BS476: Part 21 Fire Resistance Tests
Summary of Data Obtained During Tests on Web Encased Columns

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SUMMARY

BS476: PART 21 FIRE RESISTANCE TESTS
SUMMARY OF DATA OBTAINED DURING TESTS ON WEB ENCASED COLUMNS

D.E. Wainman and L.N. Tomlinson

During the five years 1986-1993 British Steel, (Sections, Plates and Commercial Steels), sponsored more than thirty standard fire resistance tests on hot rolled structural steel sections. The range of systems / component configurations investigated in these tests was much wider than in preceding years. Data arising from the tests are being summarised in a series of reports, each one dealing with either a different form of construction or generic group of test assemblies.

This is the second report issued as part of that series. It contains detailed descriptions of the design, instrumentation and construction for each of five web encased columns, (four concrete filled and one blockwork filled), together with the data arising from them.

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+ BS 4900
+ BS 449

+ BS EN 10 025
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BS476: PART 21 FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING TESTS ON WEB ENCASED COLUMNS

1. INTRODUCTION

In 1967 and 1968 research staff based at British Steel Technical, Swinden Laboratories, prepared and published two compendia\(^\text{11,12}\) in which data obtained from standard fire resistance tests were summarised. These documents covered all the British Steel sponsored fire tests which had been carried out in the UK since 1979 according to the requirements of either BS476:Part 8:1972, or the later revision, BS476:Parts 20/21:1987\(^\text{13,14}\). Only tests on hot rolled structural steel sections in which the test members were completely unprotected, or were partially protected by materials used in the fabric of the structure, such as concrete, brick and block-work, were included. Taking the two documents together, details were given for a total of 62 full scale tests plus a further 31 separate indicative, i.e. unloaded, specimens.

Since the publication of the second compendium a further 46 full scale fire resistance tests have been carried out. The range of systems/component configurations which have been investigated in these tests has been much wider than in the preceding years and has included, for example, tests on:

- 8 flange plated slim floor beams, (of which 7 were loaded and one was a full length indicative).
- 4 shelf angle floor beams, (of various types).
- 5 composite metal deck floors, (of various types).
- 6 pairs of beam / beam and beam / column connection assemblies.
- 4 composite columns with concrete infill between the flanges.
- 1 column with block-work infill between the flanges.

Plus, amongst others, three tests on concrete filled circular hollow section columns, two lattice girders formed from square hollow sections, an arched metal deck floor and two fully protected beams. Brief details of all these tests can be found in a recent Technical Note\(^\text{15}\). Tests have also been carried out on a number of indicative specimens. These were usually small assemblies which were included in the furnace alongside a full length member, though in some cases they were themselves full scale assemblies.

Much of the data generated from the individual test programmes have already been used extensively by British Steel staff and co-workers in other organisations. In particular, they have been used by the Steel Construction Institute\(^\text{16,17}\), for the preparation of Design Guides and other documents covering various forms of construction. There is, however, a need to document the test configurations and data in more detail than is usually given in such publications. Having regard to the variety and complexity of the systems examined during the last few years it has been deemed impractical to attempt to present the data for all of them in one document at the present time. It has therefore been decided that a series of reports should be prepared, each one dealing with either a different form of construction or generic group of test assemblies, and that these will eventually be combined to form a third compendium. The first report in the series was issued in September 1993\(^\text{18}\) and included material relating to the eight flange plated slim floor beams.

This is the second report issued as part of that series. It contains detailed descriptions of the design, instrumentation and construction for each of five web encased column assemblies, together with the data arising from them which are included in Appendix 1. The data are presented in a format which is generally consistent with that introduced in the previous compendia. No analyses of the data are included since these have 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, those in this document being numbered from 107 to 111 inclusive. As in the previous compendia, the thermal data are reduced to
summary values at various times throughout the duration of each test. It should be noted, however, that all the thermal data, usually recorded at one minute intervals, can be made available on PC disks. These may be obtained, on request, from British Steel Technical, Swindon Laboratories.

As before, the fire tests reported here form 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. CHANGES TO STANDARDS

The following changes to British Standards have occurred since the publication of the previous compendia.

2.1 BS4360:1888 'Weldable Structural Steels'

This standard was withdrawn with effect from March 30th 1990. The parts of BS4360 pertaining to hot rolled sections and plates were replaced from that date by EN 10025 'Hot Rolled Products of Non-Alloy Structural Steels - Technical Delivery Conditions'. BS EN 10025:1990 is the English Language version of that standard. The specification requirements for those products and grades not within the scope of EN 10025 were simultaneously re-published unchanged as BS4360:1990.

As far as the present work is concerned it should be noted that two of the tests were carried out after March 30th 1993. Steel quality BS4360:Grade 43A should therefore be referred to as BS EN 10025:1990 Grade Fe430A. However, this grade only appears in the UK edition of the standard under the heading 'Non Conflicting National Standards'. Similarly, steel quality BS4360:Grade 50B should be referred to as BS EN 10025:1990 Grade Fe510B.

The requirements of the two specifications were compared in the previous report. A detailed comparison of the two standards is given in Ref. 10.

2.2 BS476:Parts 20/21:1987

No changes were made to the standard during the period covered by this report. However, discussions are ongoing concerning certain aspects of the standard fire test procedures.


BS449:Part 2 was significantly amended in December 1989, (AMD 625f), in order to reflect the revised increased yield strength of Grade 43 steels included in BS4360. These, and earlier amendments, were incorporated into the standard which was re-issued during 1990. As far as the present work is concerned the major difference between the 1990 edition and its predecessor is to be found in the higher values for the 'Allowable stress on gross section for axial compression' given in Table 17a. (Grade 43A steel). For the sake of consistency in the calculation procedures the earlier version of the standard, which was current at the commencement of the test programme, was used throughout. It is these calculations which are summarised in Appendix 2. It should be noted that this standard has now been declared 'obsolescent' but has not yet been withdrawn.

Those parts of the loading calculations which involved reference to BS5950:Part 1 used the data given in the 1985 version of the standard. During the currency of the work described here that standard was withdrawn and replaced by BS5950:Part 1:1990. However, as far as the present work is concerned it makes no difference to the calculated values since the compressive strength data given in Table 37c of both standards are the same.

3. FIRE TESTS ON WEB ENCASED COLUMNS

In this section details are given for tests performed on five loaded column assemblies. All the tests were carried out in accordance with the requirements of BS476:Parts 20/21:1987 at the Loss Prevention
Council, (Borehamwood), between November 1989 and January 1991. The major features of the tests are summarised in Table 1.

Details describing fire resistance tests on loaded column assemblies were given in the first two compendia (1/12), and it is not, therefore, proposed to cover these items again in the present report.

The design and preparation of the five assemblies are described individually in the following sections. A number of features are, however, common to all of them and these are described here.

3.1 Features Common to all the Test Assemblies

3.1.1 Steel Quality

Unless specifically indicated to the contrary, all the steel members used in the construction of the test assemblies were manufactured by British Steel and were supplied to the requirements of the following specifications:-

(a) in the case of the three tests carried out during 1989, BS4360:1986 Grade 43A.

(b) in the case of the two tests carried out during 1990 and 1991, BS EN 10025:1990 Grades Fe435A or Fe510B.

Details of their chemical compositions and mechanical properties are included in the appropriate Data Sheets in Appendix 1.

3.1.2 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.

3.1.3 Structural Calculations

In Compendium No. 1 the load resistance calculations were based upon the design rules given in BS449. Compendium No. 2 was published following the introduction of the new limit state design philosophy and the calculated loads were also presented in terms of BS5950. However, because it is impossible to know how a member will be used in practice, the factored loads cannot be defined and therefore the loads calculated using BS449 were presented as a proportion of the members capacity. This is referred to as the load ratio and is given by:

\[
\text{Load Ratio} = \frac{M_r}{M_u}
\]

where: \(M_r\) = the applied moment at the fire limit state

and: \(M_u\) = the moment capacity at 20°C

In calculating \(M_u\), the design strength, \(p_r\), corresponding to the minimum guaranteed yield strength for the grade of steel is normally used. However, for the purpose of evaluating the effect of load ratio on, for example, the limiting temperature, the influence of variations in the strength of the as-received material can be diminished by adopting the measured yield strength for \(p_r\). These have been determined from samples removed from the members under test.

