BS 476: Part 21 Fire Resistance Tests
Summary of Data Obtained During a Test
on a Shelf Angle Floor Beam
SUMMARY

BS 467:PART 21 FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING A TEST ON A SHELF ANGLE FLOOR BEAM

D.E. Wainman

During the five years 1989-‘93 Swinden Technology Centre carried out more than thirty standard fire resistance tests on hot rolled structural steel sections. Data arising from the tests are being summarised in a series of reports, each one dealing with either a different form of construction or a generic group of test assemblies.

This is the sixth report issued as part of that series. It contains a detailed description of the design, instrumentation and construction for a single test assembly, usually referred to as the 'control' shelf angle floor beam, together with the data arising from it. The test was carried out at the Warrington Fire Research Centre.

The serial size for the steel section used was 406 x 178 mm x 54 kg/m UB. The steel grade was BS 4360:Grade 43A (now BS EN 10025 S275). The section was loaded so as to develop a bending stress of 165 N/mm², (the maximum likely service stress for such a section), in the lower flange. The performance of the test assembly was judged against the load bearing capacity criterion outlined in Section 5 of BS 476:Part 21:1987. The fire resistance rating for the assembly was found to be 49 minutes.

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BS 476: PART 21: FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING A TEST ON A SHELF ANGLE FLOOR BEAM

1. INTRODUCTION

Between 1989 and 1993 more than 30 full scale fire resistance tests were carried out on a wide range of structural assemblies. The major features of all the tests were summarised in an earlier Technical Note\(^\text{11}\). Data obtained during the tests are being presented in a series of reports, each of which is concerned with either a different form of construction or a generally similar group of test assemblies. The first report in the series was issued in 1993\(^\text{12}\) and included material relating to eight fire tested slim floor beams. Subsequent reports have given details relating to:

- five web encased column assemblies\(^\text{13}\),
- tests on connections between beams and columns\(^\text{14}\),
- a single test on an arched metal deck floor\(^\text{15}\) and
- a single test on a composite slim floor beam\(^\text{16}\).

This is therefore the sixth report issued as part of that ongoing series. It contains a detailed description of the design, instrumentation and construction for a single test assembly, together with the data arising from it which are included in Appendix I. The test assembly was a shelf angle floor beam construction. The test was carried out at the instigation of the Steel in Fire Forum (STIFF), and was designed to check on the accuracy of the various structural models developed by the participating organisations. The assembly is usually referred to as the 'control' shelf angle floor beam. The data are presented in a format which is generally consistent with that of the earlier publications. As before, no analysis of the data is included since this has already been incorporated into other publications dealing with design aspects of this form of construction. The numerical sequence of the data sheets has been maintained, the one in this document being numbered 127\(^\text{11}\). As in the previous compendia and reports the thermal data are reduced to summary values at various times throughout the duration of the test. It should be noted, however, that all the thermal data, usually recorded at one minute intervals, can be made available on a PC disk. (Refer to comments in Appendix 3.) This may be obtained, on request, from British Steel, Swindon Technology Centre.

The work reported here forms part of an ongoing research programme concerned with the evaluation and prediction of the performance of constructional steelwork in fire. Readers are therefore reminded to exercise caution when using any single test result and not to take it out of context with data for other tests of a similar nature.

2. TEST ASSEMBLY WRC 46737

The test assembly consisted of a 5 metre length of 406 x 178 mm x 54 kg/m universal beam section and two 5 metre lengths of 125 x 75 x 12 mm hot rolled angle. These were attached, by welding, one each side of the beam, such that the distance between the under-sides of the top flange and the inside face of the angle was 210 mm. Furthermore, they were positioned so that the 125 mm long leg was perpendicular to the web of the section. All the webs were 6 mm intermittent fillets. Those along the top edge of the angle were 50 mm in length with 100 mm gaps, whilst those along the lower edge were 25 mm long at 500 mm centres.
The floor was constructed using 50 pre-stressed concrete slabs supplied by ECC Building Products Ltd, based in Swindon. Each slab had nominal dimensions of 150 x 100 x 1500 mm and contained two steel reinforcing bars running the full 1500 mm length. They were arranged, 25 on each side of the beam, so that they spanned the width of the furnace, resting loosely on the furnace walls and steel angles. The slabs overlapped onto the angles by a distance of 75 mm and were laid such that the thickness of the floor was 100 mm. Each slab was insulated from the adjacent ones by tightly packed 12 mm thick ceramic fibre blanket. The cavity formed between the ends of the slabs and the web of the steel section was filled with fine dry sand which also covered the top flange of the beam to a depth of approximately 30 mm. It was considered that the concrete floor did not provide any additional strength to the beam and therefore was not classed as a composite structure.

