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BS 476:Part 21 Fire Resistance Tests
Summary of Data Obtained During Tests on
Three Composite Metal Deck Shelf Angle Floor Beams

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SUMMARY

BS 476:PART 21 FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING TESTS ON THREE COMPOSITE METAL DECK SHELF ANGLE FLOOR BEAMS

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 seventh report issued as part of that series. It contains a detailed description of the design, instrumentation and construction for three composite metal deck shelf angle floor beams, together with the data arising from them. The tests were carried out at the Warrington Fire Research Centre.

The serial sizes for the steel sections used were 254 x 146 mm x 43 kg/m UB and 406 x 178 mm x 54 kg/m UB. The steel grade was BS 4360:Grade 43A, (now BS EN 10025 S275). In each case a composite metal deck and concrete floor slab was supported from continuous 125 x 75 x 12 mm Grade 50, (S375JR), hot rolled angles which were welded to the web of the section. The metal decking was SUPER HOLORIB as supplied by Richard Lees Ltd. Both light-weight and normal weight Grade 30 concrete was used for forming the floor slabs.

The sections were loaded so as to develop a bending stress of 165 N/mm^2, (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 three assemblies were found to be:

- 254 x 146 mm x 43 kg/m UB + light-weight concrete - 49 minutes
- 254 x 146 mm x 43 kg/m UB + normal weight concrete - 52 minutes
- 406 x 178 mm x 54 kg/m UB + light-weight concrete - 29 minutes

KEYWORDS

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+BS 449

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BS 476:PART 21 FIRE RESISTANCE TESTS

SUMMARY OF DATA OBTAINED DURING TESTS ON THREE COMPOSITE METAL DECK SHELF ANGLE FLOOR BEAMS

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] and
- the 'control' shelf angle floor beam[7]

This is therefore the seventh report issued as part of that ongoing series. It contains a detailed description of the design, instrumentation and construction for three test assemblies, together with the data arising from them; see Appendix 1. The test assemblies were all composite metal deck and concrete shelf angle floor beam constructions. The data are presented in a format which is generally consistent with that of the earlier publications. As before, no analysis of the data is included since this has already been incorporated into other publications dealing with design aspects of this form of construction. The numerical sequence of the data sheets has been maintained, the ones in this document being numbered 128-130. 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 5.) 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 SHELF ANGLE FLOOR BEAMS

In this section details are given for tests performed on three loaded composite metal deck shelf angle floor beam assemblies. All the tests were carried out in accordance with the requirements of BS 476:Parts 20/21:1987 at the Warrington Fire Research Centre, (WFRC).

The design and construction of the three assemblies are described in the following sections.

2.1 Features Common to the Three 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 50B, (for the angles). These grades are now designated in accordance with BS EN 10025 as S275 and S355JR 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 three tests the applied load, together with the self weight of the system, was intended to develop a bending stress of 165 N/mm^2 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 2:1969. 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, 3 and 4. A comparison of the calculation data in terms of BS 5950:Part 1:1985 is also included.

2.1.4 Fabrication

All the test assemblies consisted of a 5 metre length of the appropriate universal beam section and two 5 metre lengths of 125 x 75 x 12 mm hot rolled angle. These were attached, by welding, one each side of the beam, such that the distance between the angle and the lower flange gave the required degree of exposure of the section to the heating conditions of the furnace. 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 500 mm centres. Welding was by the MMA process using 4 mm diameter basic coated, hydrogen controlled, general purpose welding rods.

Richard Lees Grade Z28 'SUPER HOLORIB' profiled steel decking, (1.2 mm thick), was placed on top of the angles leaving a gap of nominally 20 mm between it and the vertical leg of the angle. The decking, which ran the complete length of the beam, was attached to the angles using shot fired HILTI fixings at 300 mm centres. The over-hanging ends of the decking were left unsupported. Dimensional details for the decking are given in Fig. 1.

Grade 30 concrete, (either normal or light-weight depending on the particular assembly), was cast onto the steel decking to provide the floor section. A layer of A142 mesh, (laid onto the top surface of the steel beam), was also incorporated into the floor slab. The dovetails formed at the overlaps between adjacent sections of decking and the angles were taped over to prevent concrete from pouring through the voids.

The light-weight concrete contained Lytag aggregate at a nominal 12 mm sieve size. It was cast in accordance with a specification given by Boral / Lytag and to BS 8110:Parts 1 and 2:1985, 'The Structural Use of Concrete'. The soffit of the beam was left unprotected as was the under-side of the decking.

2.1.5 Instrumentation

The assemblies were instrumented such that the temperatures attained by the steel section and 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 WFRC for monitoring the temperature of the furnace atmosphere. These were situated at eight positions within the furnace, being evenly distributed on each side of the assembly, level with the soffit of the beam and 100 mm away from the toe of the lower flange.

Temperatures were also monitored in other parts of the assemblies, such as, for example, the concrete floor slabs. The thermocouples used for these situations were again 'K' type but were formed from glass-fibre covered Ni-Cr / Ni-Al conductors.

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, (concrete), surface using a displacement transducer connected to the WFRC 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 WFRC. They were simply supported on a refractory lined steel loading frame to give a total effective span between the roller supports of 4500 mm. This frame was supported on the outer walls of the gas fired furnace so that the length of beam actually exposed to the heating conditions of the test was 4000 mm.

2.1.7 Failure Criteria

In all cases 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 maximum allowable deflection and the maximum allowable rate of deflection for the test assemblies, as specified by the standard, were calculated from SPAN / 20 and $(SPAN)^2$ / 9000 x D, respectively, where 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 SPAN / 30. Since the span was fixed at 4500 mm the values of SPAN / 20 and SPAN / 30 were always 225 mm and 150 mm respectively.

2.1.8 Additional Data

In some cases heating of a 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 three test assemblies.

2.2.1 Test WFRC 44520

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 base of the section and the under-side of the angles was 148 mm. Taking the thickness of the angle into consideration, the proportion of the actual section depth, (267 mm), exposed to the heating conditions of the furnace was therefore 59.9%, (60% nominal). The sections of decking used were approximately 400 mm in length, giving rise to a test assembly with an overall width of 860 mm.

Grade 30 light-weight concrete was cast onto the steel decking to provide a 135 mm thick floor slab giving 28 mm of concrete cover, (25 mm nominal), above the upper flange of the beam. A transverse section through the assembly showing the arrangement of the various components is given in Fig. 2. The concrete was cast during early December 1988 which gave it an age of approximately two months at the time of the test. During this time the complete assembly was placed in an atmosphere controlled by a de-humidifier. Samples of the concrete were taken at the time of casting. The density and moisture content, measured on the day of the test, were reported as being:

- Density 1860 kg/m^3
- Moisture Content 5.0% w/w

The compressive, (crushing), strength measured 28 days after casting was reported to be 30 N/mm^2.

The thermocouple positions in the steelwork were as shown in Fig. 3, (longitudinal arrangement), and Fig. 4, (transverse arrangement). A total imposed load of 23.12 tonnes was applied to the steel section by means of four hydraulic rams positioned along the centre line of the web and at points corresponding to $^1/_8$, $^3/_8$, $^5/_8$ and $^7/_8$ of the supported span. This load was actually 66.5% greater than that required to generate a bending stress of 165 N/mm^2 in the lower flange. It was applied for the first 18 minutes of the test at which time it was reduced to the intended value of 13.89 tonnes. The error resulted from the transposition of two numbers in the value of the hydraulic pressure required, viz:-

13.89 tonnes ≡ 1083 psi whereas
23.12 tonnes ≡ 1803 psi

The maximum allowable rate of deflection, (MARD), was calculated to be 8.4 mm/min based on the actual section depth of 267 mm. In spite of the beam being overloaded this rate was not exceeded at any time during the test. The assembly attained a deflection of 152 mm after 32 minutes. The load was removed from the beam after 49 minutes at which time the mid-span deflection was 225 mm and the rate of deflection was 5 mm/min. Heating of the unloaded assembly continued up to 60 minutes in order to obtain additional heating rate data.

Since the test had not been conducted in accordance with STC's requirements WFRC were obliged to carry out a re-test. In view of this no formal report was issued for this test and no fire resistance ratings were determined. However, it may be argued that the load bearing capacity for the assembly was 49 minutes, and that this was achieved with the beam tested under more onerous conditions than those intended.

It is worth noting that the floor slab in the re-test assembly was constructed using normal weight concrete and not the light-weight product as described here. Details for the re-test assembly are given in Section 2.2.2.

Data for this test are summarised in Data Sheet No. 128.

2.2.2 Test WFRC 46386 (Retest of WFRC 44520)

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 steel beam originated from the Longwy Works of Usinor Sacilor, France. The distance between the base of the section and the under-side of the angles was 143 mm. Taking the thickness of the angle into consideration, the proportion of the actual section depth, (260 mm), exposed to the heating conditions of the furnace was therefore 59.6%, (60% nominal). The sections of decking used were approximately 325 mm in length, giving rise to a test assembly with an overall width of 720 mm.

Grade 30 normal weight concrete was cast onto the steel decking to provide a 130 mm thick floor slab giving 25 mm of cover above the upper flange of the beam. A transverse section through the assembly showing the arrangement of the various components is given in Fig. 2. The concrete was cast in mid-March 1989 which gave it an age of approximately three months at the time of the test. It was allowed to cure naturally until four weeks prior to the test at which time the complete assembly was placed in an atmosphere controlled by a de-humidifier. Samples of the concrete were taken at the time of casting. The density and moisture content, measured on the day of the test, were reported as being:

- Density 2350 kg/m^3
- Moisture Content 4.1% w/w

The compressive, (crushing), strength measured 28 days after casting was reported to be 30 N/mm^2.

The thermocouple positions in the steelwork were as shown in Fig. 3, (longitudinal arrangement), and Fig. 4, (transverse arrangement). An additional eight thermocouples were embedded in the concrete at the time of casting. These were situated as close to the mid-span of the beam as practical and at the positions shown in Fig. 5. A total imposed load of 13.14 tonnes was applied to the steel section by means of four hydraulic rams positioned along the centre line of the web and at points corresponding to $^1/_8$, $^3/_8$, $^5/_8$ and $^7/_8$ of the supported span.

