The Fire Resistance of Four Shelf Angle Floor Constructions - BS476: Part 8 Fire Tests Carried out Between 24th May 1984 and 19th December 1984

British Steel Corporation
Research Organisation
THE FIRE RESISTANCE OF FOUR SHELF ANGLE FLOOR CONSTRUCTIONS

- BS476:PART 8 FIRE TESTS CARRIED OUT BETWEEN
24TH MAY 1984 AND 17TH DECEMBER 1984

G. Thomson D.J. Latham R.R. Preston

SYNOPSIS

The report summarises the results from BS476:Part 8 fire tests carried out on four separate shelf angle floor constructions based on the use of an unprotected 406 x 178 mm x 54 kg/m universal beam. A BS4360:Grade 43A beam was incorporated in three assemblies and a Grade 50B beam in the fourth. Precast concrete floor slabs, either 200 mm or 100 mm thick and 550 mm wide were supported on 125 x 75 x 12 mm angles bolted to the web of the beam. The steel beams were subjected to different applied loads, as based on BS449.

The fire resistance of each assembly was influenced by the extent of the partial protection afforded by the floor slabs and the load applied to the beam. Both the Grade 50B beam loaded to 43% of the maximum design value and the Grade 43A beam at 80% of the maximum load exceeded the 1 h fire rating with 200 mm thick concrete slabs. Neither of the Grade 43A beams with 100 mm thick slabs loaded respectively to 100% and 60% of the maximum design value were as satisfactory, but in the latter design a fire resistance of 74 min was obtained by prolonging the test to a deflection of L/20.

KEY WORDS


23rd September 1986
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THE FIRE RESISTANCE OF FOUR SHELF ANGLE FLOOR CONSTRUCTIONS
- BS476: Part 8 FIRE TESTS CARRIED OUT BETWEEN
24TH MAY 1984 AND 19TH DECEMBER 1984

1. INTRODUCTION

When a fire breaks out in an enclosure the temperature of any steel section within it will rise at a rate depending upon its Hp/A ratio. If the steel section is not fully exposed to the fire its Hp/A is effectively reduced resulting in a lower heating rate and an increase in the fire resistance time.

The concept of partial protection can be extended to shelf angle floor systems which are used in the design of multi-storey buildings to reduce the floor/ceiling void depth. Two BS476: Part 8 fire tests were carried out on unprotected BS4360: Grade 43A beams of serial size 406 x 178 mm x 54 kg/m and 305 x 165 mm x 40 kg/m respectively which were used as part of a fully loaded shelf angle floor construction. These results suggested that the use of such a design might satisfy the requirements of the Building Regulations for '1 h' buildings. However, further testing was required to determine the behaviour of other similar floors and to provide suitable 'bench mark' observations for the derivation of a mathematical model able to predict the fire resistance of the appropriate range of beam sizes, floor depths and applied loads used in this form of design.

The present report summarises the results from four BS476: Part 8 fire tests on shelf angle floor constructions, comprising 406 x 178 mm x 54 kg/m BS4360 Grade 43A beams, 125 x 75 x 12 mm BS4360 Grade 50B angles and 200 mm or 100 mm thick precast concrete floor slabs. The steel beams were subjected to different applied loads, based on BS449 and fire tested at the Warrington Research Centre between 24th May 1984 and 19th December 1984.

2. DETAILS OF CONSTRUCTION

2.1 Steel Supply

The steel sections used in each construction were obtained either from a local steel stockholder or from Lackenby Works and comprised:

- 406 x 178 mm x 54 kg/m universal beam (BS4360)
- 125 x 75 x 12 mm angles (BS4360: Grade 50B)

Samples were taken from each of the sections for chemical analysis and mechanical testing samples. The results of these tests are shown in Table 1 and the mechanical properties in Table 2. One beam was found to comply with BS4360 Grade 50B, the remaining beams were within the limits specified for BS4360 Grade 43A and the angles were within the compositional tolerances of BS4360: Grade 50B.

2.2 Fabrication of Sections

The angles were positioned on either side of the beam to leave a 210 or 110 mm gap between the upper flange of the beam and the 125 mm leg of the angle. The shorter leg of the angle was located within the gap. Holes were drilled at 60 m centres along the mid axis of the 75 mm angle leg to accommodate M20 8.8 grade bolts. In the earlier test M20 4.6 grade bolts had been used, two of which failed at one end of the test arrangement located outside the furnace. A schematic illustration showing the test assembly is given in Fig. 1.