A transverse section through the assembly showing the arrangement of the various components is given in Fig. 1. All the steel used in the construction of the test assembly was manufactured by British Steel and was supplied to the requirements of either BS 4360:Grade 43A (beam), or Grade 50B (angles). These grades are now BS EN 10025 S275 and S355JR respectively. Details of their chemical compositions and mechanical properties are included in Data Sheet No. 127A in Appendix 1.

The age of the concrete lintels was unknown. The density and moisture content of a typical sample, measured on the day of the test, were reported as being:

- **Density:** 2260 kg/m³
- **Moisture Content:** 4.6% w/w

The compressive strength of the lintels was not reported.

The density of the ceramic fibre insulation used in the floor construction, measured on the day of the test, was found to be 97.1 kg/m³.

### 3. DIMENSIONS AND SECTION PROPERTIES

The nominal dimensions and section properties, as specified in BS4:Part 1:1980 for the steel sections used in the construction of the test assembly are included in Data Sheet No. 127A. The actual dimensions of the sections are also given, together with the calculated section properties.

### 4. INSTRUMENTATION

The test assembly was instrumented such that the temperature attained by the steel sections could be recorded throughout the duration of the heating period. For this purpose fifty-five 3 mm diameter mineral insulated "K" type thermocouples, (NiCr / NiAl), with insulated hot junctions and Inconel 600 sheaths were used. The thermocouples were embedded to the mid-thickness position in the steel sections. The thermocouple positions were as shown in Fig. 2, (longitudinal arrangement), and Figs. 3-6, (transverse arrangements).

Thermocouples of the same type were installed by WFRSC for monitoring the temperature of the furnace atmosphere. These were situated at eight positions within the furnace, being evenly distributed on each side of the assembly, level with the soffit of the beam and 100 mm away from the toe of the lower flange.

 Provision was also made for monitoring the vertical deflection of the assembly throughout the test. These measurements were made at the geometric centre of the upper, (concrete), surface using a
displacement, transducer-connected to the WfRC data logging facility. The deflection values recorded are included in Data Sheet No. 127B in Appendix 1.

5. ASSEMBLY

The test assembly was positioned so as to form part of the roof of the floor furnace at WfRC. It was simply supported on a refractory lined steel loading frame so as to give a total effective span between the roller supports of 4500 mm. This frame was supported on the outer walls of the gas-fired furnace so that the length of beam actually exposed to the heating conditions of the test was 4000 mm.

6. LOADING

A total imposed load of 20.0 tonnes was applied to the steel section by means of two hydraulic rams positioned along the centre line of the web and at points corresponding to 1/4 and 3/4 of the supported span. The applied load, together with the self weight of the system, was intended to develop a bending stress of 165 N/mm² in the lower flange of the steel section. This is the is the maximum allowable bending stress for a BS4360: Grade 43A steel section according to the design rules in BS449: Part 2: 1969. The applied load was kept constant for the first 54 minutes of the test, at which time it was removed.

The load to be applied to the test assembly was initially calculated on the basis of the nominal dimensions and section properties for the steel member concerned. These calculations were subsequently repeated to take account of the actual dimensions and mechanical properties of the section. Calculations relating to the applied load level are given in Appendix 2. A comparison of the calculation data to BS950: Part 1: 1985 is also included.

7. FAILURE CRITERIA

The performance of the test assembly was judged against the load bearing capacity criterion outlined in Section 5 of BS476: Part 21: 1987. The maximum allowable deflection and the maximum allowable rate of deflection for the test assembly, as specified by the standard, were calculated to be 225 mm., (span/ 20), and 5.5 mm/min., (span² x D), respectively, where D = 405 mm, the measured depth of the section. The allowable rate of deflection criterion is not applicable until the deflection exceeds span / 30, i.e. 150 mm.

The assembly attained a deflection of 152 mm after 47 minutes. The maximum allowable rate of deflection criterion was exceeded after 49 minutes. A mid-span deflection of 207 mm was attained after 54 minutes at which time the rate of deflection was 11 mm/min. The load was removed at this time but heating of the assembly continued for a further 16 minutes in order to obtain additional thermal data.

In accordance with the failure criteria outlined above the load bearing capacity of the beam was deemed to be 49 minutes.

8. CONCLUSIONS

1. Data arising from a standard fire resistance test carried out on a shelf angle floor beam have been collected and reported. Details of the test assembly are given, together with a summary of the material properties, structural calculations and the thermal data recorded.

5
The performance of the test assembly was judged against the load bearing capacity criterion outlined in Section 5 of BS 476:Part 21:1987. The fire resistance rating for the assembly was found to be 49 minutes.