The maximum allowable rate of deflection, (MARD), was calculated to be 8.65 mm/min based on the actual section depth of 260 mm. This value was not exceeded at any time during the test. The assembly attained a deflection of 152 mm after 33 minutes. The load was removed from the beam after 53 minutes at which time the mid-span deflection was 226 mm and the rate of deflection was 4 mm/minute. Heating of the unloaded assembly continued up to 80 minutes in order to obtain additional heating rate data.

In accordance with the failure criteria outlined in Section 2.1.7 the load bearing capacity of the beam was deemed to be 52 minutes.

Data for this test are summarised in Data Sheet No. 129.

2.2.3 Test WFRC 44176

A shelf angle floor beam construction consisting of a universal beam of serial size 406 x 178 mm x 54 kg/m and 125 x 75 x 12 mm angles assembled as outlined in Section 2.1.4. The distance between the base of the section and the under-side of the angles was 282 mm. Taking the thickness of the angle into consideration, the proportion of the actual section depth, (404 mm), exposed to the heating conditions of the furnace was therefore 72.8%, (70% nominal). The sections of decking used were approximately 365 mm in length, giving rise to a test assembly with an overall width of 800 mm.

Grade 30 light-weight concrete was cast onto the steel decking to provide a 135 mm thick floor slab giving 25 mm of concrete cover above the upper flange of the beam. A transverse section through the assembly showing the arrangement of the various components is given in Fig. 6. The concrete was cast during early December 1988 and so was approximately two months old at the time of the test. During this curing period the complete assembly was placed in an atmosphere controlled by a de-humidifier. Samples of the concrete were taken at the time of casting. The density and moisture content, measured on the day of the test, were reported as being:

- Density 1850 kg/m^3
- Moisture Content 4.8% w/w

The compressive, (crushing), strength measured 28 days after casting was reported to be 30 N/mm^2.

The thermocouple positions in the steelwork were as shown in Fig. 3, (longitudinal arrangement) and Fig. 7, (transverse arrangement). A total imposed load of 25.09 tonnes was applied to the steel section by means of four hydraulic rams positioned along the centre line of the web and at points corresponding to $^1/_8$, $^3/_8$, $^5/_8$ and $^7/_8$ of the supported span.

The maximum allowable rate of deflection, (MARD), was calculated to be 5.6 mm/min based on the actual section depth of 404 mm. In the test a mid-span deflection of 150 mm was attained after 29 minutes at which time the MARD had already been exceeded. This was effectively the end of the test and in accordance with the failure criteria outlined in Section 2.1.7 the load bearing capacity of the beam was deemed to be 29 minutes. However, since the rate of deflection was remaining fairly uniform approval was given to continue heating the assembly under the same load conditions. After about 33 minutes the casing of one of the hydraulic rams fractured and the load was reduced to zero. It was re-applied, at the same total value, via the remaining three rams, approximately two minutes later. After 39 minutes a mid-span deflection of 226 mm was indicated with the rate of deflection increasing significantly. The load was removed from the beam but heating of the assembly continued up to 60 minutes in order to obtain additional thermal data.

It is questionable whether the values indicated by the deflection transducer following the unloading and re-loading of the assembly between 33 and 35 minutes are completely reliable. It is therefore considered unsafe to claim that this assembly actually attained a deflection corresponding to SPAN / 20.

Data for this test are summarised in Data Sheet No. 130.

3. CONCLUSIONS

1. Data arising from three standard fire resistance tests carried out on composite metal deck and concrete shelf angle floor beams 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.

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 three assemblies were found to be:-

-	Section	254 x 146 mm x 43 kg/m UB†
	% Exposed	59.9
	Floor Slab	Light-weight concrete
	Fire Resistance	49 minutes
	Load Ratio (*)	0.789 up to 18 minutes 0.489 thereafter
-	Section	254 x 146 mm x 43 kg/m UB†
	% Exposed	59.6
	Floor Slab	Normal weight concrete
	Fire Resistance	52 minutes
	Load Ratio (*)	0.47
-	Section	406 x 178 mm x 54 kg/m UB
	% Exposed	72.8
	Floor Slab	Light-weight concrete
	Fire Resistance	29 minutes
	Load Ratio (*)	0.434

(*) Calculated using actual applied loads and section properties

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REFERENCES

1. D.E. Wainman: 'Summary of All Fire Resistance Tests Carried Out by British Steel Since December 1988', Technical Note SL/HED/TN/2/-/92/A, British Steel Technical, Swinden Laboratories, 1992.

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† The major difference between the two tests using 254 x 146 mm x 43 kg/m sections is that the one employing light-weight concrete was loaded to 166.5% of the specified value for the first 18 minutes of the test. However, in spite of this the difference in fire resistance rating for the assembly was only marginally reduced.

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3. D.E. Wainman: 'BS476:Part 21 Fire Resistance Tests - Summary of Data Obtained During Tests on Web Encased Columns', Report SL/HED/R/S2442/1/94/C, British Steel Technical, Swinden Laboratories, 1994.

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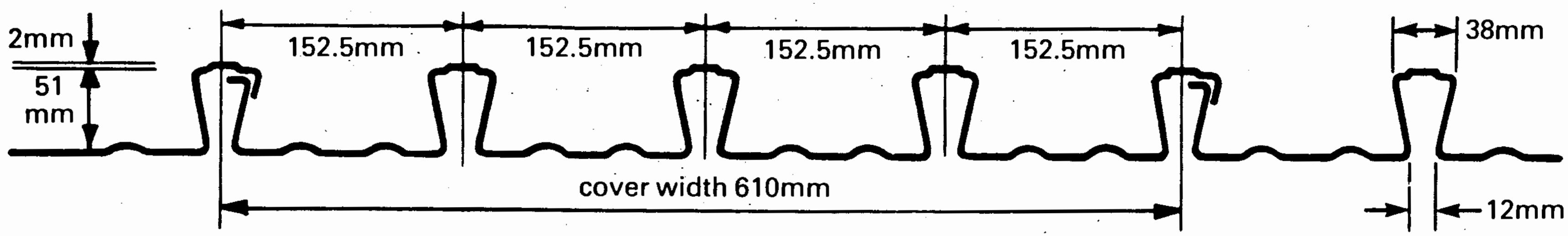
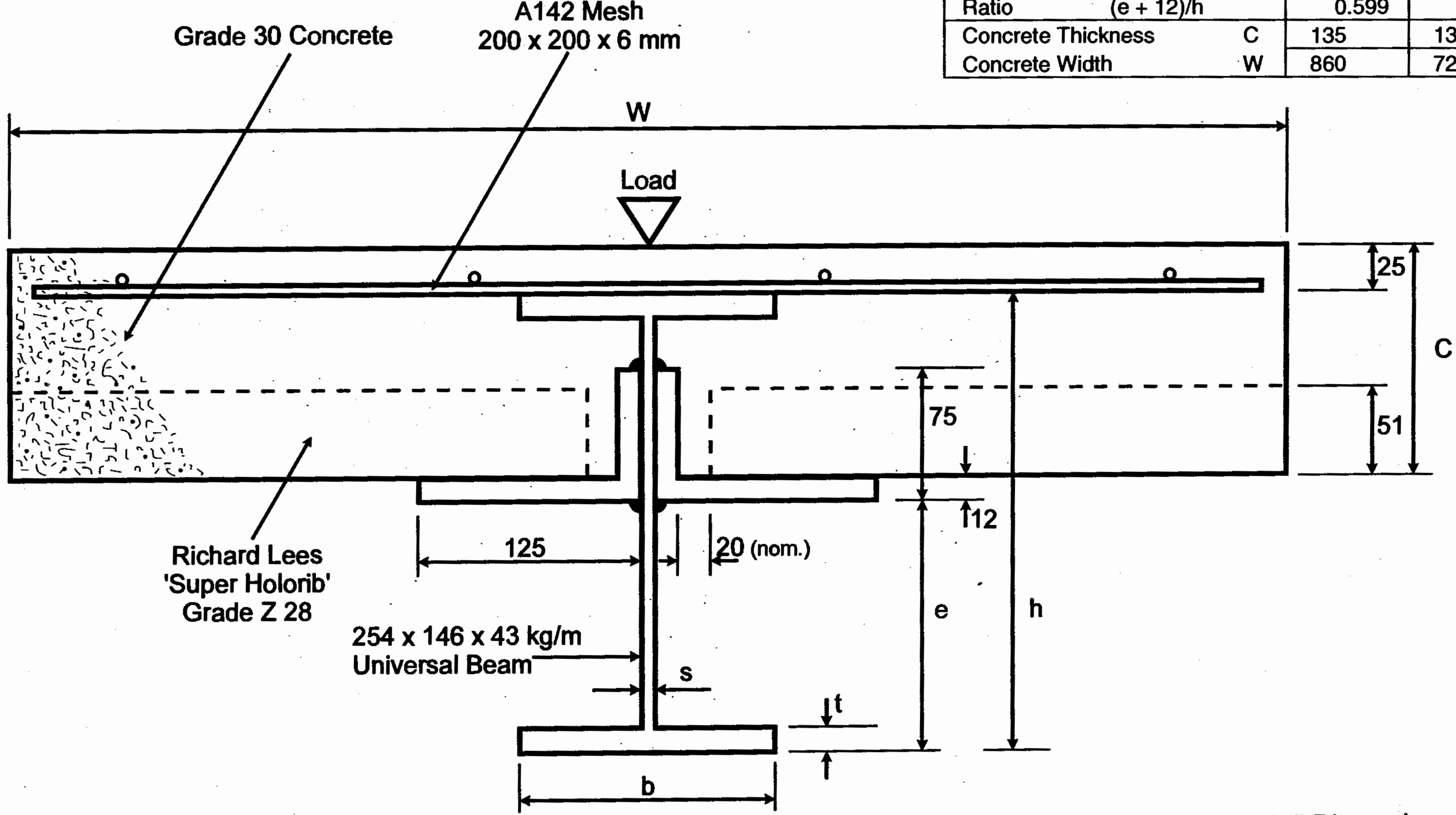


