BS 476: Part 21 Fire Resistance Tests

Summary of Data Obtained During Tests on

Two Floor Beam Assemblies at the Technical Centre

for Fire Prevention - TNO, Rijswijk, Holland

British Steel plc
Swinden Technology Centre
Moorgate
Rotherham  S60 3AR
Telephone:  (01709) 820166
Fax:  (01709) 825357
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SUMMARY

BS 476:PART 21 FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING TESTS ON TWO FLOOR BEAM ASSEMBLIES AT THE TECHNICAL CENTRE FOR FIRE PREVENTION - TNO, RIJSWIJK, HOLLAND

D.E. Wainman

During the five years 1989-1993 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 eighth report issued as part of that series. It contains a detailed description of the design, instrumentation and construction for a simply supported concrete topped floor beam and a shelf angle floor beam assembly, together with the data arising from them. The tests were carried out at the Technical Centre for Fire Prevention, TNO, at Rijswijk, Neer Delt, Holland.

The serial size for the steel sections used was 254 x 146 mm x 43 kg/m UB. The steel grade was S3 4360/Grade 43A, (now BS EN 10025 S275).

In the case of the simply supported beam the concrete floor slab was cast in-situ onto the upper flange. In the shelf angle floor beam pre-cast concrete floor slabs were supported from continuous 125 x 75 x 12 mm Grade 50D, (S375/25), hot rolled angles which were welded to the web of the section. Normal weight Grade 35 concrete was used for forming the floor slabs in both cases.

The sections were 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 assemblies was judged against the load bearing capacity criterion outlined in Section 5 of BS 476:Part 21:1987. The fire resistance ratings for the two assemblies were found to be:

- Test 1
  Simply supported floor beam with concrete topping - 15 minutes

- Test 2
  Simply supported shelf angle floor beam with concrete slabs - 59 minutes

KEYWORDS

Sections (Structural)  Fire Resistance
Beams  Load (Mechanical)
Fire Tests  Building Floors
+BS 5950  Lab Reports
+BS 449
INITIAL CIRCULATION

BS SECTIONS, PLATES & COMMERCIAL STEELS

Commercial Office
- Structural Sections

Mr J. Dowling
Mr J.T. Robinson (50)

BS TECHNOLOGY CENTRES

Swindon Technology Centre

Dr K.N. Melton
Mr T.R. Kay
Dr B.R. Kirby
Dr D.M. Martin
Dr D.J. Naylor
Dr M. O'Connor
Dr D.J. Price*
Mr L.N. Tomlinson
Mr D.E. Wainman (3)

Library

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BS 476:PART 21 FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING TESTS ON TWO FLOOR BEAM ASSEMBLIES AT
THE TECHNICAL CENTRE FOR FIRE PREVENTION - TNO, RIJSWIJK, HOLLAND

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[1]. 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 generically similar group of
test assemblies. The first report in the series was issued in 1993[2] and included material relating
to eight flange plated slim floor beams. Subsequent reports have given details relating to
- five web encased column assemblies[3],
- tests on connections between beams and columns[4],
- a single test on an arched metal deck floor[5]
- a single test on a composite slim floor beam[6]
- the 'control' shelf angle floor beam[7] and
- three composite metal deck shelf angle floor beams[8]

This is therefore the eighth report issued as part of that ongoing series. It contains a detailed
description of the design, instrumentation and construction for two test assemblies, together with
the data arising from them; see Appendix 1. The test assemblies were a simply supported floor
beam with a concrete topping slab cast in-situ onto the upper flange and a shelf angle floor beam
supporting pre-cast concrete floor units. 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 these
forms of construction. The numerical sequence of the data sheets has been maintained, the ones
in this document being numbered 131 and 132. As in 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 4.) This may be obtained,
on request, from British Steel, Swinden 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. FIRE TESTS ON SIMPLY SUPPORTED FLOOR BEAMS

In this section details are given for tests performed on two loaded floor beam assemblies, one of
which was a shelf angle floor beam. The tests were carried out in accordance with the
requirements of BS 476:Parts 20/21:1987 at the Technical Centre for Fire Prevention, TNO, at
Rijswijk, Near Delft, Holland.

The design and construction of the test assemblies are described in the following sections.
2.1 Features Common to Both Test Assemblies

2.1.1 Steel Quality

Unless noted otherwise all of the steel members used in the construction of the test assemblies were manufactured by British Steel and supplied to the requirements of either BS 4360:Grade 43A, for the beam sections), or Grade 50D, (for the angles). These grades are now designated in accordance with BS EN 10025 as S275 and S355J2 respectively. Details of their chemical compositions and mechanical properties are included in the appropriate Data Sheets in Appendix 1.

2.1.2 Dimensions and Section Properties

The nominal dimensions and section properties, as specified in BS 4:Part 1:1980, for the steel members used in the construction of the test assemblies are included in the Data Sheets. The actual dimensions of the members are also given, together with calculated section properties.

2.1.3 Loading

For each of the tests 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 maximum allowable bending stress for a fully restrained BS 4360:Grade 43A, steel section according to the design rules in BS 449:Part 2:1999. The loads to be applied to the individual assemblies were initially calculated on the basis of nominal dimensions and section properties for the steel members concerned. These calculations were subsequently repeated to take account of the actual dimensions, mechanical and physical properties of all the materials involved in the construction. Calculations relating to the applied load levels are given in Appendices 2 and 3. A comparison of the calculation data in terms of BS 5950:Part 1:1985 is also included.

In both tests the imposed load was generated by two hydraulic rams situated along the centre line of the web of the steel section. This load was re-distributed along the length and breadth of the test assembly by the use of appropriate load spreaders.

2.1.4 Fabrication

Both test assemblies consisted of a 5 metre length of 254 x 146 mm x 43 kg/m universal beam section and, in the case of the shelf angle floor beam assembly, 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-side of the upper flange and the inside face of the angle was 165 mm. Furthermore, they were positioned so that the 125 mm long leg was perpendicular to the web of the section. All the welds 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 100 mm centres. Welding was by the MMA process using 4 mm diameter basic coated, hydrogen controlled, general purpose welding rods.

The concrete floor units for both test assemblies were cast by TNO using normal weight Grade 35 concrete.

2.1.5 Instrumentation

The assemblies were instrumented such that the temperatures attained by the steel section and, in the case of the SAFB the angles, could be recorded throughout the duration of the heating
period. For this purpose 3 mm diameter mineral insulated 'K' type thermocouples, (Ni-Cr / Ni-Al), with insulated hot junctions and Inconel 600 sheaths were used. These thermocouples were embedded to the mid-thickness position of the relevant steel section.

Thermocouples of the same type were installed by TNO for monitoring the temperature of the furnace atmosphere. These were situated at six 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 deflections of the assemblies throughout the test. These measurements were made at the geometric centre of the upper surface using a displacement transducer connected to the TNO data logging facility. The deflection values recorded are included in the appropriate Data Sheets in Appendix 1.

2.1.6 Assembly

The test assemblies were positioned so as to form part of the roof of the floor furnace at TNO. The furnace has dimensions of 4150 x 4000 x 2050 mm, (length x width x height), and is gas fired. The beams were supported by means of a 40 mm diameter x 150 mm long steel roller at one end of the furnace and a 40 mm square x 150 mm long steel bar at the opposite end. The total effective span between the two supports was 4500 mm. The length of beam actually exposed to the heating conditions of the test was 4150 mm.

2.1.7 Failure Criteria

The performance of both test assemblies was judged against the load bearing capacity criterion outlined in Section 5 of BS-476:Part 21:1987. The maximum allowable deflection and the maximum allowable rate of deflection for the test assemblies, as specified by the standard, were calculated from \[ \text{SPAN} / 20 \text{ and (SPAN)}^2 / 9000 \times \text{D}, \] respectively, where \( \text{D} \) is the measured depth of the section. The allowable rate of deflection criterion is not applicable until the deflection exceeds a value equal to \( \text{SPAN} / 30 \). Since the span was fixed at 4500 mm the values of \( \text{SPAN} / 20 \) and \( \text{SPAN} / 30 \) were always 225 mm and 150 mm respectively.

