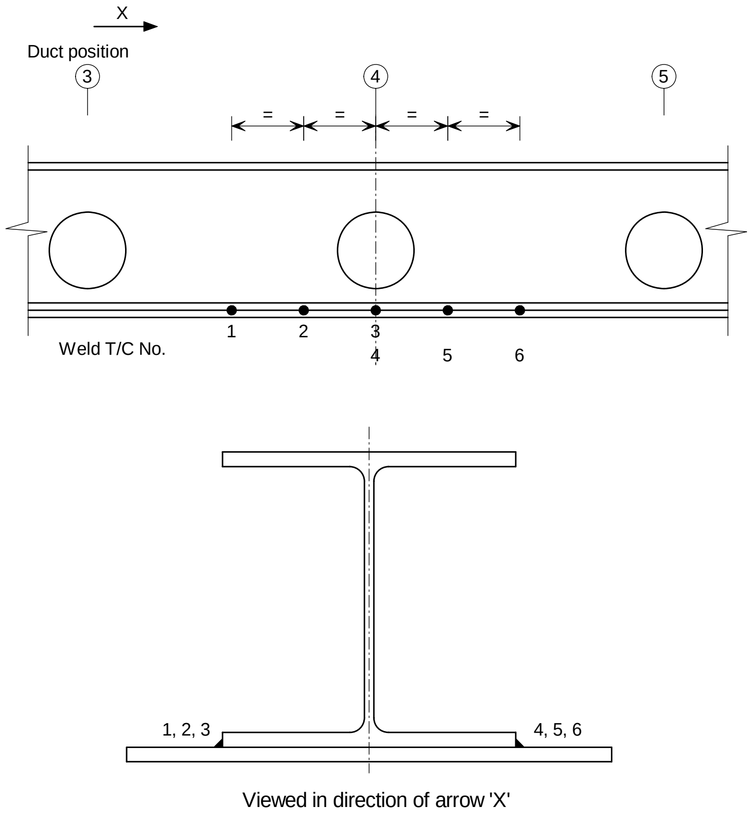


Figure 3.14 *Thermocouple positions on weld*

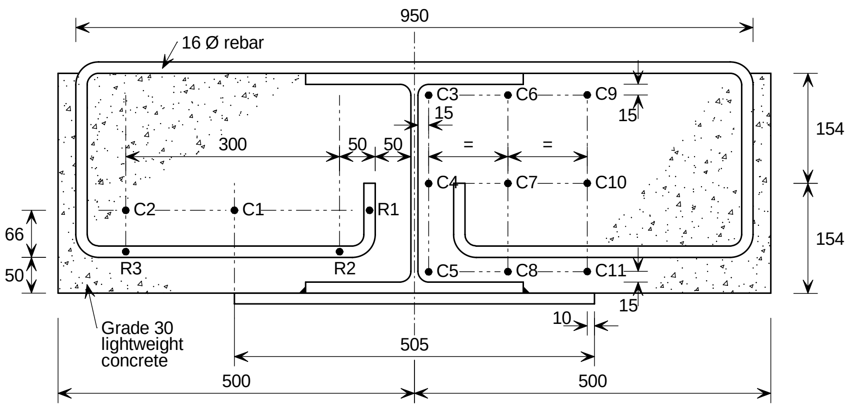


Figure 3.15 *Thermocouple locations in concrete and on reinforcement bars at position C (Position D mirror image)*

Results

The load bearing performance of the test specimen was evaluated against the load bearing criteria defined in BS 476-21. The maximum allowable deflection of the test specimen and the maximum allowable rate of deflection are defined by the standard. The maximum deflection was calculated as 225mm (span/20) and the maximum rte of deflection was calculated as 6.9mm/min. This maximum rate of deflection criterion is not applied until the total deflection has reached a value of span/30, 150mm in this case.

After 71 minutes of heating a fault occurred with one of the rams. This resulted in the load applied by the rams being reduced to zero for a period of 4 minutes. After removing the defective ram from the hydraulic system the 50% of the test load was reapplied to the beam and heating was continued up to 92 minutes to allow thermal data to be recorded. However, in accordance with the fire testing standard the reported fire resistance was 71 minutes. Given that the rate of deflection was 8mm/min the test would probably been terminated when the deflection reached 150mm which is likely to have within 2 minutes of the recorded failure time.

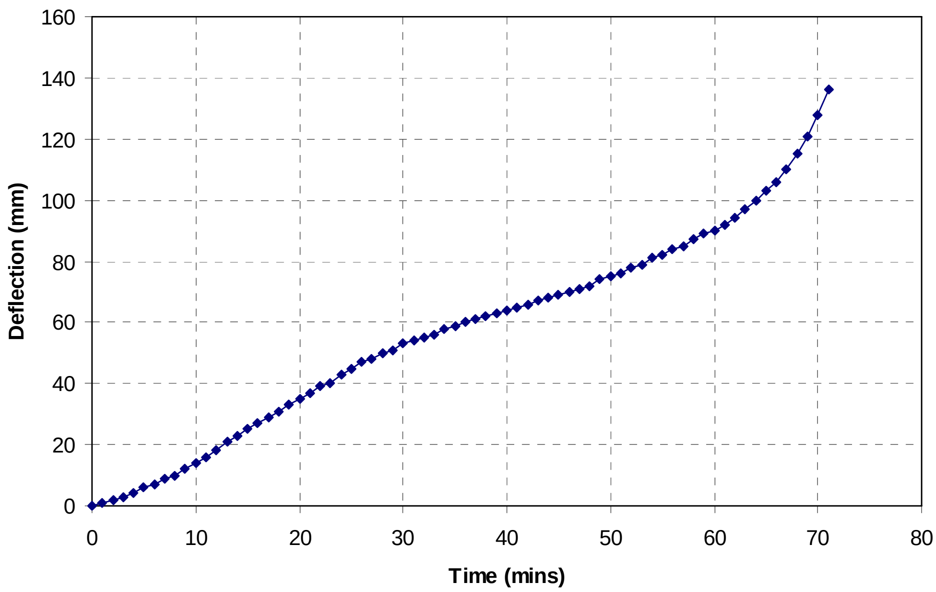


Figure 3.16 *Measured mid span deflection.*

3.4 Test TNO 1995

This fire test was conducted as part of an ECSC project by TNO in the Netherlands on 24 March 1995. The results of the fire test were reported in a TNO Report(12).

Test Specimen

The test specimen is illustrated in Figure 3.17 and Figure 3.18. The test was carried out on a composite floor slab measuring approximately 7.9m long and 4.6m wide supported on 3 Slimflor beams. The slab was 280 mm deep constructed using PMF CF210 profiled steel deck which was supported on the bottom plates of slim floor beams. The internal beam was fabricated from an HEB 240 section with a 440mm wide by 15mm thick steel plate and the edge beams were fabricated from HEB 200 sections with a 330mm wide by 15mm thick steel plate. Beam spans were 4600 mm. The slab was constructed from normal weight concrete reinforced with a steel mesh which consisted of 8mm diameter bars at 250mm centres in both directions and 16mm reinforced bars in each rib at an axis distance of 60mm.

The self weight of the system was 3kN/m^2 with an additional 9 kN/m^2 applied uniformly to the slab. This resulted in a load ratio of 0.45 on the internal beam. The load ratio for the composite slab was calculated to be 0.17. Further details of the bending resistance of the Slimflor beams and the applied moments are given in P248(10).

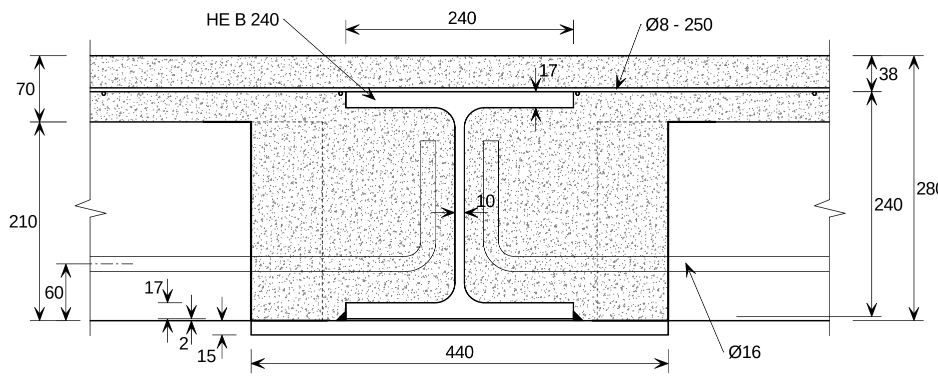


Figure 3.17 *Cross section showing internal Slimflor beam.*

Instrumentation

The location of instrumented cross sections on the internal Slimflor beam is shown in Figure 3.18. The locations of thermocouples on each of these cross sections were as shown in Figure 3.19 to Figure 3.25. Theromcouples where also located at two cross sections on the edge beam, as shown in Figure 3.26 to Figure 3.27. The locations of instrumented cross sections in the composite slab were, as shown in Figure 3.28. The locations of thermocouples in the concrete, reinforcement and steel deck were as shown in Figure 3.29 to Figure 3.33. The locations of surface thermocouples installed on the test specimen are shown in Figure 3.34.

The test specimens was instrumented with 11 displacement measurement locations, two curvature measurement locations and two loads cells to measure the reactions at the end of the internal ASB. The locations of these transducers were as shown in Figure 3.35.

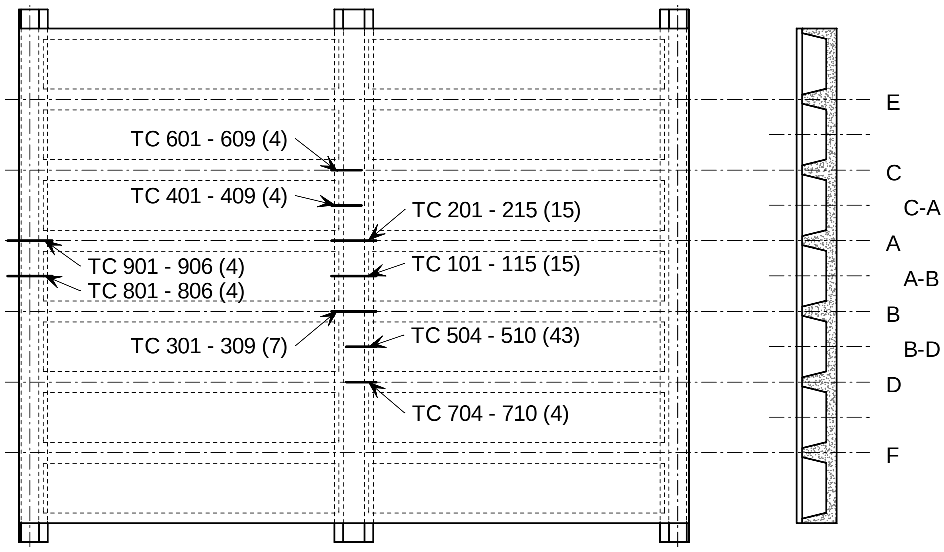


Figure 3.18 *Plan view – Thermocouple positions on fabricated Slimflor beams*

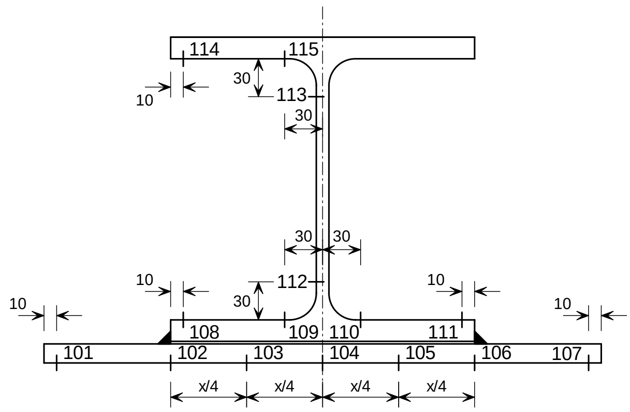


Figure 3.19 *Internal beam transverse arrangement of thermocouples at position AB*

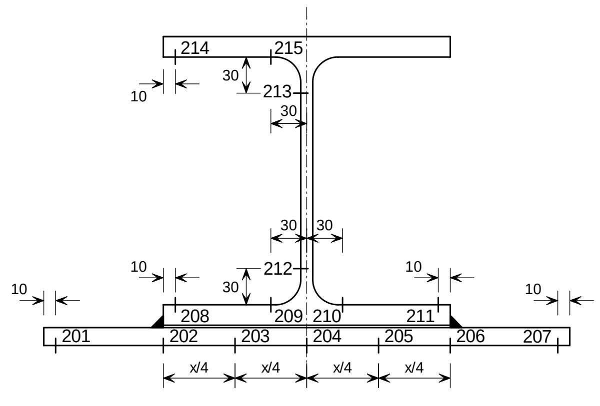


Figure 3.20 *Internal beam transverse arrangement of thermocouples at position A*

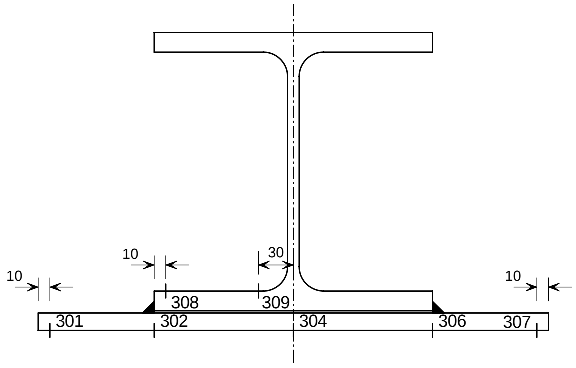


Figure 3.21 *Internal beam transverse arrangement of thermocouples at position B*

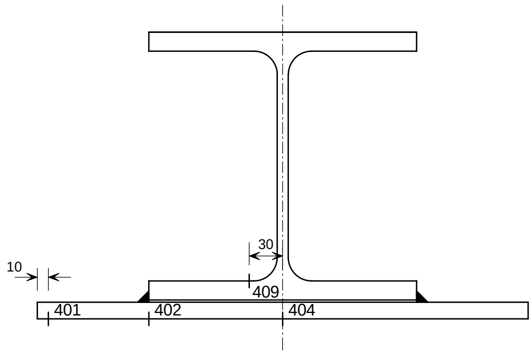


Figure 3.22 *Internal beam transverse arrangement of thermocouples at position CA*

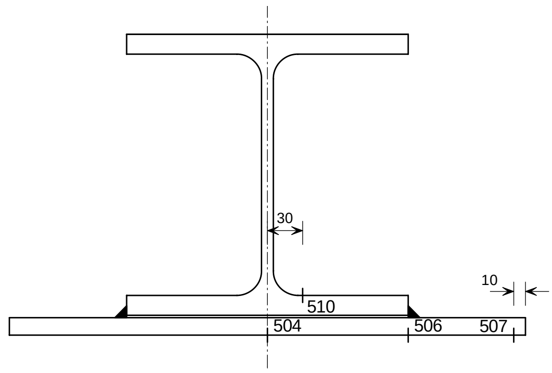


Figure 3.23 *Internal beam transverse arrangement of thermocouples at position BD*

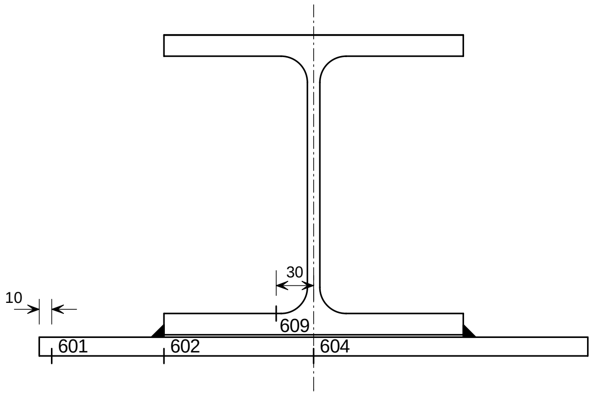


Figure 3.24 *Internal beam transverse arrangement of thermocouples at position C*

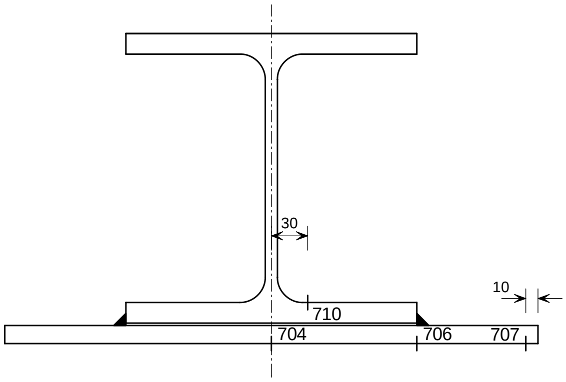


Figure 3.25 *Internal beam transverse arrangement of thermocouples at position D*