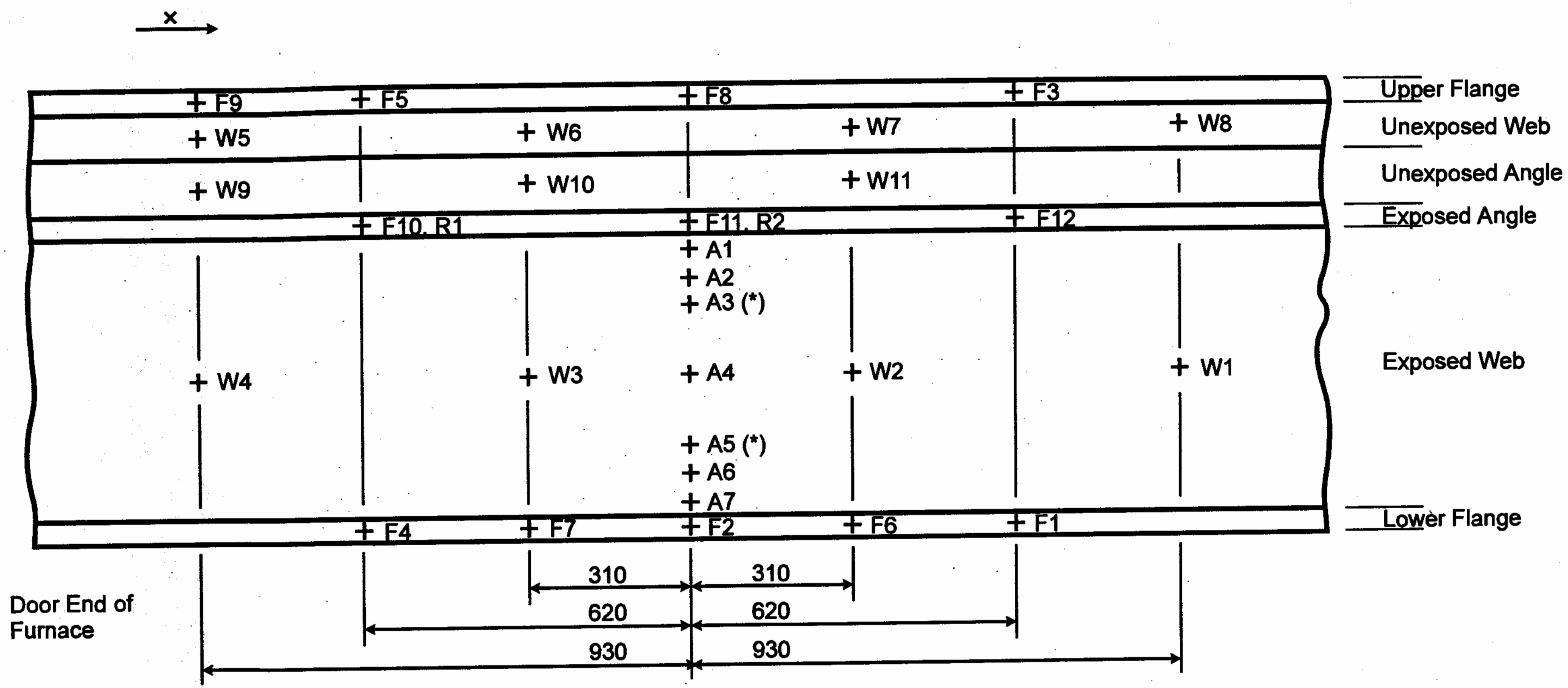
FIG. 1 DIMENSIONAL DETAILS FOR THE RICHARD LEES 'SUPER HOLORIB' PROFILED STEEL DECKING

Dimension		WFRC 44520	WFRC 46386
Depth of Section	h	267	260
Breadth of Section	b	147	145
Thickness of Flange	t	12.8	12.2
Thickness of Web	s	8.3	7.05
Exposed Length	e	148	143
Ratio (e + 12)/h		0.599	0.596
Concrete Thickness	C	135	130
Concrete Width	W	860	720



(All Dimensions in mm)

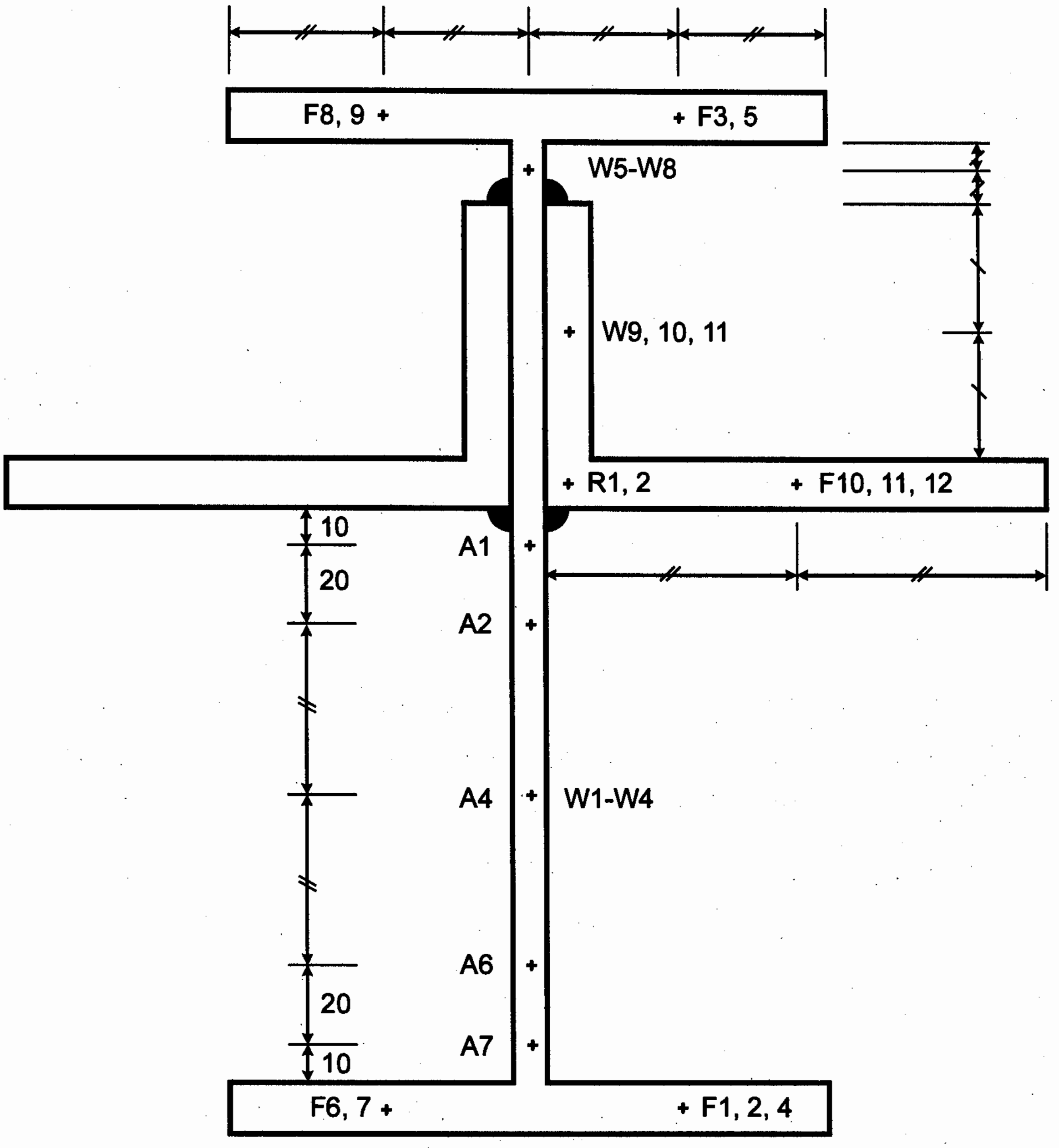
FIG. 2 SCHEMATIC ARRANGEMENT OF COMPONENTS - TEST NOS. WFRC 44520 AND 46386 (TRANSVERSE SECTION) (D0413C05)