The loads to be applied to the various assemblies were calculated on the basis of the nominal dimensions and section properties for the steel members concerned. These initial calculations were subsequently repeated to take account of the actual dimensions and mechanical properties of the sections used in the construction. It should be noted that in the case of the blockwork filled column, (Test No. TE 7436), no mechanical properties data for the section have so far been traced. Loading calculations for each of the five assemblies are presented in Appendix 2.

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The columns were subjected to loads of 0.35 to 0.55 times the "cold" capacity of the steel section. In the case of the four concrete filled sections varying numbers of shot fired shear connectors were used in order to develop 'composite' action during the fire. In two of the tests this behaviour was further enhanced by welding web stiffeners at the top end of the columns.

3.1.4 Fabrication

All the test assemblies were formed from 3400 mm long universal column sections. 'Standard' LPC bearing plates, (406 mm square × 19 mm thick), were welded to both ends of the section using four cleats formed from 90 × 90 × 12 mm rolled steel angle. These were placed on either side of the web and on the outer flange faces. Attachment of the plates to the section was effected only via the angle cleats, i.e. there was no direct connection between the column and the plates. Welding was by the MMA process using 4 mm diameter basic coated, hydrogen controlled, general purpose welding rods. The welds were intermittent 8 mm fillets. The only other fabrication work required was the placing of the web stiffeners in the final two assemblies. This item is covered in the test descriptions, (see Section 3.2).

3.1.5 Instrumentation

3.1.5.1 Temperature Measurement

The test assemblies were instrumented such that the temperatures attained by the steel section 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. Temperatures were also monitored in other parts of the assemblies, such as, for example, the concrete infill. The thermocouples used for these situations were again 'K' type but were usually formed from glass fibre covered Ni-Cr / Ni-Al conductors.

3.1.5.2 Column Extension

The longitudinal extension of the column was monitored throughout each test, (by LPC personnel), using a linear displacement transducer situated below the centre of the crosshead transmitting the load from the hydraulic jacks to the column. The data are included in the appropriate Data Sheets in Appendix 1.

3.1.6 Assembly / Loading

Each complete test assembly was positioned vertically between the upper and lower column furnace crossheads, to which they were attached by bolting through the holes in the welded on end plates. Both ends of the column were protected by the application of a mineral fibre blanket so that the length of column actually exposed to the heating conditions of the test was 3100 mm.

The load was applied to the column by means of two hydraulic jacks acting through the lower crosshead member. It was applied at least 15 minutes prior to the commencement of the heating period, and was kept constant throughout the test by allowing the column to expand against the applied load.

3.1.7 Failure Criteria

The performance of all five test assemblies was judged against the load bearing capacity criterion outlined in Section 6 of BS476: Part 21:1987 and in accordance with the general principles embodied in BS476: Part 20:1987.

The standards state that a column is regarded as having a fire resistance rating, (expressed in minutes), that is equal to the elapsed time, (in completed minutes), between the commencement of heating and the termination of heating or until failure to meet the load bearing capacity criterion occurs, whichever is the sooner.

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3.1.8 Additional Data

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

3.2 Loaded Test Assemblies

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

3.2.1 Test No. TE 7436

The test assembly consisted of a universal column section of serial size 305 × 305 mm × 240 kg/m which was partially protected by block-work cemented into the flange / web cavities. The column was BS4360:Grade 43A material. The protection comprised 23 'Celcon' aerated, autoclaved concrete blocks, each nominally 290 mm long × 210 mm deep × 135 mm thick, which were cemented into the section cavities, (14 each side), and finished flush with, or slightly proud of, the flange tips. A nominal 10 mm thick mortar joint was maintained between adjacent blocks and the block / steel interfaces. The arrangement is shown schematically in Fig. 1. The blocks were positioned so as to leave a 300 mm long portion of the web exposed at the top end of the column. The lower half of this was protected throughout the duration of the test by an infill of insulating ceramic fibre blanket material. The ends of the columns were additionally protected with mineral fibre blanket, (see Section 3.1.6).

The following properties were quoted by the manufacturer for the 'Celcon' blocks.

- Typical stabilised water content 3%
- Density (at 3% moisture level) 680 kg/m³
- Density (fully dried) 650 kg/m³
- Compressive Strength 4.0 N/mm²
- Coefficient of expansion 8 × 10⁻⁶ mm/°C
- Nominal dimensions, length 440 mm
depth 210 mm
thickness 150 mm

A total of 18 thermocouples were used to monitor the temperature of the steel section throughout the 60 minute heating period of the test. The thermocouple positions were as shown in Fig. 2.

A load of 4370 kN was applied to the column. This was calculated to be the maximum permissible load, assuming nominal dimensions and properties for the steel section, when calculated in accordance with BS5449:Part 2:1969. Loading calculations are given in Appendix 2.1. It should be noted that no mechanical properties data are available for the steel section and so it has not been possible to carry out a proper retrospective calculation using a measured value for the design strength, p_d. However, the calculations in Appendix 2.1 indicate that the load ratio, as defined by BS5950:Part 1:1985 was at least 0.599.

Data for this test are summarised in Data Sheet No. 107.

3.2.2 Test No. TE 7381

The test assembly consisted of a universal column section of serial size 254 × 254 mm × 73 kg/m which was partially protected by a concrete infill in the flange / web cavities. The column was BS4360:Grade 43A material. Hilti HYB110 shear connectors were attached to both faces of the web using ENFP 211.15 shot fired pins. The fixing locations for each connector were offset from the vertical centre line of the web by an amount equal to half the connector width. This resulted in one shear connector on each face of the web set at the same vertical height, but with a horizontal fixing displacement relative to one another equal to the connector width. The location of the connectors was as shown in Fig. 3 and comprised ten connectors...
secured to each face of the web with a vertical separation of 300 mm between them. The concrete, which was nominally Grade 30, comprised ballast and cement in a ratio of approximately 4:1. The ballast contained aggregate with a maximum nominal size of 20 mm. The concrete was finished flush with the flange tips and stopped approximately 270 mm from the top of the column. Samples of the concrete were taken at the time of filling the flange / web cavities for subsequent moisture, density and strength determinations. The following values were recorded at the time of the test:

- Density 2360 kg/m³
- Mean weight loss after drying at 105ºC 4.96%
- Density (dried at 105ºC) 2243 kg/m³
- Compressive strength 62.5 N/mm²

A total of 23 thermocouples were used to monitor the temperature of the steel section throughout the 60 minute heating period of the test. The thermocouple positions were as shown in Fig. 4. A further 22 thermocouples were used to monitor the temperatures within the concrete and on the 6th shear connector from the base. The positions were as shown in Fig. 5.

A load of 1332 kN was applied to the column. Based on nominal dimensions and properties for the steel section it was calculated that this represented approximately 87% of the maximum permissible load of 1500 kN, calculated in accordance with BS449-Part 2:1969. The reduction in load was required in order to test the assembly at a load ratio of 0.5, as defined by BS5950-Part 1:1985. A retrospective calculation using actual section properties data indicates that the load ratio was actually somewhat lower at 0.474. Loading calculations are presented in Appendix 2.2.

Data for this test are summarised in Data Sheet No. 108.

3.2.3 Test No. TE 7382

The test assembly was identical in construction to the previous one (TE 7381), except for the number and position of the Hilti shear connectors. These were located as shown in Fig. 6 and comprised six connectors secured to each face of the web with a vertical separation of 500 mm between them. The concrete, which again was nominally Grade 30, stopped approximately 250 mm from the top of the column. The following values were recorded for the concrete at the time of the test:

- Density 235/kg m³
- Mean weight loss after drying at 105ºC 5.0%
- Density (dried at 105ºC) 2230 kg/m³
- Compressive strength 62.5 N/mm²

A total of 23 thermocouples were used to monitor the temperature of the steel section throughout the 73 minute heating period of the test. The thermocouple positions were as shown in Fig. 4. A further 22 thermocouples were used to monitor the temperatures within the concrete and on the 4th shear connector from the base. The positions were as shown in Fig. 5.

A load of 792.4 kN was applied to the column. Based on nominal dimensions and properties for the steel section it was calculated that this represented approximately 61% of the maximum permissible load of 1300 kN, calculated in accordance with BS449-Part 2:1969. The reduction in load was required in order to test the assembly at a load ratio of 0.35, as defined by BS5950-Part 1:1985. A retrospective calculation using actual section properties data indicates that the load ratio was actually somewhat lower at 0.332. Loading calculations are presented in Appendix 2.3.

Data for this test are summarised in Data Sheet No. 109.