D.E. Wainman
Investigator

D.M. Martin
Manager
Product Design & Engineering

REFERENCES


FIG. 2  THERMOCOUPLE POSITIONS IN THE STEELWORK - LONGITUDINAL ARRANGEMENT

(D0303C05)
THERMOCOUPLE POSITIONS IN THE STEELWORK - TRANSVERSE ARRANGEMENT AT POSITION 'B' IN DIRECTION OF ARROW X IN FIG. 2

FIG. 4

F4
FIG. 5
THERMOCOUPLE POSITIONS IN THE STEELWORK - TRANSVERSE ARRANGEMENT
AT POSITION 'C' IN DIRECTION OF ARROW 'x' IN FIG. 2

(All dimensions in mm)
FIG. 6
THERMOCOUPLE POSITIONS IN THE STEELWORK - TRANSVERSE ARRANGEMENT
AT ALL OTHER POSITIONS IN DIRECTION OF ARROW 'x' IN FIG. 2

(All dimensions in mm)
APPENDIX 1

DATA SHEET NO. 127
### SHELF ANGLE FLOOR BEAM

#### DIMENSIONS AND PROPERTIES

<table>
<thead>
<tr>
<th>Section Size</th>
<th>Depth of Section (mm)</th>
<th>Width of Section (mm)</th>
<th>Thickness (mm)</th>
<th>Elastic Modulus (kN/mm²)</th>
<th>Plastic Modulus (kN/mm²)</th>
<th>Moment of Inertia (cm⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>406 x 178</td>
<td>177.6</td>
<td>7.5</td>
<td>10.9</td>
<td>955.3</td>
<td>114.5</td>
<td>1048</td>
</tr>
<tr>
<td>Beam</td>
<td>402.6</td>
<td>7.87</td>
<td>10.50</td>
<td>113.2</td>
<td>109.3</td>
<td>1040</td>
</tr>
<tr>
<td>125 x 76 x 12</td>
<td>75</td>
<td>12</td>
<td>45.2</td>
<td>15.9</td>
<td>77.56</td>
<td>31.42</td>
</tr>
<tr>
<td>Angle</td>
<td>124</td>
<td>12.5</td>
<td>43.4</td>
<td>17.6</td>
<td>79.24</td>
<td>32.72</td>
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#### CHEMICAL COMPOSITION (PRODUCT ANALYSIS - Wt. %)

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<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>V</th>
<th>Cu</th>
<th>Nb</th>
<th>Al</th>
<th>N</th>
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<tr>
<td>Beam</td>
<td>0.11</td>
<td>0.24</td>
<td>1.28</td>
<td>0.017</td>
<td>0.022</td>
<td>&lt;0.005</td>
<td>&lt;0.02</td>
<td>&lt;0.005</td>
<td>0.03</td>
<td>&lt;0.005</td>
<td>0.0047</td>
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<tr>
<td>Angle</td>
<td>0.11</td>
<td>0.30</td>
<td>1.33</td>
<td>0.016</td>
<td>0.011</td>
<td>&lt;0.005</td>
<td>0.02</td>
<td>0.060</td>
<td>0.08</td>
<td>&lt;0.005</td>
<td>0.031</td>
<td>0.002</td>
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#### ROOM TEMPERATURE TENSILE PROPERTIES

<table>
<thead>
<tr>
<th>Test Type</th>
<th>LYS (N/mm²)</th>
<th>UTS (N/mm²)</th>
<th>Elongation (%)</th>
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<tbody>
<tr>
<td>Beam</td>
<td>375</td>
<td>494</td>
<td>39.5</td>
</tr>
<tr>
<td>Angle</td>
<td>307</td>
<td>518</td>
<td>29</td>
</tr>
</tbody>
</table>

### TEST CONDITIONS

- Inset ambient temperature = 25°C.
- Based on an initial ambient temperature of 20°C.
- No cold work recorded.
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>THERMOCOUPLE</th>
<th>TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)</th>
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<tr>
<td>Upper Flange</td>
<td>F9</td>
<td>26 26 26 26 27 27 29 31 33 33 34 41 41 55 62 72 85 98 109</td>
</tr>
<tr>
<td>T5</td>
<td>25 25 25 26 27 28 29 31 33 33 36 42 42 55 63 73 83 101 110</td>
<td></td>
</tr>
<tr>
<td>T21</td>
<td>25 26 26 26 27 28 29 31 33 34 37 44 44 52 61 69</td>
<td></td>
</tr>
<tr>
<td>T31</td>
<td>26 26 27 27 27 28 29 31 33 33 35 40 47 54 61</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>26 26 26 26 27 27 29 31 33 33 36 42 49 57 64 73 87 100 110</td>
<td></td>
</tr>
</tbody>
</table>