2.3 Concrete Slabs

The concrete slabs were similar to those used in earlier tests and were cast into 1550 x 550 x 200 mm thick blocks, or 1550 x 550 x 150 mm thick blocks with one end tapering to 100 mm thick over a distance of 300 mm. The concrete contained steel reinforcement as shown in Fig. 2 and complied with BS8110: Grade 30 compressive strength.
2.4 Instrumentation

A total of 32 mineral insulated thermocouples of the chromel/alumel type, each with insulated hot junctions and an inconel sheath were used to monitor the heating rate of the steel during each test. The thermocouples were located at the positions shown in Fig. 3: in summary, five thermocouples were embedded in the lower flange of the beam, four thermocouples in the exposed part of the web, four were attached to the protected part of the web and four were attached to the upper flange of the beam. These thermocouples were located around the central part of the beam.

Nine thermocouples were embedded in the shelf angles, three on the exposed leg, three on the unexposed leg and three on the root of the angle.

Thermocouples were also installed after the construction was assembled to monitor furnace atmosphere temperatures at six positions along the beam adjacent to the lower flange.

2.5 Assembly

The beam with the angles attached was placed on the furnace in the standard position to give an effective length of 4.5 m between the roller supports. Each slab was then manoeuvred into position between the shelf angle and the upper flange to utilise a 75 mm load bearing length on the shelf angle. This left a gap of 50 mm between the end of the slab and the web of the beam. The other end of the slab rested on a wall which was built along the edges of the furnace. Two shelf angles were attached vertically. Ceramic fibre blanket material was used to cover the gap at both ends.

Once the 16 slabs were in position the 50 mm gap between the slab end and web was completely filled in with dried sand. The upper flange of the beam was also covered with a 25 mm layer of sand in order to simulate the thermal characteristics of a floor beam which is used in site practice.

Photographs of the construction during assembly are shown in Figs. 4 and 5.

2.6 Loading

The load to the beam was applied through the concrete slabs and angles to simulate service conditions. Four hydraulic jacks were positioned on either side of the beam at a distance of 0.5 m from its centreline. Loads were applied to eight points onto the concrete slabs using 1 m lengths of 152 x 152 mm x 23 kg/m universal column and local spreaders. Details of the loading calculations used in each test are given in Appendix 1. A photograph of the completed construction is shown in Fig. 6.

Deflection measurements were taken at the centre of the beam by the Warrington Research Centre staff using their potentiometric system. Additional measurements were also taken from the central concrete slabs using a theodolite system.

3. TEST RESULTS

It is convenient to consider the four tests separately and in the following order.

3.1 Grade 50 Beam - Test A

Loaded to a design stress of 100 N/mm² using 100 mm thick concrete floor slabs. This construction achieved a fire resistance period of 94 min, at which time the L/30 failure criterion in the BS476:Part 8 fire test was reached.

3.1.1 Deflection Measurements

The deflection measurements made on the beam at the centre of the construction in Test A are shown in Fig. 7. The rate of deflection was greater in the first 30 min of the test but thereafter remained almost constant until failure occurred.

2
3.1.2 Temperature Measurements

A summary of steel temperatures and furnace atmosphere temperatures at various stages during the test is presented in Table 3.

The furnace atmosphere heating curves are compared with the International temperature/time curve in Fig. 8 which shows that the heating rate was generally in accordance with the standard curve throughout the test.

Average heating curves recorded at different positions across the shelf angle beam are compared in Fig. 9. At failure there was little scatter between the temperatures measured on the lower flange which were within the range 951 to 999°C with a mean of 992°C. The final temperatures in the exposed web were within the range 964 to 981°C with a mean of 977°C; the corresponding temperature range in the unexposed part of the web was between 229 and 257°C with a mean of 243°C. The upper flange reached a mean temperature of 103°C. The final average temperatures of the exposed and unexposed angle flanges were 945 and 716°C respectively.

3.1.3 Observations

In order to check an equipment malfunction it became necessary to remove the load after 16 min into the test which was then reapplied within 60 s. The concrete slabs developed a stepwise pattern as the beam deflected and several units exhibited vertical and shear edge cracks at the end of the test. The angles deformed in a uniform manner.

All the bolts remained intact after the reload test.

3.2 Grade 43A Beam - Test B

Loaded to a design stress of 132 N/mm² using 200 mm thick concrete slabs. This construction achieved a fire resistance time of 70 min at a deflection of L/30.

3.2.1 Deflection Measurements

The deflection measurements made on the beam at the centre of the construction in Test B are shown in Fig. 10.

3.2.2 Temperature Measurements

A summary of steel temperatures and furnace atmosphere temperatures at various stages during the test is presented in Table 4.

The furnace atmosphere heating curves are compared with the International temperature/time curve in Fig. 11, which shows that the heating rate was generally in accordance with the standard curve throughout the test.