3.2.4 Test No. TE 80470

The test assembly consisted of a universal column section of serial size 203 × 203 mm × 60 kg/m which was partially protected by a concrete infill in the flange / web cavities. The column was BS EN 10025

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Grade Fe510B material. Hilti HV880 shear connectors were attached to both faces of the web using ENP3-211.15 shot fired pins. All the connectors were positioned in the 'leg down' orientation with the exception of the uppermost one on each side of the web which was positioned 'leg up'. The fixing locations for each connector were offset from the vertical centre line of the web as described in Section 3.2.2. The location of the connectors was as shown in Fig. 7 and comprised eight connectors secured to each face of the web with a vertical separation of 423 mm between them. Web stiffeners, formed from nominally 10 mm thick Grade Fe510B plate, were welded into the flange / web cavities on each side of the web at a distance of 250 mm from the top of the section. All webs were 8 mm continuous fillets. The concrete, which was nominally Grade 30, filled the flange / web cavities up to the underside of the web stiffeners. As before it was finished flush with the flange tips. Samples of the concrete were taken at the time of filling the cavities. The following values were recorded at the time of the test:

- Density 2235 kg/m³
- Mean weight loss after drying at 105°C 4.75%  
- Density dried at 100°C 2152 kg/m³
- Compressive strength Not given

A total of 23 thermocouples were used to monitor the temperature of the steel section throughout the 70 minute heating period of the test. The thermocouple positions were as shown in Fig. 8. A further 14 thermocouples were used to monitor the temperatures within the concrete and on the 4th, (SC1), and 5th, (SC2), shear connectors from the base, (on one side only). The positions were as shown in Fig. 9.

A load of 976 kN was applied to the column. Based on nominal dimensions and properties for the steel section it was calculated that this represented approximately 68.5% of the maximum permissible load of 1429 kN, calculated in accordance with BS449:Part 2:1969. The reduction in load was required in order to test the assembly at a load ratio of 0.45, as defined by BS5950:Part 1:1990. A retrospective calculation using actual section properties data indicates that the load ratio was actually somewhat lower at 0.420. Loading calculations are presented in Appendix 2.4.

Data for this test are summarised in Data Sheet No. 110.

3.2.5 Test No. TE 80471

The test assembly consisted of a universal column section of serial size 254 × 254 mm × 73 kg/m which was partially protected by a concrete infill in the flange / web cavities. The column was BS EN 10025 Grade Fe430A material. Hilti HV880 shear connectors were attached to both faces of the web in the manner described for the previous test, (TE 80470). Web stiffeners, formed from nominally 10 mm thick Grade Fe430A plate, were welded into both flange / web cavities at a distance of 250 mm from the top of the section. All webs were 8 mm continuous fillets. The concrete, which again was nominally Grade 30, filled the flange / web cavities up to the underside of the web stiffeners. As before it was finished flush with the flange tips. Samples of the concrete were taken at the time of filling the cavities. The following values were recorded at the time of the test:

- Density 2240 kg/m³
- Mean weight loss after drying at 105°C 4.36%  
- Density dried at 105°C 2156 kg/m³
- Compressive strength Not given

A total of 23 thermocouples were used to monitor the temperature of the steel section throughout the 73.5 minute heating period of the test. The thermocouple positions were as shown in Fig. 8. A further 14 thermocouples were used to monitor the temperatures within the concrete and on the 4th, (SC1), and 5th, (SC2), shear connectors from the base, (on one side only). The positions were as shown in Fig. 9.

A load of 1244 kN was applied to the column. Based on nominal dimensions and properties for the steel section it was calculated that this represented approximately 85.6% of the maximum permissible load of 1300 kN, calculated in accordance with BS449:Part 2:1969. The reduction in load was required in order to test the assembly at a load ratio of 0.55, as defined by BS5950:Part 1:1995. A retrospective calculation
using actual section properties data indicates that the load ratio was actually somewhat lower at 0.631.
Loading calculations are presented in Appendix 2.6.

Data for this test are summarised in Data Sheet No 111.

4. CONCLUSIONS

Data arising from five standard fire resistance tests carried out on web encased columns have been collected and reported. Details of the test assemblies are given, together with summaries of the material properties, structural calculations and the thermal data recorded.

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Investigator

D.E. Wainman
Investigator

D.M. Martin
Manager
Heavy Engineering & Design Department

D.J. Price
Research Manager
General Steel Products

REFERENCES


<table>
<thead>
<tr>
<th>Test Date</th>
<th>LPC Test No.</th>
<th>Nominal Section Dimensions (mm x mm x kg/m)</th>
<th>Steel Grade</th>
<th>Construction Details</th>
<th>Lead Bearing Capacity (kN)</th>
<th>Lead Ratio</th>
<th>Comments</th>
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<td>07.11.89</td>
<td>7436</td>
<td>305 x 305 x 240</td>
<td>43A</td>
<td>28 Standard density &quot;L&quot;-shaped blocks cemented into the flange/web cavities. (See Fig. 1)</td>
<td>48</td>
<td>0.579</td>
<td>0.599</td>
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<td>7381</td>
<td>254 x 254 x 73</td>
<td>43A</td>
<td>Grade 20 concrete infill to the flange/web cavities. (300 mm not filled at top end). 10 Hilti HBV110 shear connectors on each side of section web at 300 mm spacing. (See Fig. 3)</td>
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<td>0.50</td>
<td>0.474</td>
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<td>43A</td>
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<td>71</td>
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<td>0.322</td>
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<td>13.12.90</td>
<td>80470</td>
<td>203 x 203 x 60</td>
<td>Fe510B</td>
<td>Grade 20 concrete infill to the flange/web cavities up to the web stiffeners. 9 Hilti HBV110 shear connectors on each side of section web at 423 mm spacing. 10 mm thick web stiffeners at 250 mm from top of section. (See Fig. 7)</td>
<td>69</td>
<td>0.45</td>
<td>0.420</td>
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<td>80471</td>
<td>254 x 254 x 73</td>
<td>Fe430A</td>
<td>Grade 20 concrete infill to the flange/web cavities up to the web stiffeners. 8 Hilti HBV110 shear connectors on each side of section web at 423 mm spacing. 10 mm thick web stiffeners at 250 mm from top of section. (See Fig. 7)</td>
<td>72</td>
<td>0.55</td>
<td>0.531</td>
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FIG. 1
CONSTRUCTIONAL DETAILS FOR THE 'CELCON' BLOCKWORK USED ON TEST NO. TE 7436
(All dimensions in mm)

Based on Actual Section Dimensions

150 deep ceramic fibre blanket infill to web

36.5

282.1

260

36.5

145.65

135

23.1

45.65

10 mm Standard mortar joint

Celcon blockwork finished flush, or slightly proud of steelwork
Hilti HVB 110 shear connectors fixed with ENP3 - 21L15 shot fired pins

Grade 30 concrete infill

Top of concrete
Shear connector locations
Concrete
Steel column
(254 x 254 mm x 73 kg/m)

All dimensions in mm.

FIG. 3 DETAILS OF HILTI SHEAR CONNECTOR LOCATIONS AND CONCRETE INFILL - TEST NO. TE 7381

F3
Hilti HVB 110 shear connectors fixed with EPF3 - 21L15 shot fired pins

Grade 30 concrete infill

Top of concrete

Shear connector location

Concrete

Steel column (254 x 254 mm x 73 kg/m)

All dimensions in mm.

FIG. 6 DETAILS OF HILTI SHEAR CONNECTOR LOCATIONS AND CONCRETE INFILL - TEST NO. TE 7382

(B4/2195)
FIG. 7  DETAILS OF HILTI SHEAR CONNECTOR LOCATIONS
AND CONCRETE INFILL - APPLICABLE TO
tests TE 80470 and TE 80471

Grade 30 concrete infill
Hilti HVB 80 shear connectors
fixed with ENF3 - 21L15
shot fired pins

Web stiffener. 10 mm thick
Top of concrete infill
Shear connector locations
Concrete
Steel column
(203 x 203 mm x 60 kg/m) 80470
(254 x 254 mm x 73 kg/m) 80471

All dimensions in mm.
FIG. 9  THERMOCOUPLE POSITIONS IN THE CONCRETE
- APPLICABLE TO TESTS TE 80470 AND TE 80471
   (All dimensions in mm)
APPENDIX I

DATA SHEET NUMBERS 107-111
### Dimensions and Properties

<table>
<thead>
<tr>
<th>Section</th>
<th>Dimensions and Properties</th>
<th>Mass per Metre kg</th>
<th>Depth of Section mm</th>
<th>Width of Section mm</th>
<th>Thickness</th>
<th>Elastic Modulus (Axs) x 10^3</th>
<th>Plastic Modulus (Axs) x 10^3</th>
<th>Moment of Inertia (Axs) x 10^3</th>
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<td>305 x 106 Column</td>
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<td>240</td>
<td>352.6</td>
<td>317.9</td>
<td>23.0</td>
<td>37.7</td>
<td>3699</td>
<td>1273</td>
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<td></td>
<td></td>
<td>222.9</td>
<td>355.1</td>
<td>314.4</td>
<td>22.1</td>
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<td>3569</td>
<td>1105</td>
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</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>Column</td>
<td>Grade 42A</td>
<td>0.16</td>
<td>0.27</td>
<td>1.12</td>
<td>0.014</td>
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<td>&lt;0.02</td>
<td>&lt;0.002</td>
<td>&lt;0.005</td>
<td>0.02</td>
<td>&lt;0.006</td>
<td>0.034</td>
<td>0.005</td>
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### Room Temperature Tensile Properties

<table>
<thead>
<tr>
<th>Position</th>
<th>LYS N/mm²</th>
<th>TS N/mm²</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flange</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Notes

(N/A) Not available.
(a) Since no LYS values were recorded.
(b) Heating continued with no applied load.