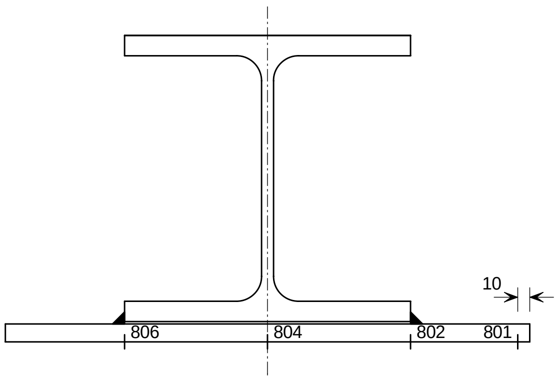


Figure 3.26 *Edge beam transverse arrangement of thermocouples at position A*

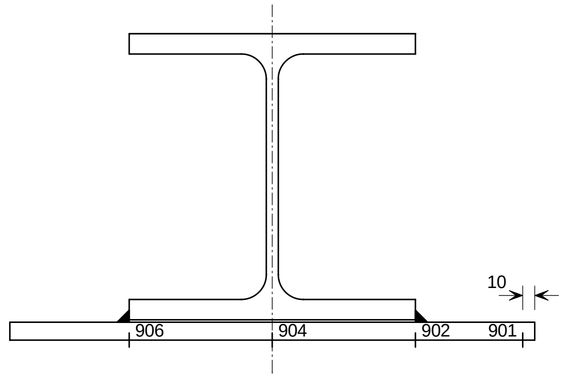


Figure 3.27 *Edge beam transverse arrangement of thermocouples at position AB*

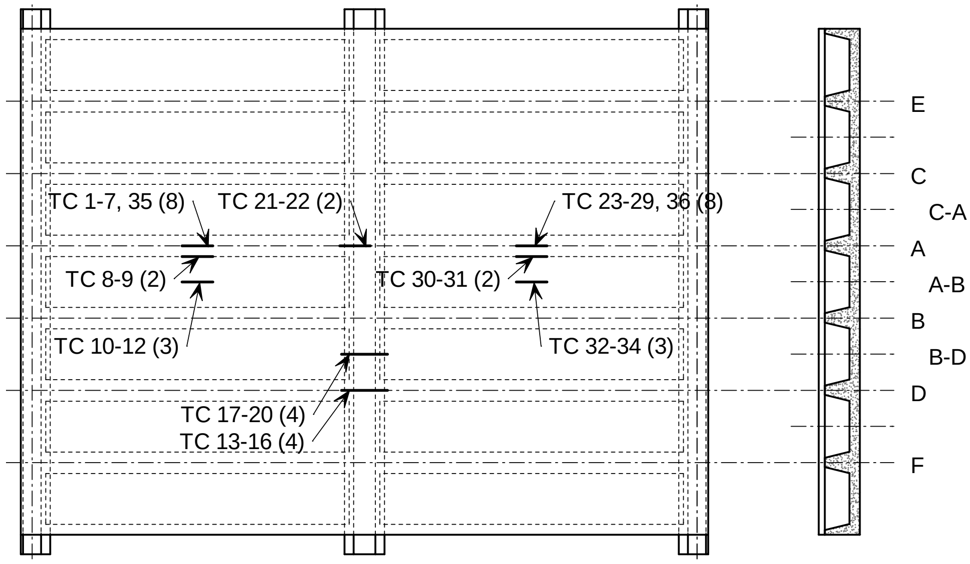


Figure 3.28 *Location of thermocouples in the composite slab*

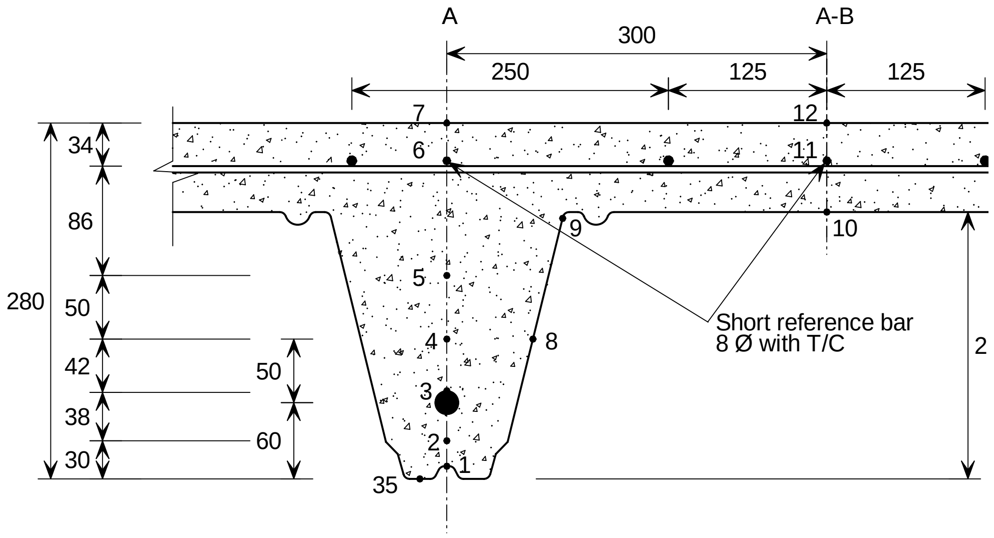


Figure 3.29 *Thermocouple locations in the composite slab span 1*

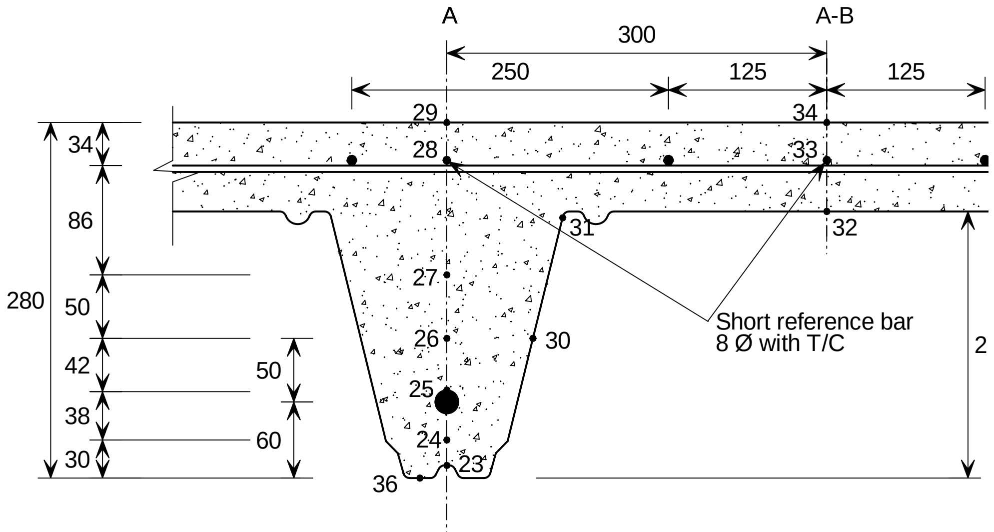


Figure 3.30 *Thermocouple locations in the composite slab span 2*

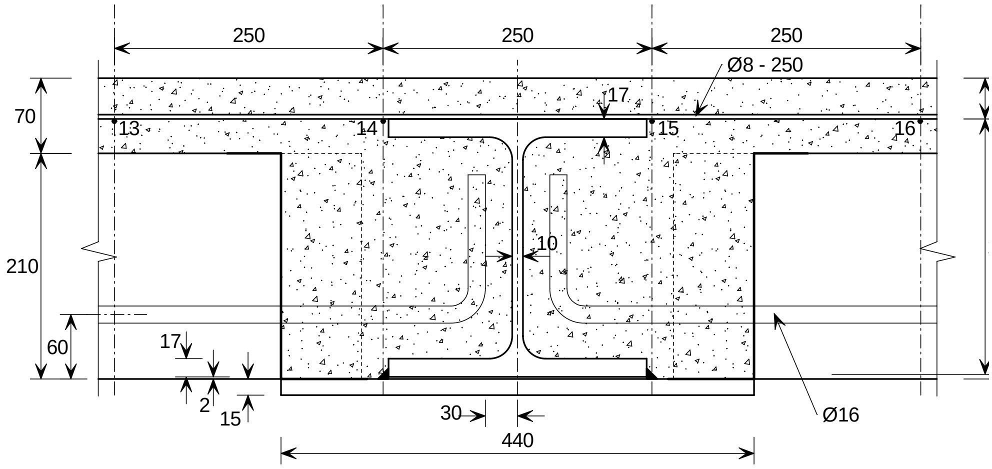


Figure 3.31 *Location of thermocouples on the reinforcement over the internal beam at position D*

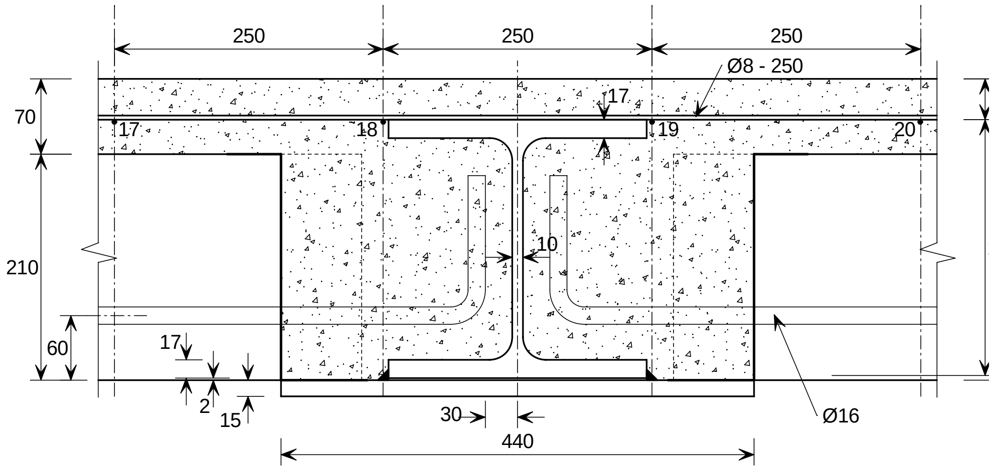


Figure 3.32 *Location of thermocouples on the reinforcement over the internal beam at position BD*

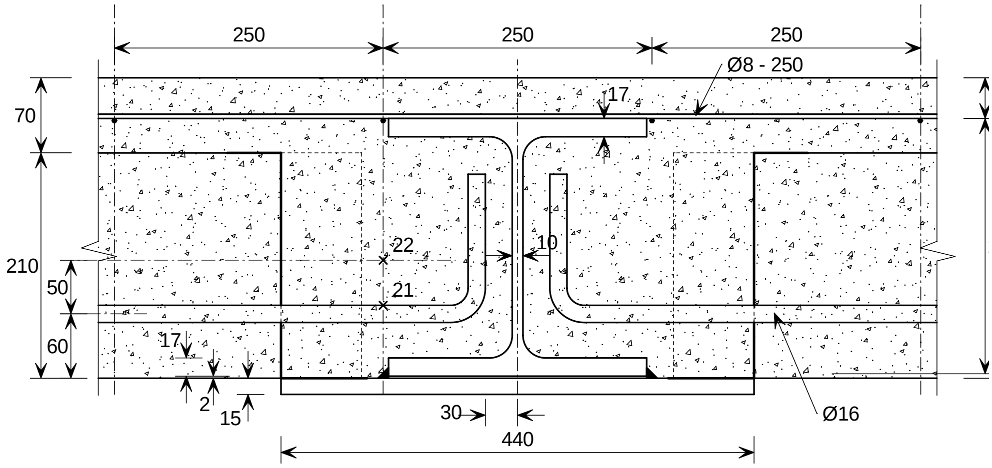


Figure 3.33 *Location of thermocouples on the reinforcement over the internal beam at position A*

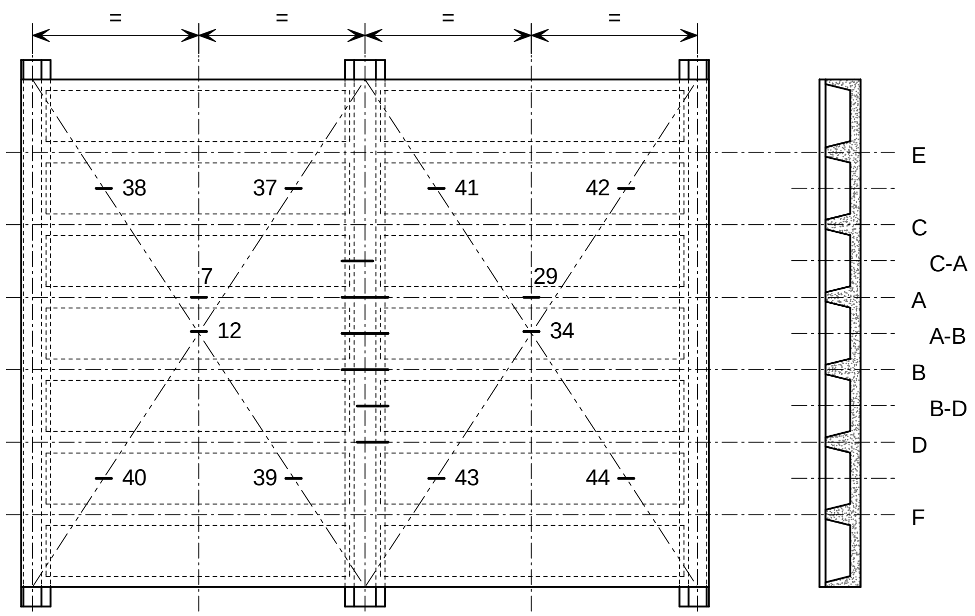


Figure 3.34 *Location of surface thermocouples*

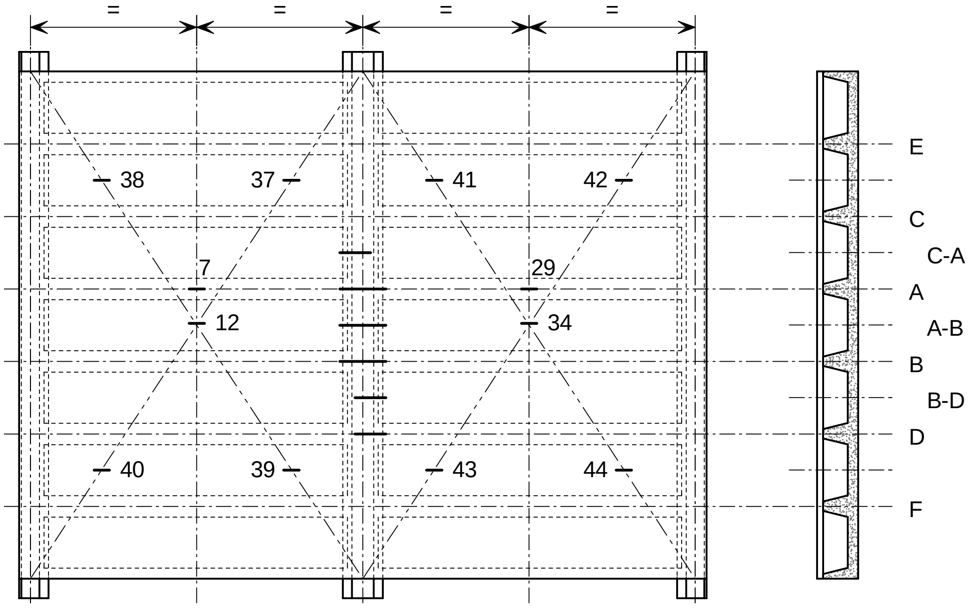


Figure 3.35 *Location of load, displacement and rotation transducers*

3.5 Test WFRC 44174

This standard fire resistance test was carried out on a loaded beam and composite slab construction. The test was carried out on 26 April 1989 at Warrington Fire Research centre, test reference number WFRC 44174. Details of the test specimen and the results of the test are given in a Technical Report[14] published by British Steel Technical.

Test Specimen

The test specimen consisted of a 254x254x89 universal column section which, initially, had grade 30 normal weight concrete cast onto the lower flange. The concrete had a nominal depth of 160 mm and was finished flush with the toes of the flange. It was held in place with ten mild steel ‘tangs’ which were tack welded to the inside face of the lower flange at 800mm centres along the length of the beam. The concrete infill was used to support 1.2 mm thick Grade S280Z “super holorib” profiled steel decking supplied by Richard Lees Ltd. Grade C30 light weight concrete was cast onto the steel decking forming a composite floor section which was nominally 840 mm wide x 120 mm thick. The slab contained A142 mesh reinforcement as shown in Figure 3.36.

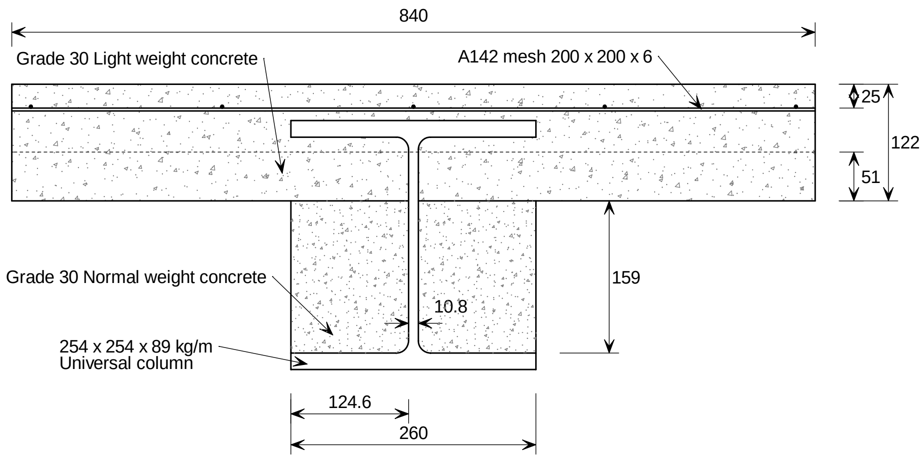


Figure 3.36 *General transverse arrangement*

The specimen was simply supported on the roof of the furnace and had a span of 4.5m. A total imposed load of 30.8 tonnes was applied to the steel section by means of four hydraulic rams positioned along the centre line of the web and at points corresponding to 1/8, 3/8, 5/8 and 7/8 of the span. The applied load together with the self weight of the test specimen was designed to in a maximum bending stress of 165 N/mm^2 the maximum permitted stress in accordance with the design rules of BS449-2. The moment due to the imposed load was calculated as 169.9kNm and the moment due to self weight of the specimen, based on measured concrete densities, was 9.13kNm, giving a total applied moment of 179kNm. Based on the nominal properties of the section the moment capacity was calculated as 325.4kNm, giving a load ratio of 0.55 in accordance with BS5950-8. Based on the measured properties of the section the actual load ratio was calculated as 0.547. During the test the applied load was kept constant.

Instrumentation

The thermocouple positions in the steelwork are shown in Figure 3.37 and Figure 3.38.

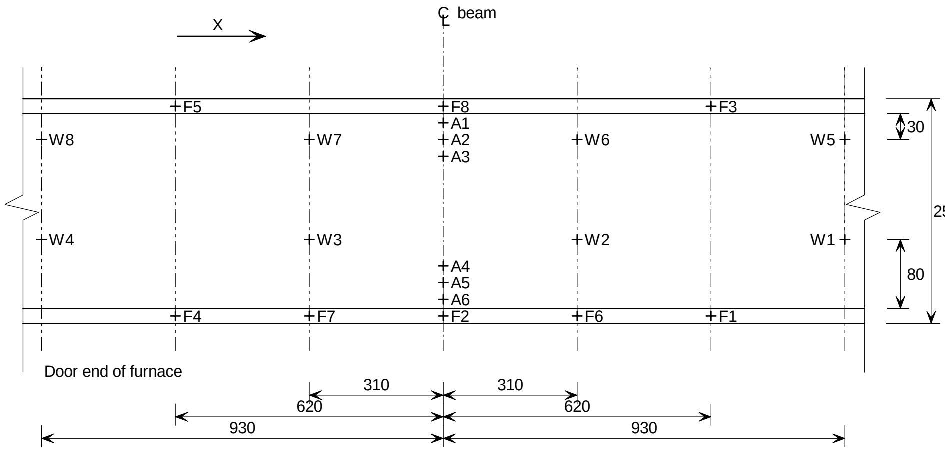


Figure 3.37 *Longitudinal thermocouples arrangement*

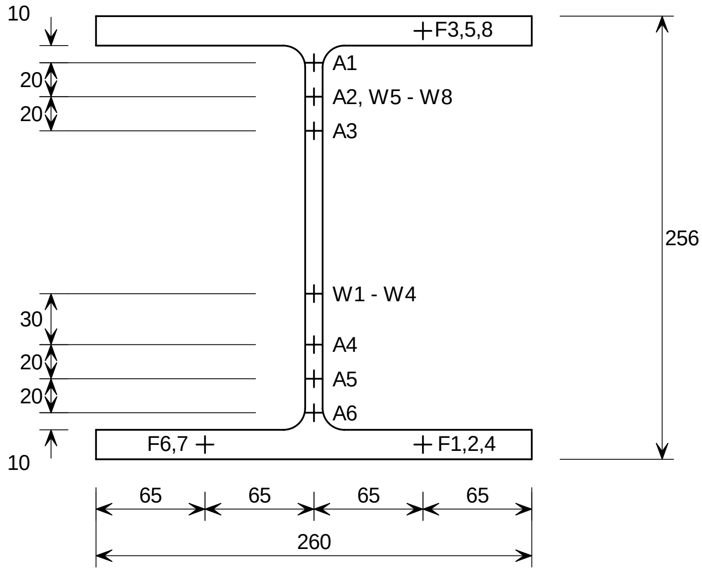


Figure 3.38 *Transverse thermocouples arrangement*

Results

The performance of this test specimen was evaluated against the load bearing criterion given in BS476-21. The maximum allowable deflection was calculated as 225mm (span/20) and the maximum rate of deflection allowed was calculated as 8.79 mm/min ($span^2$/ 9000D).

The maximum rate of deflection limit was exceeded after 41 minutes and a mid span deflection of 147mm was attained after 44 minutes. At this time the deflection was increasing at a rate of 11mm/min and the specimen was deemed to have failed. However, the load was not removed and heating of the specimen continued until 52 minutes when the mid span deflection was recorded as 226mm. At this time the load was removed and heating of the specimen continued for a further 18 minutes in order to obtain further thermal data.

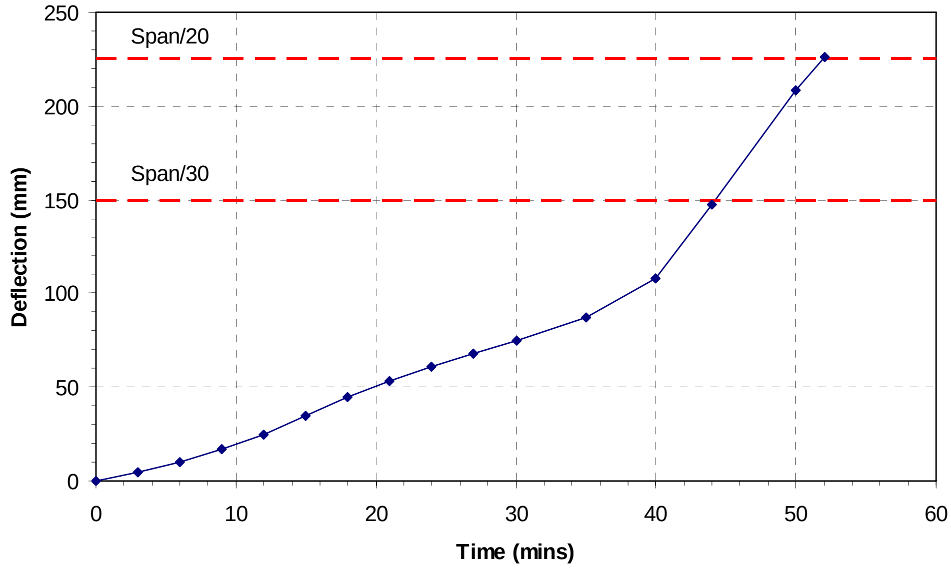


Figure 3.39 *Measured mid span deflections (WFRC 44174)*

4 Asymmetric Slimflor beams

4.1 Summary of available test data

Previous Slimflor beam sections were fabricated from a universal column section with a wide plate welded to the bottom flange to produce an asymmetric section. During 1995 it became possible to hot roll asymmetric beam sections and it was felt that these rolled sections were sufficiently different to the fabricated beams to justify further fire resistance testing.

Table 4.1 *Data available for Asymmetric Slim Floor beams*

Section details	Type	WFRC test number	Electronic Data	
			ASCI	Excel
280 ASB	A	66162	YES	YES
280 ASB Unloaded indicative	A	66163 indicative 1	YES	YES
280 ASB Unloaded indicative	A	66163 indicative 2	YES	YES
280 ASB Unloaded indicative	A	66163 indicative 3	YES	YES
SF300G	A	67756	YES	YES

Beam Type:

A Deep decking

B Edge beam

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4.2 Test WFRC 66162

This fire test was carried out at Warrington Fire Research Centre on 14 February 1996. The test reference number is WFRC 66162. Full details of the test are reported in a Technical Note[15] published by British Steel Technical. The data recorded during the fire test is available as an Excel file on the CD which accompanies this report.

Test Specimen

The test specimen consisted of a 280x280/180x104 rolled asymmetric beam section. The section was manufacturer from S355 JR steel (equivalent to Fe510 B or 50B steel grades given in earlier material standards). The nominal dimensions of the cross section are given in Figure 4.1.

The floor was formed using 210 mm deep metal decking, supplied by Precision Metal Forming Ltd., on top of which was cast a nominally 1 metre wide x 80 mm thick concrete slab which incorporated A142 reinforcing mesh as shown in Figure 4.1. The concrete used was normal weight Grade 30 material. The finished surface of the composite slab was 30mm above the top of the steel profile and incorporated A142 mesh reinforcement.