Unexposed Web | 10 mm Below U.F. | 25 25 25 26 27 30 33 37 42 47 53 65 77 90 100 115 137 149 161 |

71 mm Below U.F. | W5 | 20 25 30 36 44 53 65 77 94 107 124 157 178 194 218 270 212 287 292 |
| W6 | 25 27 30 37 47 59 73 88 105 120 144 173 195 212 231 258 276 292 |
| T19 | 25 27 31 38 49 62 77 94 111 127 156 182 206 223 245 270 287 303 |
| W7 | 25 27 31 38 48 60 74 89 104 119 146 169 191 206 226 248 266 282 |
| T30 | 25 27 31 38 47 58 71 86 101 115 132 156 182 207 232 271 305 363 |
| W6 | 28 32 38 47 58 71 86 101 115 142 166 192 219 245 272 307 357 411 |
| Mean | 25 27 31 37 47 58 72 87 103 118 145 169 191 207 226 251 268 284 |

10 mm Above Top of Angle | T18 | 27 35 52 76 105 139 174 208 240 269 318 371 422 450 482 506 528 |
| T29 | 26 34 47 62 92 120 149 178 206 232 272 303 329 350 376 403 439 462 |
| Mean | 27 35 50 72 99 130 162 193 223 251 296 332 363 386 413 448 473 495 |

10 mm Below Top of Angle | T19 | 29 43 68 103 143 184 226 266 305 340 379 416 446 486 513 544 577 602 627 |
| T28 | 30 43 66 97 135 175 215 254 292 329 370 413 444 486 519 546 577 605 |
| Mean | 30 43 67 100 139 180 221 260 299 336 383 430 465 490 519 550 590 616 |

20 mm Above Inside Face of Angle | T16 | 32 51 83 124 168 213 259 303 345 382 434 494 532 564 595 628 654 679 |
| Mean | 40 68 112 162 214 266 317 366 411 450 516 576 608 638 669 702 730 755 |

Exposed Web | 10 mm Below Angle | T4 | 80 142 225 294 361 425 479 539 573 609 669 716 751 778 812 846 870 887 |
| T24 | 110 176 257 327 391 447 496 543 579 614 669 707 739 762 792 825 849 866 |
| Mean | 95 159 241 311 376 436 488 536 576 612 669 712 745 770 802 836 860 877 |

80 mm Above U.F. | W4 | 101 198 308 438 492 550 614 657 691 718 760 798 828 846 870 888 916 924 |
| W3 | 113 213 347 441 526 659 682 713 740 781 820 864 886 914 932 947 966 984 |
| T3 | 112 210 335 438 524 659 694 717 741 776 824 867 896 929 947 966 984 999 |
| W2 | 123 233 344 447 539 610 647 687 718 749 787 825 863 897 918 933 942 950 |
| T23 | 117 213 327 430 515 598 628 671 702 729 759 807 831 856 880 900 924 937 |
| W1 | 124 219 325 422 504 591 619 656 694 726 762 801 826 845 865 884 912 919 |
| Mean | 115 212 330 431 515 583 632 647 704 732 772 813 837 856 880 900 924 937 |

Lower F.W. Junction | T2 | 91 197 332 452 547 618 668 707 735 758 801 859 900 924 940 950 956 958 |

Lower Flange | F4 | 203 318 455 557 626 673 711 739 758 803 837 862 895 929 948 951 957 961 |
| F7 | 104 222 360 478 570 638 684 721 745 766 813 847 889 905 929 951 956 960 |
| F3 | 113 224 367 482 571 637 683 719 743 766 811 843 885 908 932 951 961 970 |
| F6 | 107 225 362 479 572 648 686 723 747 771 817 849 879 908 930 956 961 964 |
| T22 | 114 217 352 466 555 620 677 707 733 762 796 828 849 876 905 929 932 937 |
| Mean | 108 221 358 474 556 632 679 716 741 763 808 841 863 881 902 924 940 948 |