Initial Ambient Temperature = 15°C

### Test Conditions

<table>
<thead>
<tr>
<th>NOMINAL</th>
<th>ACTUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Length, mm</td>
<td>3400</td>
</tr>
<tr>
<td>Column Exposed Length, mm</td>
<td>3100</td>
</tr>
<tr>
<td>Column Effective Length, mm</td>
<td>2380</td>
</tr>
<tr>
<td>Area of Cross Section, mm²</td>
<td>30543.6</td>
</tr>
<tr>
<td>Least Radius of Gyration, mm</td>
<td>81.36</td>
</tr>
<tr>
<td>Strain Ratio</td>
<td>29.25</td>
</tr>
</tbody>
</table>

**BS449: Part 3: 1969**

| Allowable Stress, N/mm² | 143 | 143 |
| Maximum Permissible Load, kN | 4242.2 | 4242.2 |
| Load Applied, kN | 4568 | 4370 |

**BS690: Part 1: 1985**

<p>| Design Strength, N/mm² | 265 | 265 (a) |
| Compressive Strength, N/mm² | 247 | 246 |
| Load Capacity, kN | 7544.3 | 7297.8 |
| Load Ratio | 0.079 | 0.599 |</p>
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TEMPERATURE Deg. C AFT ER VARIOUS TIMES (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed Plunges</td>
<td>3</td>
</tr>
<tr>
<td>East @ 2550 mm</td>
<td>24</td>
</tr>
<tr>
<td>West @ 2550 mm</td>
<td>25</td>
</tr>
<tr>
<td>@ 1550 mm</td>
<td>26</td>
</tr>
<tr>
<td>Overall Mean</td>
<td>27</td>
</tr>
<tr>
<td>Plunge-Wap Junction East @ 450 mm</td>
<td>28</td>
</tr>
<tr>
<td>West @ 1550 mm</td>
<td>29</td>
</tr>
<tr>
<td>Mean</td>
<td>30</td>
</tr>
</tbody>
</table>

| Extention (mm)   | 0  | 0.5 | 1.5 | 2.0 | 2.5  | 3.0  | 3.5  | 4.0  | 4.5  | 5.0  | 5.5  | 6.0  | 6.5  | 7.0  | 7.5  | 8.0  | 8.5  |

Note: The table above provides the temperature in degrees Celsius after various times (in minutes) for different locations. The data includes measurements for exposed plunges and a plunge-wap junction. The mean values are also provided for each set of measurements.
COLUMN WITH BLOCCED IN WEB

VERTICAL EXTENSION (cm)

TIME (min)

A1/4
## Dimensions and Properties

<table>
<thead>
<tr>
<th>Section Serial Size and Type mm</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 mm</th>
<th>Elastic Modulus Axis X /Y kN/mm²</th>
<th>Plastic Modulus Axis X /Y kN/mm²</th>
<th>Moment of Inertia Axis X /Y mm⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>254 x 254 Column</td>
<td>Nominal Actual</td>
<td>73</td>
<td>254.0</td>
<td>254.0</td>
<td>8.6</td>
<td>955.5</td>
<td>205.6</td>
<td>11,971</td>
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## Chemical Composition (Product Analysis - Wt. %)

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<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>N</th>
<th>Al</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>Grade 43A</td>
<td>0.12</td>
<td>0.27</td>
<td>1.34</td>
<td>0.016</td>
<td>&lt;0.02</td>
<td>&lt;0.005</td>
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<td>&lt;0.005</td>
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## Room Temperature Tensile Properties

<table>
<thead>
<tr>
<th>Position</th>
<th>LYS / N/mm²</th>
<th>TS / N/mm²</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flanges</td>
<td>215</td>
<td>466</td>
<td>33.0</td>
</tr>
</tbody>
</table>

## Test Conditions

<table>
<thead>
<tr>
<th>Nominal</th>
<th>Actual</th>
</tr>
</thead>
</table>

| Cylindrical Length, mm | 3400   | 3400   |
| Column Exposed Length, mm | 3100   | 3100   |
| Column Effective Length, mm | 2380   | 2380   |
| Area of Cross Section, mm² | 1292.2 | 9084.8 |
| Least Radius of Gyration, mm | 61.65  | 64.66  |
| Shear Strength Ratio | 36.83  | 36.81  |

<table>
<thead>
<tr>
<th>BS5449-Part 2:1989</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Stress, N/mm²</td>
</tr>
<tr>
<td>Maximum Permissible Load, kN</td>
</tr>
<tr>
<td>Load Applied, kN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BS5950:Part 1:1985</th>
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</thead>
<tbody>
<tr>
<td>Design Strength, N/mm²</td>
</tr>
<tr>
<td>Compressive Strength, N/mm²</td>
</tr>
<tr>
<td>Load Capacity, kN</td>
</tr>
<tr>
<td>Load Ratio</td>
</tr>
<tr>
<td>Load Ratio Required</td>
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</tbody>
</table>

**Notes**
- (a) denotes not analyzed.
- (b) denotes not applied load.
- (*) denotes no data recorded.

Initial Ambient Temperature = 10°C
COLUMNS WITH CONCRETE INFILL BETWEEN FLANGES

VERTICAL EXTENSION (mm)

TIME (min)

A/B
**COLUMN WITH CONCRETE INFILL BETWEEN FLANGES**

### DIMENSIONS AND PROPERTIES

<table>
<thead>
<tr>
<th>Section</th>
<th>Dimensions 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</th>
<th>Plastic Modulus</th>
<th>Moment of Inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>254 x 264 Column</td>
<td>Nominal Actual</td>
<td>73</td>
<td>71.3</td>
<td>254.0</td>
<td>256.1</td>
<td>8.6</td>
<td>14.2</td>
<td>869.5</td>
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</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>Column</td>
<td>Grade 43A</td>
<td>0.11</td>
<td>0.6</td>
<td>1.34</td>
<td>0.010</td>
<td>0.014</td>
<td>&lt;0.02</td>
<td>&lt;0.005</td>
<td>&lt;0.02</td>
<td>&lt;0.005</td>
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<td>N/A</td>
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### ROOM TEMPERATURE TENSILE PROPERTIES

<table>
<thead>
<tr>
<th>Position</th>
<th>LYS N/mm²</th>
<th>TS N/mm²</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flanges</td>
<td>298</td>
<td>446</td>
<td>33.0</td>
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</tbody>
</table>

### TEST CONDITIONS

<table>
<thead>
<tr>
<th>NOMINAL</th>
<th>ACTUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Length, mm</td>
<td>3400</td>
</tr>
<tr>
<td>Column Exposed Length, mm</td>
<td>3100</td>
</tr>
<tr>
<td>Column Effective Length, mm</td>
<td>2380</td>
</tr>
<tr>
<td>Area of Cross Section, mm²</td>
<td>9292.2</td>
</tr>
<tr>
<td>Least Radius of Gyration, mm</td>
<td>64.62</td>
</tr>
<tr>
<td>Slenderness Ratio</td>
<td>36.83</td>
</tr>
</tbody>
</table>

**BS449 Part 2:1989**

- Statically Indeterminate Structures

| Allowable Stress, N/mm² | 140 | 140 |
| Maximum Permissible Load, kN | 1300.9 | 1271.9 |
| Load Applied, kN | - | 792.4 (a) |

**BS5950 Part 1:1995**

- Design Stress, N/mm²
- Compressive Stress, N/mm²
- Load Capacity, kN
- Load Ratio

**NOTES**

(N/A) Not analysed.