2.1.8 Additional Data

In both cases heating of the test assembly continued beyond the time at which 'failure' was deemed to have occurred and the load removed from the beam. This was done in order to enable further data concerning the heating rates of the various members of the assembly to be recorded.

2.2 Loaded Test Assemblies

The following sections describe in greater detail aspects concerning the construction, instrumentation and loading of the two test assemblies.

2.2.1 Test No. THO 8-89-724A

The test assembly consisted of a 5 metre length of 254 x 146 mm x 43 kg/m universal beam section onto which a concrete topping slab was cast in-situ. The slab was cast in four segments each 1250 mm long x 800 mm wide x 130 mm thick. These were held in place by means of eight mild steel tangs formed from 50 mm wide x 3 mm thick strip which were tack welded at 550 mm centres to the upper flange of the section. The tongs of the tongs were bent outwards in alternate
directions. Details relating to the tangs and their disposition on the beam are given in Figs. 1 and 2.

The concrete was cast, without any reinforcement, on the 7th September 1989 thus giving it an age of only 28 days at the time of the test. The material was understood to have been normal weight Grade 35 concrete although this is not confirmed in the report prepared by TNO. It is worth noting that in accordance with normal TNO practice a polyethylene separating member was placed on the upper flange of the section prior to casting the slabs. The concrete was allowed to cure naturally until five days prior to the test at which time the complete assembly was placed in a conditioning room with an air temperature of 50°C and a relative humidity of 10%. Samples of the concrete were taken at the time of casting. The properties, measured on the day of the test, were reported as being

- Density: 2409 kg/m³
- Moisture Content: 3.8% w/w
- Compressive Strength: 42.2 N/mm²

The thermocouple positions in the steelwork were as shown in Fig. 3, (longitudinal arrangement), and Fig. 4, (transverse arrangement). A bad of 13 907 kg 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 \( \frac{1}{4} \), \( \frac{1}{3} \) and \( \frac{1}{4} \) of the supported span. Each ram acted on a load spreader so that the actual points of application of the load to the beam corresponded to \( \frac{1}{4} \), \( \frac{1}{3} \), \( \frac{1}{2} \) and \( \frac{3}{4} \) of the supported span. The load spreaders were formed from 1.5 metre long pieces of HE200A column section with a weight of 44 kg/m. The general arrangement of the components is shown in Figs. 5-7 which should be viewed in conjunction with the schedule of components given in Table 1.

The maximum allowable rate of deflection was calculated to be 8.62 mm/min based on the actual section depth of 261 mm. In the test, this rate was exceeded after 13 minutes. A mid-span deflection of 140 mm was attained after 16 minutes at which time the rate of deflection was 41 mm/min. The load was removed from the beam after 16.5 minutes. Heating of the unloaded assembly continued up to 60 minutes in order to obtain additional thermal data.

In accordance with the failure criteria outlined in Section 2.1.7 the load bearing capacity of the beam was deemed to be 15 minutes.

Data for this test are summarised in Data Sheet No. 131.

2.2.2 Test No. TNO B-89-724B

A shelf angle floor beam construction consisting of a universal beam of serial size 254 x 146 mm x 43 kg/m and 125 x 75 x 12 mm angles assembled as outlined in Section 2.1.4. The distance between the under-side of the upper flange and the inside face of the angle was 165 mm. The actual section depth was 261 mm and therefore the distance between the base of the section and the under-side of the angles was 71.2 mm. Taking the thickness of the angle into consideration, the proportion of the actual section depth exposed to the heating conditions of the furnace was 31.9%.

Sixteen concrete slabs were cast by TNO in six separate batches, between July 26th and August 25th 1989. Each slab was 2050 mm in length x 550 mm wide x 150 mm thick and contained two layers of steel mesh reinforcement, details of which are shown in Fig. 8. The concrete used is understood to have been normal weight Grade 35 material although this
information is not included in the report prepared by TNO. All the concrete slabs were allowed to
cure naturally until the day of the test at which time their ages ranged from 54 to 84 days.
Samples of the concretes were taken at the time of casting. The properties, measured on the day
of the test, showed very little variation between the six batches. The mean values were reported as being-

- Density 2424 kg/m³
- Moisture Content 5.8% w/w
- Compressive Strength 48.8 N/mm²

The floor was constructed using the sixteen pre-cast slabs which were arranged, eight 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 over-lapped onto the angles and walls by distances of 75 mm
and 104 mm respectively. They were butted up close to each other, any irregularities at the joints
being accommodated within a 12 mm thick compressed ceramic fibre blanket seal. 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 flanges 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 it was not classed as a composite structure. The general arrangement of the
components is shown in Figs. 9-11 which should be viewed in conjunction with the schedule of
components given in Table 2.

The thermocouple positions in the steelwork were as shown in Fig. 12, (longitudinal arrangement),
and Fig. 13, (transverse arrangement). A load of 14 552 kg was applied to the test assembly 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. In the test it was required to apply load ONLY
to the concrete floor slabs and at a distance of 500 mm on either side of the steel section. In
order to achieve this each ram acted on an H-frame which in turn acted on four load spreaders,
(see Fig. 14). The H-frames weighed 166 kg each. The eight load spreaders were formed from
1.0 metre long pieces of HE200A column section weighing 44 kg each.

The maximum allowable rate of deflection was calculated to be 8.62 mm/min based on the actual
section depth of 261 mm. In the test the assembly attained a mid-span deflection of 150 mm after
48 minutes at which time the rate of deflection was only 2 mm/min. The maximum allowable rate
of deflection was exceeded after 59 minutes. A mid-span deflection of 225 mm was attained after
61 minutes at which time the load was removed. Heating of the unloaded assembly continued up
to 90 minutes in order to obtain additional thermal data.

In accordance with the failure criteria outlined in Section 2.1.7 the load bearing capacity of the
beam was deemed to be 59 minutes.

Data for this test are summarised in Data Sheet No. 132.

3. CONCLUSIONS

1. Data arising from two standard fire resistance tests carried out at the Technical
Centre for Fire Prevention, TNO, Rijswijk, Holland have been collected and reported.
The tests were performed on a simply supported floor beam with a concrete topping
slab cast in-situ onto the upper flange and a sheet angle floor beam supporting
pre-cast concrete floor units. The steel section was 254 x 146 mm x 43 kg/m UB in
both cases. Details of the test assemblies are given, together with summaries of the
material properties, structural calculations and the thermal data recorded.
2. The performance of the test assemblies was judged against the load bearing capacity criterion outlined in Section 5 of BS 476:Part 21:1987. The fire resistance ratings for the assemblies were found to be:

(a) Simply Supported Beam

- Section 254 x 146 mm x 43 kg/m UB
- Floor Slab In-situ normal weight Grade 35 concrete
- Fire Resistance 15 minutes
- Load Ratio (*) 0.493

(b) Shelf Angle Floor Beam

- Section 254 x 146 mm x 43 kg/m UB
- % Exposed 31.9
- Floor Slab Pre-cast concrete slabs (Normal weight Grade 35 concrete)
- Fire Resistance 59 minutes
- Load Ratio (*) 0.502