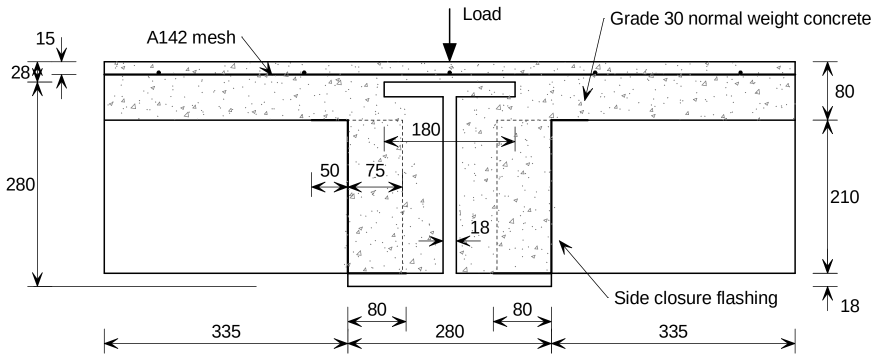


Figure 4.1 *General transverse arrangement*

Four point loads of 84.6 kN were applied to the test specimen by four hydraulic rams, positioned along the centre line of the web of the steel section at points corresponding to 1/8, 3/8, 5/8 and 7/8 of the supported span. The loads were applied directly to the upper flange of the steel section and not to the concrete slab situated above it.

The applied loads together with the self weight of the specimen were calculated to give a load ratio of 0.423, ignoring composite action between the steel beam and the floor slab.

Instrumentation

A total of 153 thermocouples were used to record the temperature of the steel section, decking, concrete infill and furnace atmosphere during the fire test. The location of instrumented cross sections are shown in Figure 4.2. Each instrumented cross section has a number of thermocouples attached to the steel section as indicated in Figure 4.2 and shown in Figure 4.3 and Figure 4.5. Cross sections F and G also had thermocouples embedded in the concrete encasement around the steel section and at cross section G thermocouples were also located in the rib of the slab. At cross sections B, D and F a single thermocouple was located on the closure flashing, the location of which is shown for Position F in Figure 4.3. Between sections B & C and F & G thermocouples are located at 50mm intervals along the web at mid-height of the steel section. The thermocouples located between cross sections B & C are denoted as X1 to X5 and those located between cross sections F & G are denoted as X6 to X10. The location of these thermocouples is shown in Figure 4.6 and Figure 4.7

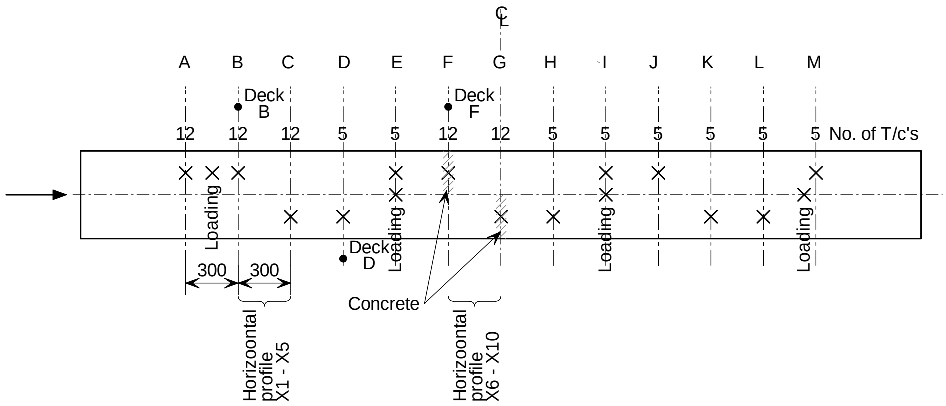
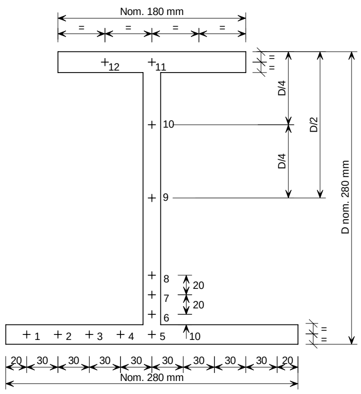
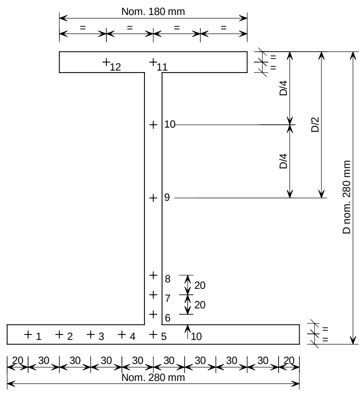


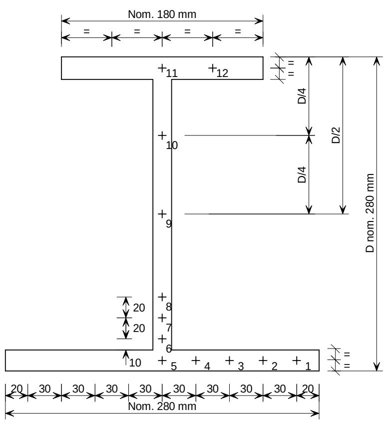
Figure 4.2 *Plan view – Position of thermocouple cross sections*



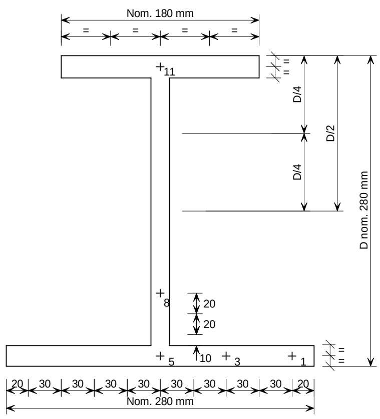
Position A



Position B



Position C



Position D

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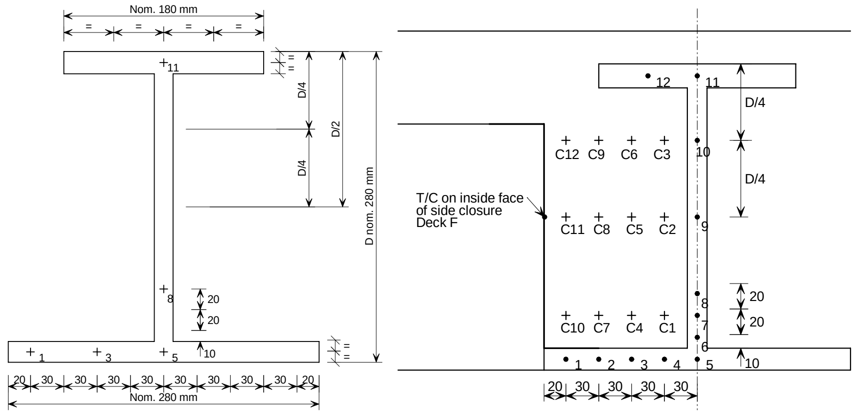
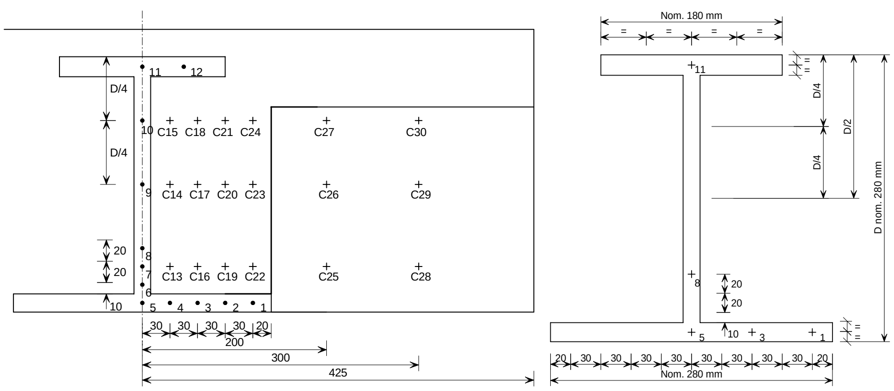
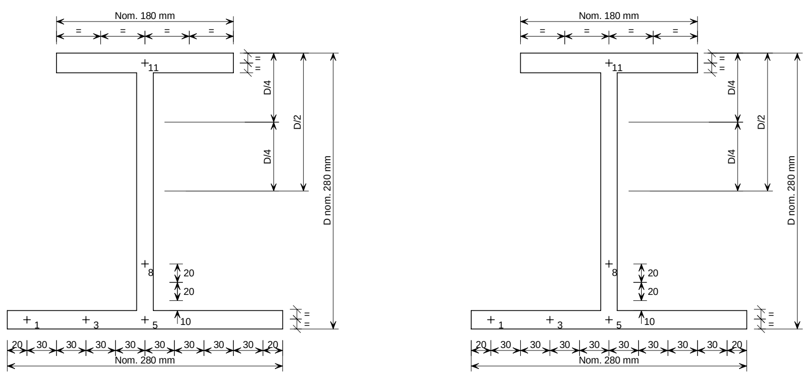


Position E Position F

Figure 4.3 *Transverse arrangement at position A to F*



Position G Position H



Position I Position J

Figure 4.4 *Transverse arrangement at position G to J*

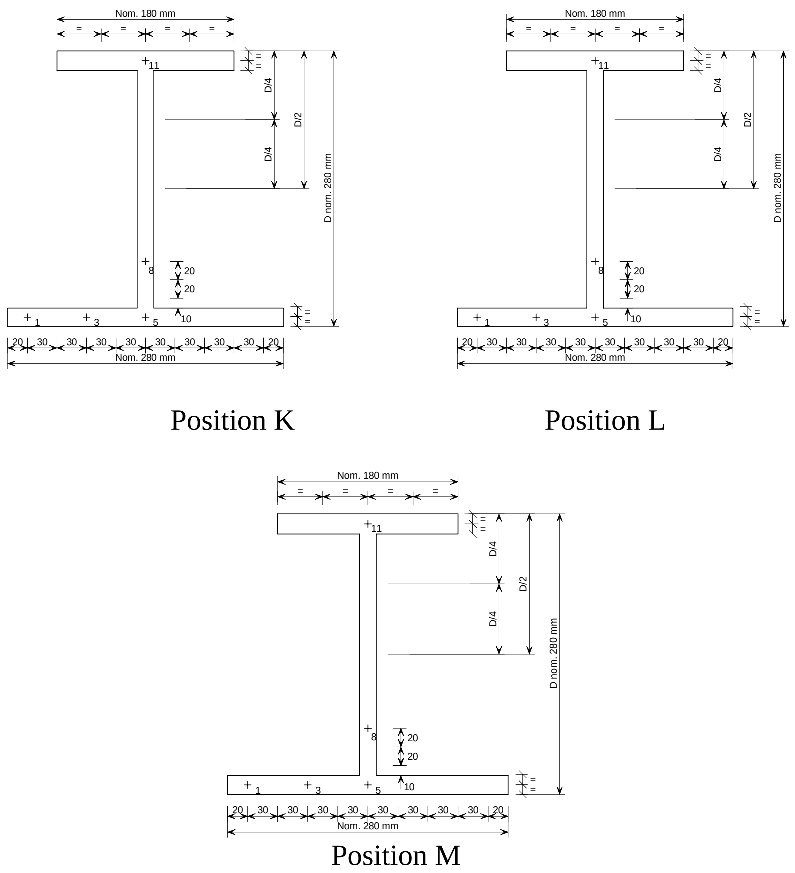


Figure 4.5 *Transverse arrangement at position K to M*

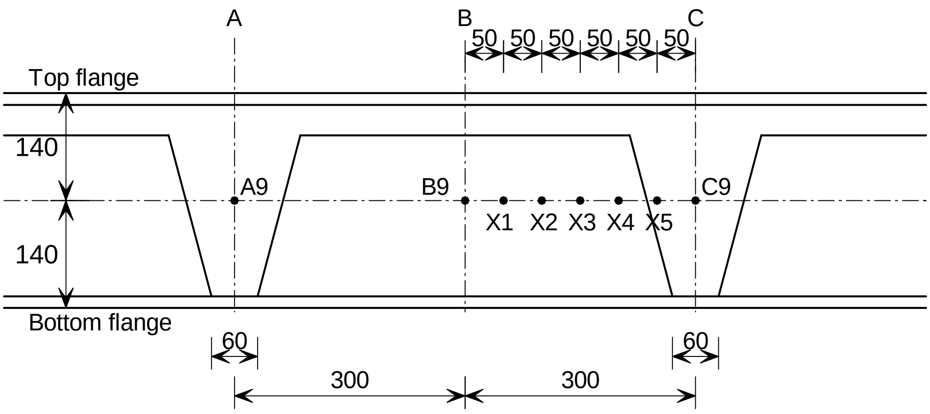


Figure 4.6 *Horizontal temperature profile between sections B & C*

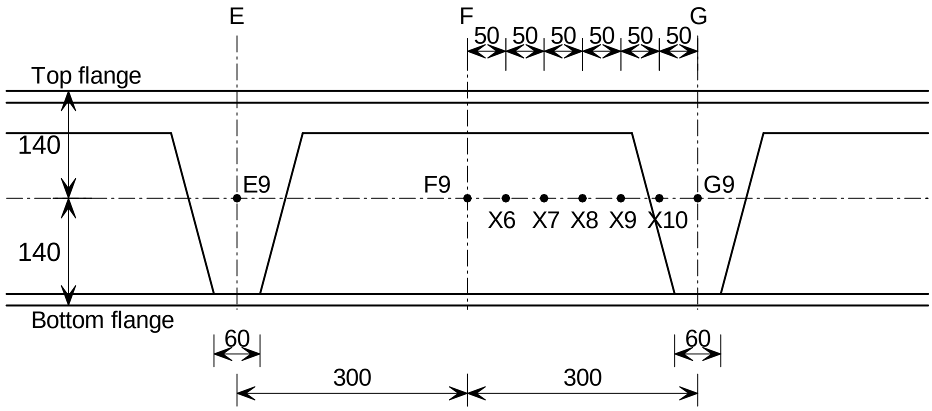


Figure 4.7 *Horizontal temperature profile between sections F & G*

Results

The performance of the test assembly was assessed against the load bearing criteria outlined in BS476-21. The maximum allowable deflection of the test specimen was calculated as 225mm (span/20) and the maximum rate of deflection was calculated as 7.26mm/min ($Span^2/9000\ D$). The variable D is the depth of the section which was measured as 310mm. The rate of deflection limit is not applied until the mid span deflection of the test specimen has reached a value of 150mm (Span/30).

The test specimen attained a mid span deflection of 150mm (Span/30) after 92 minutes and the deflection reached the maximum allowable value of 225mm after 107.5 minutes. The rate of deflection limit was not exceeded during the test. The fire resistance of the test specimen was therefore recorded as 107 minutes.

The load was removed from the test specimen after 108 minutes, but heating of the specimen continued until 120 minutes to allow further thermal data to be obtained.

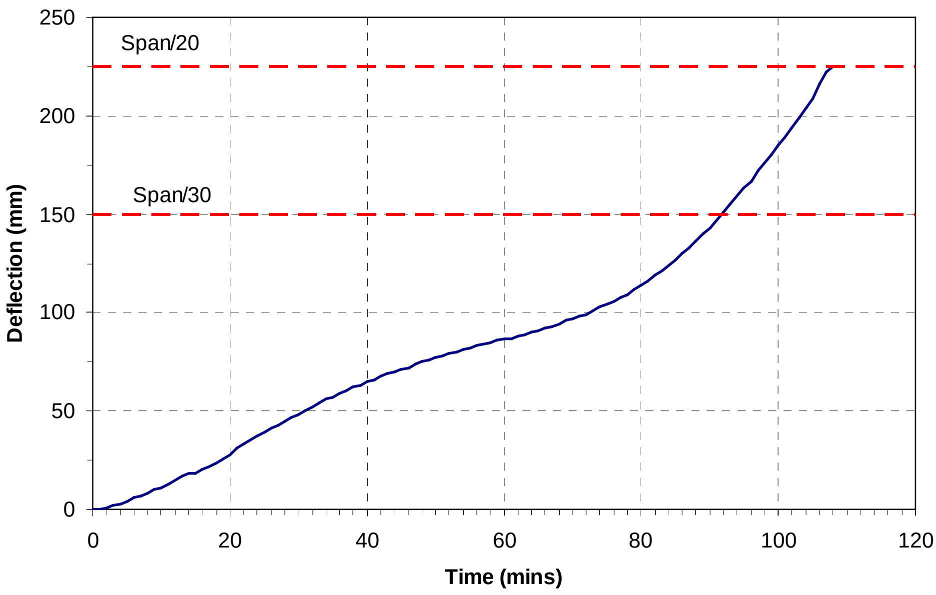


Figure 4.8 *Measured mid span deflections (WFRC 66162)*

4.3 Test WFRC 66163

This fire resistance test was carried out on three unloaded test specimens each 3.6m long spanning across the width of the furnace. The test specimens consisted of a rolled asymmetric section each with an 850mm wide composite floor slab constructed using a deep steel decking profile. The fire test lasted for a total of 210 minutes during which time thermal data was recorded for each of the three indicative specimens. The test data is provided in Excel file and ASCII file format on the CD that accompanies this report. A separate Excel file is provided for each indicative specimen.

4.3.1 Indicative 1

Test Specimen

The test specimen consisted of a 280 ASB rolled asymmetric beam with three 180mm diameter holes in half the length of the beam as shown by Figure 4.9. The composite slab for this indicative specimen was constructed using CF210 deep decking and normal weight concrete. The top surface of the concrete was 30mm above the top surface of the steel section.

Instrumentation

Thermocouples were positioned on the steel beam at eight different cross sections, labelled Positions A to H as shown in Figure 4.9. This figure also shows the number of thermocouples attached to the steel section at each cross section and the crosses indicate which side of the specimen was instrumented. The arrangements of the thermocouples on each cross section are shown in Figure 4.10 to Figure 4.17. At Positions B, C, F and G thermocouples were also embedded in the concrete encase around the steel section and in the ribs of the composite slab. These thermocouple positions are also shown in Figure 4.11, Figure 4.12, Figure 4.15and Figure 4.16.

Two thermocouples one on either side of the specimen were also included in the ducts at positions B and D. The locations of these thermocouples within the ducts were as shown in Figure 4.11.

The horizontal temperature along the web at mid height of the section was measured at two locations between Positions B and C and Positions F and G as shown in Figure 4.9. Thermocouples were located at 50mm intervals these cross sections. Although because of the opening a position B only four thermocouples could be accommodated between Positions B and C. These thermocouples were labelled X11 to X19 and the locations of these thermocouples were as shown in Figure 4.18 and Figure 4.19.