(α) Equals 60.92% of the maximum permissible load according to BS449 Part 2:1989.

(*) No data recorded.

Initial Ambient Temperature = 9°C
<table>
<thead>
<tr>
<th>Temperature Deg. C. After Various Times (Minutes)</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
<th>21</th>
<th>24</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
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</thead>
<tbody>
<tr>
<td>Unplastered</td>
<td>12</td>
<td>15</td>
<td>22</td>
<td>31</td>
<td>42</td>
<td>57</td>
<td>73</td>
<td>94</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>114</td>
<td>112</td>
<td>150</td>
<td>159</td>
<td>237</td>
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<tr>
<td>Plastered</td>
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<td>Exposed Neoprene</td>
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<td>109</td>
<td>120</td>
<td>140</td>
<td>160</td>
<td>180</td>
<td>200</td>
<td>220</td>
<td>240</td>
<td>260</td>
<td>280</td>
<td>300</td>
<td>320</td>
<td>340</td>
<td>360</td>
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<td>159</td>
<td>189</td>
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<td>249</td>
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<td>309</td>
<td>339</td>
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<td>199</td>
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<td>439</td>
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<td>470</td>
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<td>64</td>
<td>127</td>
<td>180</td>
<td>233</td>
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<td>339</td>
<td>392</td>
<td>445</td>
<td>498</td>
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<td>657</td>
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<td>229</td>
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<td>12.5</td>
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<td>20.3</td>
<td>21.9</td>
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<td>200</td>
<td>220</td>
<td>240</td>
<td>260</td>
<td>280</td>
<td>300</td>
<td>320</td>
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<tr>
<td>Mean</td>
<td>15</td>
<td>39</td>
<td>59</td>
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<td>120</td>
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<td>160</td>
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<td>200</td>
<td>220</td>
<td>240</td>
<td>260</td>
<td>280</td>
<td>300</td>
<td>320</td>
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<tr>
<td>Mortar Paste</td>
<td>392</td>
<td>572</td>
<td>628</td>
<td>684</td>
<td>717</td>
<td>759</td>
<td>800</td>
<td>840</td>
<td>880</td>
<td>920</td>
<td>960</td>
<td>1000</td>
<td>1040</td>
<td>1080</td>
<td>1120</td>
<td>1160</td>
</tr>
<tr>
<td>Mean</td>
<td>392</td>
<td>572</td>
<td>628</td>
<td>684</td>
<td>717</td>
<td>759</td>
<td>800</td>
<td>840</td>
<td>880</td>
<td>920</td>
<td>960</td>
<td>1000</td>
<td>1040</td>
<td>1080</td>
<td>1120</td>
<td>1160</td>
</tr>
<tr>
<td>Standard Curve</td>
<td>0.3</td>
<td>1.2</td>
<td>3.7</td>
<td>4.3</td>
<td>6.7</td>
<td>9.2</td>
<td>10.9</td>
<td>12.5</td>
<td>14.0</td>
<td>15.6</td>
<td>17.1</td>
<td>18.7</td>
<td>20.3</td>
<td>21.9</td>
<td>23.5</td>
<td>25.1</td>
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<tr>
<td>Extension (mm)</td>
<td>15</td>
<td>39</td>
<td>59</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>140</td>
<td>160</td>
<td>180</td>
<td>200</td>
<td>220</td>
<td>240</td>
<td>260</td>
<td>280</td>
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<tr>
<td>Mean</td>
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<td>39</td>
<td>59</td>
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<td>100</td>
<td>120</td>
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<td>220</td>
<td>240</td>
<td>260</td>
<td>280</td>
<td>300</td>
<td>320</td>
</tr>
</tbody>
</table>
COLUMN WITH CONCRETE INFILL BETWEEN FLANGES

VERTICAL EXTENSION (mm)

TIME (min)

-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80

A1/12
### Dimensions and Properties

<table>
<thead>
<tr>
<th>Section Serial Size and Type</th>
<th>Dimensions and Properties</th>
<th>Depth of Section [mm]</th>
<th>Width of Section [mm]</th>
<th>Thickness</th>
<th>Elastic Modulus</th>
<th>Plastic Modulus</th>
<th>Moment of Inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>203 x 203 Column</td>
<td>Nominal</td>
<td>62.4</td>
<td>211.1</td>
<td>206.2</td>
<td>9.2</td>
<td>14.2</td>
<td>9.6</td>
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</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>Column</td>
<td>Grade Fe510B</td>
<td>0.15</td>
<td>0.02</td>
<td>1.46</td>
<td>0.015</td>
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<td>&lt;0.03</td>
<td>&lt;0.006</td>
<td>&lt;0.006</td>
<td>0.032</td>
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</table>

### Room Temperature Tensile Properties

<table>
<thead>
<tr>
<th>Position</th>
<th>LYS N/mm²</th>
<th>TS N/mm²</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flange</td>
<td>277</td>
<td>512</td>
<td>22.0</td>
</tr>
</tbody>
</table>

### Notes

- Equal to 68.52% of the maximum permissible load according to BS449:Part 2:1969.
- No data recorded.

Initial Ambient Temperature = 10°C

### Test Conditions

- **Nominal**:
  - Column Length, mm: 3400
  - Column Exposed Length, mm: 3100
  - Column Effective Length, mm: 2380
  - Area of Cross Section, mm²: 7602.2
  - Least Radius of Gyration, mm: 51.88
  - Slenderness Ratio: 45.88

- **Actual**:
  - Column Length, mm: 3400
  - Column Exposed Length, mm: 3100
  - Column Effective Length, mm: 2380
  - Area of Cross Section, mm²: 7699.3
  - Least Radius of Gyration, mm: 51.84
  - Slenderness Ratio: 45.82

BS449:Part 2:1969
- Allowable Stress, N/mm²: 188
- Maximum Permissible Load, kN: 1429.2
- Load Applied, kN: 976 (a)

BS5950:Part 1:1996
- Design Strength, N/mm²: 355
- Compressive Strength, N/mm²: 286.3
- Load Capacity, kN: 2176.5
- Load Ratio: 0.65
- Load Ratio Required: 0.45
<table>
<thead>
<tr>
<th>TIME</th>
<th>TEMP</th>
<th>THROBBER COUPLING LOCATION</th>
<th>MEAN</th>
<th>Overall Mean</th>
<th>Flange Web Junction</th>
<th>PS</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
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</thead>
<tbody>
<tr>
<td>TEST CENTRE: LPC-BOREHAMWOOD</td>
<td>TEST DATE: 15th DECEMBER 1991</td>
<td>TEST NUMBER: TE 0470</td>
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<td>7 9 10 14 17 21 27 30 35 40 45 50 55 60 65 70</td>
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<td>LOAD BEARING CAPACITY: 46 MILLISECONDS</td>
<td>RELOAD TEST: SATISFACTORY</td>
<td>FIRE RESISTANCE: 60 MILLISECONDS</td>
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<td></td>
<td></td>
<td>6 9 10 12 15 18 21 24 27 30 35 40 45 50 55 60 65 70</td>
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<td>THERMOCOUPLE TEMPERATURE DEGREES C AFTER VARIOUS TIMES MINUTES</td>
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<td>Unexposed Flanges F1</td>
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<td>10</td>
<td>14</td>
<td>17</td>
<td>21</td>
<td>27</td>
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<tr>
<td>F2</td>
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<td>9</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>22</td>
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</tr>
<tr>
<td>Exposed Flanges</td>
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<td>9</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>22</td>
<td>27</td>
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<tr>
<td>Mean</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>22</td>
<td>27</td>
<td>31</td>
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</tr>
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<tr>
<td>Overall Mean</td>
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<td>9</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>22</td>
<td>27</td>
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<td>42</td>
</tr>
<tr>
<td>Overall Mean</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>22</td>
<td>27</td>
<td>31</td>
<td>36</td>
<td>42</td>
</tr>
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<td>17</td>
<td>22</td>
<td>27</td>
<td>31</td>
<td>36</td>
<td>42</td>
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</table>
COLUMNS WITH CONCRETE INFILL BETWEEN FLANGES
## COLUMN WITH CONCRETE INFILL BETWEEN FLANGES