(*) WFRC 44176 only

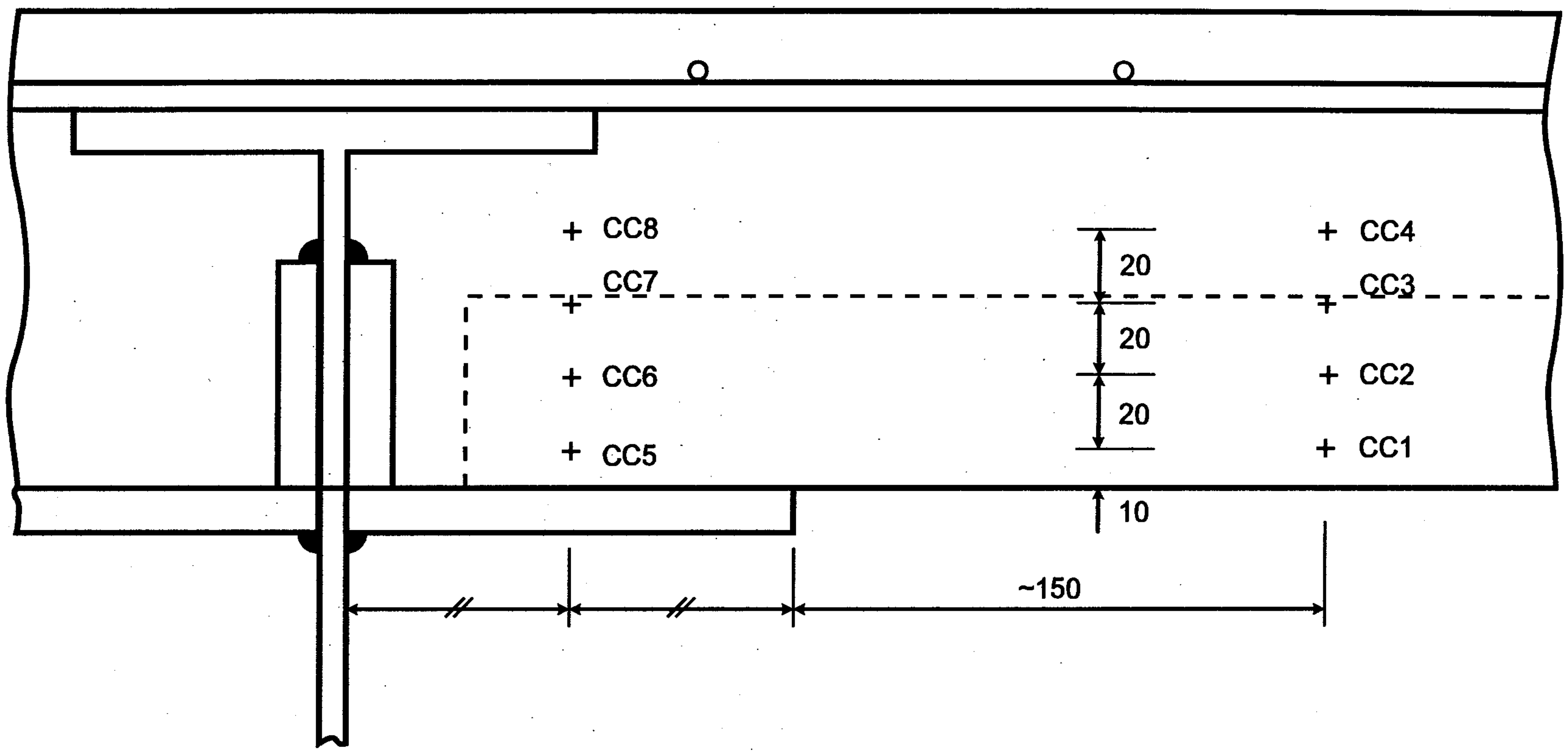
(All dimensions in mm)

FIG. 3 THERMOCOUPLE POSITIONS IN THE STEELWORK - LONGITUDINAL ARRANGEMENT (D0413C05)



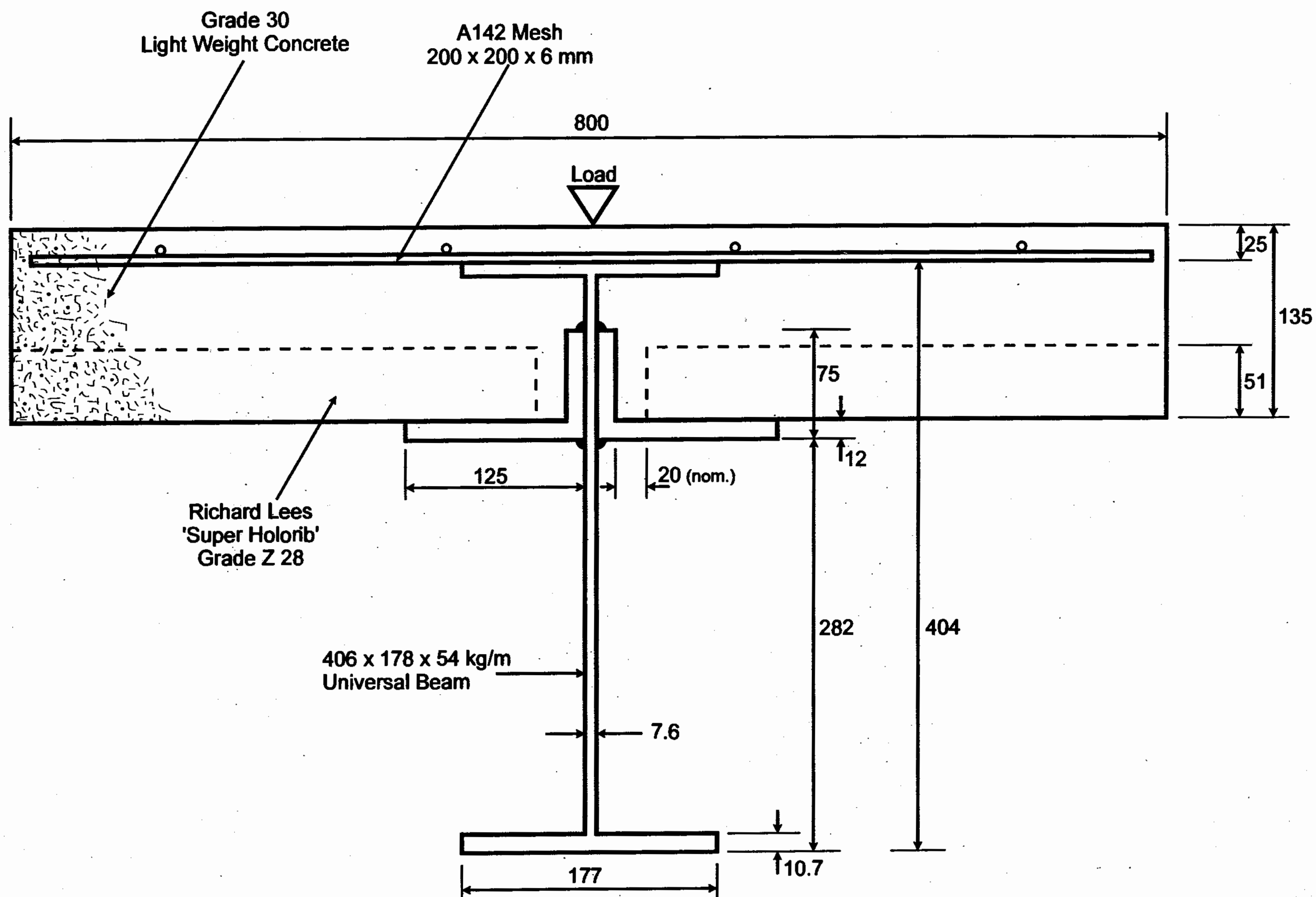
(All dimensions in mm)

FIG. 4 THERMOCOUPLE POSITIONS IN THE STEELWORK - TEST NOS. WFRC 44520 AND 46386 TRANSVERSE ARRANGEMENT IN DIRECTION OF ARROW 'x' IN FIG. 3 (D0413C06)



(All dimensions in mm)

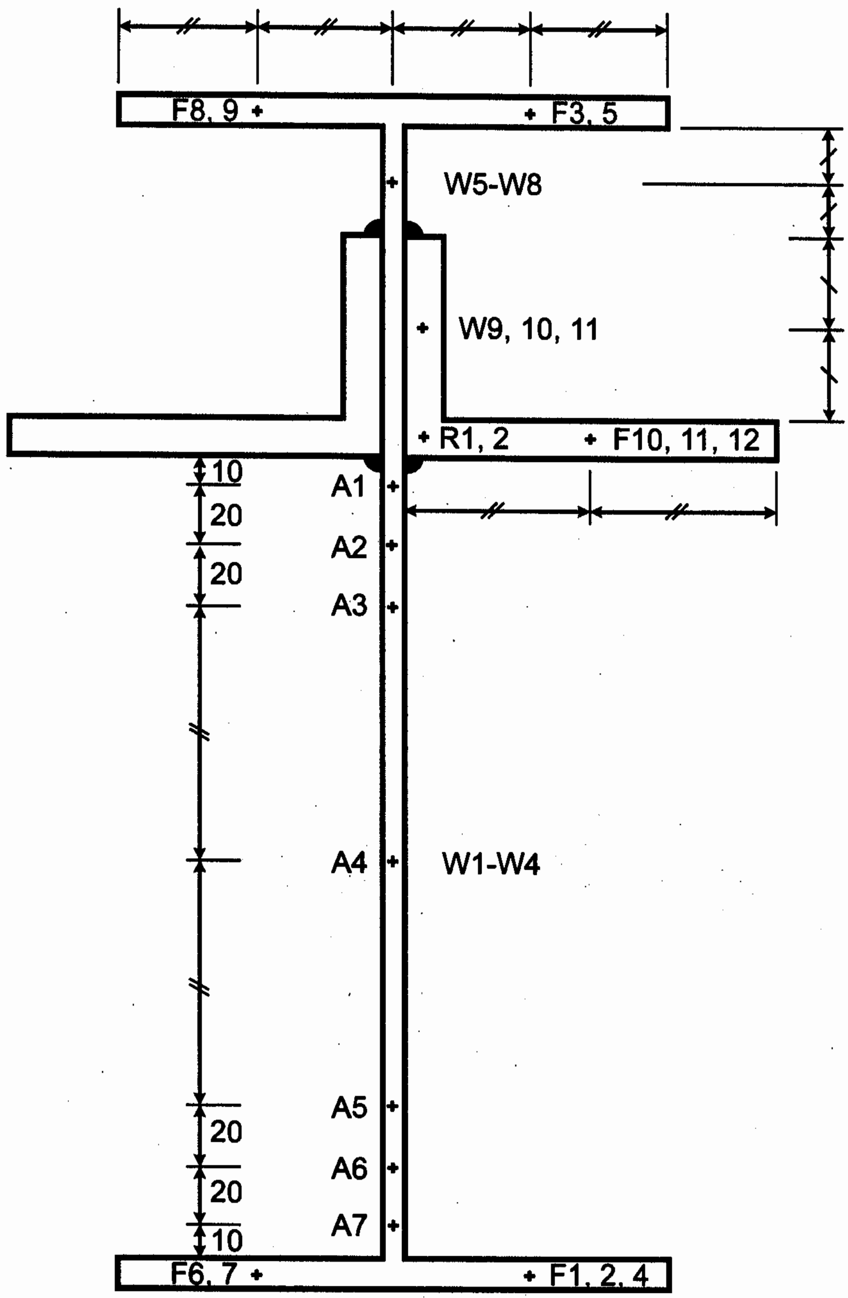
FIG. 5 THERMOCOUPLE POSITIONS IN THE CONCRETE - TEST NO. WFRC 46386 (TRANSVERSE ARRANGEMENT IN DIRECTION OF ARROW 'x' IN FIG. 3) (D0413C05)