(Cont. ...)
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TEMPERATURE Deg, C AFTER VARIOUS TIMES (MINUTES)</th>
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<tbody>
<tr>
<td>Unexposed Flange of Angle 10 mm Below Tip</td>
<td></td>
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<tr>
<td>T11</td>
<td>27 38 57 86 121 161 201 240 278 316 367 415 454 480 509 543 571 597 621</td>
</tr>
<tr>
<td>T14</td>
<td>28 42 66 100 140 181 223 265 304 339 376 415 464 486 514 544 578 603 627</td>
</tr>
<tr>
<td>Mean</td>
<td>28 40 62 93 131 211 273 291 326 383 432 470 497 526 561 587 612 637 662</td>
</tr>
<tr>
<td>20 mm Above Inside Face</td>
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</tr>
<tr>
<td>W9</td>
<td>31 47 75 111 152 195 238 283 324 360 396 448 490 509 538 571 609 635 659</td>
</tr>
<tr>
<td>W10</td>
<td>32 48 77 115 158 203 249 293 335 373 432 481 521 548 580 616 642 666 688</td>
</tr>
<tr>
<td>T10</td>
<td>32 50 81 121 166 212 258 303 345 383 444 494 538 587 596 632 658 684</td>
</tr>
<tr>
<td>T11</td>
<td>34 49 79 118 162 207 253 297 339 378 437 490 532 561 593 656 685 617</td>
</tr>
<tr>
<td>W11</td>
<td>32 50 79 118 163 209 255 299 342 380 400 440 500 531 561 619 653 686 680</td>
</tr>
<tr>
<td>Mean</td>
<td>32 49 78 117 160 205 251 295 337 374 434 478 525 577 587 622 648 673</td>
</tr>
<tr>
<td>10 mm Above Inside Face</td>
<td></td>
</tr>
<tr>
<td>T9</td>
<td>35 57 93 138 186 240 290 339 385 425 450 490 544 581 616 649 683 711 737</td>
</tr>
<tr>
<td>T12</td>
<td>37 62 101 148 199 251 303 353 400 440 480 507 552 606 658 688 720 756</td>
</tr>
<tr>
<td>Mean</td>
<td>36 60 97 143 194 245 296 346 394 436 493 539 587 626 659 693 721 747</td>
</tr>
</tbody>
</table>

**Exposed Flange of Angle 10 mm from Tip**

| Tip       | 65 120 200 276 361 425 484 545 593 635 685 735 774 800 830 867 913  |
| T6       | 72 123 194 266 338 408 468 525 569 608 667 710 743 764 797 834 862 883  |
| Mean     | 69 122 197 271 345 417 478 535 581 621 681 742 785 814 851 876 898 921 |

**60 mm from Web**

| Web       | 77 126 182 239 304 370 429 484 532 573 637 687 727 753 784 823 849 871 |
| T6       | 84 108 176 242 309 377 438 494 543 584 649 699 730 761 791 832 861 884  |
| T8       | 76 117 183 246 310 377 437 491 547 587 650 709 739 769 796 824 857 890  |
| Mean     | 72 117 179 241 307 372 431 486 534 575 639 687 724 749 780 820 849 872 |

**30 mm from Web**

| Web       | 63 100 157 215 277 340 398 452 501 542 590 641 697 729 765 825 864  |
| Angle Root | 40 65 103 149 200 255 310 364 414 457 525 580 623 663 673 723 751 779  |
| T8       | 42 72 119 171 227 283 339 391 435 480 546 600 643 671 703 737 767 796  |
| T27      | 41 65 105 154 207 261 315 366 414 453 519 569 606 635 660 707 736 761 786  |
| Mean     | 41 67 109 158 211 266 321 374 424 464 520 583 625 685 686 722 751 779  |

**At 1500 mm from Mid Span**

| Upper Flange Unexposed Web, 71 mm Below U.F. | |
| Erupted Web, 80 mm Above U.F. | |
| Lower Flange Exposed Flange of Angle, 60 mm from Web | |
| Angle Root | |
| Mean Furnace Gas | 509 614 690 723 762 791 811 831 845 866 886 905 922 932 944 972 980 981  |
| Standard Curve | 502 603 662 705 736 765 788 808 826 841 864 884 902 915 929 945 957 968  |
| Deflection (mm) | 5 15 27 40 50 59 69 78 87 96 110 125 142 162 207  |
| Deflection Rate (mm/min) | 2 4 4 4 4 3 3 3 3 3 3 3 3 3 6 11  |
APPENDIX 2

LOAD CALCULATION SUMMARY SHEETS

A2.1  TEST NO. WFRC 46737 ON 31 MAY 1990
A2.2  CALCULATIONS BASED ON BS449:PART 2:1969
A2.3  CALCULATIONS BASED ON BS5950:PART 1:1985
A2.4  COMPARISON OF LOADINGS