### DIMENSIONS AND PROPERTIES

<table>
<thead>
<tr>
<th>Section Number</th>
<th>Dimensions and Properties</th>
<th>Mass per Section kg</th>
<th>Depth of Section mm</th>
<th>Width of Section mm</th>
<th>Thickness Web mm</th>
<th>Flange mm</th>
<th>Elastic Modulus Axia x x cm²</th>
<th>Plastic Modulus Axia y y cm³</th>
<th>Moment of Inertia Axia y y cm⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>254 x 254</td>
<td>Nominal</td>
<td>71</td>
<td>256.8</td>
<td>246.4</td>
<td>8.6</td>
<td>14.1</td>
<td>995.5</td>
<td>305.5</td>
<td>11732</td>
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<tr>
<td></td>
<td>Actual</td>
<td>71.9</td>
<td>256.5</td>
<td>246.5</td>
<td>8.5</td>
<td>13.9</td>
<td>892.1</td>
<td>200.3</td>
<td>11441</td>
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</table>

### CHEMICAL COMPOSITION (PRODUCT ANALYSES - 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>Column</td>
<td>Grade Fe420</td>
<td>0.10</td>
<td>0.27</td>
<td>1.20</td>
<td>0.018</td>
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<td>&lt;0.005</td>
<td>0.02</td>
<td>&lt;0.005</td>
<td>0.000</td>
<td>0.000</td>
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</table>

### ROOM TEMPERATURE TENSILE PROPERTIES

<table>
<thead>
<tr>
<th>Position</th>
<th>L¹/² Nom²</th>
<th>T² Nom²</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flanges</td>
<td>280</td>
<td>400</td>
<td>31.0</td>
</tr>
</tbody>
</table>

### NOTES

- (a) Equals 98.8% of the maximum permissible load according to BS4499: Part 2:1988.
- (*) No data recorded.

**Initial Ambient Temperature = 14°C**

## TEST CONDITIONS

<table>
<thead>
<tr>
<th>NOMINAL</th>
<th>ACTUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Length, mm</td>
<td>3400</td>
</tr>
<tr>
<td>Column Exposed Length, mm</td>
<td>3100</td>
</tr>
<tr>
<td>Column Effective Length, m</td>
<td>2380</td>
</tr>
<tr>
<td>Area of Cross Section, m²</td>
<td>9292.1</td>
</tr>
<tr>
<td>Least Radius of Gyration, mm</td>
<td>64.62</td>
</tr>
<tr>
<td>Slenderness Ratio</td>
<td>36.83</td>
</tr>
</tbody>
</table>

**BS4499: Part 2:1988**

- Allowable Stress, N/mm²: 140
- Maximum Permissible Load, kN: 1300.8
- Load Applied, kN | 1346 (a)

**BS5950: Part 1:1985**

- Design Strength, N/mm²: 275
- Compressive Strength, N/mm²: 243.7
- Load Capacity, kN: 254.0
- Load Ratio: 0.574
- Load Ratio Required: 0.55

A1/18
| TEMPERATURE Deg C AFTER VAROUS TIMES (MINUTES) | 3 6 9 12 15 18 21 24 27 30 35 40 45 50 55 60 65 70 75 |
| Unexposed Flanges | P1 | 15 | 16 | 16 | 16 | 17 | 20 | 23 | 28 | 33 | 44 | 57 | 77 | 93 | 108 | 132 | 167 | 192 | 217 |
| P5 | 15 | 16 | 16 | 16 | 15 | 19 | 24 | 31 | 41 | 51 | 64 | 83 | 105 | 127 | 149 | 171 | 193 | 214 | 236 |
| Mean | 15 | 16 | 16 | 15 | 16 | 18 | 23 | 30 | 38 | 48 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 |
| Exposed Flanges | P5 | 15 | 16 | 16 | 16 | 17 | 20 | 24 | 31 | 41 | 51 | 64 | 83 | 105 | 127 | 149 | 171 | 193 | 214 | 236 |
| P9 | 15 | 16 | 16 | 16 | 16 | 18 | 23 | 30 | 38 | 48 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 |
| Mean | 15 | 16 | 16 | 16 | 16 | 17 | 21 | 29 | 38 | 48 | 59 | 75 | 95 | 115 | 135 | 155 | 175 | 195 | 215 |
| Masonry | 45 | 58 | 44 | 199 | 144 | 257 | 291 | 349 | 394 | 449 | 494 | 549 | 603 | 658 | 713 | 768 | 823 | 878 | 933 |
| Overall Mean | 47 | 59 | 44 | 199 | 133 | 257 | 293 | 350 | 407 | 464 | 521 | 578 | 635 | 692 | 749 | 806 | 863 | 920 | 977 |
| Flange/No Flange junction | P5 | 30 | 66 | 133 | 185 | 232 | 279 | 336 | 393 | 450 | 507 | 564 | 621 | 678 | 735 | 792 | 849 | 906 | 963 |
| Mean | 30 | 64 | 133 | 185 | 232 | 279 | 336 | 393 | 450 | 507 | 564 | 621 | 678 | 735 | 792 | 849 | 906 | 963 |

**Sheet Connectors**

| SC1 Top | 16 | 16 | 16 | 16 | 17 | 19 | 22 | 27 | 32 | 39 | 50 | 59 | 69 | 79 | 90 | 101 | 112 | 123 | 134 |
| SC1 Bottom | 16 | 16 | 16 | 16 | 16 | 17 | 19 | 22 | 27 | 32 | 39 | 50 | 59 | 69 | 79 | 89 | 99 | 109 | 119 |

**Overall Mean**

| 16 | 16 | 16 | 16 | 16 | 17 | 19 | 22 | 27 | 32 | 39 | 49 | 59 | 69 | 79 | 89 | 99 | 109 | 119 |

**Full Exposure Gas**

| 409 | 599 | 670 | 747 | 773 | 796 | 818 | 841 | 864 | 887 | 911 | 934 | 959 | 983 | 1007 | 1031 | 1054 | 1078 | 1101 |

| *Expansion* (mm) | 9.3 | 1.0 | 2.5 | 4.2 | 7.0 | 9.7 | 11.4 | 13.0 | 14.8 | 16.6 | 18.4 | 20.2 | 22.0 | 23.8 | 25.6 | 27.4 | 29.2 | 31.0 | 32.8 |

**Cone**

| C1 | 29 | 41 | 79 | 109 | 140 | 180 | 231 | 292 | 377 | 462 | 547 | 632 | 717 | 802 | 887 | 972 | 1057 | 1142 |
| C2 | 25 | 35 | 66 | 109 | 140 | 180 | 231 | 292 | 377 | 462 | 547 | 632 | 717 | 802 | 887 | 972 | 1057 | 1142 |
| C3 | 20 | 25 | 35 | 54 | 73 | 92 | 111 | 130 | 149 | 168 | 187 | 206 | 225 | 244 | 263 | 282 | 301 | 320 |
| C4 | 16 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |

**Standing Curve**

| 251 | 253 | 255 | 257 | 259 | 261 | 263 | 265 | 267 | 269 | 271 | 273 | 275 | 277 | 279 | 281 | 283 | 285 | 287 |

**Data Sheet Numbers**

| Data Sheet Numbers | 111B | 112B | 113B | 114B | 115B | 116B | 117B | 118B | 119B | 120B | 121B | 122B | 123B | 124B | 125B | 126B | 127B | 128B | 129B |

**LOADING CAPACITY**

| 73 MINUTES | SATISFIED | 73 MINUTES |

**FIRE RESISTANCE**

| TEST CENTRE: LPC-BORNEHAMWOOD | TEST DATE: 23rd JANUARY 1991 | TEST NUMBER: 194471 |

**ES476: PART 21: 1997 ASSESSMENT**

**Reloading Capacity:** 73 minutes | **Fire Resistance:** 73 minutes
COLUMN WITH CONCRETE INFILL BETWEEN FLANGES

VERTICAL EXTENSION (cm)

TIME (min)

A1/20
APPENDIX 2

LOAD CALCULATION SUMMARY SHEETS

A2/1
A2.1 TEST NO. TE 7436 ON 7-NOV-1986

DATA:
Universal Column - 305 × 305 mm × 240 kg/m
Steel Grade - BS4360: Grade 43A

Column Length \( L = 3400 \) mm
Column Effective Length \( \ell = 0.7 \times L = 0.7 \times 3400 = 2380 \) mm

A2.1.1 Section Properties Based on Nominal Dimensions
Area of Cross Section \( A = 30543.6 \) mm²
Least Radius of Gyration \( r_y = 81.36 \) mm

A2.1.2 Calculations Based on Nominal Dimensions
Slenderness Ratio \( \lambda = \frac{\ell}{r_y} = \frac{2380}{81.36} = 29.24 \)

From Table 17A, (Page 60), of BS448: Part 2:1969.
Allowable Stress, \( p_a \), for \( \lambda = 29.25 \) is 143 N/mm².