(*) Calculated using actual applied loads and section properties

D.E. Wainman
Investigator

D.M. Martin
Manager
Product Design & Engineering

REFERENCES


### TABLE 1
SCHEDULE OF COMPONENTS FOR TEST NO. TNO B-89-724A
(Refer to Figs. 5-7)

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1        | Universal Beam Section  
(Serial Size 254 x 146 mm x 43 kg/m) |
| 2        | Steel Roller, 40 mm dia. x 150 mm |
| 3        | Steel Plate, 200 x 150 x 20 mm |
| 4        | Concrete Topping Slab  
(Wide 600 mm, Depth 130 mm) |
| 5        | Steel Loading Beam. (Load Spreader)  
(HE200A Section, 44 kg/m) |
| 6        | Steel Roller, 50 mm dia. x 200 mm |
| 7        | Steel Plate, 200 x 150 x 20 mm |
| 8        | Concrete Furnace Topping  
(Cover Slab) |
| 9        | Steel Bar, 30 mm square x 200 mm |
| 10       | Steel Bar, 40 mm square x 150 mm |

### TABLE 2
SCHEDULE OF COMPONENTS FOR TEST NO. TNO B-89-724B
(Refer to Figs. 9-11)

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1        | Universal Beam Section  
(Serial Size 254 x 146 mm) x 43 kg/m with two angles 125 x 75 x 12 mm |
| 2        | Steel Roller, 40 mm dia. x 150 mm |
| 3        | Steel Plate, 200 x 150 x 20 mm |
| 4        | Pre-cast Concrete Floor Slab  
(2050 x 550 x 150 mm) |
| 5        | Steel Loading Beam, (Load Spreader)  
(HE200A Section, 44 kg/m) |
| 6        | Steel Plate, 200 x 150 x 20 mm |
| 7        | Dish Wheel Support, 80 mm dia. |
| 8        | Steel Loading System  
(H-shape Frame, Weight 166 kg) |
| 9        | Fins Dry Sard - Approx. 70 kg/m |
| 10       | Rockwool 750, Thickness 50 mm |
(a) Side elevation showing fixing direction of mild steel tangs
(b) Plan showing the tangs splayed out in alternate directions

FIG. 2
PREPARATION OF THE TEST BEAM
TEST NO. 889-724A

(D0992C06)
FIG. 4  THERMOCOUPLING POSITIONS IN THE STEELWORK
TEST NO. B-89-724A
TRANSVERSE ARRANGEMENT IN DIRECTION OF
ARROW "x" IN FIG. 3
FIG. 5  
TYPICAL VERTICAL CROSS SECTION  
TEST NO. B-89-724A  

(F0992C07)
Design Details of the Reinforced Concrete Floor Units for Use with the Shelf Angle Floor Beam

Test No. B-89-724B
FIG. 10

SECTION THROUGH BEAM AND SLABS
TEST NO. B-69-724B
(BASED ON ACTUAL DIMENSIONS, mm)
FIG. 11
DESIGN DETAILS FOR LOADING THE SHELF ANGLE FLOOR BEAM ASSEMBLY
TEST NO. B-89-724B

(D0992C06)
FIG. 13 THERMOCOUPLE POSITIONS IN THE STEELWORK TEST NO. B-89-724B TRANSVERSE ARRANGEMENT IN DIRECTION OF ARROW 'X' IN FIG. 12

F13
FIG. 14 SCHEMATIC ARRANGEMENT OF COMPONENTS FOR LOADING THE SHELF ANGLE FLOOR BEAM
TEST NO. B-69-724B (D0992C06)
APPENDIX 1

DATA SHEET NOS. 131/132
## SIMPLY SUPPORTED FLOOR BEAM

### Dimensions and Properties

<table>
<thead>
<tr>
<th>Section</th>
<th>Dimension and Properties</th>
<th>Mass per Metre (kg)</th>
<th>Depth of Section (mm)</th>
<th>Width of Section (mm)</th>
<th>Thickness (mm)</th>
<th>Elastic Modulus Axis x (GPa)</th>
<th>Elastic Modulus Axis y (GPa)</th>
<th>Plastic Modulus Axis x (GPa)</th>
<th>Plastic Modulus Axis y (GPa)</th>
<th>Moment of Inertia Axis x (cm⁴)</th>
<th>Moment of Inertia Axis y (cm⁴)</th>
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<tr>
<td>254 x 146 Beam</td>
<td>Nominal</td>
<td>43</td>
<td>259.6</td>
<td>147.3</td>
<td>7.3</td>
<td>12.7</td>
<td>5053</td>
<td>92.0</td>
<td>566.2</td>
<td>141.2</td>
<td>6558</td>
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<tr>
<td>Beam</td>
<td>Actual</td>
<td>45</td>
<td>261.0</td>
<td>147.0</td>
<td>8.13</td>
<td>12.8</td>
<td>517.1</td>
<td>92.4</td>
<td>585.4</td>
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### Chemical Composition Product Analysis - Wt. %

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<th>Section</th>
<th>Steel Quality</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</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>Grade 43A</td>
<td>0.11</td>
<td>0.24</td>
<td>1.23</td>
<td>0.015</td>
<td>0.015</td>
<td>0.02</td>
<td>0.006</td>
<td>0.03</td>
<td>&lt;0.005</td>
<td>0.04</td>
<td>&lt;0.005</td>
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### Room Temperature Tensile Properties

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<tr>
<th>Position</th>
<th>Position</th>
<th>LYS (N/mm²)</th>
<th>UTS (N/mm²)</th>
<th>Elongation (%)</th>
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<tr>
<td>Beam</td>
<td>294</td>
<td>452</td>
<td>34.0</td>
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### Notes

(a) Initial ambient temperature = 24°C.

(b) Based on an initial ambient temperature of 20°C.
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TEMPERATURE DEG. C AFTER VARIOUS TIMES (MINUTES)</th>
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<tbody>
<tr>
<td>Upper Flange</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>90.1 151 213 280 355 388 420 472 518 546 586 657 710 750 792 832 865</td>
</tr>
<tr>
<td>F5</td>
<td>94.1 159 238 301 376 407 466 545 579 616 664 713 740 766 793 834 867</td>
</tr>
<tr>
<td>F8</td>
<td>107.1 162 221 287 353 374 418 483 537 585 624 673 710 743 770 806 839</td>
</tr>
<tr>
<td>F9</td>
<td>95.1 161 239 315 365 426 493 561 609 645 675 722 754 794 830 863 897</td>
</tr>
<tr>
<td>Mean</td>
<td>97.1 158 225 296 368 399 449 515 560 596 637 691 729 763 798 834 871</td>
</tr>
<tr>
<td>Extended Web</td>
<td></td>
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<tr>
<td>10 mm Below UF</td>
<td>135.2 208 281 256 424 445 488 548 595 639 673 719 754 787 813 844 875</td>
</tr>
<tr>
<td>30 mm Below UF</td>
<td>175.2 265 351 432 502 524 583 616 655 692 723 763 795 825 849 876 902</td>
</tr>
<tr>
<td>50 mm Below UF</td>
<td>175.2 281 382 471 543 555 602 651 686 717 742 776 814 841 866 890 914</td>
</tr>
<tr>
<td>Mid-High</td>
<td>A4 194.2 322 440 539 610 621 661 702 728 752 779 815 838 862 885 906 929</td>
</tr>
<tr>
<td>W1</td>
<td>176.2 319 450 551 624 646 682 721 747 775 800 836 861 884 907 928 946</td>
</tr>
<tr>
<td>W2</td>
<td>185.2 345 452 550 621 643 678 718 742 770 796 831 855 879 902 922 943</td>
</tr>
<tr>
<td>W3</td>
<td>189.2 327 451 554 627 647 672 719 742 770 793 827 850 874 896 917 938</td>
</tr>
<tr>
<td>W4</td>
<td>204.2 350 486 589 633 683 723 753 783 809 828 851 879 902 922 942 962</td>
</tr>
<tr>
<td>Mean</td>
<td>180.2 326 456 557 629 648 685 723 749 775 799 834 857 880 902 923 943</td>
</tr>
<tr>
<td>50 mm Above LF</td>
<td>A5 165.2 287 403 503 580 601 637 678 705 726 749 782 805 829 849 868 888</td>
</tr>
<tr>
<td>30 mm Above LF</td>
<td>A6 143.2 258 372 475 557 581 619 662 693 714 748 774 800 824 845 864 884</td>
</tr>
<tr>
<td>10 mm Above LF</td>
<td>A7 123.2 235 350 454 538 562 599 644 677 702 721 759 789 823 852 872 893</td>
</tr>
<tr>
<td>Lower Flange</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>157.2 291 433 549 631 665 694 730 764 794 819 859 879 900 923 942 960</td>
</tr>
<tr>
<td>F2</td>
<td>143.2 256 368 475 559 579 611 657 695 722 741 782 813 837 857 897 909</td>
</tr>
<tr>
<td>F3</td>
<td>185.2 329 471 589 673 699 731 773 804 831 852 882 909 919 938 955 975</td>
</tr>
<tr>
<td>F4</td>
<td>159.2 247 458 541 621 645 686 725 761 796 806 842 868 892 915 933 952</td>
</tr>
<tr>
<td>F5</td>
<td>145.2 271 402 517 604 626 662 703 729 756 782 819 843 868 896 909 931</td>
</tr>
<tr>
<td>Mean</td>
<td>158.2 287 420 534 618 641 677 718 749 777 800 836 860 884 905 924 944</td>
</tr>
</tbody>
</table>