Average heating curves recorded at different positions across the shelf angle beam are compared in Fig. 12. At failure there was little scatter between the temperatures measured on the lower flange which were within the range 910 to 922°C with a mean of 914°C. The final temperatures in the exposed web were within the range 878 to 899°C with a mean of 890°C; the corresponding temperature range in the unexposed part of the web was between 172 and 219°C with a mean of 191°C. The upper flange reached a mean temperature of 94°C. The final average temperatures of the exposed and unexposed angle flanges were 839 and 613°C respectively.

3.2.3 Observations

The shelf angle floor assembly satisfied the reload test. Nothing unusual occurred during the test.

3.3 Grade 43A Beam - Test C

Loaded to a design stress of 100 N/mm² using 100 mm thick concrete slabs. This construction achieved a fire resistance time of 43 min at a deflection of L/30 and 74 min at a deflection of L/20.
3.3.1 Deflection Measurements

The deflection measurements made on the beam at the centre of the construction in Test C are shown in Fig. 13. The rate of deflection increased to a maximum of 4 mm/min and decreased to 2 mm/min after 45 min.

3.3.2 Temperature Measurements

A summary of steel temperatures and furnace atmosphere temperatures at various stages during the test is presented in Table 5.

The furnace atmosphere heating curves are compared with the International temperature/time curve in Fig. 14, which shows that the heating rate was generally in accordance with the standard curve throughout the test.

Average heating curves recorded at different positions across the shelf angle beam are compared in Fig. 15. At failure there was little scatter between the temperatures measured on the lower flange, which were within the range 907 to 921°C with a mean of 915°C. The final temperatures in the exposed web were within the range 889 to 903°C with a mean of 900°C; the corresponding temperature range in the unexposed part of the web was between 287 and 340°C with a mean of 317°C. The upper flange reached a mean temperature of 422°C. The final average temperatures of the exposed and unexposed angle flanges were 804 and 516°C respectively.

3.3.3 Observations

The two mm thick concrete slabs were used for the first time in a BS476: Part 8 fire test on a shelf angle assembly and behaved in a similar manner to the thicker blocks. After the test, none of the slabs exhibited cracking (Fig. 16(a)). The deflection of both the beam and angle was uniform (Fig. 16(b)). The assembly satisfied the reload test and all the bolts remained intact.

J.4 Grade 43A Beam - Test D

Loaded to a design stress of 165 N/mm² using 110 mm thick concrete slabs. This construction achieved a fire resistance time of 29 min at a deflection of 1/30. Copies of the letters received from the WRC confirming the general results from each test are given in Appendix 2.

3.4.1 Deflection Measurements

The deflection measurements made on the beam at the centre of the construction in Test D are shown in Fig. 17.

3.4.2 Temperature Measurements

A summary of steel temperatures and furnace atmosphere temperatures at various stages during the test is presented in Table 6.

The furnace atmosphere heating curves are compared with the International temperature/time curve in Fig. 18 which shows that the heating rate was generally in accordance with the standard curve throughout the test.

Average heating curves recorded at different positions across the shelf angle beam are compared in Fig. 19. At failure there was little scatter between the temperatures measured on the lower flange, which were within the range 724 to 738°C with a mean of 731°C. The final temperatures in the exposed web were within the range 707 to 724°C with a mean of 715°C; the corresponding temperature range in the unexposed part of the web was between 152 and 480°C with a mean temperature of 167°C. The upper flange reached a mean temperature of 97°C. The final average temperatures of the exposed and unexposed angle flanges were 571 and 368°C respectively.

3.4.3 Observations

Six minutes after the start of the test white fumes were emitted from the concrete slabs and these were present throughout the test. On completion of the experiment
the majority of the slabs contained either shear or vertical edge cracks which were located in the tapered portion of the slab and originated from the vicinity of the flange tip.

4. DISCUSSION

The serial size of beam used in these experiments has never been subjected to a BS446: Part F fire test in the unprotected form. However, a study of the changing temperature distributions measured across other unprotected steel members tested in this way suggests that a fire resistance for the 405 x 170 mm x 34 kg/m beam of 19 min would be expected when loaded to maximum design load (BS449). If the temperature profiles are used as input data to the FABRUS II finite element programme which calculates the changes in stress and deflection of a fire resistance of 23 min is predicted for a BS4360: Grade 43A section and 21 min for a Grade 50B section.

However, during a fire beneath a shelf angle floor beam the concrete floor keeps the temperatures of the top flange and the upper parts of the web to modest levels. The net result is that as the bottom flange gets hotter and gradually loses some of its load bearing capacity the neutral axis shifts upward and tensile loads begin to be taken up by the shelf angles. Hence, the time to failure under load is lower than for bare unprotected beams having the floor slabs resting on the top flanges. Clearly, the use of different precast concrete floor slab thicknesses provide more or less protection to the web of the beam. In an earlier test in which the BS4360: Grade 43A beam in a shelf angle floor construction incorporating 200 mm thick concrete slabs was loaded to the maximum design value a fire resistance time of 67 min was observed. The use of 100 mm thick slabs in the present exercise reduced the fire resistance time to 29 min.