(All dimensions in mm)

FIG. 6 SCHEMATIC ARRANGEMENT OF COMPONENTS - TEST NO. WFRC 44176 (TRANSVERSE SECTION)

(D0413C05)



(All dimensions in mm)

FIG. 7 THERMOCOUPLE POSITIONS IN THE STEELWORK - TEST NO. WFRC 44176 TRANSVERSE ARRANGEMENT IN DIRECTION OF ARROW 'x' IN FIG. 3 (D0413C06)

APPENDIX 1

DATA SHEET NOS. 128-130

DATA SHEET NUMBER	128A

SHELF ANGLE FLOOR BEAM

DIMENSIONS AND PROPERTIES

Section Serial Size and Type (mm)	Dimensions and Properties	Mass per Metre (kg)	Depth of Section (mm)	Width of Section (mm)	Thickness		Elastic Modulus		Plastic Modulus		Moment of Inertia	
					Web (mm)	Flange (mm)	Axis x-x (cm^3)	Axis y-y (cm^3)	Axis x-x (cm^3)	Axis y-y (cm^3)	Axis x-x (cm^4)	Axis y-y (cm^4)
254 x 146 Beam	Nominal	43	259.6	147.3	7.3	12.7	505.3	92.0	568.2	141.2	6558	677
	Actual	45.7	267.0	147.0	8.3	12.8	533.9	92.4	605.1	142.7	7128	679.0
125 x 75 x 12 Angle	Nominal	17.8	125	75	12	12	43.2	16.9	77.36	31.42	354	95.5
	Actual	17.8	125	75	12	12	43.2	16.9	77.36	31.42	354	95.5

CHEMICAL COMPOSITION (PRODUCT ANALYSIS - Wt. %)

Section	Steel Quality	C	Si	Mn	P	S	Cr	Mo	Ni	V	Cu	Nb	Al	N
Beam	Grade 43A	0.22	0.04	0.81	0.014	0.020	0.02	<0.005	0.03	<0.005	<0.02	<0.005	<0.005	0.0079
Angle	Grade 50B	0.13	0.31	1.27	0.016	0.012	0.03	<0.005	0.03	0.06	0.04	<0.005	0.036	0.0043

ROOM TEMPERATURE TENSILE PROPERTIES

Position	LYS (N/mm^2)	UTS (N/mm^2)	Elongation (%)
Beam	281	490	29.0
Angle	357	520	31.0

TEST CONDITIONS

NOTES

(a) Initial ambient temperature = 20°C.

(b) Based on an initial ambient temperature of 20°C.

(*) No data recorded.

(†) The system was 66.5% overloaded for the first 18 minutes of the test.

TEST CENTRE : Warrington Research
TEST DATE : 8th February 1989
TEST NUMBER : WFRC 44520

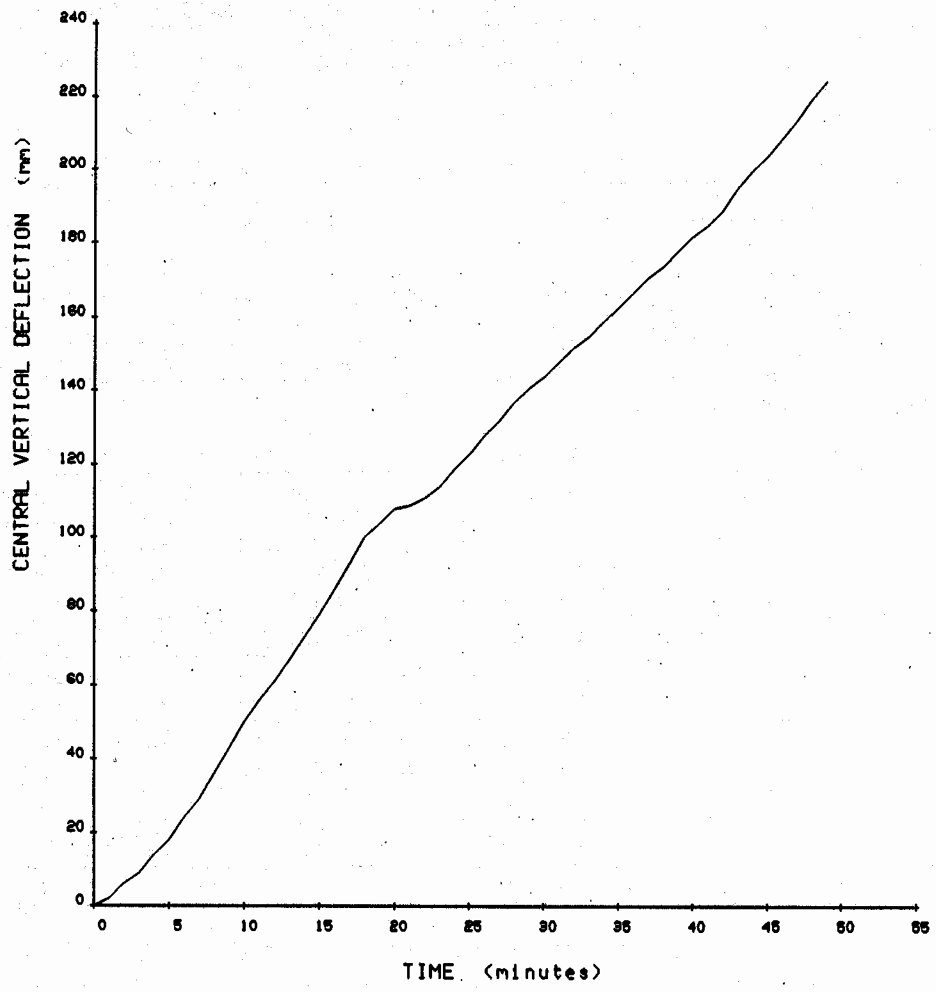
BS 476:PARTS 20 & 21: 1987
RESULTS (†)

Time to L/30	: 31 minutes
Time to L^2/9000 D	: Not attained
Time to L/20	: 49 minutes
Reload Test	: Not carried out
Load Bearing Capacity	: Not assessed
Fire Resistance	: Not assessed

DATA SHEET NUMBER **128B**

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																
		3	6	9	12	15	18	21	24	27	30	32	35	40	45	49	55	60
Upper Flange	F3	16	17	20	24	31	38	48	59	71	85	92	101	116	131	144	164	181
	F5	16	18	20	25	32	41	53	65	78	88	96	108	123	141	154	174	190
	F8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	F9	17	18	20	26	32	41	51	63	77	92	99	108	123	139	153	174	193
	Mean	16	18	20	25	32	40	51	62	75	88	96	106	121	137	150	171	188
Unexposed Web	W5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	W6	17	25	37	55	74	96	112	132	154	180	196	218	252	283	307	341	367
	W7	18	27	41	59	79	99	106	148	174	198	213	234	266	296	318	349	374
	W8	18	26	38	55	75	95	113	134	156	177	191	211	242	271	292	322	346
	Mean	18	26	39	56	76	97	110	138	161	185	200	221	253	283	306	337	362
Exposed Web																		
10 mm Below Angle	A1	67	128	192	255	312	365	423	474	521	556	578	608	655	700	731	773	805
30 mm Below Angle	A2	88	168	251	332	403	463	524	575	619	648	666	693	735	781	812	851	877
Mid-Height	A4	123	227	333	432	515	579	637	679	714	734	744	767	809	852	875	904	926
	W1	100	199	294	389	473	540	598	640	677	705	721	739	781	822	849	883	905
	W2	107	210	313	410	496	563	623	667	703	724	735	754	799	844	868	899	921
	W3	121	234	343	441	523	587	643	684	717	739	749	775	817	856	880	909	931
	W4	108	211	311	400	477	541	595	636	671	705	722	742	783	820	848	880	903
	Mean	112	216	319	414	497	562	619	661	696	721	734	755	798	839	864	895	917
30 mm Above LF	A6	99	207	322	434	527	597	654	695	726	738	753	776	816	858	879	907	927
10 mm Above LF	A7	89	200	320	437	535	607	664	705	732	746	761	785	824	865	886	913	933
Lower Flange	F1	113	230	352	466	560	629	681	720	745	761	775	797	835	873	893	919	938
	F2	169	287	418	530	618	679	728	761	778	795	809	828	864	899	918	941	958
	F4	107	232	361	478	572	639	691	728	749	772	789	813	850	879	900	924	942
	F6	119	239	365	482	576	644	697	736	756	775	790	811	850	887	906	930	949
	F7	106	228	360	483	582	650	704	742	759	782	797	822	861	894	914	938	956
	Mean	123	243	371	488	582	648	700	737	757	777	792	814	852	886	906	930	949
Angle																		
Unexposed Flange	W9	21	37	59	87	116	143	174	205	236	268	288	317	363	404	435	477	509
	W10	21	39	64	94	123	157	192	229	264	298	319	349	395	437	469	512	543
	W11	22	40	66	99	119	147	184	211	260	298	322	353	397	438	467	507	537
	Mean	21	39	63	93	119	149	183	215	253	288	310	340	385	426	457	499	530
Exposed Flange	F10	83	149	208	263	327	392	451	501	549	587	606	641	691	735	766	807	839
	F11	73	149	229	310	380	442	503	553	597	629	649	676	718	760	787	831	862
	F12	70	133	180	244	309	369	428	479	530	570	595	627	682	729	762	804	840
	Mean	75	144	206	272	339	401	461	511	559	595	617	648	697	741	772	814	847
Angle Root	R1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	R2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Mean	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mean Furnace Gas	(a)	491	604	664	712	739	760	780	798	818	824	833	848	876	894	914	939	955
Standard Curve	(b)	502	603	663	705	739	766	789	809	826	842	851	865	885	902	915	932	945
Deflection (mm)		9	24	43	61	79	100	109	119	132	144	152	163	182	204	225	-	-
Deflection Rate (mm/min)		3	6	7	5	6	7	1	5	4	3	4	4	4	4	5	-	-