| Mass Furnace (A) | 484.6 996 658 711 743 755 773 796 816 830 848 869 899 925 959 985 |
| Standard Curve  | 502.6 663 705 736 748 766 789 809 826 842 856 885 906 918 926 935 |

| Deflection (mm) | 11.2 6 47 65 119 160 - - - - |
| Deflection Rate (mm/min) | 3 6 6 8 31 4 |

A1/3
### SHELF ANGLE FLOOR BEAM

#### Dimensions and Properties

<table>
<thead>
<tr>
<th>Section</th>
<th>Dimensions and Properties</th>
<th>Mass per Meter (kg)</th>
<th>Depth of Section (mm)</th>
<th>Width of Section (mm)</th>
<th>Thickness</th>
<th>Elastic Modulus (E)</th>
<th>Plastic Modulus (EPS)</th>
<th>Moment of Inertia (EI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>254 x 146 Beam</td>
<td>Nominal Actual</td>
<td>43</td>
<td>259.6</td>
<td>147.3</td>
<td>12.7</td>
<td>505.3</td>
<td>92.0</td>
<td>556.2</td>
</tr>
<tr>
<td>128 x 75 x 12 Angle</td>
<td>Nominal Actual</td>
<td>17.8</td>
<td>125</td>
<td>75</td>
<td>12</td>
<td>43.2</td>
<td>16.9</td>
<td>77.36</td>
</tr>
</tbody>
</table>

#### Chemical Composition (Product Analysis - wt. %)

<table>
<thead>
<tr>
<th>Section</th>
<th>Steel Quality</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Cu</th>
<th>Nb</th>
<th>Al</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>Grade 43A</td>
<td>0.11</td>
<td>0.24</td>
<td>1.23</td>
<td>0.015</td>
<td>0.015</td>
<td>0.02</td>
<td>0.006</td>
<td>0.03</td>
<td>&lt;0.005</td>
<td>0.04</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>0.0059</td>
</tr>
<tr>
<td>Angle</td>
<td>Grade 50D</td>
<td>0.12</td>
<td>0.30</td>
<td>1.34</td>
<td>0.018</td>
<td>0.011</td>
<td>0.03</td>
<td>&lt;0.005</td>
<td>0.07</td>
<td>0.02</td>
<td>0.02</td>
<td>&lt;0.005</td>
<td>0.030</td>
<td>0.0051</td>
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</table>

#### Room Temperature Tensile Properties

<table>
<thead>
<tr>
<th>Position</th>
<th>YS (N/mm²)</th>
<th>UTS (N/mm²)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>294</td>
<td>452</td>
<td>34.0</td>
</tr>
<tr>
<td>Angle</td>
<td>371</td>
<td>520</td>
<td>33.0</td>
</tr>
</tbody>
</table>

#### Test Conditions

- Initial ambient temperature = 27°C.
- Based on an initial ambient temperature of 20°C.

---

**NOTES**

(a) Initial ambient temperature = 27°C.
(b) Based on an initial ambient temperature of 20°C.
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Flange</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>24 25 27 29 33 42 44 56 82 104 120 133 146 168 195 210</td>
</tr>
<tr>
<td>F5</td>
<td>23 23 23 25 29 37 59 72 77 98 114 129 141 162 183 204</td>
</tr>
<tr>
<td>F6</td>
<td>22 22 22 24 27 31 36 43 51 60 104 125 143 157 176 199 222</td>
</tr>
<tr>
<td>Mean</td>
<td>23 24 24 26 29 34 43 52 60 70 102 118 132 145 164 194 214</td>
</tr>
<tr>
<td>Unexposed Web</td>
<td></td>
</tr>
<tr>
<td>W5</td>
<td>23 27 36 48 65 83 103 126 147 167 225 262 291 312 343 376 408</td>
</tr>
<tr>
<td>W6</td>
<td>25 29 36 48 62 79 98 120 139 157 204 236 265 286 320 354 385</td>
</tr>
<tr>
<td>W7</td>
<td>26 30 36 44 60 89 100 122 143 161 216 251 279 322 353 396 378</td>
</tr>
<tr>
<td>W8</td>
<td>25 28 36 47 71 97 115 136 154 210 245 272 292 324 356 385 385</td>
</tr>
<tr>
<td>Mean</td>
<td>25 29 37 48 65 80 100 121 141 160 214 249 277 306 330 364 394</td>
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<tr>
<td>Exposed Web</td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>123 202 299 365 467 523 579 625 655 683 770 822 862 889 938 970</td>
</tr>
<tr>
<td>W2</td>
<td>131 220 311 396 465 518 571 615 646 674 759 810 865 927 957 985</td>
</tr>
<tr>
<td>W3</td>
<td>120 198 288 369 451 508 564 609 638 668 751 803 843 889 916 978</td>
</tr>
<tr>
<td>W4</td>
<td>170 246 331 416 490 536 591 632 664 692 778 828 864 900 938 974 1002</td>
</tr>
<tr>
<td>Mean</td>
<td>136 217 307 391 468 521 576 620 651 679 765 815 855 881 929 955 993</td>
</tr>
<tr>
<td>Web Profile</td>
<td></td>
</tr>
<tr>
<td>10 mm Below Angle</td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>101 159 219 282 309 390 441 486 527 562 661 720 764 789 822 897 970</td>
</tr>
<tr>
<td>A2</td>
<td>133 189 256 325 387 438 491 558 575 609 701 757 799 820 859 888 936</td>
</tr>
<tr>
<td>10 mm Above LF</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>123 196 272 348 415 469 523 549 604 636 722 775 817 837 875 911 941</td>
</tr>
<tr>
<td>LF/Nb Junction</td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>119 205 296 364 411 516 565 581 636 753 762 803 839 856 889 923 955</td>
</tr>
<tr>
<td>Window Flange</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>164 268 385 487 573 624 672 712 759 834 878 909 933 977 1002 1037</td>
</tr>
<tr>
<td>F2</td>
<td>150 248 349 438 513 567 617 669 712 757 828 862 871 905 935 962 999</td>
</tr>
<tr>
<td>F3</td>
<td>166 281 407 511 598 654 705 738 789 797 871 907 957 996 1032 1044</td>
</tr>
<tr>
<td>F4</td>
<td>150 265 384 466 565 616 664 704 735 750 820 866 900 920 963 989 1013</td>
</tr>
<tr>
<td>F5</td>
<td>149 249 366 463 553 607 659 699 718 753 817 858 886 906 943 986 1008</td>
</tr>
<tr>
<td>Mean</td>
<td>156 262 378 477 560 614 649 704 722 755 837 889 919 957 986 1010</td>
</tr>
<tr>
<td>Angle</td>
<td></td>
</tr>
<tr>
<td>Unexposed Flange</td>
<td></td>
</tr>
<tr>
<td>W9</td>
<td>36 61 97 142 191 238 282 325 353 398 500 569 604 649 744 779 848</td>
</tr>
<tr>
<td>W10</td>
<td>34 54 83 122 165 209 253 293 329 360 446 517 570 609 659 710 755</td>
</tr>
<tr>
<td>W11</td>
<td>36 60 94 138 183 229 273 316 356 391 488 552 599 634 681 729 771</td>
</tr>
<tr>
<td>Mean</td>
<td>36 58 91 133 180 225 269 311 349 383 479 544 593 629 678 728 772</td>
</tr>
<tr>
<td>Exposed Flange</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>83 130 201 270 336 388 440 484 523 573 679 767 825 868 926 966 994</td>
</tr>
<tr>
<td>P2</td>
<td>76 125 179 233 280 324 375 425 469 510 625 693 737 763 809 886 923</td>
</tr>
<tr>
<td>P12</td>
<td>47 104 157 210 272 324 378 432 482 533 615 713 775 811 874 933 997 994</td>
</tr>
<tr>
<td>Mean</td>
<td>85 139 205 263 328 373 428 482 522 565 678 745 796 838 890 922 964</td>
</tr>
<tr>
<td>Root</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>47 78 123 178 239 293 348 397 440 484 604 673 723 764 828 870 919</td>
</tr>
<tr>
<td>R2</td>
<td>50 80 121 167 216 262 309 356 400 450 545 602 663 697 730 790 833</td>
</tr>
<tr>
<td>Mean</td>
<td>49 79 122 173 223 278 329 377 426 482 578 647 696 739 785 838 876</td>
</tr>
<tr>
<td>Mean Furnace G4</td>
<td></td>
</tr>
<tr>
<td>Standard Curve</td>
<td></td>
</tr>
<tr>
<td>(a)</td>
<td>504 598 663 705 744 773 800 821 835 854 903 938 949 951 991 1004 1011</td>
</tr>
<tr>
<td>(b)</td>
<td>502 603 663 705 739 766 789 808 826 842 885 912 932 948 962 988 1008</td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td></td>
</tr>
<tr>
<td>Diameter (mm/min)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>28 44 58 71 79 88 96 103 110 132 150 178 225</td>
</tr>
<tr>
<td>3</td>
<td>6 6 5 4 3 3 3 3 2 2 2 2 2 2 2 2 2 2 2 2 2 2</td>
</tr>
</tbody>
</table>