Previous work on unprotected steel beams showed that the fire resistance was improved by reducing the stress in the centre of the tensile flange of the beam. A similar effect occurred in the shelf angle floor tests. For example, with a floor thickness of 100 mm the fire resistance time increased by 14 min as a consequence of reducing the applied load by 40%.

The shelf angle floor design offers the scope for achieving a 1 h fire resistance without recourse to passive protection. If the benefits offered by this form of construction are to be recognized in the high percentage of building designs requiring such fire resistance it is necessary to evaluate the behaviour of all potential systems. The current study has provided valuable benchmark data for use in the development of a mathematical model for predicting the performance of the remaining sections without incurring the expense of fire testing.

5. CONCLUSIONS

Four BS446: Part F fire tests were carried out on shelf angle floor constructions based on a 405 x 170 mm x 34 kg/m universal beam and 125 x 75 x 12 mm angles supporting either 200 mm or 100 mm thick precast concrete slabs. The assemblies were subjected to different applied loads, based on BS449.

The BS4360 Grade 50B beam loaded to a design stress of 100 N/mm² using 200 mm thick slabs achieved a fire resistance of 94 min.

The BS4360 Grade 43A beam loaded to a design stress of 132 N/mm² using 200 mm thick slabs achieved a fire resistance of 70 min.

The BS4360 Grade 43A beam loaded to a design stress of 100 N/mm² using 100 mm thick slabs achieved a fire resistance of 43 min and 74 min at a deflection of L/20.

The BS4360 Grade 43A beam loaded to a design stress of 165 N/mm² using 100 mm thick slabs achieved a fire resistance of 29 min.

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6. REFERENCES

1. Thomson, G., Hogan, G. and Smith, C.I., Sheffield Laboratories Report No. SH/RD/3664/1/83/B.


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D.J. Latham
Principal Investigator

R.R. Proston
Manager,
Rails and Sections Department

J. Lessells
Research Manager -
General Steel Products
| Table 1: Composition of the Stud Section Used in the Fatigue Test |
|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                 | Cr (wt%)          | Ni (wt%)          | Mo (wt%)          | Si (wt%)          | Mn (wt%)          | P (wt%)           | S (wt%)           | Cu (wt%)   |
| ST355           | 0.21              | 1.27              | 0.18              | 0.03              | 0.64              | 0.02              | 0.03              | 0.001      | 0.004 |
| ST405           | 0.11              | 1.43              | 0.14              | 0.03              | 0.89              | 0.02              | 0.03              | 0.001      | 0.005 |
| ST455           | 0.14              | 1.33              | 0.24              | 0.04              | 0.89              | 0.02              | 0.03              | 0.001      | 0.005 |