DATA SHEET NUMBER	128C



DATA SHEET NUMBER **129A**

SHELF ANGLE FLOOR BEAM

DIMENSIONS AND PROPERTIES

Section Serial Size and Type (mm)	Dimensions and Properties	Mass per Metre (kg)	Depth of Section (mm)	Width of Section (mm)	Thickness		Elastic Modulus		Plastic Modulus		Moment of Inertia	
					Web (mm)	Flange (mm)	Axis x-x (cm^3)	Axis y-y (cm^3)	Axis x-x (cm^3)	Axis y-y (cm^3)	Axis x-x (cm^4)	Axis y-y (cm^4)
254 x 146 Beam	Nominal Actual	43 41.2	259.6 260.0	147.3 145.0	7.3 7.05	12.7 12.2	505.3 482.4	92.0 85.6	568.2 541.9	141.2 131.4	6558 6271	677 620.7
125 x 75 x 12 Angle	Nominal Actual	17.8 17.8	125 125	75 75	12 12	12 12	43.2 43.2	16.9 16.9	77.36 77.36	31.42 31.42	354 354	95.5 95.5

CHEMICAL COMPOSITION (PRODUCT ANALYSIS - Wt. %)

Section	Steel Quality	C	Si	Mn	P	S	Cr	Mo	Ni	V	Cu	Nb	Al	N
Beam	Grade 43A	0.14	0.07	0.80	0.023	0.020	0.04	0.008	0.06	<0.005	0.12	<0.005	<0.005	0.0080
Angle	Grade 50B	0.11	0.31	1.29	0.016	0.010	0.03	<0.005	0.03	0.055	0.04	<0.005	0.036	0.0035

ROOM TEMPERATURE TENSILE PROPERTIES

Position	LYS (N/mm^2)	UTS (N/mm^2)	Elongation (%)
Beam	306	465	27.5
Angle	356	499	36.0

TEST CONDITIONS

NOTES

(a) Initial ambient temperature = 30°C.

(b) Based on an initial ambient temperature of 20°C.

(*) No data recorded.

TEST CENTRE	: Warrington Research
TEST DATE	: 20th June 1989
TEST NUMBER	: WFRC 46386

BS 476:PARTS 20 & 21: 1987
RESULTS

Time to L/30	: 32 minutes
Time to L^2/9000 D	: Not attained
Time to L/20	: 52 minutes
Reload Test	: Not carried out
Load Bearing Capacity	: 52 minutes
Fire Resistance	: 52 minutes

DATA SHEET NUMBER **129B**

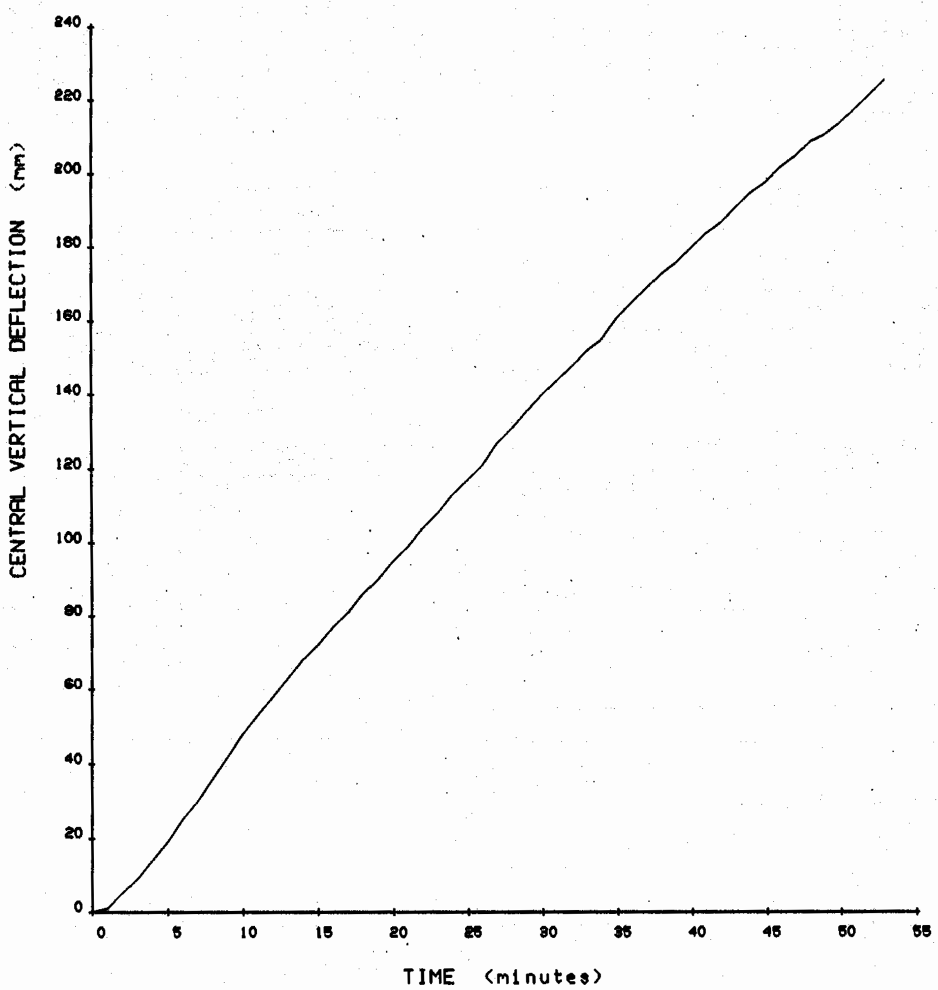
THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																		
		3	6	9	12	15	18	21	24	27	30	33	35	40	45	50	53	60	70	80
Upper Flange	F3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	F5	30	32	35	40	51	66	85	94	100	109	119	127	144	162	179	189	211	245	279
	F8	30	31	33	38	45	56	71	85	92	102	113	121	139	156	172	181	205	242	279
	F9	31	32	36	41	51	66	85	93	102	113	124	131	149	168	187	198	224	261	298
	Mean	30	32	35	40	49	63	80	91	98	108	119	126	144	162	179	189	213	249	285
Unexposed Web	W5	32	39	51	68	87	101	122	153	178	198	217	229	258	284	310	325	358	405	450
	W6	38	46	57	71	89	99	102	132	160	183	202	214	244	270	296	311	343	387	432
	W7	32	38	48	62	80	100	102	132	160	181	199	210	238	263	289	303	334	376	418
	W8	31	37	46	59	76	92	104	126	149	169	186	198	226	252	278	291	322	364	405
	Mean	33	40	51	65	83	98	108	136	162	183	201	213	242	267	293	308	339	383	426
Exposed Web																				
10 mm Below Angle	A1	110	184	245	312	368	419	469	520	562	603	636	657	707	750	783	797	831	874	909
30 mm Below Angle	A2	122	213	295	375	442	498	551	601	641	677	706	724	770	813	842	853	882	920	947
Mid-Height	A4	149	256	356	452	525	581	631	675	708	736	757	775	819	857	879	887	911	943	966
	W1	131	229	326	414	492	549	603	641	676	706	729	743	787	824	854	863	889	923	948
	W2	138	233	334	428	507	565	617	659	694	723	744	764	806	843	868	876	901	935	960
	W3	147	244	341	426	501	557	611	654	691	721	743	761	805	845	869	878	903	937	961
	W4	150	247	338	422	493	550	603	641	679	707	730	744	787	827	854	864	890	925	952
	Mean	143	242	339	428	504	560	613	654	690	719	741	757	801	839	865	874	899	933	957
30 mm Above LF	A6	121	232	347	454	541	602	653	695	726	746	772	790	832	869	891	897	919	951	973
10 mm Above LF	A7	119	230	347	456	544	606	657	697	726	746	772	790	829	867	888	894	916	947	970
Lower Flange	F1	146	264	385	497	584	643	692	727	755	776	800	816	850	883	903	909	930	958	978
	F2	122	249	375	491	582	644	694	734	757	783	809	826	861	896	915	920	941	969	989
	F4	120	245	367	475	566	629	681	721	746	772	797	814	852	889	908	914	934	964	984
	F6	140	266	393	510	597	656	705	743	766	790	812	828	859	893	910	915	936	963	983
	F7	132	256	382	492	583	644	695	734	756	782	806	821	857	894	911	916	937	967	987
	Mean	132	256	380	493	582	643	693	732	756	781	805	821	856	891	909	915	936	964	984
Angle																				
Unexposed Flange	W9	37	57	84	116	152	185	219	258	296	332	364	385	431	472	509	526	565	613	656
	W10	41	64	95	128	161	189	220	262	301	337	369	389	436	478	517	535	574	622	666
	W11	36	52	76	106	141	173	199	239	278	314	346	367	414	456	494	512	551	598	641
	Mean	38	58	85	117	151	182	213	253	292	328	360	380	427	469	507	524	563	611	654
Exposed Flange	F10	84	141	189	239	297	354	413	468	518	566	605	630	685	733	768	783	824	874	912
	F11	77	134	183	246	307	367	424	481	530	576	613	637	689	734	768	786	826	875	912
	F12	76	133	193	261	325	383	444	494	540	578	610	629	672	709	740	754	791	842	882
	Mean	79	136	188	249	310	368	427	481	529	573	609	632	682	725	759	774	814	864	902
Root	R1	44	71	105	142	183	227	275	323	370	416	455	481	538	587	629	648	689	741	789
	R2	47	77	114	155	203	249	297	343	388	432	469	494	549	597	638	657	696	748	795
	Mean	46	74	110	149	193	238	286	333	379	424	462	488	544	592	634	653	693	745	792
Mean Furnace Gas	(a)	505	612	671	715	745	769	798	818	836	852	867	879	899	928	934	939	959	983	998
Standard Curve	(b)	502	603	663	705	739	766	789	809	826	842	856	865	885	902	918	927	945	968	988
Deflection (mm)		9	25	42	58	72	86	99	113	127	140	152	161	180	198	214	226	-	-	-
Deflection Rate (mm/min)		4	6	6	5	4	5	4	5	6	4	4	6	4	3	3	4	-	-	-