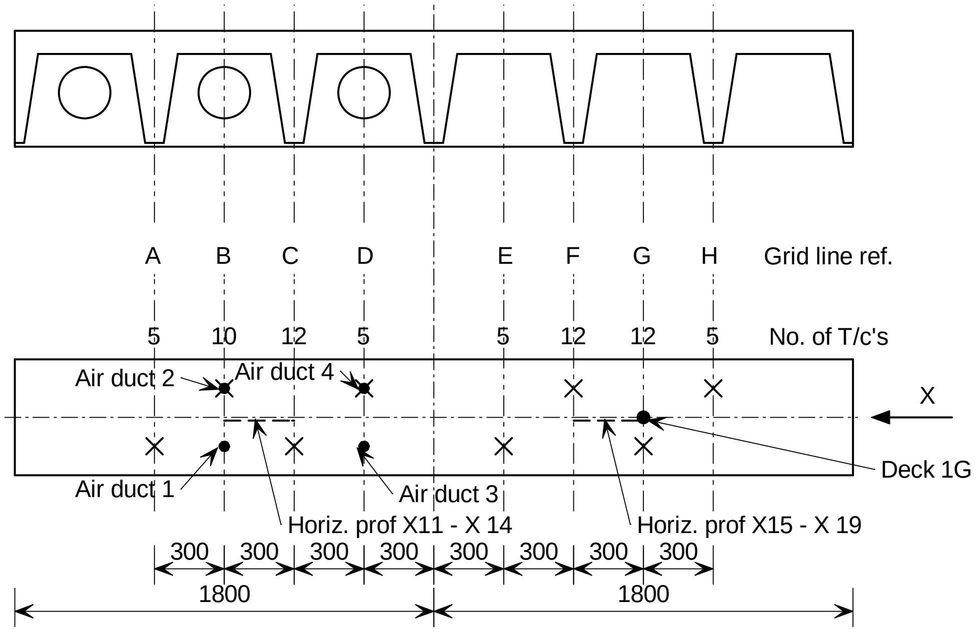


Figure 4.9 *Plan view – Position of thermocouple cross sections*

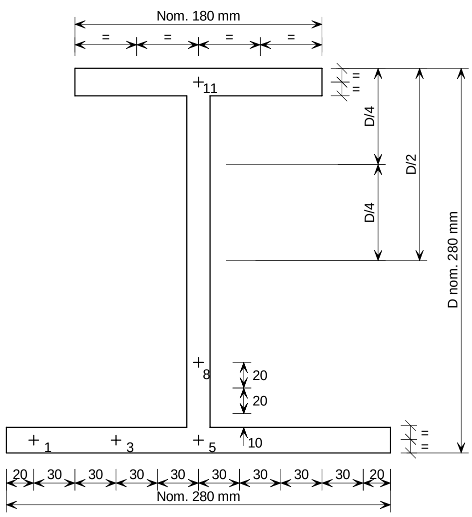


Figure 4.10 *Transverse arrangement at position A*

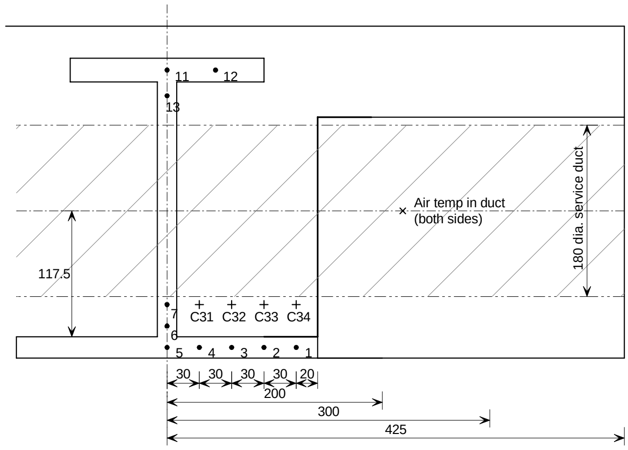


Figure 4.11 *Transverse arrangement at position B*

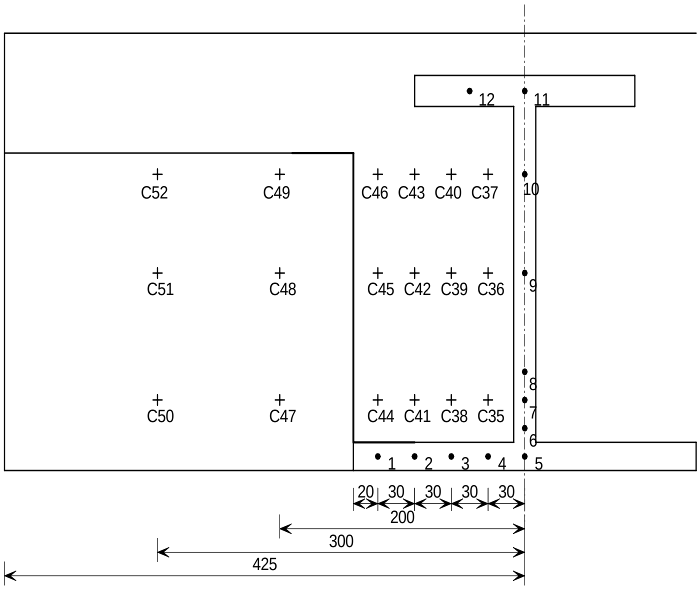


Figure 4.12 *Transverse arrangement at position C*

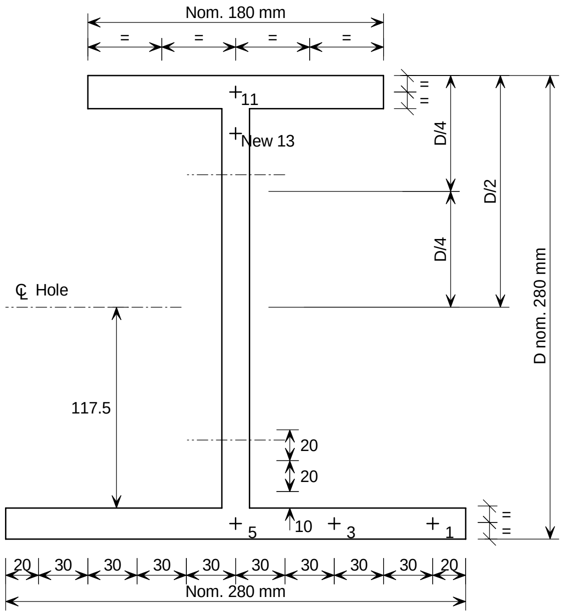


Figure 4.13 *Transverse arrangement at position D*

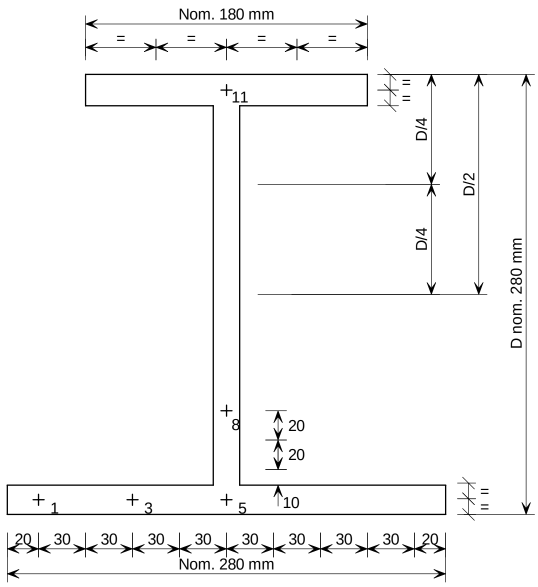


Figure 4.14 *Transverse arrangement at position E*

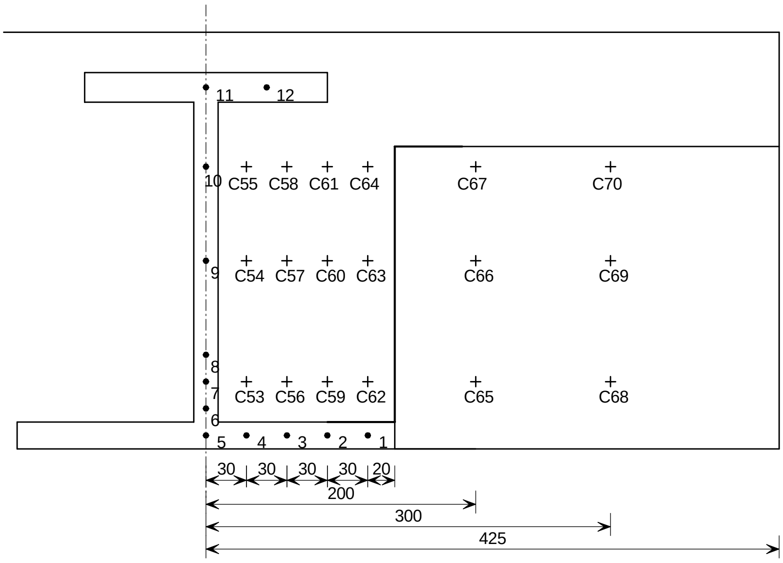


Figure 4.15 *Transverse arrangement at position F*

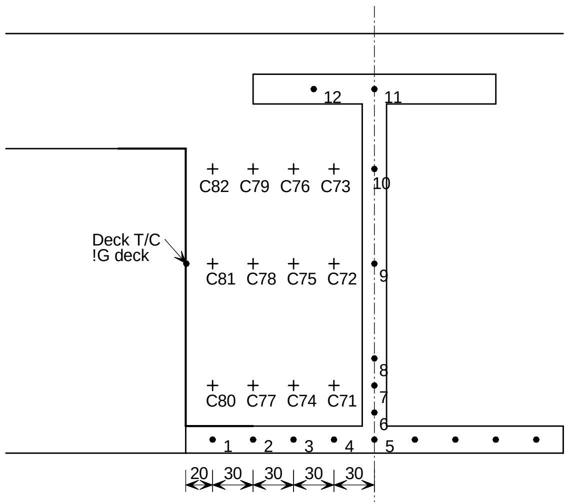


Figure 4.16 *Transverse arrangement at position G*

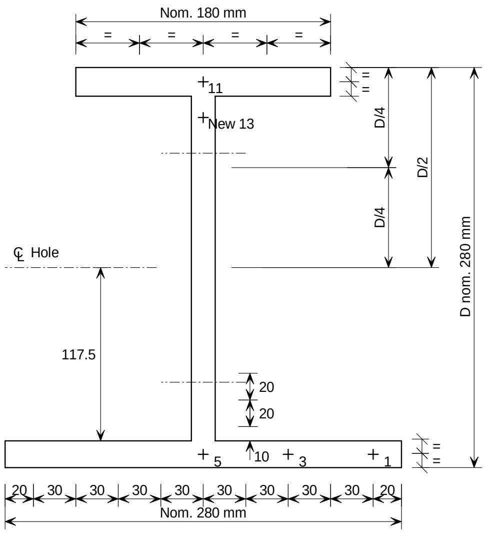


Figure 4.17 *Transverse arrangement at position H*

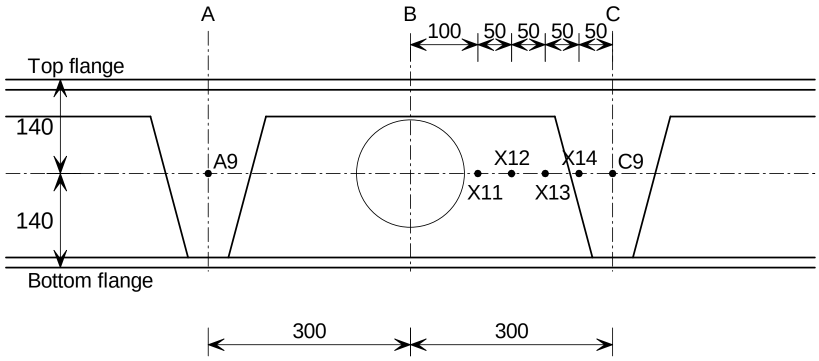


Figure 4.18 *Horizontal temperature profile between Positions B & C (Thermocouples X11 to X14)*

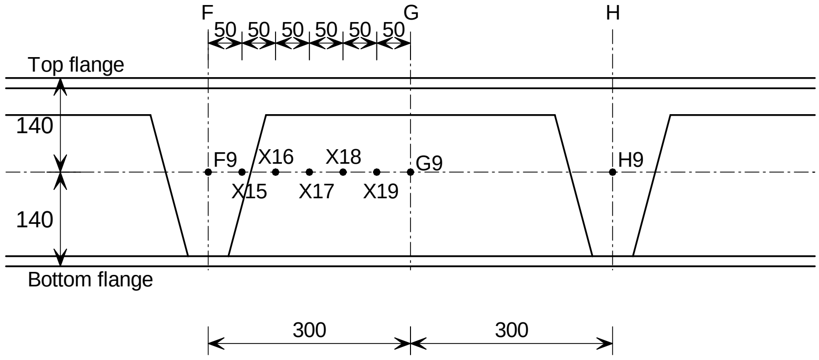


Figure 4.19 *Horizontal temperature profile between Positions F & G (Thermocouples X15 to X19)*

4.3.2 Indicative 2

Test Specimen

The test specimen consisted of a 280 ASB rolled asymmetric beam supporting a composite slab as shown by Figure 4.20. The composite slab for this indicative specimen was constructed using CF210 deep decking and normal weight concrete. The top surface of the concrete was 30mm above the top surface of the steel section.

Instrumentation

Thermocouples were positioned on the steel beam at eight different sections as shown in Figure 4.20. Thermocouples were also embedded in the concrete at Positions B and C. Position B also included a thermocouple on the closure flashing as shown in Figure 4.16. The locations of the steel thermocouples on Positions A to H were as shown in Figure 4.21 to Figure 4.28.

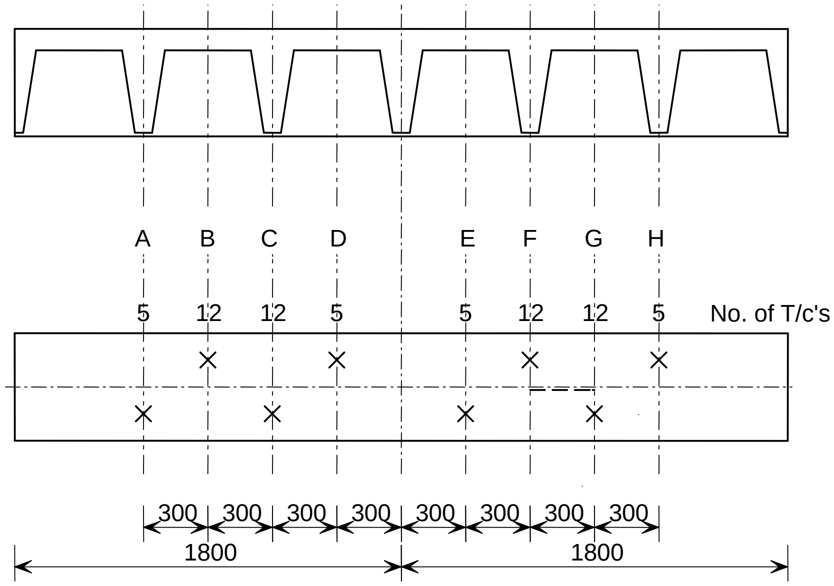


Figure 4.20 *Plan view – Position of thermocouple cross sections*

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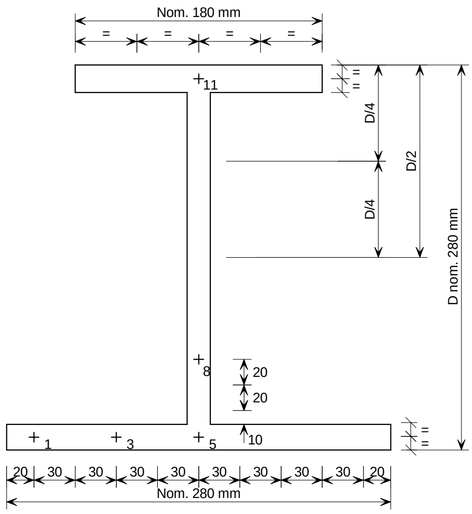
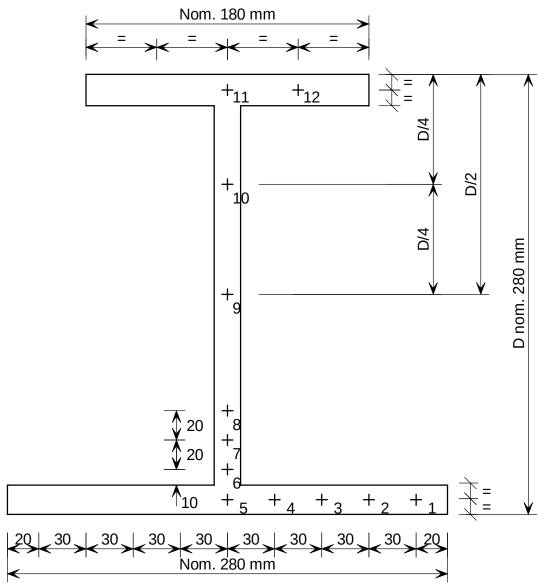


Figure 4.21 *Transverse arrangement at position A*



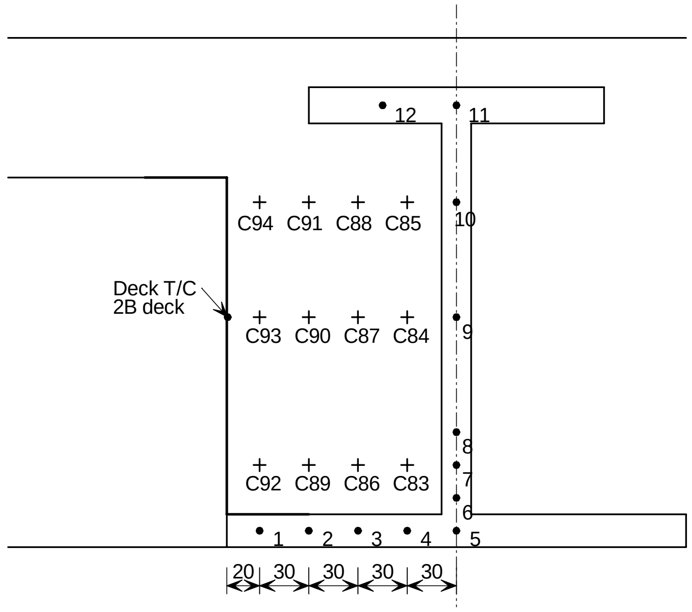


Figure 4.22 *Transverse arrangement at position B*

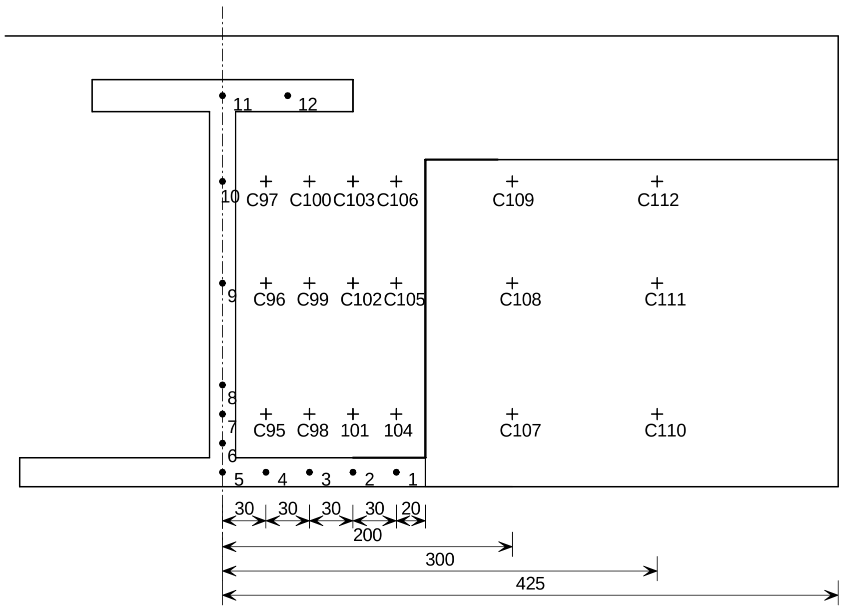


Figure 4.23 *Transverse arrangement at position C*

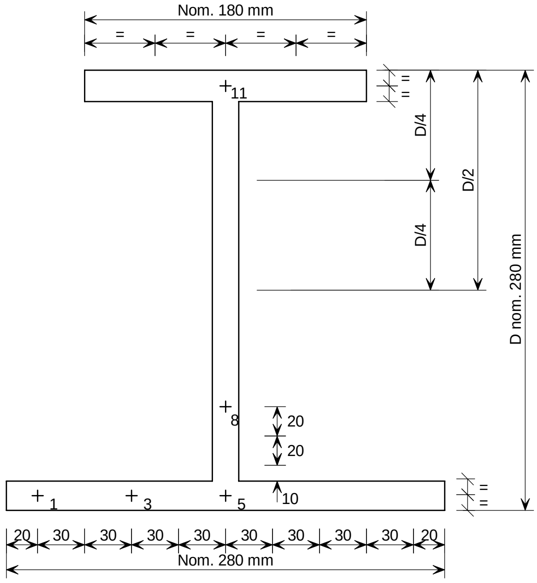


Figure 4.24 *Transverse arrangement at position D*

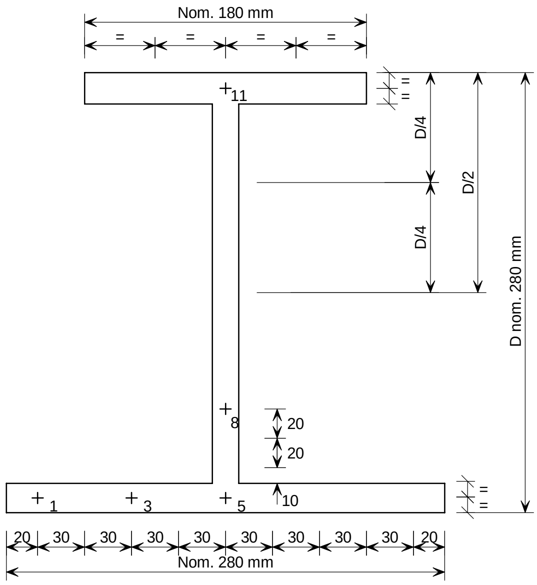


Figure 4.25 *Transverse arrangement at position E*

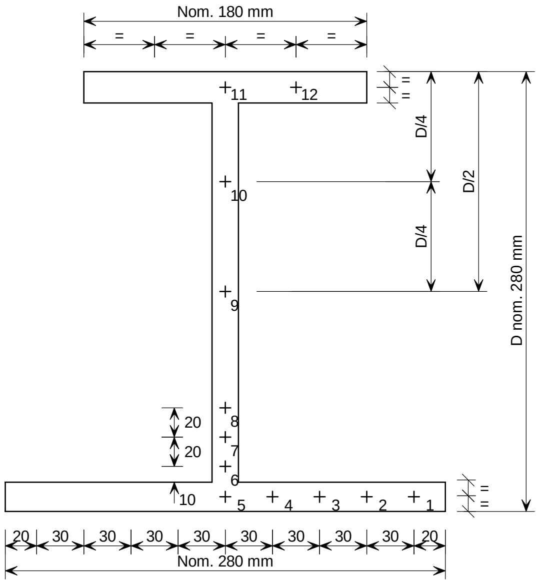


Figure 4.26 *Transverse arrangement at position F*

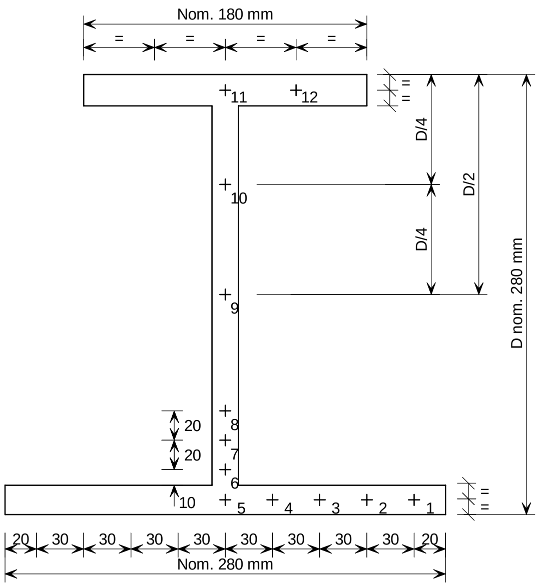


Figure 4.27 *Transverse arrangement at position G*

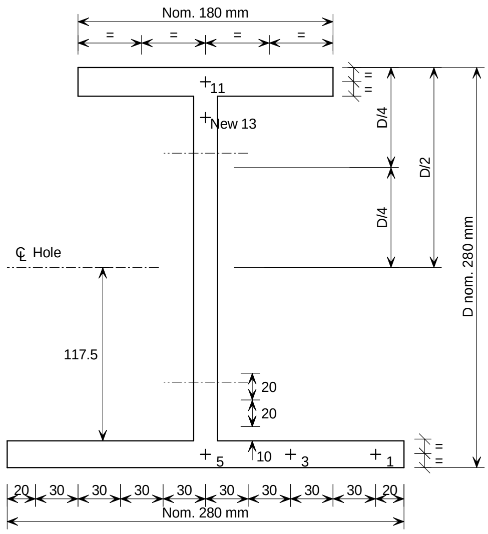


Figure 4.28 *Transverse arrangement at position H*

4.3.3 Indicative 3

Test Specimen

The test specimen consisted of a 280 ASB rolled asymmetric beam supporting a composite slab as shown by Figure 4.29. The composite slab for this indicative specimen was constructed using CF210 deep decking and normal weight concrete. The top surface of the concrete was 30mm above the top surface of the steel section.