| Table 2: Tensile Test Results From Various Materials Used in the Fatigue Test |
|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                  | Tensile Strength | Ultimate Strain  | Elongation        |                  |                  |                  |                  |
|                  | (MPa)             | (%)               | (%)               |                  |                  |                  |                  |
| ST355            | 437              | 3.9               | 19.6              |                  |                  |                  |                  |
| ST405            | 554              | 4.9               | 21.2              |                  |                  |                  |                  |
| ST455            | 519              | 5.1               | 22.3              |                  |                  |                  |                  |
| Temperature, °C After Various Time, min | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| Lower Flange                           |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| P1                                     | 91 | 185 | 317 | 425 | 520 | 607 | 654 | 685 | 707 | 724 | 742 | 770 | 798 | 824 | 851 | 874 | 894 | 914 |
| P2                                     | 85 | 178 | 310 | 415 | 533 | 606 | 655 | 687 | 709 | 728 | 747 | 776 | 806 | 835 | 862 | 885 | 903 | 922 |
| P3                                     | 91 | 204 | 345 | 400 | 538 | 603 | 651 | 683 | 704 | 723 | 740 | 757 | 786 | 800 | 824 | 850 | 874 | 902 |
| P4                                     | 104 | 205 | 333 | 431 | 534 | 602 | 649 | 680 | 702 | 719 | 734 | 748 | 769 | 792 | 822 | 851 | 875 | 893 |
| Mean Lower Flange                      | 91 | 197 | 327 | 434 | 536 | 604 | 652 | 685 | 705 | 723 | 741 | 759 | 788 | 812 | 838 | 867 | 891 | 914 |
| Web 1 Position (Exposed)               | 107 | 192 | 360 | 437 | 577 | 649 | 537 | 585 | 620 | 648 | 669 | 690 | 722 | 747 | 759 | 780 | 805 | 833 |
| Web 2 Position (Exposed)               | 96 | 184 | 299 | 369 | 490 | 556 | 605 | 639 | 663 | 685 | 715 | 736 | 765 | 796 | 826 | 853 | 873 | 894 |
| Web 3 Position (Exposed)               | 153 | 204 | 304 | 396 | 505 | 660 | 685 | 716 | 737 | 767 | 800 | 830 | 856 | 888 | 909 | 934 | 952 | 979 |
| Web 4 Position (Exposed)               | 133 | 217 | 319 | 394 | 483 | 547 | 594 | 628 | 655 | 677 | 708 | 732 | 757 | 779 | 819 | 847 | 869 | 889 |
| Exposed Web                            | 110 | 197 | 304 | 386 | 481 | 547 | 596 | 630 | 657 | 679 | 710 | 733 | 758 | 790 | 819 | 847 | 869 | 890 |
| Upper Flange                           |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| P5                                     | 17 | 20 | 25 | 32 | 40 | 53 | 62 | 74 | 87 | 100 | 127 | 165 | 188 | 200 | 212 | 225 | 238 | 251 |
| P6                                     | 18 | 20 | 24 | 30 | 37 | 46 | 51 | 58 | 67 | 75 | 90 | 106 | 118 | 130 | 142 | 154 | 165 | 177 |
| Unexposed Web                          | 18 | 20 | 24 | 30 | 37 | 46 | 51 | 58 | 67 | 75 | 90 | 106 | 118 | 130 | 142 | 154 | 165 | 177 |
| Web 1 Position (Unexposed)             | 17 | 19 | 23 | 29 | 35 | 42 | 47 | 52 | 58 | 64 | 72 | 82 | 90 | 102 | 112 | 122 | 135 | 150 |
| Web 2 Position (Unexposed)             | 18 | 20 | 24 | 30 | 37 | 46 | 51 | 58 | 67 | 75 | 90 | 106 | 118 | 130 | 142 | 154 | 165 | 177 |
| Web 3 Position (Unexposed)             | 17 | 19 | 23 | 29 | 35 | 42 | 47 | 52 | 58 | 64 | 72 | 82 | 90 | 102 | 112 | 122 | 135 | 150 |
| Web 4 Position (Unexposed)             | 18 | 20 | 24 | 30 | 37 | 46 | 51 | 58 | 67 | 75 | 90 | 106 | 118 | 130 | 142 | 154 | 165 | 177 |
| Exposed Flange (Angle)                 | 67 | 133 | 202 | 257 | 326 | 391 | 447 | 482 | 504 | 545 | 556 | 566 | 587 | 605 | 661 | 704 | 738 | 766 |
| Unexposed Flange (Angle)               | 67 | 120 | 185 | 244 | 319 | 385 | 450 | 494 | 523 | 551 | 581 | 607 | 641 | 669 | 722 | 758 | 780 | 819 |
| Angle Hi                               | 40 | 41 | 46 | 51 | 58 | 69 | 79 | 85 | 93 | 101 | 115 | 130 | 148 | 165 | 182 | 204 | 230 | 260 |
| Angle Lo                               | 33 | 36 | 41 | 46 | 58 | 69 | 79 | 85 | 93 | 101 | 115 | 130 | 148 | 165 | 182 | 204 | 230 | 260 |
| Mean Angle                          | 35 | 38 | 43 | 49 | 58 | 69 | 79 | 85 | 93 | 101 | 115 | 130 | 148 | 165 | 182 | 204 | 230 | 260 |
| Mean Atmosphere                       | 636 | 601 | 649 | 697 | 762 | 767 | 761 | 781 | 803 | 815 | 835 | 864 | 875 | 905 | 927 | 945 | 960 | 977 |
| Central Beam Deflection, mm           | 7 | 11 | 20 | 29 | 39 | 50 | 60 | 69 | 79 | 85 | 108 | 119 | 130 | 148 | 165 | 182 | 204 | 230 |

**TABLE 4**

*Gusle Angle Floor Test B - Temperature Data Sheet*

<table>
<thead>
<tr>
<th>Sections</th>
<th>400 x 178 x 34 kg/m³</th>
<th>Grade 43A Beam</th>
<th>Tested at 90º of design load - BS449</th>
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**Concrete Floor**