TEST CENTRE	: Warrington Research
TEST DATE	: 20th June 1989
TEST NUMBER	: WFRC 46386

DATA SHEET NUMBER **129B**

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																		
		3	6	9	12	15	18	21	24	27	30	33	35	40	45	50	53	60	70	80
Concrete																				
10 mm Above Deck	CC1	76	112	150	196	251	305	356	384	447	498	537	561	622	678	726	747	795	849	883
30 mm Above Deck	CC2	54	89	107	121	167	216	267	314	377	432	479	509	577	637	682	701	745	802	846
50 mm Above Deck	CC3	43	70	105	109	118	147	177	202	227	259	291	314	372	427	477	501	552	618	673
70 mm Above Deck	CC4	33	44	63	97	107	110	111	112	123	140	157	170	206	246	286	308	357	419	474
10 mm Above Angle	CC5	31	36	48	67	80	93	109	122	125	129	146	165	215	266	322	351	414	495	564
30 mm Above Angle	CC6	31	33	41	55	70	82	94	101	105	110	116	122	148	183	226	255	303	373	441
50 mm Above Angle	CC7	31	31	34	41	51	63	75	87	97	105	107	108	109	121	146	161	202	269	333
70 mm Above Angle	CC8	31	31	32	36	41	50	63	77	87	95	103	105	107	108	110	112	136	204	263

DATA SHEET NUMBER	**129C**



DATA SHEET NUMBER **130A**

SHELF ANGLE FLOOR BEAM

DIMENSIONS AND PROPERTIES

Section Serial Size and Type (mm)	Dimensions and Properties	Mass per Metre (kg)	Depth of Section (mm)	Width of Section (mm)	Thickness		Elastic Modulus		Plastic Modulus		Moment of Inertia	
					Web (mm)	Flange (mm)	Axis x-x (cm³)	Axis y-y (cm³)	Axis x-x (cm³)	Axis y-y (cm³)	Axis x-x (cm⁴)	Axis y-y (cm⁴)
406 x 178 Beam	Nominal	54	402.6	177.6	7.6	10.9	925.3	114.5	1048	177.5	18 626	1017
	Actual	53.3	404.0	177.0	7.6	10.7	916.7	111.9	1040	173.7	18 518	990.7
125 x 75 x 12 Angle	Nominal	17.8	125	75	12	12	43.2	16.9	77.36	31.42	354	95.5
	Actual	17.8	125	75	12	12	43.2	16.9	77.36	31.42	354	95.5

CHEMICAL COMPOSITION (PRODUCT ANALYSIS - Wt. %)

Section	Steel Quality	C	Si	Mn	P	S	Cr	Mo	Ni	V	Cu	Nb	Al	N
Beam	Grade 43A	0.15	0.28	0.92	0.019	0.021	<0.02	<0.005	<0.02	<0.005	0.03	<0.005	0.020	0.0050
Angle	Grade 50B	0.13	0.31	1.28	0.017	0.013	0.03	<0.005	0.02	0.06	0.04	<0.005	0.036	0.0045

ROOM TEMPERATURE TENSILE PROPERTIES

Position	LYS (N/mm²)	UTS (N/mm²)	Elongation (%)
Beam	321	493	34.0
Angle	363	521	30.0

TEST CONDITIONS

NOTES

(a) Initial ambient temperature = 19°C.

(b) Based on an initial ambient temperature of 20°C.

(*) No data recorded.

(e) Estimated value.

TEST CENTRE	: Warrington Research
TEST DATE	: 15th February 1989
TEST NUMBER	: WFRC 44176

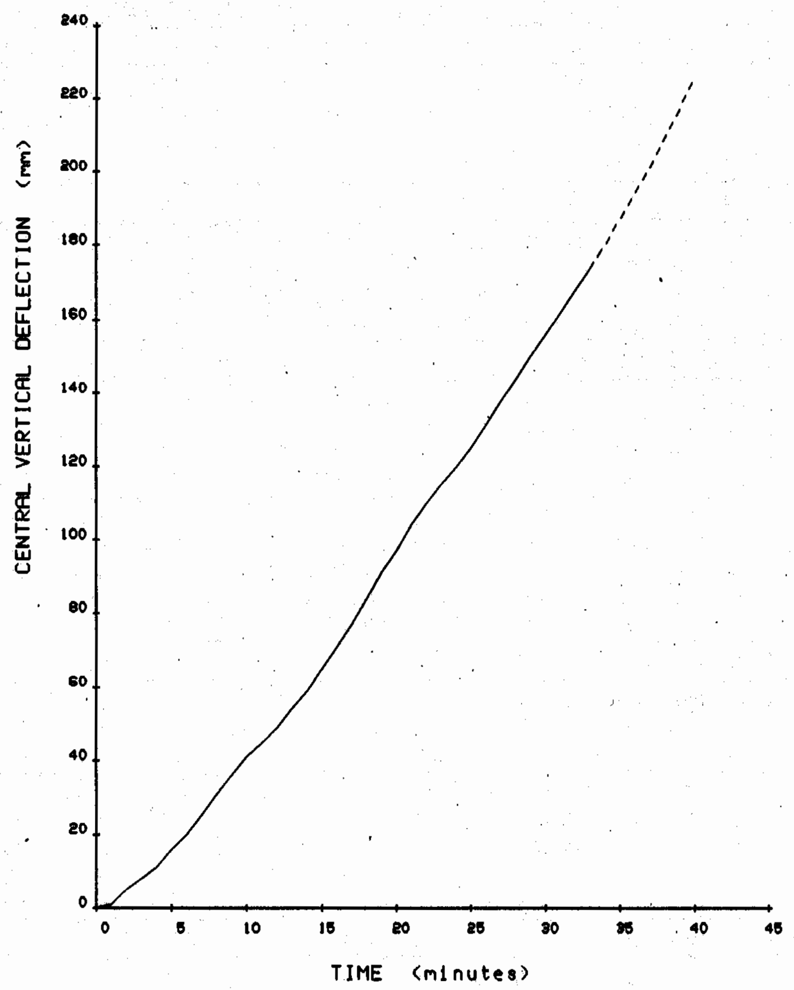
BS 476:PARTS 20 & 21: 1987 RESULTS

Time to L/30	: 29 minutes
Time to L^2/9000 D	: 18 minutes
Time to L/20	: 39 minutes (e)
Reload Test	: Not carried out
Load Bearing Capacity	: 29 minutes
Fire Resistance	: 29 minutes

DATA SHEET NUMBER 130B

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																
		3	6	9	12	15	18	21	24	27	29	33	35	40	45	50	55	60
Upper Flange	F3	13	15	16	19	24	30	37	46	56	63	78	86	103	115	128	141	157
	F5	15	15	16	19	24	30	36	44	54	60	77	85	100	113	127	140	154
	F8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	F9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Mean	14	15	16	19	24	30	37	45	55	62	78	86	102	114	128	141	156
Unexposed Web	W5	16	23	33	48	65	83	101	109	123	141	167	180	209	239	267	293	318
	W6	15	21	31	45	62	77	95	107	121	131	152	164	193	226	254	280	305
	W7	16	22	34	49	65	87	98	103	135	148	173	185	214	240	264	286	309
	W8	16	22	34	49	67	84	100	115	132	148	178	191	222	252	279	302	326
	Mean	16	22	33	48	65	83	99	109	128	142	168	180	210	239	266	290	315
Exposed Web																		
10 mm Below Angle	A1	98	164	235	295	350	403	454	487	531	555	606	629	680	728	774	809	841
30 mm Below Angle	A2	138	228	319	393	457	516	565	591	631	651	695	714	759	805	846	874	901
50 mm Below Angle	A3	136	245	350	435	505	567	614	638	674	693	732	748	793	836	873	898	923
Mid-Height	A4	143	287	419	521	598	656	699	720	746	754	791	808	843	876	907	928	950
	W1	139	275	396	494	570	628	668	692	719	735	760	777	817	850	883	906	928
	W2	140	282	408	512	590	648	690	711	738	747	782	797	835	869	899	921	942
	W3	153	297	430	532	608	664	705	726	754	763	800	814	850	878	904	925	945
	W4	140	276	402	502	577	632	674	703	732	748	775	792	829	855	880	901	921
	Mean	143	283	411	512	589	646	687	710	738	749	782	798	835	866	895	916	937
50 mm Above LF	A5	127	255	388	499	586	650	695	719	745	753	790	807	842	876	906	926	947
30 mm Above LF	A6	130	253	382	494	582	648	694	719	744	751	789	806	841	875	904	926	946
10 mm Above LF	A7	104	231	367	485	578	647	695	723	745	755	792	810	845	879	908	929	950
Lower Flange	F1	128	258	391	503	592	659	705	729	750	766	803	817	854	886	914	935	955
	F2	126	261	401	517	607	673	719	742	762	779	813	829	862	894	923	943	963
	F4	124	257	391	504	593	656	701	736	756	775	812	828	862	887	909	928	948
	F6	126	256	387	505	595	660	708	734	753	769	805	820	854	887	914	935	954
	F7	117	251	391	512	604	669	717	743	766	784	818	832	865	893	917	937	955
	Mean	124	257	392	508	598	663	710	737	757	775	810	825	859	889	915	936	955
Angle Unexposed Flange	W9	21	38	63	93	115	143	173	202	233	254	296	317	361	409	450	486	521
	W10	23	43	70	103	131	164	202	240	274	296	340	361	408	454	498	536	571
	W11	21	39	65	102	119	157	191	223	253	277	323	345	394	441	482	517	549
	Mean	22	40	66	99	122	155	189	222	253	276	320	341	388	435	477	513	547
Exposed Flange	F10	68	115	164	214	277	334	388	448	495	528	585	612	672	718	757	789	828
	F11	46	87	142	192	257	323	383	432	479	507	565	593	653	708	758	800	839
	F12	63	108	157	211	275	341	402	445	495	522	579	602	661	715	761	800	842
	Mean	59	103	154	206	270	333	391	442	490	519	576	602	662	714	759	796	836
Root	R1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	R2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Mean	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mean Furnace Gas	(a)	501	608	666	713	751	775	798	797	823	824	851	858	885	914	934	951	966
Standard Curve	(b)	502	603	663	705	739	766	789	809	826	837	856	865	885	902	918	932	945
Deflection (mm)		8	20	36	49	65	84	104	120	138	150	174	187(e)	226(e)	-	-	-	-
Deflection Rate (mm/min)		3	4	5	4	6	7	7	5	7	6	6	7	9	-	-	-	-