A2/1
A2.1 TEST NO. WFRC 46737 ON 31 MAY 1990

A2.1.1 Geometry

Figure 1 gives the relevant details

A2.1.2 Material Properties

(a) Steel

Universal Beam - 406 x 178 mm x 54 kg/m
Steel Grade - BS4360 Grade 43A

(b) Summary of Nominal and Actual Dimensions and Properties

<table>
<thead>
<tr>
<th>Nominal</th>
<th>Actual</th>
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</thead>
<tbody>
<tr>
<td>Depth of Section</td>
<td>h (mm)</td>
</tr>
<tr>
<td>Breadth of Section</td>
<td>b (mm)</td>
</tr>
<tr>
<td>Thickness of Flange</td>
<td>t (mm)</td>
</tr>
<tr>
<td>Thickness of Web</td>
<td>a (mm)</td>
</tr>
<tr>
<td>Area of Section</td>
<td>A (mm²)</td>
</tr>
<tr>
<td>Mass</td>
<td>m (kg/m)</td>
</tr>
<tr>
<td>Weight</td>
<td>m (N/m)</td>
</tr>
<tr>
<td>Distance of Neutral Axis from Base of Beam</td>
<td>y (mm)</td>
</tr>
<tr>
<td>Effective Span of Beam</td>
<td>L (mm)</td>
</tr>
<tr>
<td>Moment of Inertia (x-x')</td>
<td>I (cm⁴)</td>
</tr>
<tr>
<td>Elastic Modulus (x-x')</td>
<td>E (cm⁴)</td>
</tr>
<tr>
<td>Plastic Modulus (x-x')</td>
<td>S (cm³)</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>E (kN/mm²)</td>
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<tr>
<td>Design Strength</td>
<td>f (N/mm²)</td>
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<tr>
<td>Classification</td>
<td>Class 1, Plastic (Table 7, BS5950)</td>
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</tbody>
</table>

(c) Concrete

The maximum moisture content of the concrete slabs, measured on the day of the test, was found to be 4.6%. Their density was reported to be 2260 kg/m³. The density of normal weight concrete is typically 2400 kg/m³.
(d) Summary of Nominal and Actual Dimensions and Properties

<table>
<thead>
<tr>
<th></th>
<th>Nominal</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth d (mm)</td>
<td>100</td>
<td>103</td>
</tr>
<tr>
<td>Width w (mm)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Length l (mm)</td>
<td>1 550</td>
<td>1 550</td>
</tr>
<tr>
<td>Area of Section A_s  (mm²)</td>
<td>15 000</td>
<td>15 450</td>
</tr>
<tr>
<td>Mass m_s (kg/m)</td>
<td>36.0</td>
<td>34.9</td>
</tr>
<tr>
<td>Weight m_s (N/m)</td>
<td>353.2</td>
<td>342.5</td>
</tr>
<tr>
<td>Density D_s (kg/m³)</td>
<td>2 400</td>
<td>2 260</td>
</tr>
</tbody>
</table>

A2.2 CALCULATIONS BASED ON BS449:PART 2:1969

In the following calculations any contribution made by the shelf angles is ignored.

A2.2.1 Calculations Using Nominal Dimensions and Properties

Maximum allowable bending stress, Table 2, (for steel with a minimum yield stress of 275 N/mm²):

\[ f_{\text{max}} = 165 \text{ N/mm}^2 \]

Percentage of allowable bending stress required during the test is 100%.

Therefore, bending stress required is 165 N/mm²

\[ f = 165 \text{ N/mm}^2 \]

The required bending moment is given by \((f I)/y\).

\[ \frac{f I}{y} = \frac{wL^2}{8} \]

Therefore, \(w\), the load per metre run, (in N/m), is given by:

\[ w = \frac{8fI}{yL^2} = \frac{8 \times 165 \times 18.628 \times 10^7}{201.3 \times 4500 \times 4500} \text{ N/m} = 60.215 \text{ N/m} \]

The concrete load per metre run is 353.2 N.

Total Self Weight of Beam and Concrete Slabs, (Dead Load).

\[ w_t = 530 + 353.2 \text{ N/m} = 883.2 \text{ N/m} \]

A2/3
Total load to produce required bending stress

\[ w_2 = 60.315 - 883.2 \text{ N/m} \]
\[ = 59.432 \text{ N/m} \]

Therefore total imposed load

\[ W = 59.432 \times 4.5 \text{ N} \]
\[ = 267.444 \text{ N} \]
\[ = 267.44 \text{ kN} \]

Using two point loads at \( \frac{1}{4} \) and \( \frac{3}{4} \) of the supported span, equivalent to \( W/2 \).

Point Loads Required are:

\[ P = \frac{267.44}{2} \text{ kN} \] (i.e. 27 262 / 2 kg)
\[ = 133.72 \text{ kN} \] (i.e. 13 331 kg)
\[ \approx 13.63 \text{ tonnes} \]

The total load actually applied was 20.0 tonnes.

A2.2.2 Retrospective Calculations Using Actual Dimensions and Properties

The required bending moment is given by (fl) / y

\[ f l \]
\[ y \]
\[ = \frac{w L^2}{8} \]

Therefore, \( w \), the load per metre run, (in N/m), is given by

\[ w = \frac{8 f l}{y L^2} \]
\[ = \frac{8 \times 18 \times 493 \times 10^7}{302.5 \times 4500 \times 4500} \text{ N/m} \] ... (A2/1)

Since the load actually applied was 20.0 tonnes

\[ W = 20 \text{ 000 kg} \]
\[ = 196 \text{ 200 N} \]
and therefore the total load generating the bending stress is

\[ w_2 = \frac{196200}{4.5} \text{ N/m} \]
\[ = 43800 \text{ N/m} \]

The concrete load per metre run is 342.5 N.