Instrumentation

Thermocouples were positioned on the steel beam at eight different sections, as shown in Figure 4.29. The locations of thermocouples on the cross section at Positions A to H are shown in Figure 4.30 to Figure 4.37.

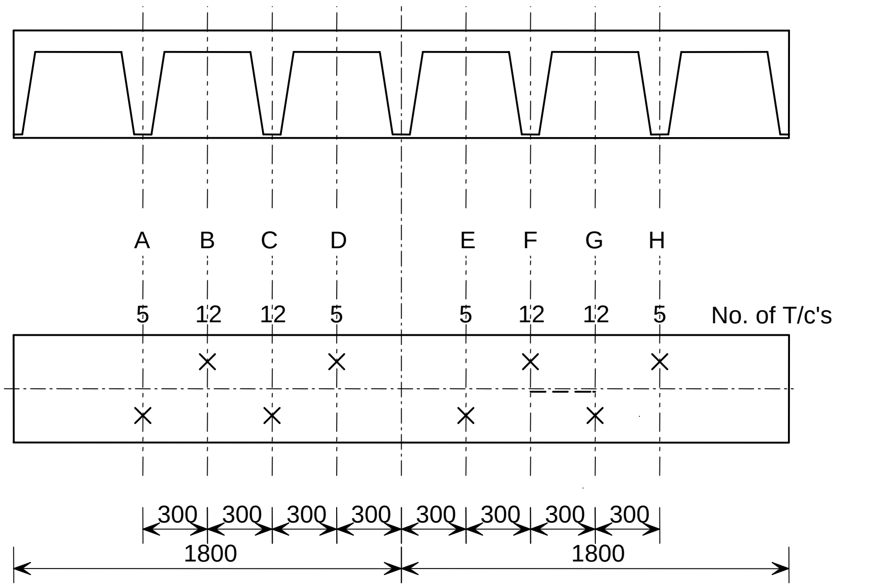


Figure 4.29 *Plan view – Position of thermocouple cross sections*

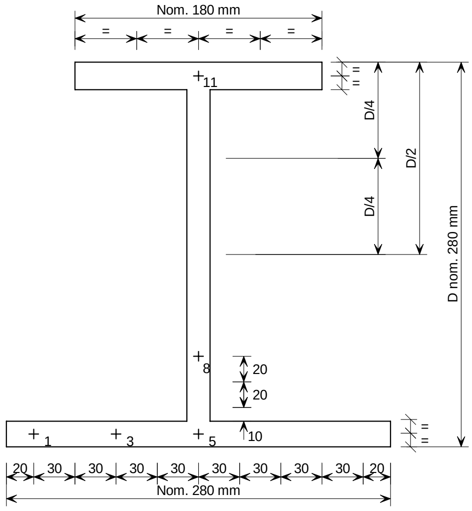


Figure 4.30 *Transverse arrangement at position A*

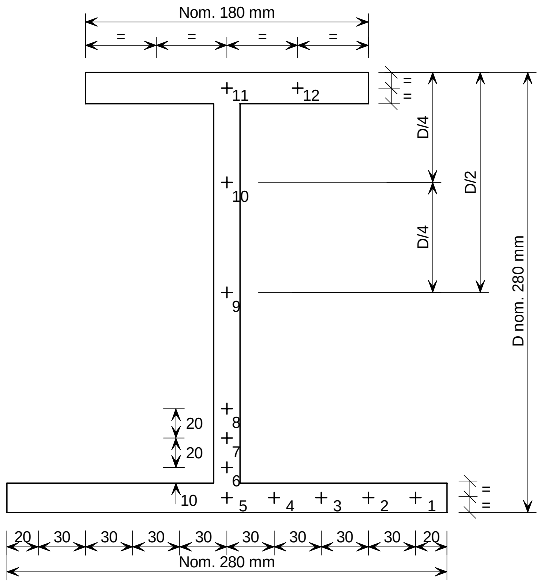


Figure 4.31 *Transverse arrangement at position B*

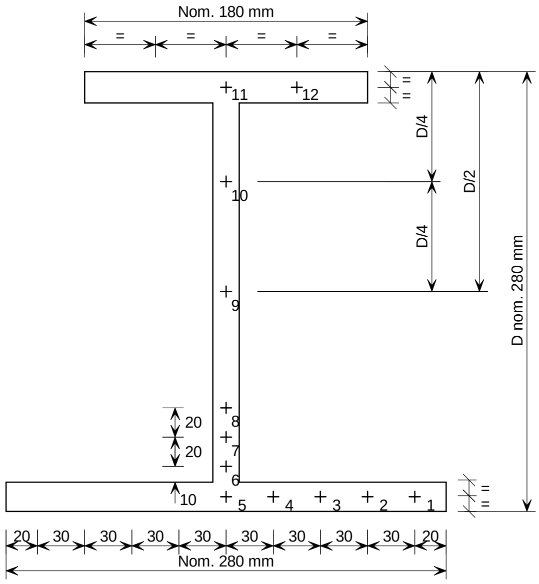


Figure 4.32 *Transverse arrangement at position C*

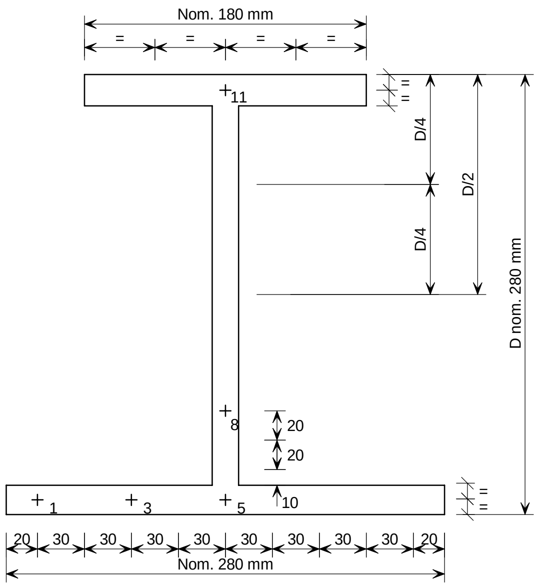


Figure 4.33 *Transverse arrangement at position D*

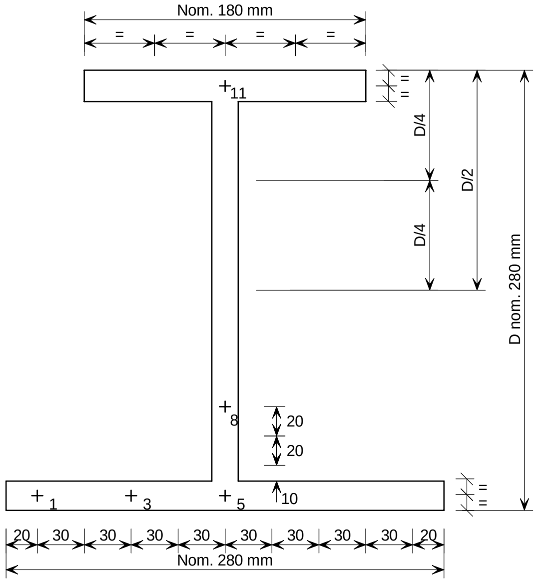


Figure 4.34 *Transverse arrangement at position E*

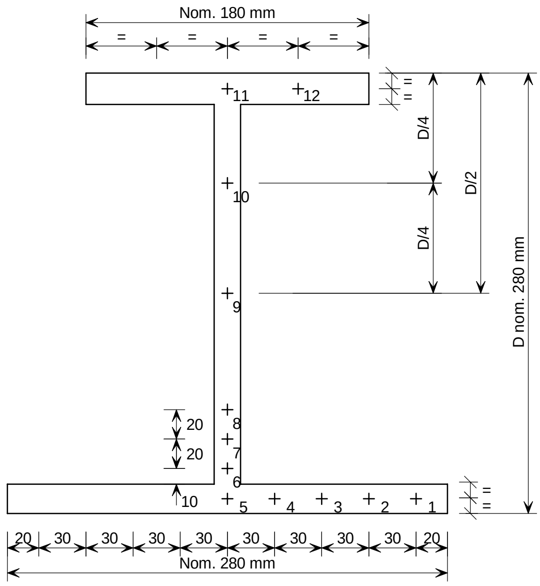


Figure 4.35 *Transverse arrangement at position F*

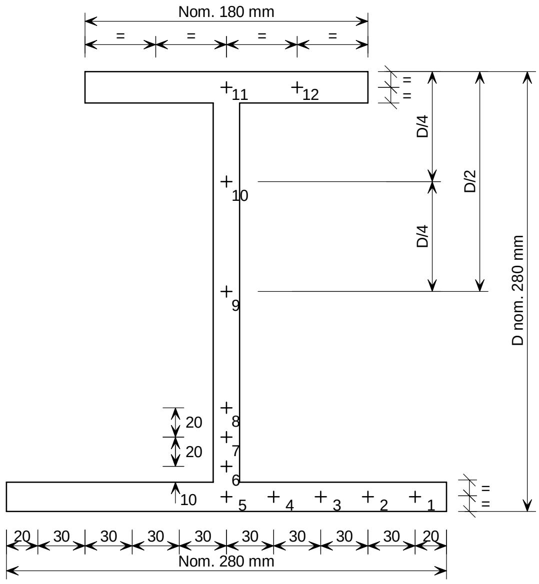


Figure 4.36 *Transverse arrangement at position G*

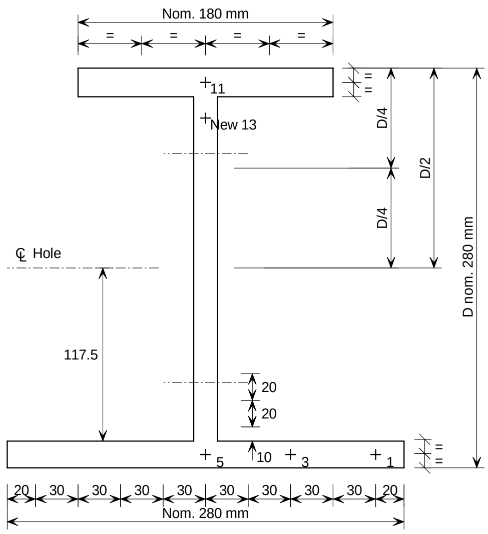


Figure 4.37 *Transverse arrangement at position H*

4.4 Test WFRC 67756

This was a loaded fire resistance test carried out on a rolled asymmetric steel section that supported a composite floor slab constructed with CF210 steel decking. The test was conducted at Warrington Fire Research Centre on 4 September 1996, and was assigned the fire test reference number WFRC67756.

Test Specimen

The test specimen consisted of 5 m rolled asymmetric steel beam manufactured from Grade S355 steel. The beam supported a composite slab constructed from CF225 steel decking supported on the bottom flange and normal weight concrete with 30N/mm^2 cube strength. The composite slab was nominally 1m wide and the concrete was cast to a depth of 30mm above the top surface of the top flange of the steel section, giving a slab depth of 314mm. The concrete also contained A143 reinforcing mesh, as shown in Figure 4.38. The ribs of the slab contained 16mm reinforcing bars, but these where used to obtained thermal data rather than for structural purposes. The axis distance of the bar from the bottom of the rib differed on either side of the beam.

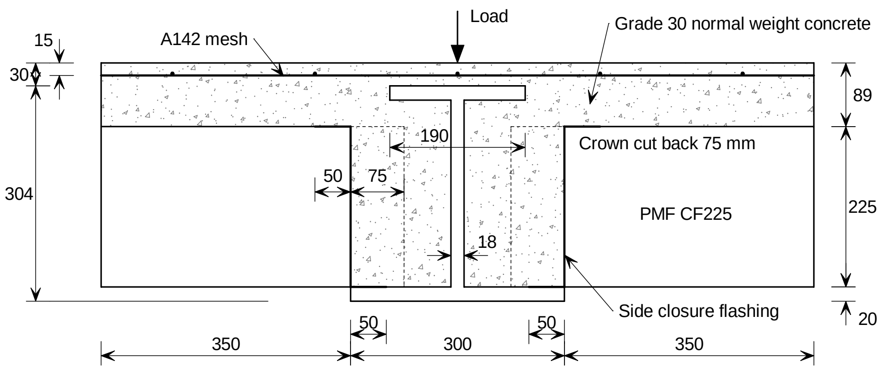


Figure 4.38 *General transverse arrangement*

The beam was loaded with four hydraulic rams each applying a point load of 85 kN to the concrete surface of the slab above the web of the steel section. The rams were positioned symmetrically about the mid span of the beam and spaced at 520mm. The applied load combined with the self weight of the specimen gave a total moment of 310kNm. Based on the measured geometry of the section, given in Table 4.2, and the measured yield strength (392 N/mm^2) the moment resistance at room temperature was calculated to be 796kNm, giving a load ratio of 0.39[16].

Table 4.2 *Section Dimensions*

Section Dimensions		**Nominal**	**Measured**
Top Flange	Width	190	198
	Thickness	20	21.7
Bottom Flange	Width	300	306
	Thickness	20	20.6
Web Thickness		18	17.2
Section Depth		304	305.8

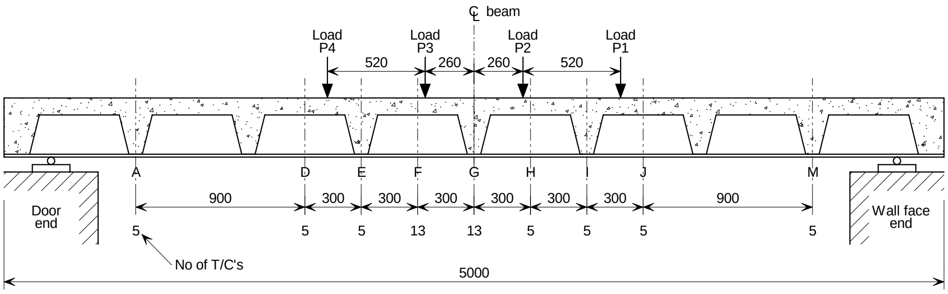


Figure 4.39 *Longitudinal arrangement of loading rams*

Instrumentation

The cross sections instrumented with thermocouples and the numbers of thermocouples on the steel section at each position are shown in Figure 4.42. At cross sections F and G thermocouples were also embedded in the concrete encasement the location of the thermocouples relative to the steel section is indicated by the shading in the figure. The location of thermocouples on the steel cross section and concrete encasement is shown in Figure 4.41 and Figure 4.42.

The horizontal temperature profile was measured between Positions F and G using 5 thermocouples spaced at 50mm intervals along the web at mid height of the steel section, as shown in Figure 4.43.

The composite slab had 230mm long reinforcement bar located in the rib of the profile at 6 locations along the span as indicated in Figure 4.42. The reinforcement bars were located at an axis distance of 90mm or 70mm from the bottom of the rib as shown in Figure 4.44. Thermocouples are also located in the void from between the lower dovetail in the deck profile and the top surface of the bottom flange. The thermocouple was located 37.5mm from the toe of the bottom flange as shown in Figure 4.44. The dovetail thermocouples are located on either side of the beam at Positions E, G and I along the length of the specimen as shown in Figure 4.42. Figure 4.44 also shows the location of the deck thermocouples which were sandwiched between the over lapping portions of the adjacent deck profiles at the top of the lower dovetail. Deck thermocouples are located at Positions C, E, I and K.

In addition to the standard measurement of the mid span deflection, this test specimen was also instrumented with 9 further potentiometers located along the length of the specimen as shown by Figure 4.45.

The test specimen was also instrumented with strain gauges located on the steel section and the surface of the concrete slab. Three strain gauges on the surface of the concrete are located at mid span, Position G. One strain gauge is located on the centre line of the specimen and two further strain gauges are located at 150mm on either side of the centre line of the section. Two steel cross sections located 25mm either side of mid span (Position G) are instrumented with six strain gauges. The location of the strain gauges on each cross section was as shown in Figure 4.46.

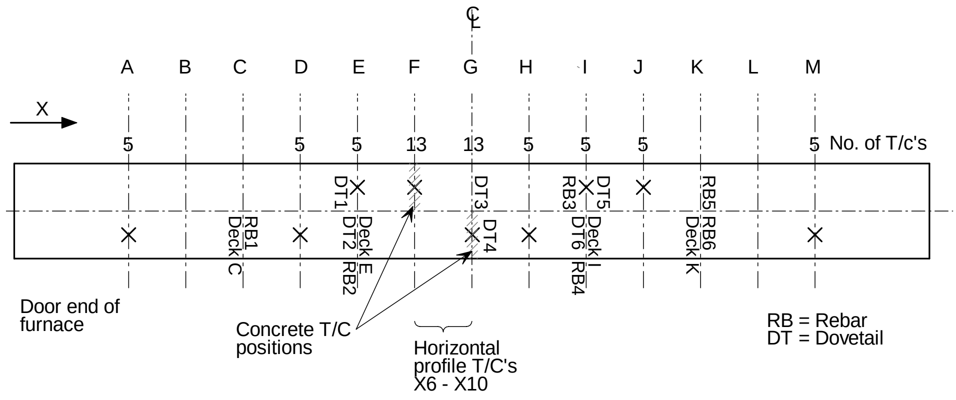
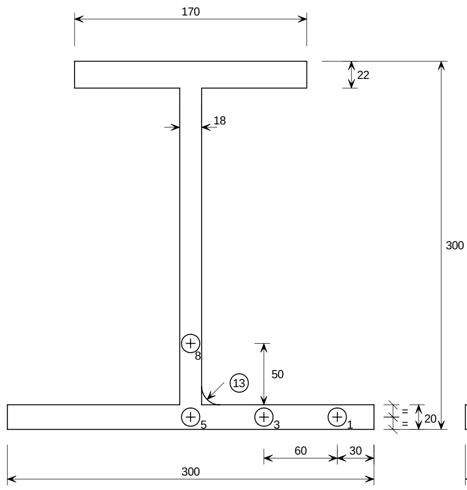
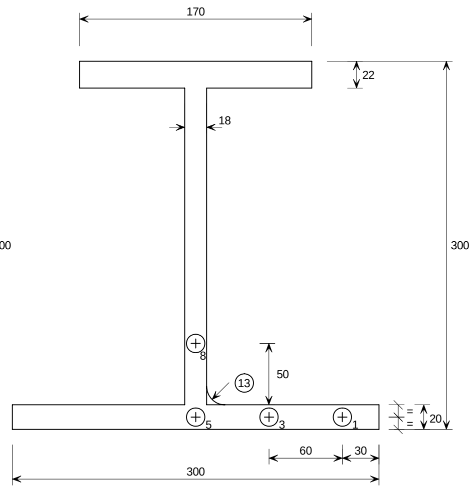


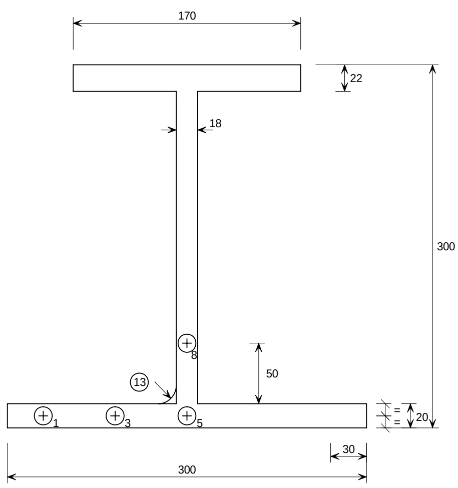
Figure 4.40 *Plan view– Position of thermocouple cross sections*