A1/7
APPENDIX 2

LOAD CALCULATION SUMMARY SHEETS

A2.1 TEST NO. TNO-B-89-724A ON 5 OCTOBER 1989
A2.2 CALCULATIONS BASED ON BS 449:PART 2:1969
A2.3 CALCULATIONS BASED ON BS 5950:PART 1:1985
A2.4 COMPARISON OF LOADINGS
A2.1 TEST NO. TNO-B-89-724A ON 5 OCTOBER 1989

A2.1.1 Geometry

Figure 6 gives the relevant details

A2.1.2 Material Properties

(a) Steel

Universal Beam - 254 x 146 mms x 43 kg/m
Steel Grade - BS 4360 Grade 43A

(b) 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 of Section</td>
<td>259.6</td>
<td>251.0</td>
</tr>
<tr>
<td>Breath of Section</td>
<td>147.3</td>
<td>147.0</td>
</tr>
<tr>
<td>Thickness of Flange</td>
<td>12.7</td>
<td>12.8</td>
</tr>
<tr>
<td>Thickness of Web</td>
<td>7.3</td>
<td>8.13</td>
</tr>
<tr>
<td>Area of Section</td>
<td>5510</td>
<td>5727</td>
</tr>
<tr>
<td>Mass</td>
<td>43</td>
<td>45</td>
</tr>
<tr>
<td>Weight</td>
<td>422</td>
<td>441</td>
</tr>
<tr>
<td>Distance of Neutral Axis from Base of Beam</td>
<td>129.3</td>
<td>130.5</td>
</tr>
<tr>
<td>Effective Span of Beam</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td>Moment of Inertia (x-x)</td>
<td>6558</td>
<td>6751</td>
</tr>
<tr>
<td>Elastic Modulus (x-x)</td>
<td>505.3</td>
<td>517.3</td>
</tr>
<tr>
<td>Plastic Modulus (x-x)</td>
<td>568.2</td>
<td>585.4</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>205</td>
<td>205</td>
</tr>
<tr>
<td>Design Strength</td>
<td>275</td>
<td>294</td>
</tr>
<tr>
<td>Classification</td>
<td>Class 1, Plastic (Table 7, BS 5950)</td>
<td></td>
</tr>
</tbody>
</table>

A2.2 Concrete

The mean moisture content of the concrete, measured on the day of the test, was found to be 3.8% w/w. The mean compressive strength of the concrete was reported to be 42.2 N/mm², (Range 39.9 to 43.8 N/mm²), and its mean density was reported to be 2409 kg/m³, (Range 2405 to 2414 kg/m³).
### 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>130</td>
<td>130</td>
</tr>
<tr>
<td>Width w (mm)</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Area of Section</td>
<td>104 000</td>
<td>104 000</td>
</tr>
<tr>
<td>Mass m1 (kg/m²)</td>
<td>239.2</td>
<td>250.5</td>
</tr>
<tr>
<td>Weight m2 (N/m)</td>
<td>2347</td>
<td>2467</td>
</tr>
<tr>
<td>Density D (kg/m³)</td>
<td>2300</td>
<td>2409</td>
</tr>
</tbody>
</table>

#### A2.2 CALCULATIONS BASED ON BS 449:PART 2:1969

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

#### A2.2.1 Initial Calculations Using Nominal Dimensions and Properties

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

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

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 \( f L / y \).

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

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

\[
w = \frac{8fL}{yL^2}
\]

\[
= \frac{8 \times 165 \times 6558 \times 10^2}{129.8 \times 4500 \times 4500} \text{ N/m}
\]

\[
= 32,934 \text{ N/m}
\]

The concrete load per metre run is 2347 N (based on an assumed density of 2300 kg/m³).

Total Self Weight of Beam and Concrete Slab, (Dead Load):

\[
w_t = 422 + 2347 \text{ N/m}
\]

\[
= 2769 \text{ N/m}
\]

A2/3
Total load to produce required bending stress

\[ w \frac{1}{2} = 32934 - 2769 \text{ N/m} \]
\[ = 30165 \text{ N/m} \]

Therefore total imposed load

\[ W = 30165 \times 4.5 \text{ N} \]
\[ = 135743 \text{ N} \]
\[ = 135.74 \text{ kN} \quad (\text{i.e. } 13837 \div 4 \text{ kg}) \]

Using four point loads at \( \frac{1}{4}L, \frac{2}{3}L, \frac{3}{4}L \) and \( \frac{5}{8}L \) of the supported span, equivalent to \( W/4 \).

Point Loads Required are:-

\[ P = 135.74 \div 4 \text{ kN} \quad (i.e. 13837 \div 4 \text{ kg}) \]
\[ = 33935 \text{ kN} \quad (i.e. 3459 \text{ kg}) \]

Referring to Fig. 6

Loads per hydraulic ram are:-

\[ P_{pp} = (13837 \div 2) - \text{load spreader kg} \]
\[ = 6918.5 - 66 \text{ kg} \]
\[ = 6852.5 \text{ kg} \]

The load actually applied was 6953.4 kg at each hydraulic ram.