Total self-weight of the Beam and Concrete Slabs is given by

\[ w_i = 526 + 342.5 \text{ N/m} \]
\[ = 868.5 \text{ N/m} \]

Therefore the load available to generate a bending moment is

\[ w = 43600 + 868.5 \text{ N/m} \]
\[ = 44468.5 \text{ N/m} \]

Substituting \( w \) in the earlier expression (A2/1) we have:

\[ 44468.5 = \frac{8 \times 18493 \times 10^7}{202.5 \times 4500 \times 4500} \text{ N/mm}^2 \]

\[ \therefore f = \frac{44468.5 \times 202.5 \times 4500 \times 4500}{8 \times 18493 \times 10^7} \]
\[ = 123.3 \text{ N/mm}^2 \]

The retrospective calculation, based on actual dimensions and properties, suggests that the steel section was loaded to 74.7% of the maximum allowable bending stress (BS449 Design Rules).

A2.3 CALCULATIONS BASED ON BS5950:PART 1:1985

In the following calculations any contribution made by the shear angles to the moment capacity of the beam is ignored.

A2.3.1 Initial Calculations Using Nominal Dimensions and Properties

(a) Moment Capacity of beam for a plastic or compact section, with assumed low shear load.

\[ M_0 = p_s S \text{ but} \leq 1.2 p_s Z \]
\[ = 275 \times 10^3 \times 10^3 \text{ kN m} \]
\[ = 288.2 \text{ kN m} \]
Check whether $p_r S \leq 1.2 p_r Z$

$$1.2 \ p_r Z = 1.2 \times 275 \times 225.3 \times 10^{-3} \text{ kN m}$$

$$= 305.3 \text{ kN m}$$

So $p_r S$ is less than $1.2 p_r Z$

(b) From A2.2.1, Self Weight of beam and Concrete Slabs, (dead load), is 883.2 N/m

So $w = 0.8832 \text{ kN/m}$

Moment produced by dead load is given by

$$M_1 = \frac{(w \times L^2)}{8} \text{ kN m}$$

$$= \frac{0.8832 \times 4.5 \times 4.5}{8} \text{ kN m}$$

$$= 2.2356 \text{ kN m}$$

From A2.2.1, Total Imposed Load is 267 444 N.

So $W = 267,444 \text{ kN}$

Assuming a uniformly distributed load, the moment produced by the imposed load is given by

$$M_2 = \frac{(W \times L)}{8} \text{ kN m}$$

$$= \frac{267,444 \times 4.5}{8} \text{ kN m}$$

$$= 150,437 \text{ kN m}$$

Total Moment Applied, (dead + imposed loads)

$$M_e = 2,2356 + 150,437 \text{ kN m}$$

$$= 152,673 \text{ kN m}$$

Since $M_e$ also equals the applied moment at the fire limit state, $M_a$, then the load ratio is

$$LR = \frac{M_a}{M_e}$$

$$= 152.673 / 288.2$$

$$= 2.530$$

(c) Check Shear Force, ($F_s$), does not exceed shear capacity, ($P_s$)

Maximum Shear Force at the ends

A2/6
\[ F_v = \frac{wL}{2} \]
\[ = \frac{(60.315 \times 4.5)}{2} \text{ kN} \]
\[ = 135.71 \text{ kN} \]

Shear Capacity
\[ P_v = 0.6 p_e A_v \]
where \( A_v \) is the shear area.

For an I section \( A_v = h \times s \)
\[ \therefore P_v = 0.6 \times 275 \times 402.6 \times 7.6 \times 10^{-6} \text{ kN} \]
\[ = 504.86 \text{ kN} \]

Therefore since \( F_v < P_v \), the low shear load calculation, (a), is acceptable.

**A2.3.2 Calculations Using Actual Dimensions and Properties**

(a) Moment Capacity of Beam for a plastic or compact section, with assumed low shear load.
\[ M_p = p_e S \text{ but } \leq 1.2 p_e Z \]
\[ = 355 \times 1040 \times 10^{-3} \text{ kN m} \]
\[ = 369.2 \text{ kN m} \]

Check whether \( p_e S \leq 1.2 p_e Z \)
\[ 1.2 p_e Z = 1.2 \times 355 \times 913.2 \times 10^{-3} \text{ kN m} \]
\[ = 389.0 \text{ kN m} \]

So \( p_e S \) is less than \( 1.2 p_e Z \).