Maximum Permissible Load,
\[ P = p_a \times A = \frac{143 \times 30543.8}{1000} = 4387.7 \text{ kN} \]

Calculate the load capacity of the section in accordance with BS5950: Part 1:1965.

From Table 6, (Page 16).
For a Grade 43A steel section with a flange thickness >16 mm but ≤40 mm the design strength, \( p_b \), is 265 N/mm².

From Table 27C, (Page 83).
For a slenderness ratio of 29.25 the compressive strength, \( p_c \), is 247 N/mm².

Load Capacity,
\[ P_c = A \times p_c = \frac{(30543.6 \times 247)}{1000} = 7544.3 \text{ kN} \]

Load Ratio
\[ = \frac{\text{Applied Load at Limit State}}{\text{Load Capacity at } 20^\circ C} \]
\[ = \frac{4387.7}{7544.3} \]
\[ = 0.579 \]

A2/2
A2.1.3 Section Properties Based on Actual Dimensions

Area of Cross Section, A = 29666.0 mm²
Least Radius of Gyration, \( r_{g} \) = 79.90 mm

A2.1.4 Calculations Based on Actual Dimensions

Slenderness Ratio, \( \lambda = \frac{\ell}{r_{g}} \)
\[ = \frac{2330}{79.90} \]
\[ = 29.79 \]

From Table 17A, (Page 60), of BS4400:Part 2:1969.

Allowable Stress, \( (p_{d}) \), for \( \lambda = 29.79 \) is 143 N/mm².

Maximum Permissible Load,
\[ P = \frac{p_{d} \times A}{1000} \]
\[ = \frac{(143 \times 29666.0)}{1000} \]
\[ = 4242.2 \text{ kN} \]

But the load actually applied was that calculated in A2.1.2, i.e. 4368 kN.

Calculate the total capacity of the section in accordance with BS5950:Part 1:1985.

Since no LYS values were recorded for the material, the design strength, \( p_{d} \), has been assumed to be 265 N/mm², (Table 6, Page 18).

From Table 27C, (Page 63).

For a slenderness ratio of 29.79 the compressive strength, \( p_{c} \), is 246 N/mm².

Load Capacity,
\[ P_{c} = \frac{A \times p_{c}}{1000} \]
\[ = \frac{(29666.0 \times 246)}{1000} \]
\[ = 7297.8 \text{ kN} \]

Load ratio, based on the actual load applied.
\[ = \frac{4368}{7297.8} \]
\[ = 0.599 \]
A2.2

TEST NO. TE 7881 ON 29-NOV-1989

DATA:
Universal Column - 254 × 254 mm × 73 kg/m
Steel Grade - BS4360: Grade 43A

Column Length: L = 3400 mm
Column Effective Length: \( \ell \) = 0.7 \times L = 0.7 \times 3400 = 2380 mm

A2.2.1

Section Properties Based on Nominal Dimensions

Area of Cross Section: A = 9292.2 mm²
Least Radius of Gyration: \( r_{x,y} \) = 64.62 mm

A2.2.2

Calculations Based on Nominal Dimensions

Slenderness Ratio: \( \lambda \) = \( \ell / r_{x,y} \) = 2380 / 64.62 = 36.83

From Table 17A, (Page 60), of BS449:Part 2:1989.
Allowable Stress, (\( p_a \)), for \( \lambda = 36.83 \) is 140 N/mm².

Maximum Permissible Load,
\[ P = p_a \times A \]
\[ = (140 \times 9292.2) / 1000 \]
\[ = 1300.9 \text{ kN} \]

Calculate the load capacity of the section in accordance with BS5950:Part 1:1985.

From Table 6, (Page 15).
For a Grade 43A steel section with a flange thickness <16 mm the design strength, \( p_y \), is 275 N/mm².

From Table 27C, (Page 63).
For a slenderness ratio of 36.83 the compressive strength, \( p_y \), is 243.7 N/mm².

Load Capacity,
\[ P_c = A \times p_y \]
\[ = (9292.2 \times 243.7) / 1000 \]
\[ = 2264.5 \text{ kN} \]

Load Ratio = \( \frac{\text{Applied Load at Limit State}}{\text{Load Capacity at 20°C}} \)

\[ = \frac{1300.9}{2264.5} \]
\[ = 0.574 \]

A2/4
The load ratio required was 0.5.

Hence, applied load = \( \text{Load capacity} \times \text{load ratio} \)
\[ = 2284.5 \times 0.5 \]
\[ = 1142.25 \text{ kN} \]

In terms of BS449 the applied load was equal to 87.04% of the maximum permissible load of 1300.9 kN.

A2.2.3 Section Properties Based on Actual Dimensions

Area of Cross Section, \( A \) = 9084.8 mm²
Least Radius of Gyration, \( r_g \) = 64.66 mm

A2.2.4 Calculations Based on Actual Dimensions

Slenderness Ratio,
\[ \lambda = \frac{l}{r_g} \]
\[ = 2380 / 64.66 \]
\[ = 36.81 \]

From Table 17A, (Page 60), of BS449: Part 2:1969.

Allowable Stress, \( (p_s) \), for \( \lambda = 36.81 \) is 145 N/mm².

Maximum Permissible Load,
\[ P = p_s \times A \]
\[ = (145 \times 9084.8) / 1000 \]
\[ = 1711.9 \text{ kN} \]

But the load actually applied was that given in A2.2.2, i.e. 1132 kN.

Calculate the load capacity of the section in accordance with BS5950: Part 1:1985.

The measured LYS for the material was 298 N/mm².

From Table 27C, (Page 53), (2-way linear interpolation)

For a slenderness ratio of 36.81 and a design strength of 298 N/mm² the compressive strength, \( p_c \), is 282.6 N/mm².

Load Capacity,
\[ P_L = A \times p_c \]
\[ = (9084.8 \times 282.6) / 1000 \]
\[ = 2385.7 \text{ kN} \]

Load ratio, based on the actual load applied,
\[ = \frac{1132}{2385.7} \]
\[ = 0.474 \]
A2.3 TEST NO. TE 7882 ON 4-DEC-1989

DATA:

Universal Column: $254 \times 264 \text{ mm} \times 73 \text{ kg/m}$
Steel Grade: BS4360:Grade 43A

Column Length $L = 3400 \text{ mm}$
Column Effective Length $\ell = 0.7 \times L = 0.7 \times 3400 = 2380 \text{ mm}$

A2.2.1 Section Properties Based on Nominal Dimensions

From Appendix A2.2.

Area of Cross Section $A = 9892.2 \text{ mm}^2$
Least Radius of Gyration $r_{y,y} = 64.62 \text{ mm}$
Slenderness Ratio $\lambda = 36.83$
Maximum Permissible Load $P = 1300.9 \text{ kN}$
Load Capacity $P_c = 2264.5 \text{ kN}$
Load Ratio $= 0.574$

A2.2.2 Calculations

The load ratio required was 0.35.

Hence, Applied Load $= Load \ capacity \times Load \ ratio = 1300.9 \times 0.35 = 792.4 \text{ kN}$

In terms of BS449 the applied load was equal to 60.93% of the maximum permissible load of 1300.9 kN.

A2.2.3 Section Properties Based on Actual Dimensions

Area of Cross Section, $A = 9848.8 \text{ mm}^2$

A2.2.4 Calculations Based on Actual Dimensions

Slenderness Ratio, $\lambda = \ell / r_{y,y} = 2380 / 64.66 = 36.81$

From Table 17A, (Page 60), of BS449:Part 2:1969.

Allowable Stress, $(\sigma)_L$ for $\lambda = 36.81$ is 140 N/mm².

Maximum Permissible Load, $P = (140 \times 9848.8) / 1000 = 1721.1 \text{ kN}$

But the load actually applied was that given in A2.2.2, i.e. 792.4 kN.

Calculate the load capacity of the section in accordance with BS5950:Part 1:1985.
The measured LYS for the material was 298 N/mm².