A2.2.2 Retrospective Calculations Using Actual Dimensions and Properties

The required bending moment is given by \( fI/y \)

\[ fI \overline{y} = \frac{wL^2}{8} \]

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

\[ w = \frac{8fI}{yL^2} \]
\[ = \frac{8 \times 1 \times 6751 \times 10^7}{130.5 \times 4500 \times 4500} \text{ N/m} \quad \ldots \ (A2/1) \]

A2/4
The loads actually applied were:-

- by hydraulic rams \[2 \times 953.4\text{ kg}\]
- by load spreaders \[2 \times 66\text{ kg}\]

Total load applied

\[W = 13\,906.8 + 132\text{ kg}\]
\[= 14\,038.8\text{ kg}\]
\[= 137\,721\text{ N}\]

and therefore the total load generating the bending stress is

\[w_g = 137\,721 / 4.5\text{ N/m}\]
\[= 30\,605\text{ N/m}\]

The concrete load per metre run is 2457 N (based on the actual density of 2409 kg/m³).

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

\[w_i = 441 + 2457\text{ N/m}\]
\[= 2898\text{ N/m}\]

Therefore the load available to generate a bending moment is

\[w = 30\,605 + 2898\text{ N/m}\]
\[= 33\,503\text{ N/m}\]

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

\[\frac{33\,503}{130.5 \times 4500 \times 4500} = \frac{8 \times 6751 \times 10^7}{130.5 \times 4500 \times 4500}\]
\[t = 33\,503 \times \frac{130.5 \times 4500 \times 4500}{8 \times 6751 \times 10^7}\]
\[= 163.02\text{ N/mm}^2\]

The retrospective calculations, based on actual dimensions and properties, suggest that the steel section was loaded to 99.35% of the maximum allowable bending stress (BS 449 Design Rules).

**A2.3 CALCULATIONS BASED ON BS 5950: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.

\[ M_t = p_y S \quad \text{but} \leq 1.2 p_y Z \]
\[ = 275 \times 568.2 \times 10^3 \, \text{kN m} \]
\[ = 156.3 \, \text{kN m} \]

Check whether \( p_y S \leq 1.2 p_y Z \)

\[ 1.2 \, p_y \, Z = 1.2 \times 275 \times 505.3 \times 10^3 \, \text{kN m} \]
\[ = 166.7 \, \text{kN m} \]

So \( p_y S \) is less than \( 1.2 p_y Z \)

(b) From A2.2.1, Self Weight of beam and Concrete Slab, (dead load), is 2769 N/m

So \( w_i = 2769 \, \text{kN/m} \)

Moment produced by dead load is given by.

\[ \text{Moment}, I = \frac{(w_i, L^2)}{8} \, \text{kN m} \]
\[ = \frac{2769 \times 4.5 \times 4.5}{8} \, \text{kN m} \]
\[ = 7.009 \, \text{kN m} \]

From A2.2.1, Total Imposed Load is 135743 N.

So \( W = 135743 \, \text{kN} \)

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

\[ \text{Moment}, I = \frac{(W L)}{8} \, \text{kN m} \]
\[ = \frac{135743 \times 4.5}{8} \, \text{kN m} \]
\[ = 76355 \, \text{kN m} \]

Total Moment Applied, (dead + imposed loads):

\[ M_t = 7.009 + 76355 \, \text{kN m} \]
\[ = 83364 \, \text{kN m} \]

A2/6
Since $M_e$ also equals the applied moment at the fire limit state, $M_u$, then the load ratio is

$$LR = \frac{M_u}{M_e} = \frac{83.364}{156.3} = 0.533$$

(c) Check Shear Force, $(F_y)$, does not exceed shear capacity, $(P_y)$

Maximum Shear Force at the ends

$$F_y = \frac{VL}{2} = \frac{(32.934 \times 4.5) \times 2}{2} \text{ kN}$$

$$= 74.10 \text{ kN}$$

Shear Capacity

$$P_y = 0.6 \cdot p_y \cdot A_y$$

where $A_y$ is the shear area.

For an I section $A_y = h \times s$

$$\therefore \quad P_y = 0.6 \times 275 \times 259.6 \times 7.3 \times 10^{-3} \text{ kN}$$

$$= 312.7 \text{ kN}$$

Therefore since $F_y < P_y$, the low shear load calculation, (a), is acceptable.

A2.3.2 Retrospective Calculations Using Actual Dimensions and Properties

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

$$M_e = \frac{p_y \cdot S}{2} \quad \text{but} \quad \leq 1.2 \cdot p_y \cdot Z$$

$$= 294 \times 585.4 \times 10^{-3} \text{ kN m}$$

$$= 172.1 \text{ kN m}$$

Check whether $p_y \cdot S \leq 1.2 \cdot p_y \cdot Z$

$$1.2 \cdot p_y \cdot Z = 1.2 \times 294 \times 517.3 \times 10^{-3} \text{ kN m}$$

$$= 182.5 \text{ kN m}$$

So $p_y \cdot S$ is less than $1.2 \cdot p_y \cdot Z$.
(b) From A2.2.2, Self Weight of beam and concrete slab, (dead load), is 2898 N/m.

So \( w_1 = 2.888 \text{ kN/m} \)

Moment produced by dead load is given by:

\[
\text{Moment}_{1} = \frac{(w_1 L^2)}{8} \text{ kN m}
\]

\[
= \frac{2.888 \times 4.5 \times 4.5}{8} \text{ kN m}
\]

\[
= 7.336 \text{ kN m}
\]

From A2.2.2 Total imposed load is 137721 N.

So \( W = 137.721 \text{ kN} \)

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

\[
\text{Moment}_{2} = \frac{(WL)}{8} \text{ kN m}
\]

\[
= \frac{137.721 \times 4.5}{8} \text{ kN m}
\]

\[
= 77.468 \text{ kN m}
\]

Total Moment Applied, (dead + imposed loads)

\[
M_e = 7.336 + 77.468 \text{ kN m}
\]

\[
= 84.804 \text{ kN m}
\]

and therefore the load ratio given by:

\[
\text{LR} = \frac{M_e}{M_1}
\]

\[
= \frac{84.804}{172.1}
\]

\[
= 0.493
\]

A2.4 COMPARISON OF LOADINGS

A2.4.1 BS 449: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 13.84 tonnes was required. However, during the test the actual load applied was 13.91 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicate that the bending stress in the lower flange was 163.93 N/mm², or 99.35% of the maximum permitted value.
Based on nominal values and the application of the previously calculated imposed loading of 13.64 tonnes the load ratio for the test assembly was found to be 0.53. When the actual load value was used in conjunction with the actual section properties data the load ratio value was 0.493. The actual design strength of the steel section was 294 N/mm², i.e. 6.9% higher than the nominal value of 275 N/mm².
APPENDIX 3

LOAD CALCULATION SUMMARY SHEETS

A3.1 TEST NO. TNO-B-89-724B ON 18 OCTOBER 1989
A3.2 CALCULATIONS BASED ON BS 449:PART 2:1969
A3.3 CALCULATIONS BASED ON BS 5950:PART 1:1985
A3.4 COMPARISON OF LOADINGS