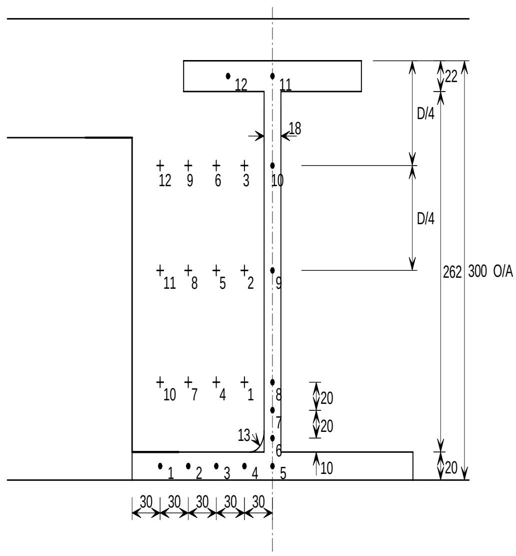
Position A



Position D

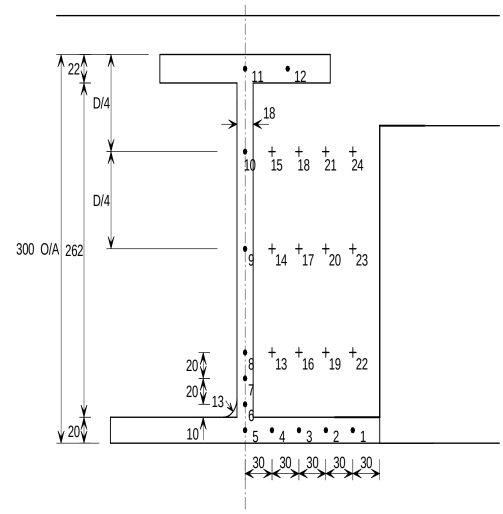


Position E

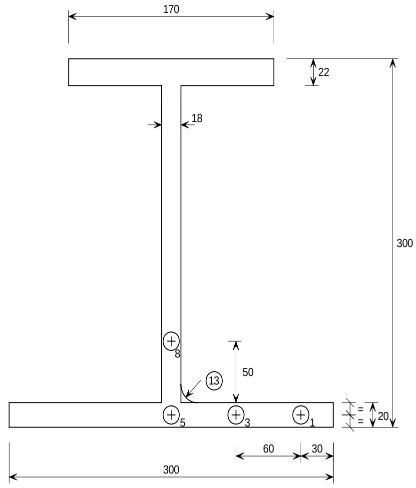


Position F

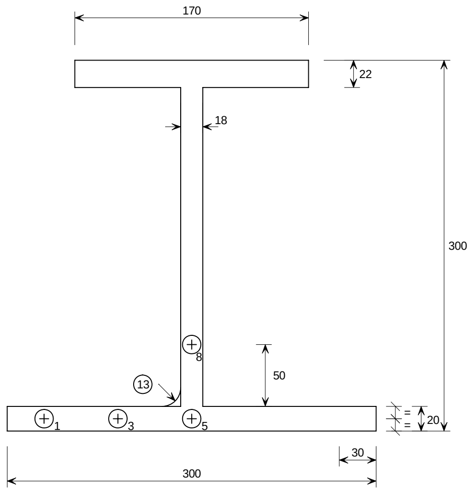
Figure 4.41 *Transverse arrangement at position A to F*



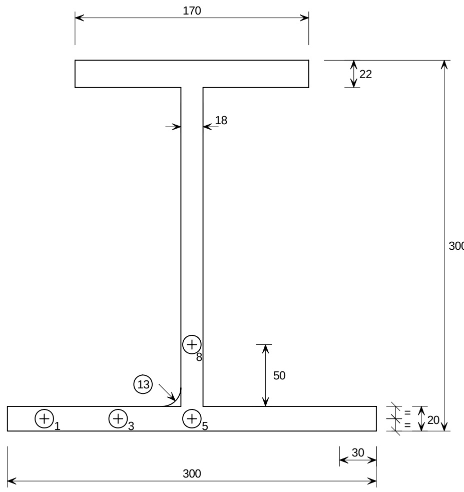
Position G



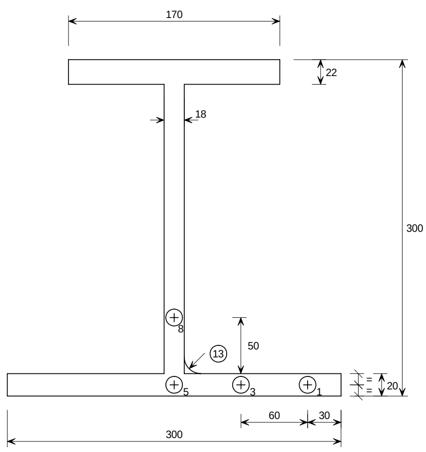
Position H



Position I



Position J



Position M

Figure 4.42 *Transverse arrangement at position G to M*

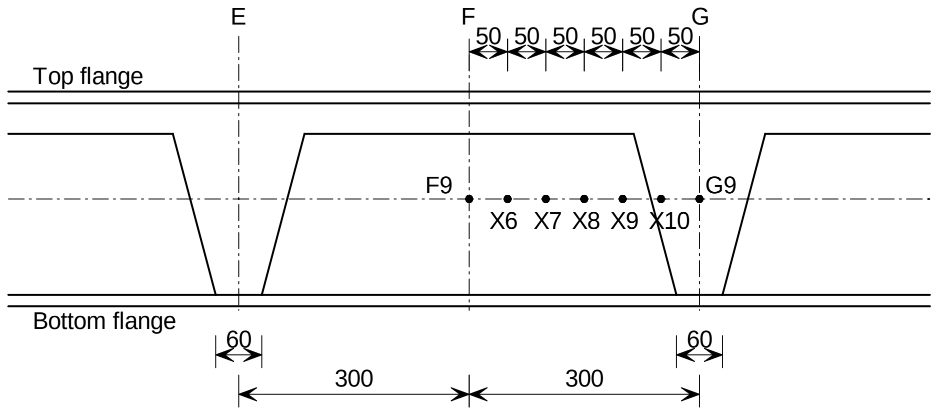


Figure 4.43 *Horizontal temperature profile (Thermocouples X6 to X10)*

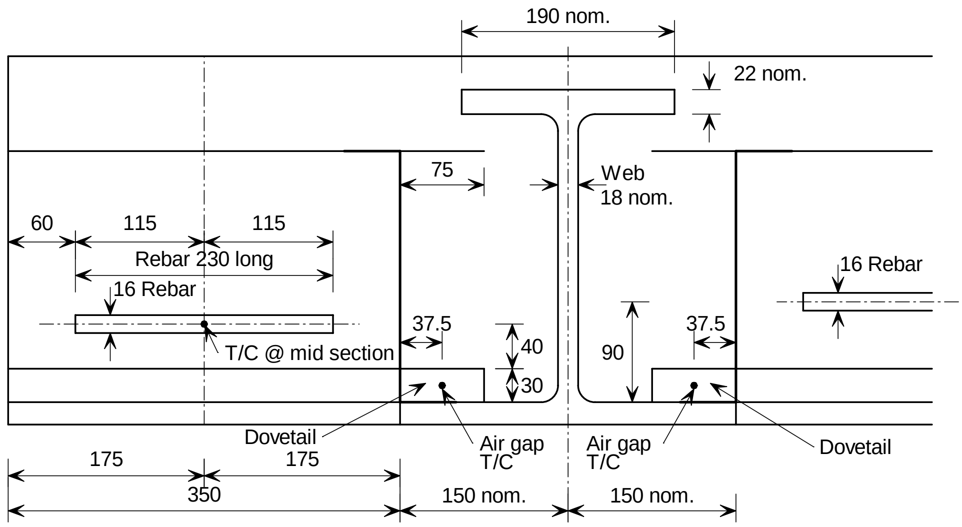


Figure 4.44 *Rebar, dovetail and deck thermocouples (viewed from direction X as indicated in Figure 4.42)*

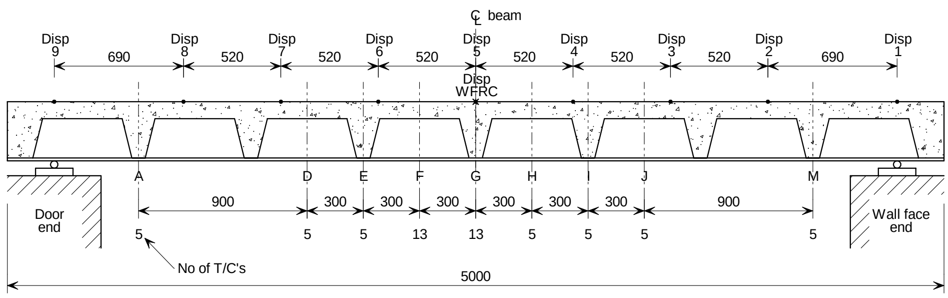


Figure 4.45 *Deflection measurement locations*

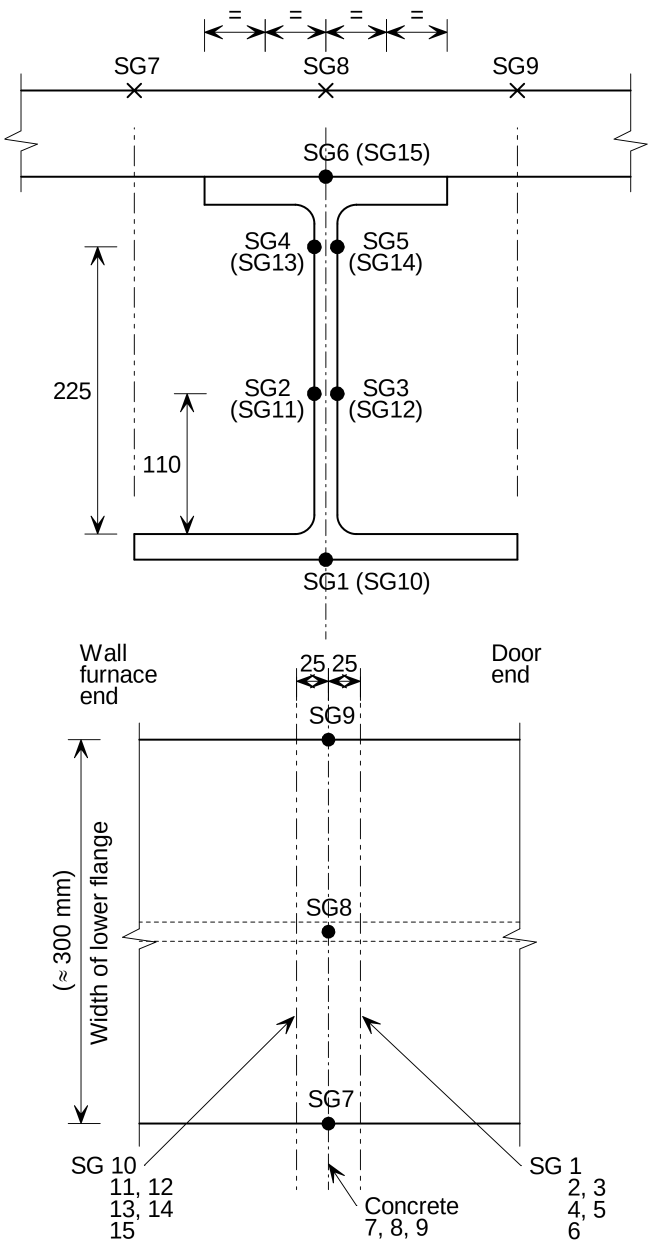


Figure 4.46 *Strain gauge locations*

Results

The load bearing performance of the test specimen was assessed in accordance with the criteria set out in BS476-21. The maximum allowable deflection was calculated as 225mm (Span/20) and the maximum allowable rate of deflection was calculated as 6.7mm/min ($Span^2/9000$ D), based on a section depth, D, of 334mm. This rate of deflection limit is only applied after the mid span deflection reaches a value of Span/30, 150mm for this specimen.

The loading was removed from the test specimen after 76minutes when the deflection reach a value of 159mm and the rate of deflection was 7.3mm/min. However, heating was continued until 90 minutes to allow further thermal data to be obtained. Additional thermal and deflection data was also recorded overnight during the cooling phase.

Electronic temperature, deflection and strain gauge data for this test specimen is provided on a CD which accompanies this report. The basic deflection and temperature data is provided in Excel format. The strain gauge information and the data recorded during the cooling phase are provided as ASCII files.

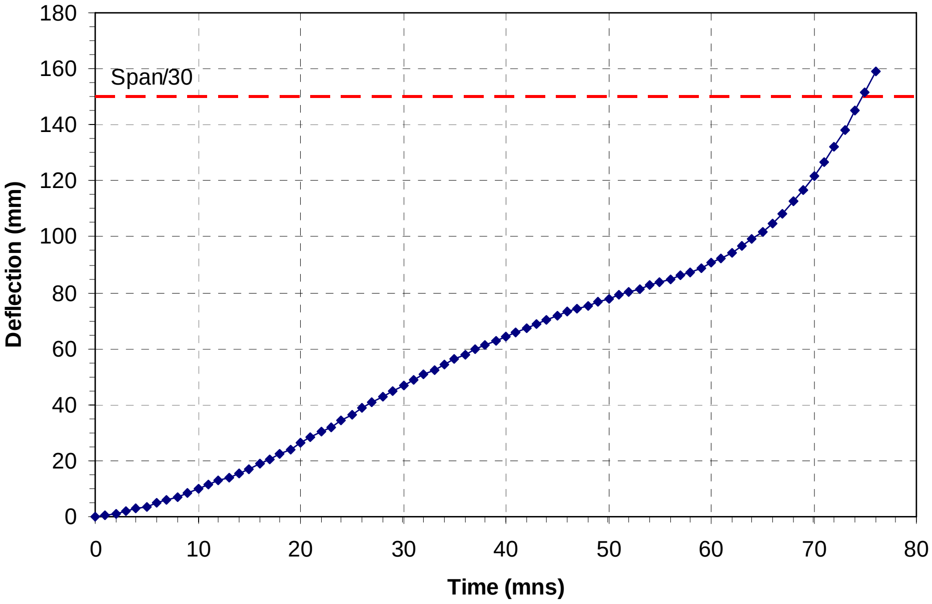


Figure 4.47 *Measured mid span deflection (WFRC 67756)*

5 RHS Slimflor edge beams

5.1 Summary of available test data

A total of three fire resistance tests have been conducted on RHS edge beam specimens. All of the specimens tested supported composite slabs constructed using deep composite decking. Tests R1 and R3 were loaded fire tests. Test R1 consisted of a composite slab constructed using deep decking supported on two RHS edge beams. Test R3 was a test carried out on a specimen which consisted of two RHS edge beams with service openings cut into the side walls. The three tests R2 was an unloaded indicative fire test used to obtain thermal data. The test was conducted on three test specimens each consisting of a pair of RHS edge beams.

	Section details	Type	WFRC	Electronic Data	
				ASCI	Excel
R1	200x100x10 SHS + 250x15 plate	A	TNO96	YES	YES
R2	250x150x10 SHS + 15 plate	A	65514	YES	YES
	200x100x10 SHS + 15 plate	A	65514	YES	YES
	250x150x10 SHS +15 plate	B	65514	YES	YES
	200x100x10 SHS + 15 plate	B	65514	YES	YES
	200x100x8 SHS + 15 plate	B	65514	YES	YES
	200x100x8 SHS + 15 plate	B	65514	YES	YES
R3	300x200x8 SHS+300x15 plate	A	106891	NO	YES

Beam Type:

A RHS edge deck normal to beam

B RHS edge deck parallel to beam

5.2 Test WFRC 65514

The indicate fire test was conducted at Warrington Fire Research Centre on 10 January 1996.

Test Specimen

Three indicative test specimens were arranged on the furnace as shown in Figure 5.1. Each test specimen consisted of two RHS edge beams separated by a short section of composite slab constructed using CF210 steel decking supported on the plates welded to the bottom of the RHS sections. The exposed side wall of each RHS section is fire protected as shown in Figure 5.2 Some sections also have fire protection applied to the bottom of the plate as indicated in Figure 5.1. No details of type or thickness of fire protection were available at the time of writing this report.

The test specimens were not loaded apart from self weight and the purpose of the test was to record the temperature development in the section with time.

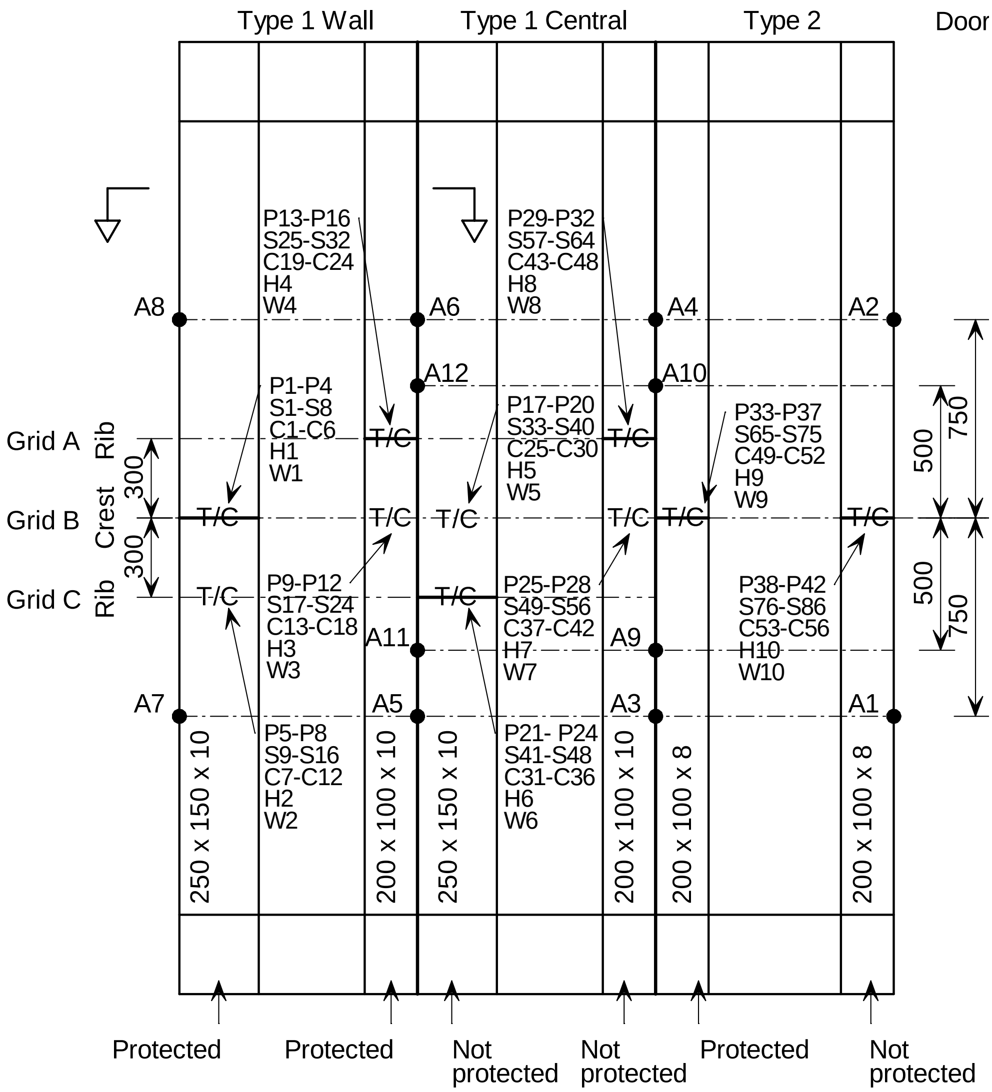


Figure 5.1 *Plan showing the layout of indicative specimens on the furnace for Test WFRC 65514.*

Instrumentation

The instrumented cross sections are indicated on Figure 5.1. The letter prefix to the thermocouple numbers indicates the general location of the thermocouple on the cross section as follows; 'P' record the temperature of the edge beam plate, 'S' record the temperature of the RHS section, 'C' record the temperature of the concrete encasement to the edge beam, 'W' record the temperature of the weld and 'H' records the temperature of the internal void of the RHS section. Details of the location of these thermocouples on each cross section are shown in Figure 5.3 to Figure 5.7. A further 12 thermocouples are used to record the atmospheric temperature within the furnace. These thermocouples were given the prefix 'A'. Thermocouples A1 to A8 are standard furnace control thermocouples, which thermocouples A9 to A12 measure the atmospheric temperature in the gap between the indicative specimens. The locations of the atmospheric thermocouples are shown in more detail in Figure 5.2.