200 mm Slabs

**Failure Time**

70 min.
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<th>Lower Flange</th>
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| Total Area | 83 |
|           |    |

| Steel Angle | 83 |
|            |    |

| Drawn Steel | 83 |
|            |    |

<p>| Steel Angle | 83 |
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<th>Temperature, °C, After Various Times, min</th>
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<td>Mean Lower Flange</td>
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<td>Web 1 Position</td>
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<td>(Exposed)</td>
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<td>W4</td>
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<tr>
<td>Mean Exposed Web</td>
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</tr>
<tr>
<td>Web 2 Position</td>
<td>W5</td>
</tr>
<tr>
<td>(Unexposed)</td>
<td>W6</td>
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<tr>
<td></td>
<td>W7</td>
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<td></td>
<td>W8</td>
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<tr>
<td>Mean Unexposed Web</td>
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<tr>
<td>Upper Flange</td>
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<td>Mean Upper Flange</td>
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<td>Exposed Flange (Angle)</td>
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<td>F11</td>
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<td>F12</td>
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<tr>
<td>Mean Exposed Flange (Angle)</td>
<td></td>
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<tr>
<td>Unexposed Flange (Angle)</td>
<td>W9</td>
</tr>
<tr>
<td></td>
<td>W10</td>
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<td></td>
<td>W11</td>
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<tr>
<td>Mean Unexposed Flange (Angle)</td>
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<tr>
<td>Angle Root</td>
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<tr>
<td>Mean Angle Root</td>
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<td>Mean Atmosphere</td>
<td></td>
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<td>ISO Curve at 24°C</td>
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<tr>
<td>Central Mean Deflection, mm</td>
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</table>
Beam size: 406 x 178 mm x 54 kg/m
Angle size: 125 x 75 x 12 mm
Bolts: M20 Grade 8.8

Dimensions in mm

SCHEMATIC ILLUSTRATION OF A TYPICAL TEST ARRANGEMENT

FIG. 1
(R1/8766)
Lifting hooks

25 mm cover

20 mm cover

A98 mesh

25 mm cover

100

Distribution bars
Y10-200 centres

Main steel Y10 MS4466
shape code 33
1550 mm

40 mm cover

A98 mesh

40 mm cover

150

Y10 Y10 Y10 Y10 Y10

550 mm

FIG. 2(a)
All dimensions in mm

Lifting nooks as necessary

25 cover  20 cover  A98 mesh

200

Distribution bars Y10-200  A98 mesh

40 cover

Y10 bars  BS4466 shape code 35

1. Concrete crushing strength
   25 N/mm² at 28 days

2. Reinforcement cold worked high yield to BS4461

PRECAST CONCRETE SLAB DESIGNS USED IN TEST

FIG. 2(b) (E2/919)
ASSEMBLY OF CONSTRUCTION

FIG. 5
CONSTRUCTION PRIOR TO TESTING

FIG. 6
CENTRAL VERTICAL DEFLECTION MEASURED ON THE 466 x 178 mm x 54 kg/m BEAM DURING TEST A

FIG. 7
COMPARISON OF FURNACE ATMOSPHERE TEMPERATURES
MEASURED IN TEST A WITH
INTERNATIONAL TIME/TEMPERATURE CURVE

FIG. 8
AVERAGE TEMPERATURES RECORDED AT DIFFERENT POSITIONS ACROSS A 454 x 178 mm x 54 kN/m SHELF ANGLE BEAM WITH 200 mm CONCRETE CAIRS IN TEST A

FIG. 9

(R2/6065)
CENTRAL VERTICAL DEFLECTION MEASURED ON THE
400 x 175 mm x 54 kg/m BEAM DURING TEST B

FIG. 10
COMPARISON OF FURNACE ATMOSPHERE TEMPERATURES
MEASURED IN TEST A WITH INTERNATIONAL TIME/TEMPERATURE CURVE

FIG. 11
Temperature, °C

Time, min

LF, UP = Lower, upper flange
W = Web, EAF = Exposed angle flange

AVERAGE TEMPERATURES RECORDED AT DIFFERENT POSITIONS ACROSS A 406 x 178 mm x 54 kg/m SHELF ANGLE BEAM WITH 209 mm CONCRETE SLABS IN TEST 2

FIG. 12 (R2/6066)

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CENTRAL VERTICAL DEFLECTION MEASURED ON THE 401 x 178 mm x 54 kg/m BEAM DURING TEST C

FIG. 13
COMPARISON OF FURNACE ATMOSPHERE TEMPERATURES MEASURES IN TEST C WITH INTERNATIONAL TIME/TEMPERATURE CURVE

FIG. 14
Temperature, °C

![Graph showing temperature over time for different materials (LP, EAP, IW, UF).](image)

**Fig. 15**

*AVERAGE TEMPERATURES RECORDED AT DIFFERENT POSITIONS ACROSS A 406 x 178 mm x 54 kg/m BEECH ANGLE BEAM WITH 100 mm CONCRETE SLABS IN THE C*