A3/1
A3.1 TEST NO. TNO-B-89-724B ON 18 OCTOBER 1989

A3.1.1 Geometry

Figures 9, 10, 11 and 14 give the relevant details

A3.1.2 Material Properties

(a) Steel

Universal Beam - 254 x 146 mm x 43 kg/m
Steel Grade - BS 4360 Grade 43A

(b) 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 of Section</td>
<td>h (mm)</td>
<td>259.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>261.0</td>
</tr>
<tr>
<td>Breadth of Section</td>
<td>b (mm)</td>
<td>147.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>147.0</td>
</tr>
<tr>
<td>Thickness of Flange</td>
<td>t (mm)</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.8</td>
</tr>
<tr>
<td>Thickness of Web</td>
<td>s (mm)</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.13</td>
</tr>
<tr>
<td>Area of Section</td>
<td>A (mm²)</td>
<td>5510</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>m (Nm/m)</td>
<td>422</td>
</tr>
<tr>
<td></td>
<td></td>
<td>441</td>
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<tr>
<td>Mass</td>
<td></td>
<td>527</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>Distance of Neutral Axis from Base of Beam</td>
<td>y (mm)</td>
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</tr>
<tr>
<td></td>
<td>L (mm)</td>
<td>4500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4500</td>
</tr>
<tr>
<td>Moment of Inertia (x-x)</td>
<td>I (cm⁴)</td>
<td>6558</td>
</tr>
<tr>
<td></td>
<td>Z (cm⁴)</td>
<td>503.5</td>
</tr>
<tr>
<td></td>
<td>S (cm⁴)</td>
<td>568.2</td>
</tr>
<tr>
<td></td>
<td>E (kN/mm²)</td>
<td>205</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td></td>
<td>205</td>
</tr>
<tr>
<td>Design Strength</td>
<td>P₀ (N/mm²)</td>
<td>275</td>
</tr>
<tr>
<td></td>
<td></td>
<td>294</td>
</tr>
<tr>
<td>Classification</td>
<td></td>
<td>Class 1, Plastic (Table 7, BS 5950)</td>
</tr>
</tbody>
</table>

(c) Concrete

The mean moisture content of the concrete, measured on the day of the test, was found to be 5.6% w/w. The mean compressive strength of the concrete was reported to be 48.8 N/mm² (Range 42.5 to 52.1 N/mm²), and its mean density was reported to be 2424 kg/m³ (Range 2389 to 2449 kg/m³).
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</td>
<td>d (mm)</td>
<td>150</td>
</tr>
<tr>
<td>Width</td>
<td>w (mm)</td>
<td>2050</td>
</tr>
<tr>
<td>Area of Section</td>
<td>A (mm²)</td>
<td>307 500</td>
</tr>
<tr>
<td>Mass</td>
<td>m (kg/m)</td>
<td>707.25</td>
</tr>
<tr>
<td>Weight</td>
<td>m (N/m)</td>
<td>6938</td>
</tr>
<tr>
<td>Density</td>
<td>D (kg/m³)</td>
<td>2300</td>
</tr>
</tbody>
</table>

A3.2 CALCULATIONS BASED ON BS 446:PART 2:1969

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

A3.2.1 Initial 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 \((f I) / y\).

\[ (f I) / y = \frac{w L^3}{6} \]

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

\[ w = \frac{8 f I}{y L^2} = \frac{8 \times 165 \times 6558 \times 10^2}{129.8 \times 4500 \times 4500} = 32934 \text{ N/m} \]

And therefore \(W\), the operating load, is given by:

\[ W = 32934 \times 4.5 \text{ N} = 148203 \text{ N} \]
Self Weight of Steel Beam = 422 N/m
Self Weight of Sand Filler = 70 kg/m (approx.)
= 687 N/m

Total Self Weight of Beam and Sand
\[ w_1 = 4.5 \times (422 + 687) \text{ N} \]
= 4990 N

Self Weight of Concrete Slabs = 16 x 0.55 x 6938 N
= 61 054 N

Self Weight of Steel Loading System (Refer to Fig. 14)
8 x 1 m long load spreaders @ 44 kg/m = 352 kg
2 x H frames @ 166 kg each = 332 kg
Total weight of loading system = 684 kg
= 6 710 N

Total Self Weight of Concrete and Loading System
\[ w_2 = 61 054 + 6 710 \text{ N} \]
= 67 764 N

Reaction on the angles due to the concrete slabs and loading system
\[ \text{Reaction} = \frac{w_2}{2} \text{ N} \]
= 67 764 / 2 N
= 33 882 N

Imposed force required by the angles to produce the required bending stress in the test beam
\[ w_2 = W - w_1 - \left( \frac{w_2}{2} \right) \text{ N} \]
= 148 203 - 4990 - 33 882 N
= 109 331 N

Therefore total load required to be applied by the hydraulic rams to the load spreaders located 500 mm on either side of the test beam,
\[ w_4 = 109 331 \times (1960.5 / 1552) \text{ N} \]
= 138 108 N
And so the load per hydraulic ram

\[ P_{eq} = \frac{138 \times 108}{2} \text{ N} \]
\[ = 69054 \text{ N} \]
\[ = 7039 \text{ kg} \]

The load actually applied was 7276 kg per ram.

### A3.2.2 Retrospective Calculations Using Actual Dimensions and Properties

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

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

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

\[ w = \frac{8 \times f \times 1 \times 6751 \times 10^7}{150.5 \times 4500 \times 4500} \text{ N/m} \]

\[ = 441 \text{ N/m} \]

Self Weight of Steel Beam

\[ = 441 \text{ N/m} \]

Self Weight of Sand Filler

\[ = 70 \text{ kg/m (approx.)} \]
\[ = 687 \text{ N/m} \]

Total Self Weight of Beam and Sand

\[ w_t = 4.5 \times (441 + 687) \text{ N} \]
\[ = 5076 \text{ N} \]

Self Weight of Concrete Stabs

\[ = 16 \times 0.55 \times 7312 \text{ N} \]
\[ = 64,346 \text{ N} \]

Self Weight of Steel Loading System

\[ = 6710 \text{ N (unchanged)} \]

Total Self Weight of Concrete and Loading System

\[ w_z = 64,346 + 6710 \text{ N} \]
\[ = 71,056 \text{ N} \]

A3/6
Reaction on the angles due to the concrete slabs and loading system

\[
\text{Reaction} = \frac{w_1}{2} N \\
= 71056 / 2 N \\
= 35528 N
\]

The load actually applied by each of the two hydraulic rams was 7276 kg.

So \[ P_{Ri} = 7276 \text{ kg} \]

Hence the total applied load

\[
w_3 = 7276 \times 2 \text{ kg} \\
= 14552 \text{ kg} \\
= 142755 \text{ N}
\]

But \[ w_4 = w_3 \times (160.5 / 1552) \text{ N} \]

Therefore \[ w_5 = w_4 \times (1552 / 160.5) \text{ N} \\
= 142755 \times (1552 / 160.5) \text{ N} \\
= 113010 \text{ N} \]

And \[ w_4 = W - w_1 - (w_2 / 2) \text{ N} \]

Therefore \[ W = w_5 + w_1 + (w_2 / 2) \text{ N} \\
= 113010 + 5076 + 35528 \text{ N} \\
= 153614 \text{ N} \]

Now, W is the operating load and so w, the load per metre run, (in N/m) is given by:

\[ w = \frac{153614}{4.5} \text{ N/m} \\
= 34136 \text{ N/m} \]

Substituting w in the earlier expression (A3.1) we have:

\[
34136 = \frac{8 \times f \times 6751 \times 10^7}{130.5 \times 4500 \times 4500} \text{ N/mm}^2
\]

Therefore \[ f = \frac{34136 \times 130.5 \times 4500 \times 4500}{8 \times 6751 \times 10^7} \text{ N/mm}^2 \\
= 167.0 \text{ N/mm}^2 \]

A3/6
The retrospective calculations, based on actual dimensions and properties, suggest that the steel section was loaded to 101.2% of the maximum allowable bending stress (BS 449 Design Rules).