From Table 27C, (Page 63), - (3-way linear interpolation)

For a slenderness ratio of 36.81 and a design strength of 298 N/mm² the compressive strength, $$p_c$$, is 263.6 N/mm²

Load Capacity,

$$P_c = A \times p_c$$

$$= (9084.8 \times 262.6) \div 1000$$

$$= 2385.7 \text{ kN}$$

Load ratio, based on the actual load applied.

$$\frac{792.4}{2385.7} = 0.332$$
A2.4  TEST NO. 80470 ON 13-DEC-1990

DATA:

Universal Column  -  203 x 203 mm x 60 kg/m
Steel Grade       -  BS EN 10025 : Grade Fe510B

Column Length     \( L = 3400 \text{ mm} \)
Column Effective Length  \( \ell = 0.7 \times L \)
\( = 0.7 \times 3400 \)
\( = 2380 \text{ mm} \)

A2.4.1  Section Properties Based on Nominal Dimensions

Area of Cross Section  \( A = 7602.2 \text{ mm}^2 \)
Least Radius of Gyration \( r_{y,\ell} = 51.88 \text{ mm} \)

A2.4.2  Calculations Based on Nominal Dimensions

Slenderness Ratio  \( \lambda = \ell / r_{y,\ell} \)
\( = 2380 / 51.88 \)
\( = 45.88 \)

From Table 17B, (Page 61), of BS449: Part 2:1969.
Allowable Stress, \( \sigma_p \), for \( \lambda = 45.88 \) is 188 N/mm².

Maximum Permissible Load, \( P = \sigma_p \times A \)
\( = (188 \times 7602.2) / 1000 \)
\( = 1429.2 \text{ kN} \)

Calculate the load capacity of the section in accordance with BS5950: Part 1:1985.

From Table 6, (Page 15).
For a Grade Fe510B steel section with a flange thickness < 16 mm the design strength, \( p_e \), is 355 N/mm².

From Table 27C, (Page 63).
For a slenderness ratio of 45.88 the compressive strength, \( p_e \), is 286.3 N/mm².

Load Capacity, \( P_t = A \times p_e \)
\( = (7602.2 \times 286.3) / 1000 \)
\( = 2178.5 \text{ kN} \)

\[ \text{Load Ratio} = \frac{\text{Applied Load at Limit State}}{\text{Load Capacity at } 20^\circ\text{C}} \]
\[ = \frac{1429.2}{2178.5} \]
\[ = 0.657 \]

A2/8
The load ratio required was 0.45.

Hence, applied load = Load capacity × load ratio
= 2076.5 × 0.45
= 927.4 kN

(The load actually applied was 976 kN.)

In terms of BS449 the applied load was equal to 68.53% of the maximum permissible load of 1429 kN.

A2.4.3 Section Properties Based on Actual Dimensions

Area of Cross Section,  \( A = 7899.3 \text{ mm}^2 \)
Least Radius of Gyration,  \( r_{gy} = 51.94 \text{ mm} \)

A2.4.4 Calculations Based on Actual Dimensions

Slenderness Ratio,  \( \lambda = \frac{\ell}{r_{gy}} \)
= \( \frac{2380}{51.94} \)
= 45.82

From Table 17B, (Page 91), of BS449:Part 2:1969.

Allowable Stress, \( (p_a) \), for \( \lambda = 45.82 \) is 188 N/mm².

Maximum Permissible Load,  \( P = p_a \times A \)
= \( (188 \times 7899.3) / 1000 \)
= 1445.5 kN

But the load actually applied was that given in A2.4.2, i.e. 976.0 kN.

Calculate the load capacity of the section in accordance with BS5950:Part 1:1985.

The measured LYS for the material was 377 N/mm².

From Table 27C, (Page 63), - (2 way linear interpolation)

For a slenderness ratio of 45.82 and a design strength of 377 N/mm² the compressive strength, \( p_c \), is 301.9 N/mm².

Load Capacity,  \( P_c = \frac{A \times p_c}{(7899.3 \times 301.9)} / 1000 \)
= 976 kN

Load ratio, based on the actual load applied.

= \( \frac{976}{2324.4} \)
= 0.420

A2/9
A2.5  TEST NO. 80471 ON 23-JAN-1991

DATA:

Universal Column - 254 × 254 mm × 73 sg/m
Steel Grade - BS EN 10025: Grade Fe430A

Column Length \( L = 3400 \text{ mm} \)
Column Effective Length \( \ell = 0.7 \times L = 2380 \text{ mm} \)

A2.5.1  Section Properties Based on Nominal Dimensions

From Appendix A2.2.

Area of Cross Section \( A = 9922.2 \text{ mm}^2 \)
Least Radius of Gyration \( r_{gy} = 64.62 \text{ mm} \)
Slenderness Ratio \( \lambda = 36.83 \)
Maximum Permissible Load \( P = 1300.9 \text{ kN} \)
Load Capacity \( P_c = 2264.5 \text{ kN} \)
Load Ratio \( = 0.574 \)

A2.5.2  Calculations

The load ratio ratio required was 0.55.

Hence, applied load \( = \text{Load capacity} \times \text{load ratio} \)
\( = 2264.5 \times 0.55 \)
\( = 1244.6 \text{ kN} \)

(The load actually applied was 1244 kN.)

In terms of BS449 the applied load was equal to 95.63% of the maximum permissible load of 1300.9 kN.

A2.5.3  Section Properties Based on Actual Dimensions

Area of Cross Section, \( A = 9157.5 \text{ mm}^2 \)
Least Radius of Gyration, \( r_{gy} = 64.59 \text{ mm} \)

A2.5.4  Calculations Based on Actual Dimensions

Slenderness Ratio, \( \lambda = \ell / r_{gy} = 2380 / 64.59 = 36.85 \)

From Table 17A, (Page 60), of BS449:Part 2:1969.

Allowable Stress, \( (p_c) \) for \( \lambda = 36.85 \) is 140 N/mm².

Maximum permissible load, \( P = \frac{p_c \times A}{(140 \times 9157.5)/1000} = 1291.1 \text{ kN} \)

But the load actually applied was that given in A2.5.2, i.e. 1244 kN.
Calculate the load capacity of the section in accordance with BS5950:Part 1:1985.

The measured LYS for the material was 290 N/mm².

From Table 27C, (Page 63), - (2 way linear interpolation)

For a slenderness ratio of 36.85 and a design strength of 290 N/mm² the compressive strength, \( p_o \), is 256.0 N/mm².

Load Capacity,

\[
P_c = A \times p_o = (9157.5 \times 256.0) / 1000 = 2344.3 \text{ kN}
\]

Load ratio, based on the actual load applied.

\[
\frac{1244}{2344.3} = 0.531
\]
APPENDIX 3

PC DISK VERSION OF DATA

As mentioned in the Introduction to this report the data recorded during each of the five 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 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 3¼ 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. from 107.DAT to 111.DAT inclusive. This numbering system is consistent with that introduced in Reference 1. Thus, for example, data from test number TE.7436 can be found in data file 107.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.107, which relates to data in file 107.DAT, is shown in Fig. A3.1.

It may be seen by reference to the data presented in Appendix 1 that there have been occasions when no temperature data were recorded. Such occurrences are indicated in the printed tables by the use of an asterisk. Since the use of such a character could cause problems if the software is expecting a numeric input, it has been replaced with the value zero in the disk held data files. It is obviously important for the user to ensure that any data have been read correctly by the particular software or program being used.

REFERENCE

TABLE A3.1
README FILE ASSOCIATED WITH DATA FILE 107.DAT

Data file 107.DAT contains data recorded during the standard flex resistance test number 76 7416 which is described in report number SL/HEED/R/3442/1/94/C - "SUMMARY OF DATA OBTAINED DURING TESTS ON WEB ENCLOSED COLUMNS" and should be used in conjunction with that document.

There are 26 items of data which, together with their mean values, are grouped in sets as shown below.

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<thead>
<tr>
<th>SET NUMBER</th>
<th>ITEMS IN COLUMN</th>
</tr>
</thead>
<tbody>
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<td>TIME, F1, F2, F3, F4, MEAN, F5, F6, F7, F8, MEAN, O/ALL MEAN</td>
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<tr>
<td>767002.DAT</td>
<td>TIME, P10, P9, MEAN</td>
</tr>
<tr>
<td>767003.DAT</td>
<td>TIME, W1, W2, W5, W8, MEAN</td>
</tr>
<tr>
<td>767004.DAT</td>
<td>TIME, W1, W6, MEAN, W4, W7, MEAN</td>
</tr>
<tr>
<td>767005.DAT</td>
<td>TIME, ISO, AT1, AT2, AT3, AT4, AT5, AT6, MEAN</td>
</tr>
<tr>
<td>767006.DAT</td>
<td>TIME, DEFLATION</td>
</tr>
</tbody>
</table>