(b) From A2.2.2, Self Weight of beam and concrete slabs, (dead load), is 868.5 N/m.
So
\[ w_i = 0.8685 \text{ kN/m} \]

Moment produced by dead load is given by
\[ \text{Moment}_i = \frac{(w_i L^2)}{8} \text{ kN m} \]
\[ = \frac{0.8685 \times 4.5 \times 4.5}{8} \text{ kN m} \]
\[ = 2.198 \text{ kN m} \]

\[ A2/7 \]
From A2.2.2 Total imposed load is 196.200 N.

So \[ W = 196.20 \text{ kN} \]

Assuming a uniformly distributed load, the moment produced by the imposed load is given by

\[ \text{Moment}_2 = \frac{(WL)}{8} \text{ kNm} \]
\[ = \frac{196.20 \times 4.5}{8} \text{ kNm} \]
\[ = 110.363 \text{ kNm} \]

Total Moment Applied, (dead + imposed loads)

\[ M_c = 2.198 + 110.363 \text{ kNm} \]
\[ = 112.561 \text{ kNm} \]

and therefore the load ratio given by

\[ LR = \frac{M_c}{M_r} \]
\[ = \frac{112.561}{369.2} \]
\[ = 0.31 \]

A2.4 COMPARISON OF LOADINGS

A2.4.1 BS449:Part 2:1969

Based on nominal dimensions and section properties it was calculated that in order to develop the maximum permissible bending stress of 165 N/mm² in the lower flange of the steel section an imposed load of 27.26 tonnes was required. However, in the test the load actually applied was 20.00 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicates that the bending stress in the lower flange was only 123.3 N/mm², or 74.7% of the maximum permitted value.

A2.4.2 BS5959:Part 1:1985

Based on nominal values and the application of the previously calculated imposed loading of 27.26 tonnes the load ratio for the test assembly was found to be 0.53. When the lower actual loading value was used in conjunction with the actual section properties data the load ratio value reduced to 0.31. The factors most effective in bringing about such a reduction are the design strength which at 355 N/mm² is much higher than the nominal value of 275 N/mm² and the actual imposed load which was approximately 27% lower than that required.
APPENDIX 3

PC DISK VERSION OF DATA

As mentioned in the Introduction to this report the data recorded during the test are available on a PC disk. The following section gives a brief outline of the material available and its format. The reader may find it useful to additionally consult Reference A3.1.

The data are held on the disk in the form of ASCII text files. This format has been chosen since the majority of commercial software packages can import files of this type. The format allows the data to be referenced either via the screen, (or printer), or read directly by PC based software. The data are initially being made available on 3½ inch DDS, 720 KB, floppy disks, but other disk sizes and formats can be supplied on request. The data files have been designated 'read only' in order to safeguard the user from accidentally corrupting or erasing them.

The data file is identified by reference to the DATA SHEET NUMBER sequence, i.e. 127.DAT. This numbering system is consistent with that introduced in Reference A3.1. The thermal data recorded during the fire test have been divided into 'SETS' which reflect the positions of the thermocouples in the steel section. Mean temperature values are included in the sets where it is considered valid to do so. In order that the columns of data in any particular 'SET' can be related to the corresponding thermocouple positions a 'README' file is associated with the data file. README.127 which relates to data in file 127.DAT is shown in Table A3.1.

REFERENCE

**TABLE A3.1**
README FILE ASSOCIATED WITH DATA FILE 127.DAT

Data file 127.DAT contains data recorded during the standard fire resistance test number WFRC 46737 which is described in report number SL/PDE/R/S2442/5/96/C - 'Summary of Data Obtained During a Test on a Shelf Angle Floor Beam' and should be read in conjunction with that document.

There are 64 items of data which, together with their mean values, are grouped in sets as shown below.

<table>
<thead>
<tr>
<th>Set Number</th>
<th>Items in Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>SET001.DAT</td>
<td>TIME, F9, F5, T21, T31, MEAN</td>
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<tr>
<td>SET002.DAT</td>
<td>TIME, T20</td>
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<tr>
<td>SET003.DAT</td>
<td>TIME, W5, W6, T19, W7, T30, W8, MEAN</td>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>SET006.DAT</td>
<td>TIME, F4, F7, T1, F6, T22, MEAN</td>
</tr>
<tr>
<td>SET007.DAT</td>
<td>TIME, T11, T14, MEAN, W9, W10, T10, T13, W11, MEAN, T9, T12, MEAN</td>
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<tr>
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<td>TIME, ISO, AT1, AT2, AT3, AT4, AT5, AT6, MEAN</td>
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<td>SET012.DAT</td>
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