A3.3 CALCULATIONS BASED ON BS 5950:PART 1:1985

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

A3.3.1 Initial Calculations Using Nominal Dimensions and Properties

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

\[
M = p_S S \text{ but } s \leq 1.2 p_Z
\]

\[
= 275 \times 588.2 \times 10^3 \text{ kN m}
\]

\[
= 155.3 \text{ kN m}
\]

Check whether \( p_S S \leq 1.2 p_Z \)

\[
1.2 p_Z = 1.2 \times 275 \times 505.3 \times 10^4 \text{ kN m}
\]

\[
= 166.7 \text{ kN m}
\]

So \( p_S S \) is less than \( 1.2 p_Z \)

(b) From A3.2.1

Total Self Weight of Beam and Sand Filler

\[
w_t = 4990 \text{ N}
\]

Moment produced by this load is given by:

\[
\text{Moment}_{t} = (w_t L) / 8 \text{ N m}
\]

\[
= (4990 \times 4.6) / 8 \text{ N m}
\]

\[
= 2807 \text{ N m}
\]

Total Self Weight of Concrete Slabs and Load Spreaders

\[
w_s = 67764 \text{ N}
\]

Reaction on the angles

\[
w_r / 2 = 33882 \text{ N}
\]
Moment produced by this reaction is given by:

$$\text{Moment}_2 = 0.5 \times (w_2 \times L) / 8 \text{ N m}$$

$$= (0.5 \times 67.764 \times 4.5) / 8 \text{ N m}$$

$$= 19.059 \text{ N m}$$

Total hydraulic force imposed on the test beam through the angles

$$w_3 = W - w_1 - (w_2 / 2) \text{ N}$$

$$= 148,203 - 4990 - 33,882 \text{ N}$$

$$= 105,331 \text{ N}$$

Moment produced by this force is given by:

$$\text{Moment}_3 = (w_3 \times L) / 6 \text{ N m}$$

$$= (109,331 \times 4.5) / 6 \text{ N m}$$

$$= 61,499 \text{ N m}$$

Total moments applied to the test beam

$$M_2 = 2807 + 19,059 + 61,499 \text{ N m}$$

$$= 83,365 \text{ N m}$$

Since $M_2$ also equals the applied moment at the first limit state, $M_a$, then the load ratio is

$$LR = M_2 / M_a$$

$$= (83,365 \times 10^3) / 156.3$$

$$= 533$$

(c) Check Shear Force, $(F_v)$, does not exceed shear capacity, $(P_v)$

Maximum Shear Force at the ends

$$F_v = \frac{wL}{2}$$

$$= (32,334 \times 4.5) / 2 \text{ kN}$$

$$= 74,10 \text{ kN}$$

A3/8
Shear Capacity

\[ P_v = 0.6 \cdot p_c \cdot A_c \]

where \( A_c \) is the shear area.

For an I section \( A_c = h \times s \)

\[ P_v = 0.6 \times 275 \times 259.6 \times 7.3 \times 10^3 \text{ kN} \]

\[ = 512.7 \text{ kN} \]

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

A3.3.2 Retrospective Calculations Using Actual Dimensions and Properties

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

\[ M_c = p_c \cdot S \quad \text{but} \leq 1.2 p_c \cdot Z \]

\[ = 294 \times 565.4 \times 10^3 \text{ kN m} \]

\[ = 172.1 \text{ kN m} \]

Check whether \( p_c \cdot S \leq 1.2 p_c \cdot Z \)

\[ 1.2 p_c \cdot Z = 1.2 \times 294 \times 517.3 \times 10^3 \text{ kN m} \]

\[ = 182.5 \text{ kN m} \]

So \( p_c \cdot S \) is less than \( 1.2 p_c \cdot Z \).

(b) From A3.2.2

Total Self Weight of Beam and Sand Filler

\[ w_t = 5076 \text{ N} \]

Moment produced by this load is given by:

\[ \text{Moment}_t = \frac{(w_t \cdot L)}{8} \text{ N m} \]

\[ = \frac{(5076 \times 4.5)}{8} \text{ N m} \]

\[ = 2855 \text{ N m} \]

Total Self Weight of Concrete Slabs and Load Spreaders

\[ w_s = 71,056 \text{ N} \]

A3/9
Reaction on the angles

\[ w_x / 2 \quad = \quad 35\,528 \, N \]

Moment produced by this reaction is given by:

\[ \text{Moment}_y \quad = \quad 0.5 \times (w_x \times L) / 8 \, N \cdot m \]
\[ = \quad (0.5 \times 71\,056 \times 4.5) / 8 \, N \cdot m \]
\[ = \quad 19\,965 \, N \cdot m \]

The load actually applied by each of the two hydraulic rams was 7276 kg

So \[ P_{in} \quad = \quad 7276 \, kg \]

and therefore the total load applied was:

\[ w_x \quad = \quad 142\,755 \, N \]

and the total hydraulic force imposed on the test beam through the angles was:

\[ w_y \quad = \quad 113\,010 \, N \]

Moment produced by this force

\[ \text{Moment}_y \quad = \quad (w_y \times L) / 8 \, N \cdot m \]
\[ = \quad (113\,010 \times 4.5) / 8 \, N \cdot m \]
\[ = \quad 63\,568 \, N \cdot m \]

Total moments applied to the test beam

\[ M_s \quad = \quad 2855 + 19\,965 + 63\,568 \, N \cdot m \]
\[ = \quad 96\,408 \, N \cdot m \]

Since \( M_s \) also equals the applied moment at the fire limit state, \( M_s \), then the load ratio is

\[ LR \quad = \quad M_s / M_s \]
\[ = \quad (96\,408 \times 10^3) / 172.1 \]
\[ = \quad 0.502 \]
A3.4 COMPARISON OF LOADINGS

A3.4.1 BS 449:Part 2:1969

Based on nominal dimensions and section properties it was calculated that in order to develop the maximum permissible bending stress of 185 N/mm² in the lower flange of the steel section an imposed load of 14.08 tonnes was required. However, in the test the load actually applied was 14.55 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicate that the bending stress in the lower flange was 167.0 N/mm² or 101.2% of the maximum permitted value.

A3.4.2 BS 5950:Part 1:1985

Based on nominal values and the application of the previously calculated imposed loading of 14.08 tonnes the load ratio for the test assembly was found to be 0.53. When the higher actual loading value was used in conjunction with the actual section properties data the load ratio value reduced to 0.502. The factor most effective in bringing about such a reduction is the design strength which at 294 N/mm² is approximately 6.9% higher than the nominal value of 275 N/mm². The actual imposed load was approximately 3.4% higher than that required.
APPENDIX 4

PC DISK VERSION OF DATA

As mentioned in the introduction to this report the data recorded during each of the fire tests are available on PC disks. The following section gives a brief outline of the material available and its format. The reader may find it useful to additionally consult reference A4.1.

The data are held on the disks 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 files are identified by reference to the DATA SHEET NUMBER sequence, i.e. 131.DAT and 132.DAT. This numbering system is consistent with that introduced in reference A4.1. Thus, for example, data from test number TNO-B-89-724A can be found in data file 131.DAT. For each individual fire test the thermal data have been sub-divided into 'SETS' which reflect the thermocouple positions in the steelwork, and other materials. Mean temperature values are also included in these data sub-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 each data file. By way of example, README.131 which relates to data in file 131.DAT, is shown in Fig. A4.1.

REFERENCE


A4/1
TABLE A4.1
README FILE ASSOCIATED WITH DATA FILE 131.DAT

Data file 131.DAT contains data recorded during the standard fire resistance test number TNO-B-89-724A which is described in report number SL/PDE/R/S2442/7/96/C - 'Summary of Data Obtained During Tests on Two Floor Beam Assemblies at the Technical Centre for Fire Prevention - TNO RIJSWIJK, Holland' and should be read in conjunction with that document.

There are 30 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>
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<td>TIME, F3, F5, F8, F9, MEAN</td>
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<tr>
<td>SET002.DAT</td>
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<tr>
<td>SET005.DAT</td>
<td>TIME, DEFORMATION, DEFORMATION RATE</td>
</tr>
</tbody>
</table>

A4/2