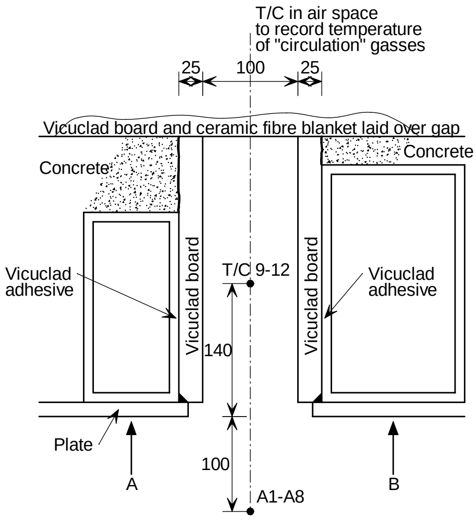


Figure 5.2 *Fire protection details and location of instrumentation in the voids between indicative specimens.*

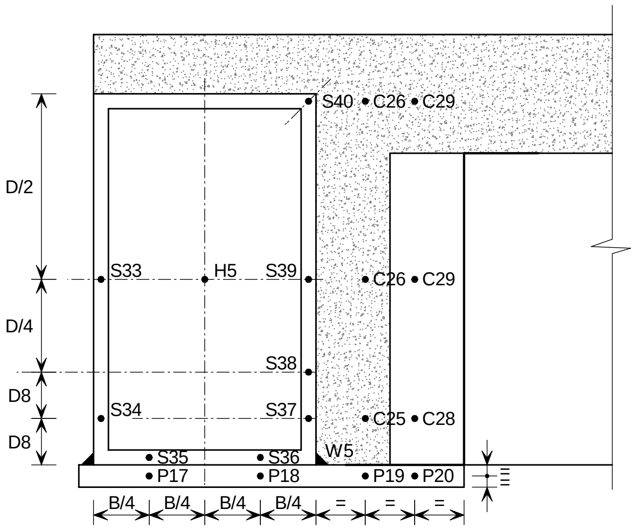


Figure 5.3 *Thermocouple positions for unprotected 250x150x10 beam, grid line B (mid span).*

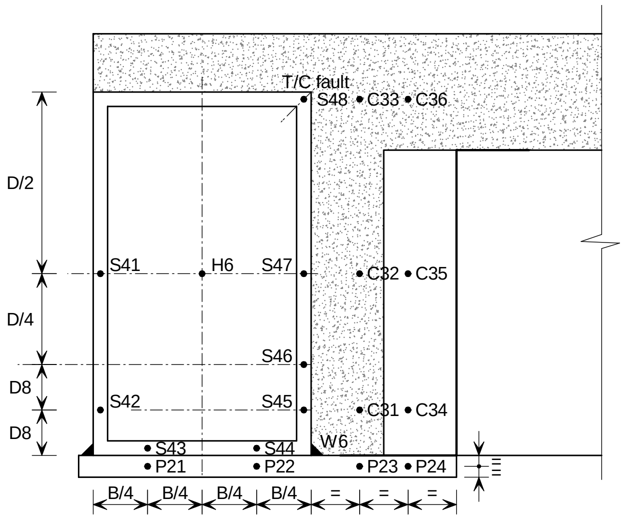


Figure 5.4 *Thermocouple positions for unprotected 250x150x10 beam, grid line C*

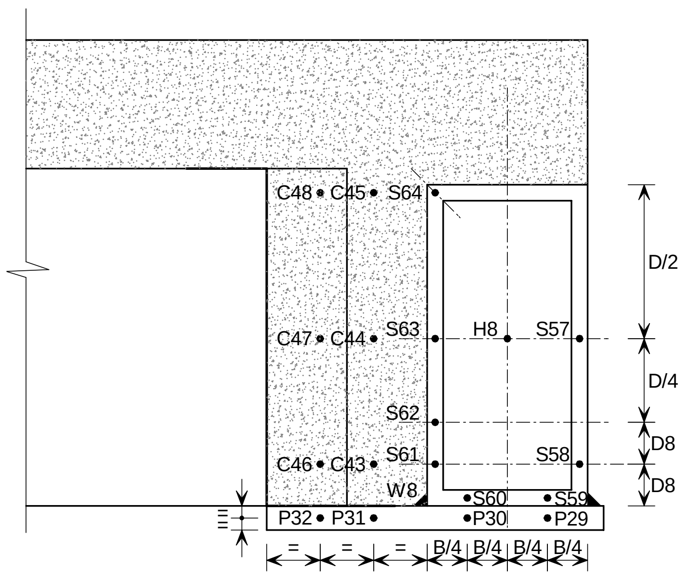


Figure 5.5 *Thermocouple positions for unprotected 200x100x10 beam, grid line A.*

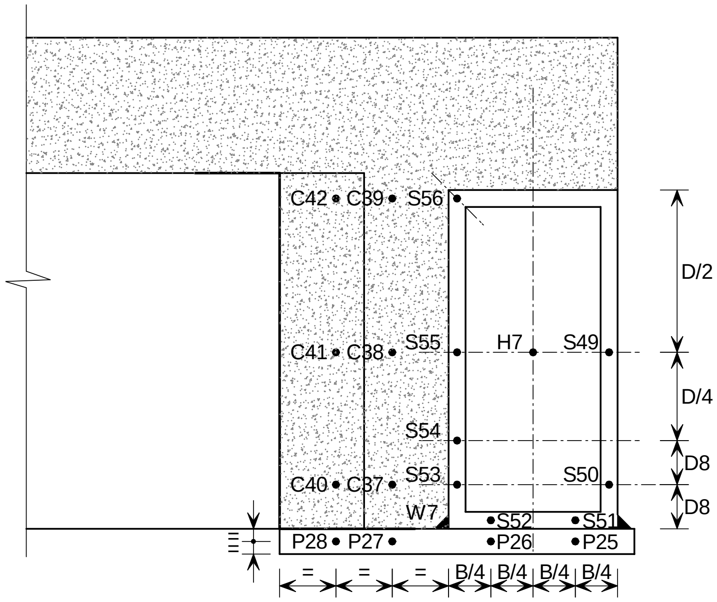


Figure 5.6 *Thermocouple positions for unprotected 200x100x10 beam, grid line B.*

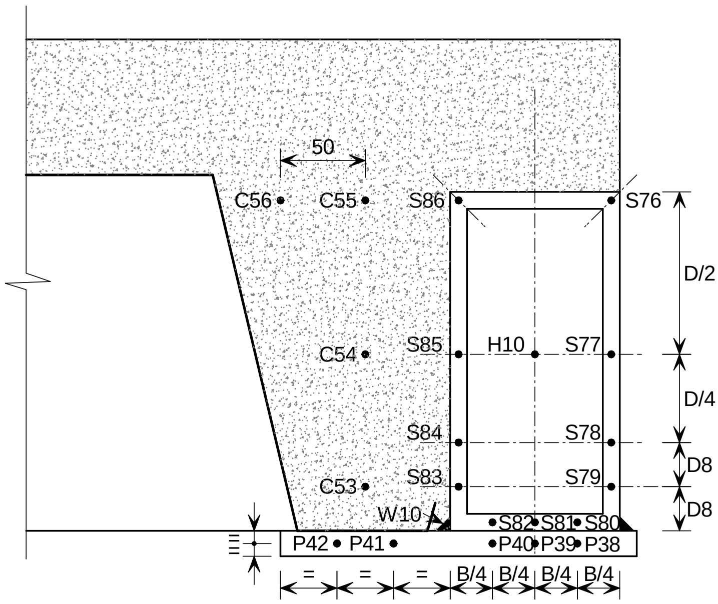


Figure 5.7 *Thermocouple positions for unprotected 200x100x8 beam, grid line B (mid span).*

5.3 TNO 1996

This test was carried out in 1996 by TNO in the Netherlands as part of a European research project funded by the European Coal and Steel Community (ECSC). A full test report was published by TNO[18]. Full ASCI data files are available for this test on the CD that accompanies this report, the test reference is TNO 1996.

Test Specimen

The layout of the test specimen used in this fire test is a shown in Figure 5.8. The test was performed on a Slimflor system, consisting of two RHS edge beams 200x100x10 supporting a composite slab constructed using deep decking. The RHS edge beams were simply supported with a span of 4.6m. The composite slab spanned approximately 5.5m between the edge beams and was constructed using Comflor 210/1.25 Grade S280. The decking was supported on a 15 mm thick and 250 mm wide bottom plate welded to the edge beams. The steel grade for beams and plates was reported as Grade S355. In addition to the normal crack control mesh each rib of the composite slab was reinforced with a 25mm diameter Grade B500 reinforcing bar located at an axis distance of 75mm from the bottom of the rib.

Load was applied to the test specimen using a system of hydraulic rams and spreader beams as shown in Figure 5.8. The slab was subjected to two distributed line loads of 9.8 kN/m. This load was in addition to the self weight of the specimen which was calculated as 3.05 KN/m^2, giving a load ratio of 0.2 for the edge beams.

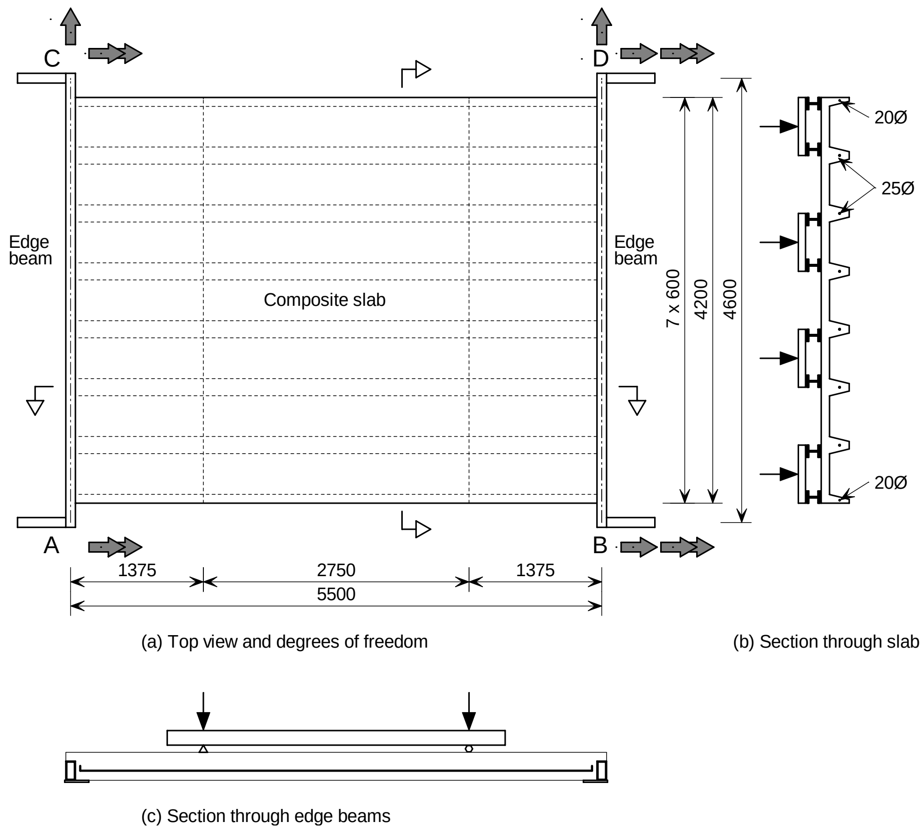


Figure 5.8 *General arrangement – Plan view*

Instrumentation

Temperatures were measured at three cross sections for each beam, as shown in Figure 5.9. At cross sections C, D, E and F, five thermocouples were placed on the bottom flange, eight on the hollow section, and six in the concrete, as shown in Figure 5.11. At cross section G and H only thermocouples labelled 1 to 13 were installed.

The location of transducers for measuring displacements and loads are as shown in Figure 5.12.

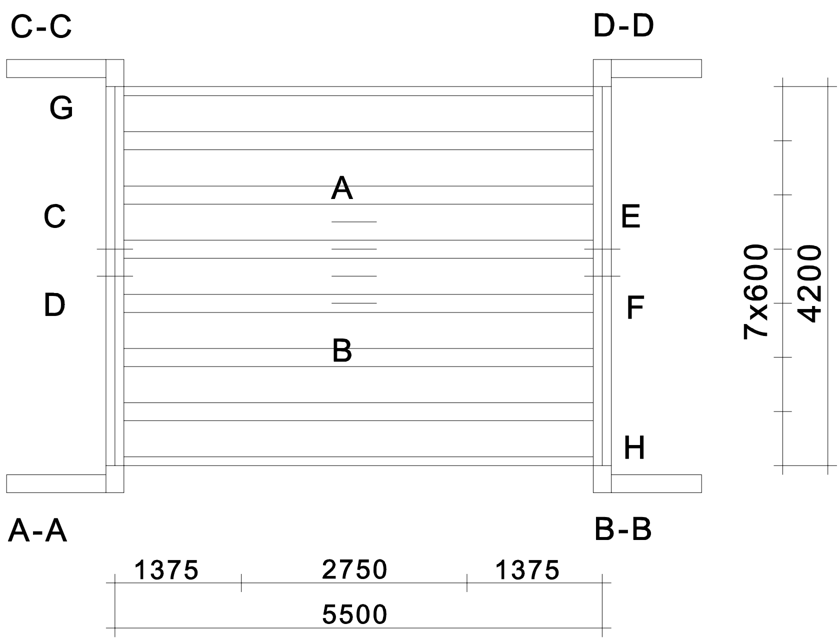


Figure 5.9 *Location of instrumented cross sections*

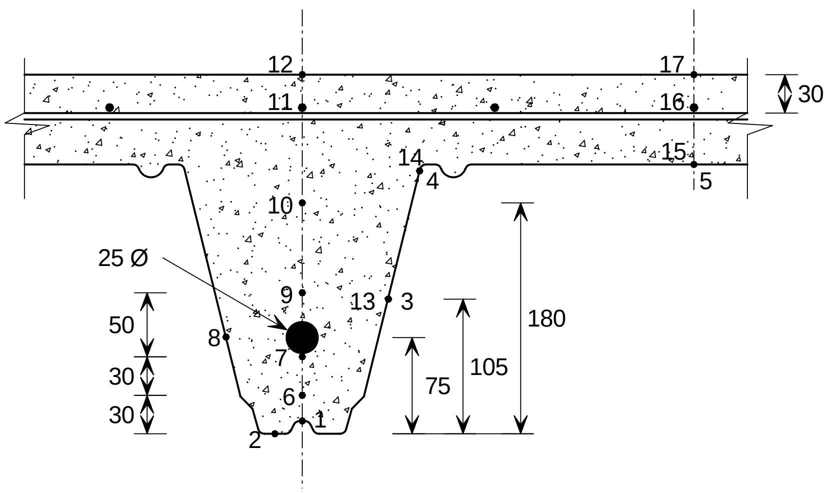


Figure 5.10 *Location of thermocouples in the composite slab at cross sections A and B shown in Figure 5.9*

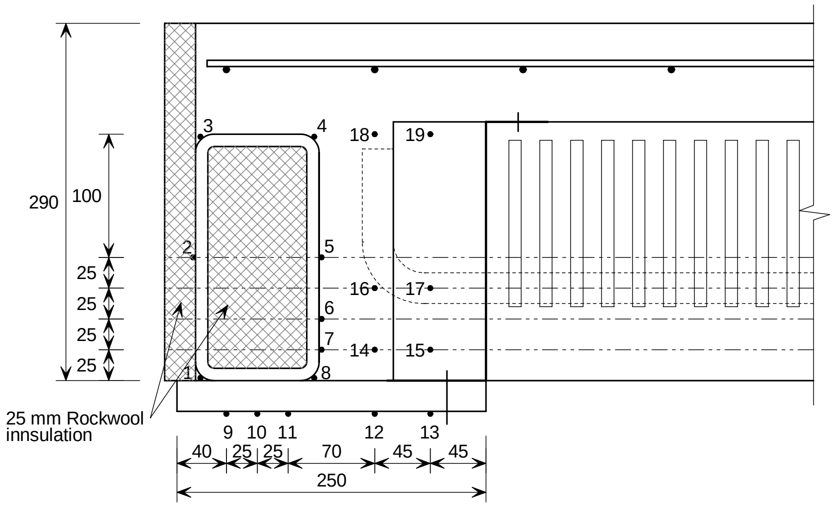


Figure 5.11 *Thermocouple location at cross section C, D, E, F, G and H (N.B: Sections G & H only TC's 1 to 13 installed).*

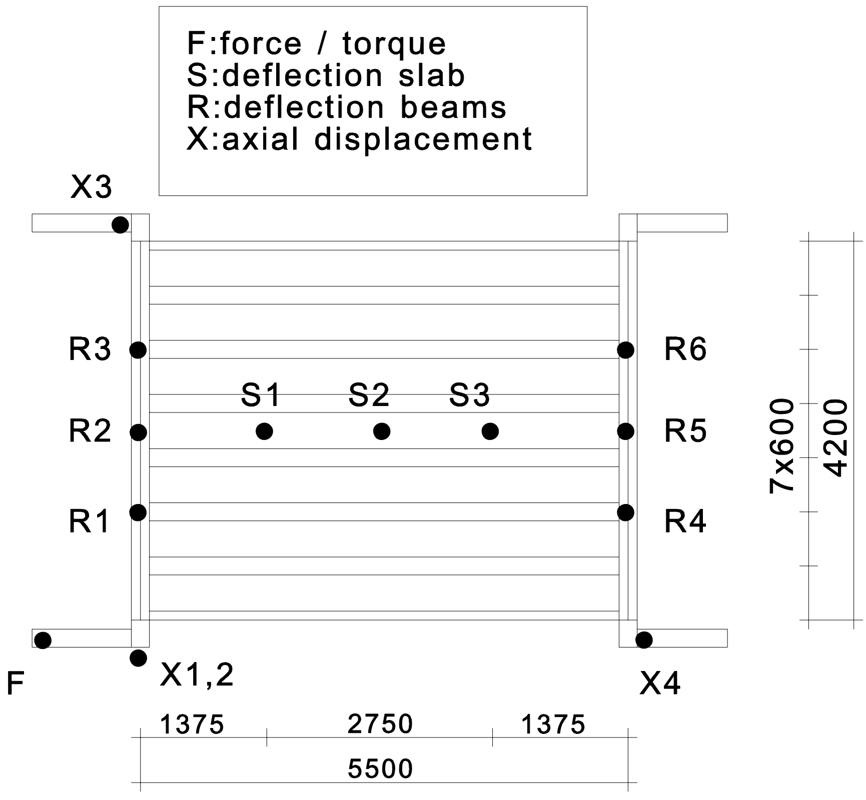


Figure 5.12 *Location of transducers*

5.4 Test WFRC 106891

Full details of the test are available in a report published by Corus[19]. Brief details of the test specimen and the results of the test are given below. The data recorded by the laboratory during this fire test is available in ASCI and Excel formats on the CD which accompanies this report.

Test Specimen

The test piece comprised two 4.5m 300x200x8 mm Rectangular Hollow Section (RHS) edge beams with plates welded to the lower sides (300 mm wide and 15mm thick). The RHS and the plates were made from S275JH and S275JO steel, respectively. The centre line of the RHS sections were spaced 1800mm apart and profiled decking (SD225) spanned between the RHS edge beams forming a composite slab, as shown in Figure 5.13. A single 12 mm diameter reinforcing bar ran through each rib and an A142 mesh was located in the top of the slab. The RHS edge beams contained elongated openings 240mm long and 160mm deep, as shown in Figure 5.14 and Figure 5.15. Further details of the test specimen are available in a SCI report[20].

Four hydraulic jacks applied were used to load the test specimen. These rams were located 700mm either side of the middle of the span and 250mm in from the outside face of the RHS, as shown by Figure 5.15 and Figure 5.16. Each jack applied a load of 60kN. The uniformly distributed load on each beam resulting from the self weight of the floor slab was calculated to be 4.85kN/m. The total moment on each beam was 105.3kNm, giving a load ratio of 0.33.

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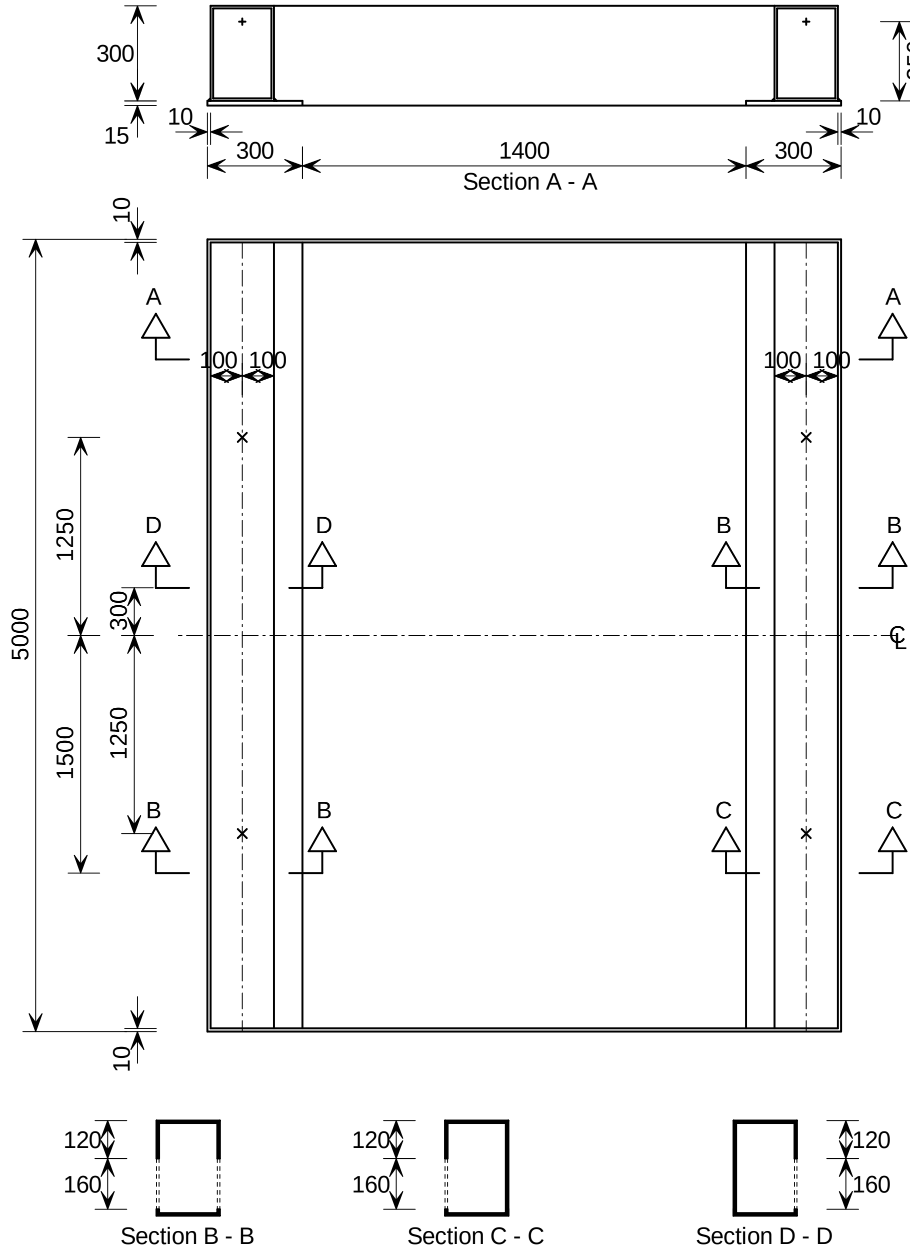