27
Cracks in 100 mm slab (a)

Uniform deflection of beam (b)

FIG. 16

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CENTRAL VERTICAL DEFLECTION MEASURED ON THE 106 x 178 mm x 54 kg/m BEAM AND CONCRETE SLABS DURING TEST D

FIG. 17
COMPARISON OF FURNACE ATMOSPHERE TEMPERATURES MEASURED ON TEST B WITH INTERNATIONAL TIME/TEMPERATURE CURVE

FIG. 18
FIG. 19

AVERAGE TEMPERATURES RECORDED AT DIFFERENT POSITIONS ACROSS A 406 x 178 mm x 84 kg/m SHELF ANGLE BEAM WITH 100 mm CONCRETE SLABS IN TEST D

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APPENDIX 1

LOAD CALCULATIONS

406 x 178 mm x 54 kg/m UB Grade 43A
125 x 75 x 12 mm Shelf Angles
Effective Span 4.5 m

Maximum safe working uniformly distributed load = 271 kN
Operating at 80% of maximum = 217 kN
60% of maximum = 163 kN

Total dead weight of cover slabs and spreader beams = 72 kN
Reaction on each shelf angle = \( \frac{72}{2} \times \frac{1}{2} = 18 \) kN

Total force required on each shelf angle to produce maximum operating stress (165 N/mm²) in test beam = \( \frac{271}{2^2} = 135.5 - 18 = 117.5 \) kN

Force required by each set of rams = \( \frac{117.5 \times 1.6}{1.1} = 171 \) kN

Force required by each ram = \( \frac{171}{4} = 42.75 \) kN

Total hydraulic forces applied = 42.75 kN x 8 = 342 kN - Test D
Total hydraulic forces applied for 80% loading = 236 kN - Test B
60% loading = 185 kN - Test C

406 x 178 mm x 54 kg/m UB Grade 50B
125 x 75 x 12 mm Shelf Angles
Effective Span 4.5 m

Safe working uniformly distributed load = 378 kN
Tested at 40% of maximum UDL = 163 kN

Total dead weight of cover slabs and spreader beams = 72 kN
Reaction on each shelf angle = \( \frac{72}{2} \times \frac{1}{2} = 18 \) kN

Total force required on each shelf angle to produce design stress in test beam = \( \frac{163}{2} = 81.5 - 18 = 63.5 \) kN

Force required by each set of rams = \( \frac{63.5 \times 1.6}{1.1} = 93.36 \) kN

Force required by each ram = \( \frac{93.36}{4} = 23.34 \) kN

Total hydraulic force applied = 23.1 kN x 8 = 185 kN

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APPENDIX 2

WARRINGTON RESEARCH CENTRE

Mr. G. Thompson
British Steel Corporation
Sheffield Laboratories
Swindon House
Moorgate
RUTHERHAM

Dear Sir,

FIRE RESISTANCE TEST RESULTS

We confine the results of a fire resistance test carried out on your behalf in accordance with BS 476: Part 8: 1972, on a steel beam of serial size 406 wc by 178 mm by 54 kg/m. Grade 50B, which supported precast reinforced concrete slabs of overall size 1550 mm long by 550 mm wide by 200 mm deep on each side of the beam. The concrete slabs were supported on a continuous angle of size 125 mm by 75 mm by 12 mm thick grade 50B on each side of the web of the beam. A total load of 184.8 kN was applied to the concrete slabs at 1/8, 3/8, 7/8 and 1/6 span positions. The load was calculated by the sponsor to be 60% of the maximum allowable for the beam. The loading was applied at a distance of 500 mm away from the centre line of the beam and each side of the beam. The ends of the concrete slabs being supported by the steel beam, were bedded in a sand and cement mortar mix. The steel beam was unprotected. The test results were as follows:

Stability: 94 minutes

Re-load Test: Satisfied

Date of Test: 24 May 1984

Our full report will follow in due course.

Yours faithfully,

L. HEALEY
Technical Officer - Structural Fire Protection
WARRINGTON RESEARCH CENTRE

W.P. Ref. 135

E. LONDON W.R.C. Civil Eng.
R. B. BARKER W.R.C. Civil Eng.
P. WILKINSON W.R.C. Civil Eng.
APPENDIX 2

Dear Sir,

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf in accordance with B.S. 476: Part 8: 1972, on a steel beam of serial no:-
406 mm x 178 mm x 54 kg/m², Grade 42A which supported precast reinforced concrete slabs of overall size 1500 mm long by 500 mm wide by 200 mm deep on each side of the beam. The concrete slabs were supported on a continuous angle of size 125 mm by 75 mm by 12 mm thick Grade 50B on each side of the web of the beam. A total load of 232 kN was applied to the concrete slabs at 1/8, 3/8, 5/8 and 7/8 span positions. The load was calculated by the sponsor to be 80% of the maximum allowable for the beam. The loading was applied at a distance of 500 mm away from the centre line of the beam on each side of the beam. The ends of the concrete slabs being supported by the steel beam, were bedded in a sand and cement mortar mix. The steel beam was unprotected. The test results were as follows:

Stability : 70 minutes
Re-load test: Satisfied
Date of test: 26th June 1984

Our full report will follow in due course.