Figure 5.13 *Construction details for the fire test specimen*

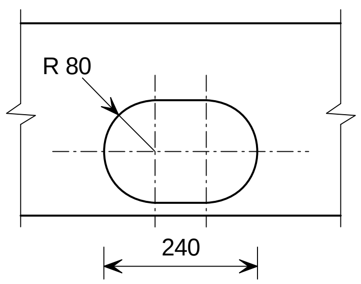

Figure 5.14 *Dimensions of service openings in side wall of RHS sections*

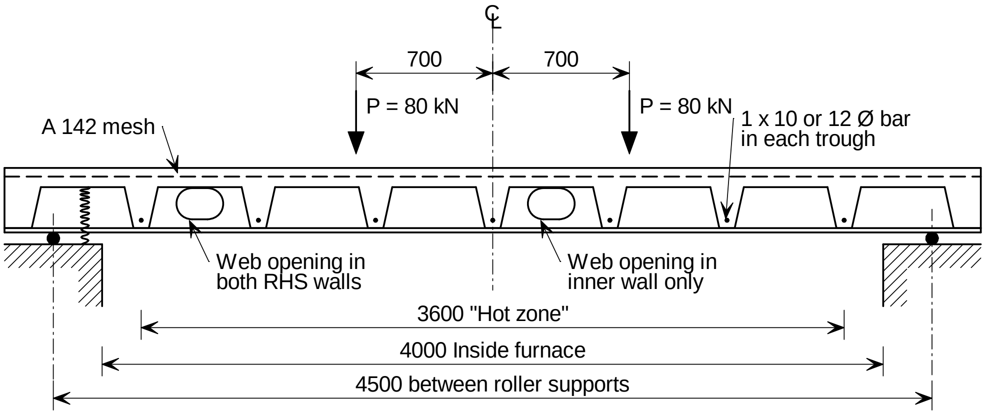

Figure 5.15 *Longitudinal section showing loading positions*

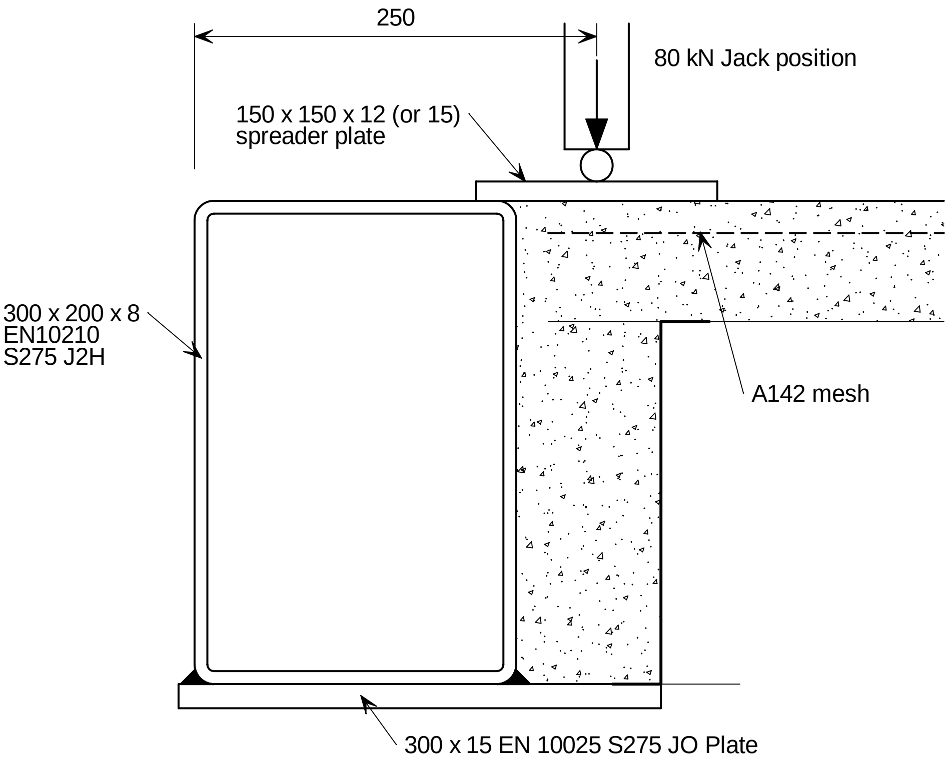

Figure 5.16 *Detail showing the location of the loading position relative to the RHS section*

Instrumentation

In order to identify the location of instrumentation attached to the beam a number of cross sections have been defined as shown in Figure 5.17. Edge beam A located on the left hand side of the specimen as shown in Section A-A above had thermocouples attached to the steel work on 5 cross sections along its length. The locations of the thermocouples on each cross section were as shown in Figure 5.18 to Figure 5.22. Edge beam B was instrumented at 3 cross sections as shown by Figure 5.23 to Figure 5.25. Thermocouples were also located in the concrete of the composite slab at three rib positions, as shown in Figure 5.26.

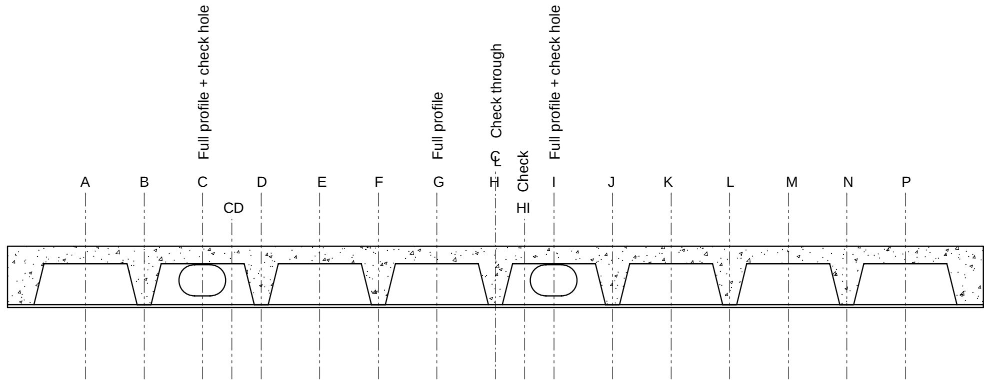

Figure 5.17 *Location of instrumented cross sections*

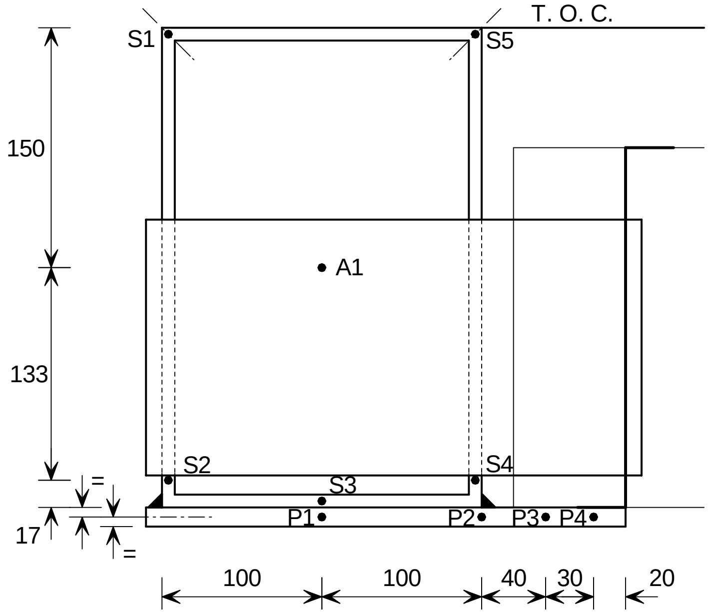

Figure 5.18 *Location of thermocouples on edge beam A cross section C*

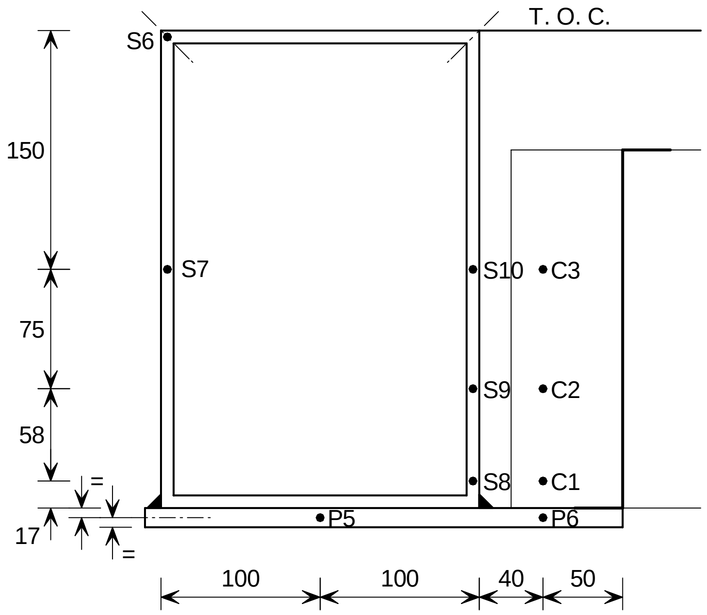

Figure 5.19 *Location of thermocouples on edge beam A cross section G*

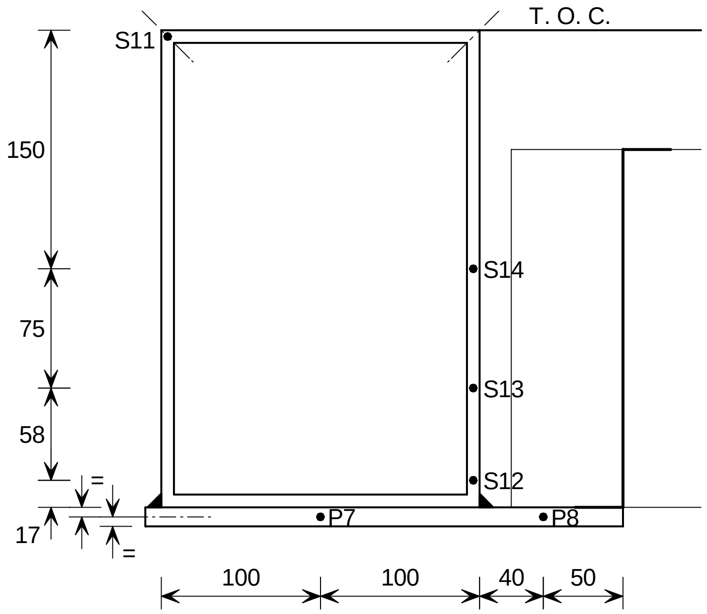

Figure 5.20 *Location of thermocouples on edge beam A cross section H*

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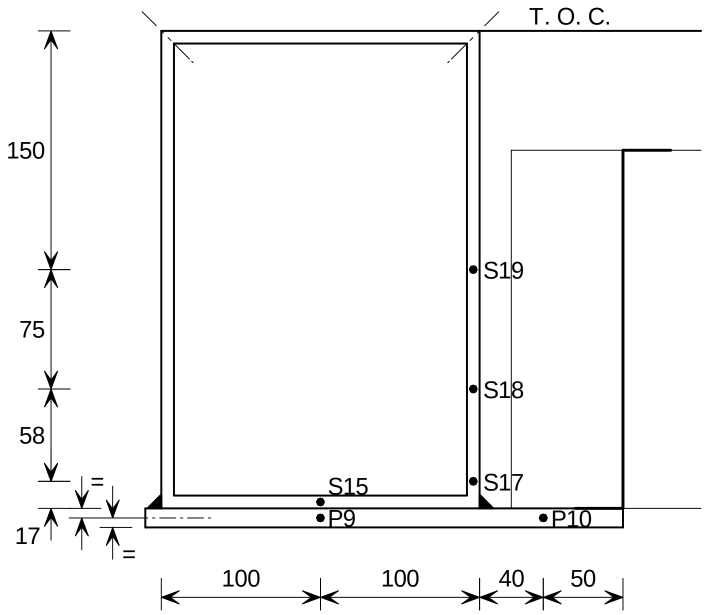

Figure 5.21 *Location of thermocouples on edge beam A cross section H-I*

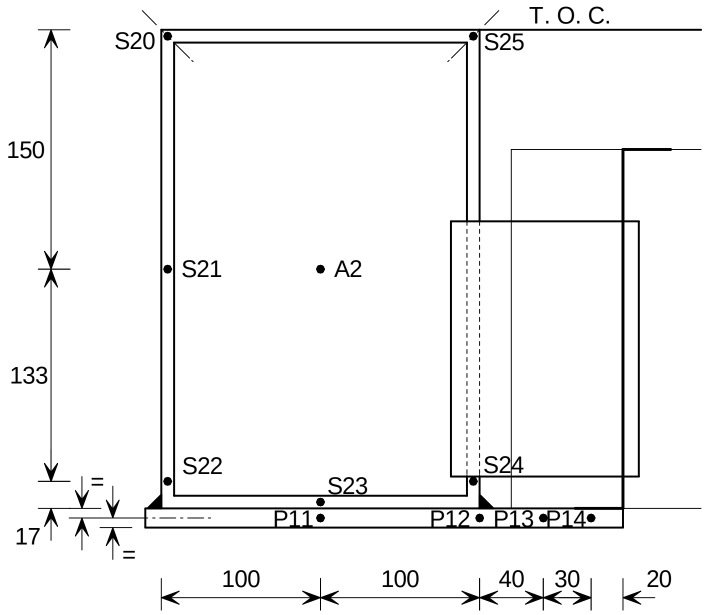

Figure 5.22 *Location of thermocouples on edge beam A cross section I*

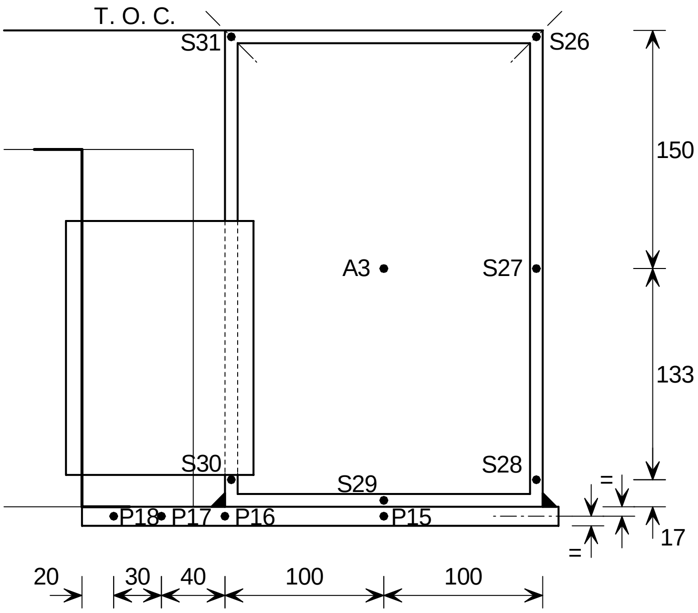

Figure 5.23 *Location of thermocouples on edge beam B cross section C*

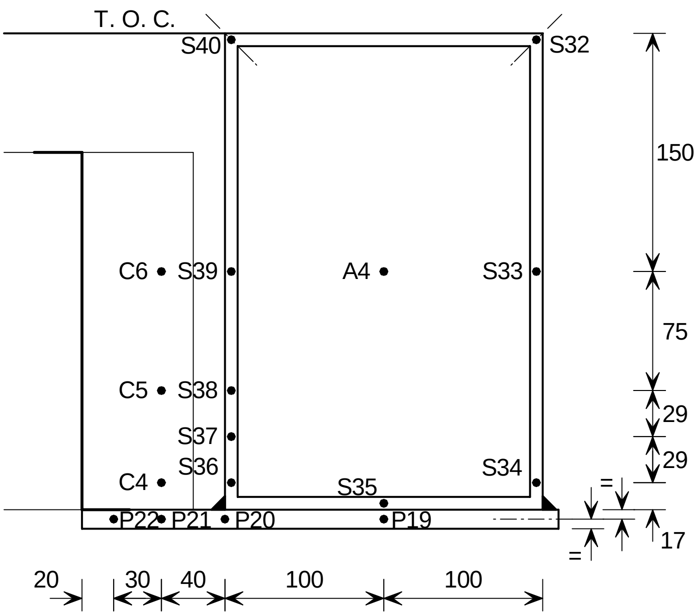

Figure 5.24 *Location of thermocouples on edge beam B cross section G*

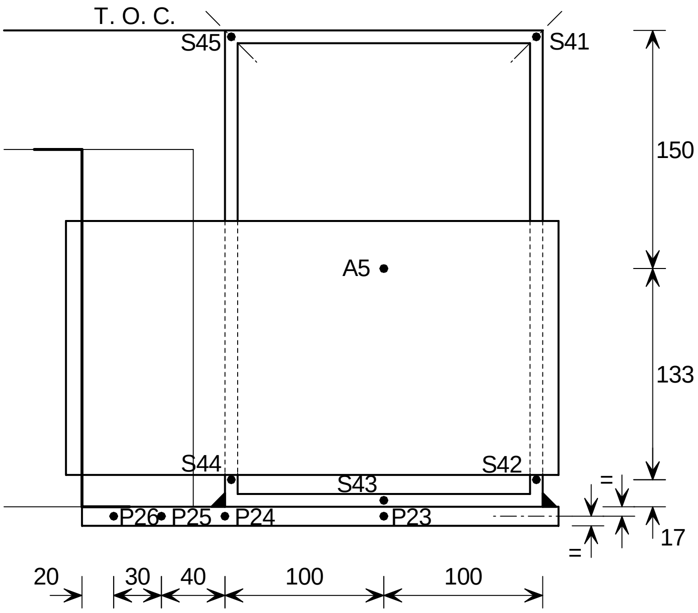

Figure 5.25 *Location of thermocouples on edge beam B cross section I*

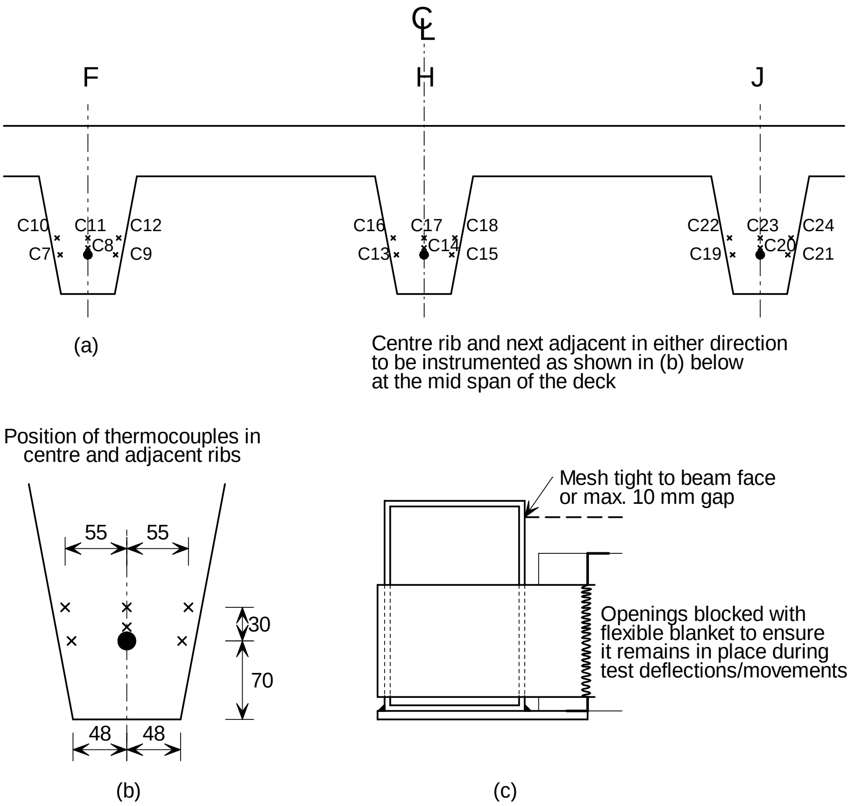

Figure 5.26 *Location of thermocouples in the composite slab at cross sections F, H and J*

Results

The loading bearing capacity of the test specimen was evaluated in accordance with the deflection criteria defined in BS476-21. The maximum allowable deflection was calculated as 225mm (Span/20) and the limiting rate of deflection was calculated as 7.14mm/min ($Span^2$/9000 D). This rate of deflection limit is only applied after the mid span deflection has reached a value of 150mm (Span/30). The loading was removed from the test specimen after 65 minutes when the mid span deflection was 153mm as the rate of deflection was 10mm/min in excess of maximum allowable rate of deflection.

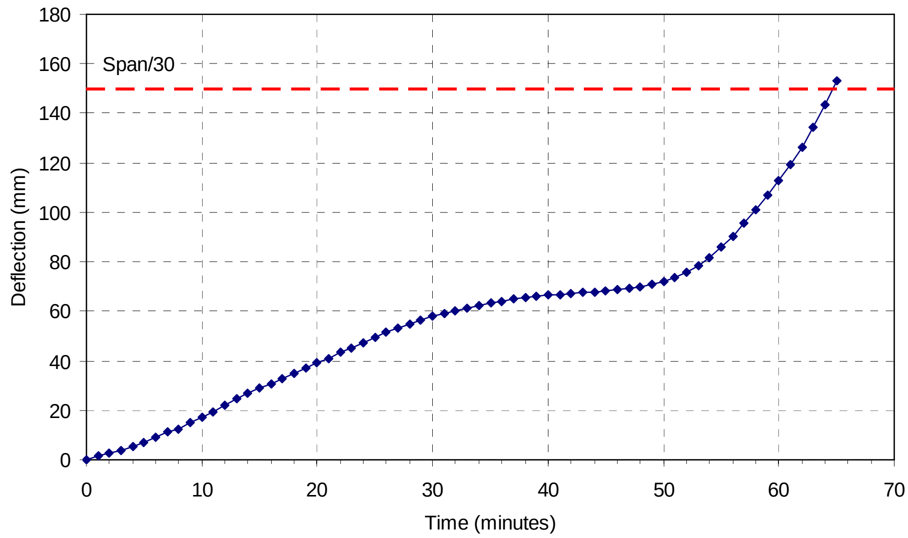

Figure 5.27 *Measured mid span deflection (WFRC 106891)*

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