Yours faithfully,

[Signature]

(L. HEALY)
Warrington Research Centre
APPENDIX 2

TEST C

WARRINGTON RESEARCH CENTRE

Fire Research, Testing and Consultancy

W.R.C.S.I. 35217 - IA/LMC
7 January 1985

British Steel Corporation
Sheffield Laboratories
Swinden House
Moorgate
BURY ST EDMUNDS

Dear Sirs,

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf in accordance with B.S. 476 : Part 8 : 1972 and to the draft amendment of the Standard, on a steel beam of serial size 456 mm x 178 mm x 54 kips, Grade 43A which supported precast reinforced concrete slabs of overall size 1550 mm long x 550 mm wide x 110 mm deep with one end of the concrete slabs tapering to 100 mm deep over a distance of 300 mm. The concrete slabs were positioned on each side of the beam. The concrete slabs were supported on a continuous angle of size 175 mm x 75 mm x 12 mm thick Grade 50 on each side of the web of the beam. The tapered ends of the concrete slabs rested on to the continuous angles. A total load of 184.8 kN was applied to the concrete slabs at 1/8, 3/8, 5/8 and 7/8 span positions. The load was calculated by the sponsor to be 620 kN of the maximum allowable for the beam. The loading was applied at a distance of 500 mm away from the central line of the beam on each side of the beam. The ends of the concrete slabs being supported by the steel beam, were bedded in a sand and cement mortar mix. The steel beam was unprotected. The test results were as follow:

- Stability (L/35) : 134 minutes
- Stability (L/25) : 74 minutes (Test discontinued)
- Re-load test : Satisfied
- Date of Test : 15 December 1984

Yours faithfully,

L. RENLEY
Warrington Research Centre
APPENDIX 2

TEST D

WARRINGTON RESEARCH CENTRE
For Research, Testing and Consultancy

W.R.C. I.T. No. 34142 - 12/84

British Steel Corporation
Sheffield Laboratories
Swindon House
Newgate, Rotherham

Dear Sirs,

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf in accordance with B.S. 476: Part 8: 1977, on a steel beam of serial size 406 mm x 178 mm x 54 kg/m. Grade 43A which supported prestressed reinforced concrete slabs of overall size 2.550 m long by 5.50 m wide by 1.50 m deep with one end of the concrete slabs tapering to 1.00 m deep over a distance of 500 mm. The concrete slabs were positioned on each side of the beam. The concrete slabs were supported on a continuous angle of size 125 mm by 75 mm by 12 mm thick Grade 50 on each side of the web of the beam. The tapered ends of the concrete slabs rested on to the continuous angles. A total load of 352 kN was applied to the concrete slabs at 1/8, 1/8, 1/8 and 7/8 span positions. The load was calculated by the sponsor to be 100% of the maximum allowable for the beam. The loading was applied at a distance of 500 mm away from the central line of the beam on each side of the beam. The ends of the concrete slabs being supported by the steel beam, were bedded in a sand and cement mortar mix. The steel beam was unproctected. The test results were as follows:

Stability: 28 minutes
Re-load test: Satisfied
Date of test: 11th July 1984.

Yours faithfully,

[Signature]

(L. HAILEY)

Warrington Research Centre
INITIAL CIRCULATION

Swinden Laboratories
Mr. T.M. Kay
Dr. B.R. Kirby
Mr. J. Lessells
Mr. D.E. Wainman
Mr. E.F. Walker

Teesside Laboratories
Dr. R. Baker

GENERAL STEELS GROUP

BSC Plates, Sections and Commercial Steels

Swinden Laboratories
Mr. T.M. Kay
Dr. B.R. Kirby
Mr. J. Lessells
Mr. D.E. Wainman
Mr. E.F. Walker

Teesside Laboratories
Dr. R. Baker

GENERAL STEELS GROUP

BSC Plates, Sections and Commercial Steels

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Mr. J.T. Robinson
Mr. M.J. Thorndike

Sconthorpe
Dr. M.J. Pettifor
Dr. T.J. Pike

Lackenby
Mr. C. Mortlock
Mr. E.D. Smith