DATA SHEET NUMBER **130C**



APPENDIX 2

LOAD CALCULATION SUMMARY SHEETS

A2.1 TEST NO. WFRC 44520 ON 8 FEBRUARY 1989

A2.1.1 Geometry

Figure 2 gives the relevant details

A2.1.2 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

			Nominal	Actual
Depth of Section	h	(mm)	259.6	267.0
Breadth of Section	b	(mm)	147.3	147.0
Thickness of Flange	t	(mm)	12.7	12.8
Thickness of Web	s	(mm)	7.3	8.3
Area of Section	A	(mm^2)	5510	5816
Mass	m	(kg/m)	43	45.7
Weight	m	(N/m)	422	448
Distance of Neutral Axis from Base of Beam	y	(mm)	129.8	133.5
Effective Span of Beam	L	(mm)	4500	4500
Moment of Inertia (x-x)	I	(cm^4)	6558	7128
Elastic Modulus (x-x)	Z	(cm^3)	505.3	533.9
Plastic Modulus (x-x)	S	(cm^3)	568.2	605.1
Modulus of Elasticity	E	(kN/mm^2)	205	205
Design Strength	p_y	(N/mm^2)	275	281
Classification	Class 1, Plastic (Table 7, BS 5950)			

(c) Concrete

The maximum moisture content of the concrete, measured on the day of the test, was found to be 5.0%. The characteristic strength of the concrete was accepted as being 30 N/mm^2 based on the results from the 28 day cube strength tests. The density was reported to be 1860 kg/m^3 which is approximately 77.5% of typical normal weight concrete density of 2400 kg/m^3.

(d) Summary of Nominal and Actual Dimensions and Properties

			Nominal	Actual
Depth	d	(mm)	129	135
Width	w	(mm)	860	860
Area of Section	A_c	(mm^2)	110 940	116 100
Mass	m_c	(kg/m)	210.8	215.9
Weight	m_c	(N/m)	2068	2118
Density	D_c	(kg/m^3)	1900	1860

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 Calculations Using Nominal Dimensions and Properties

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

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

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

Therefore, bending stress required is 165 N/mm^2

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

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

$$\frac{f\,I}{y} = \frac{wL^2}{8}$$

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

$$w = \frac{8\,f\,I}{y\,L^2}$$

$$= \frac{8 \times 165 \times 6558 \times 10^7}{129.8 \times 4500 \times 4500} \text{ N/m}$$

$$= \underline{32\,934 \text{ N/m}}$$

The concrete load per metre run is 2068 N (based on an assumed density of 1900 kg/m^3).

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

$$w_1 = 422 + 2068 \text{ N/m}$$

$$= \underline{2490 \text{ N/m}}$$

Total load to produce required bending stress

$$w_2 = 32\,934 - 2490 \text{ N/m}$$

$$= \underline{30\,444 \text{ N/m}}$$

Therefore total imposed load

$$W = 30\,444 \times 4.5 \text{ N}$$

$$= 136\,998 \text{ N}$$

$$= \underline{136.99 \text{ kN}}$$

Using four point loads at $^1/_8$, $^3/_8$, $^5/_8$ and $^7/_8$ of the supported span, equivalent to W/4.

Point Loads Required are:-

$$P = 136.99 / 4 \text{ kN} \quad \text{(i.e. } 13\,965 / 4 \text{ kg)}$$

$$= \underline{34.25 \text{ kN}} \quad \text{(i.e. } 3491 \text{ kg)}$$

$$\underline{3.49 \text{ tonnes}}$$

The total loads actually applied were 23.12 tonnes for the first 18 minutes and 13.89 tonnes thereafter.

A2.2.2 Retrospective Calculations Using Actual Dimensions and Properties

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

$$\frac{f\,I}{y} = \frac{w\,L^2}{8}$$

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

$$w = \frac{8\,f\,I}{y\,L^2}$$

$$= \frac{8 \times f \times 7128 \times 10^7}{133.5 \times 4500 \times 4500} \text{ N/m} \qquad \text{... (A2/1)}$$

A2.2.2.1 For the First 18 minutes of the Test

The load actually applied was 23.12 tonnes

$$W = 23\,120 \text{ kg}$$

$$= \underline{226\,807 \text{ N}}$$

and therefore the total load generating the bending stress is

$$w_2 = 226\,807 / 4.5 \text{ N/m}$$

$$= \underline{50\,402 \text{ N/m}}$$

The concrete load per metre run is 2118 N (based on the actual density of 1860 kg/m^3).

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

$$w_1 = 448 + 2118 \text{ N/m}$$

$$= \underline{2566 \text{ N/m}}$$

Therefore the load available to generate a bending moment is

$$w = 50\,402 + 2566 \text{ N/m}$$

$$= \underline{52\,968 \text{ N/m}}$$

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

$$52\,968 = \frac{8 \times f \times 7128 \times 10^7}{133.5 \times 4500 \times 4500} \text{ N/mm}^2$$

$$\therefore \quad f = \frac{52\,968 \times 133.5 \times 4500 \times 4500}{8 \times 7128 \times 10^7}$$

$$= \underline{251.1 \text{ N/mm}^2}$$

A2.2.2.2 Between 18 and 49 minutes

The load actually applied was 13.89 tonnes

$$W = 13\,890 \text{ kg}$$

$$= \underline{136\,261 \text{ N}}$$

and therefore the total load generating the bending stress is

$$w_2 = 136\,261 / 4.5 \text{ N/m}$$

$$= \underline{30\,280 \text{ N/m}}$$

The concrete load per metre run is 2118 N.

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

$$w_1 = 448 + 2118 \text{ N/m}$$

$$= \underline{2566 \text{ N/m}}$$

Therefore the load available to generate a bending moment is

$$w = 30\,280 + 2566 \text{ N/m}$$

$$= \underline{32\,846 \text{ N/m}}$$

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

$$32\,846 = \frac{8 \times f \times 7128 \times 10^7}{133.5 \times 4500 \times 4500} \text{ N/mm}^2$$

$$\therefore \quad f = \frac{32\,846 \times 133.5 \times 4500 \times 4500}{8 \times 7128 \times 10^7}$$

$$= \underline{155.7 \text{ N/mm}^2}$$

The retrospective calculations, based on actual dimensions and properties, suggest that during the first 18 minutes of the test the steel section was loaded to 152.2% of the maximum allowable bending stress (BS 449 Design Rules). After the load had been reduced the stress in the lower flange was 155.7 N/mm^2, approximately 94.4% of the permitted maximum value of 165 N/mm^2.

A2.3 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.

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.

$$M_c = p_y S \quad \text{but} \le 1.2\, p_y Z$$

$$= 275 \times 568.2 \times 10^{-3} \text{ kN m}$$

$$= \underline{156.3 \text{ kN m}}$$

Check whether $p_y S \le 1.2\, p_y Z$

$$1.2\, p_y Z = 1.2 \times 275 \times 505.3 \times 10^{-3} \text{ kN m}$$

$$= \underline{166.7 \text{ kN m}}$$

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 2490 N/m

So $w_1 = \underline{2.490 \text{ kN/m}}$

Moment produced by dead load is given by

$$\text{Moment}_1 = (w_1 L^2) / 8 \text{ kN m}$$

$$= \frac{2.490 \times 4.5 \times 4.5}{8} \text{ kN m}$$

$$= \underline{6.303 \text{ kN m}}$$

From A2.2.1, Total Imposed Load is 136 998 N.

So $W = \underline{136.998 \text{ kN}}$

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

$$\text{Moment}_2 = (WL) / 8 \text{ kN m}$$

$$= \frac{136.998 \times 4.5}{8} \text{ kN m}$$

$$= \underline{77.06 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 6.303 + 77.06 \text{ kN m}$$

$$= \underline{83.363 \text{ kN m}}$$

Since M_x also equals the applied moment at the fire limit state, M_f, then the load ratio is

$$LR = M_f / M_c$$

$$= 83.363 / 156.3$$

$$= \underline{0.533}$$

(c) Check Shear Force, (F_V), does not exceed shear capacity, (P_V)

Maximum Shear Force at the ends

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

$$= (32.934 \times 4.5) / 2 \text{ kN}$$

$$= \underline{74.10 \text{ kN}}$$

Shear Capacity

$$P_V = 0.6 \, p_y \, A_v$$

where A_v is the shear area.

For an I section A_v = h x s

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

$$= \underline{312.7 \text{ kN}}$$

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

A2.3.2 Calculations Using Actual Dimensions and Properties

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

$$M_c = p_y S \quad \text{but} \leq 1.2\, p_y Z$$

$$= 281 \times 605.1 \times 10^{-3} \text{ kN m}$$

$$= \underline{170.0 \text{ kN m}}$$

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

$$1.2\, p_y Z = 1.2 \times 281 \times 533.9 \times 10^{-3} \text{ kN m}$$

$$= \underline{180.0 \text{ kN m}}$$

So $p_y S$ is less than $1.2\, p_y Z$.

(b) From A2.2.2, Self Weight of beam and concrete slab, (dead load), is 2566 N/m.

So $$w_1 = \underline{2.566 \text{ kN/m}}$$

Moment produced by dead load is given by

$$\text{Moment}_1 = (w_1 L^2) / 8 \text{ kN m}$$

$$= \frac{2.566 \times 4.5 \times 4.5}{8} \text{ kN m}$$

$$= \underline{6.495 \text{ kN m}}$$

A2.3.2.1 For the First 18 minutes of the Test

From A2.2.2.1 Total imposed load is 226 807 N.

So $$W = 226.807 \text{ kN}$$

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

$$\text{Moment}_2 = (WL) / 8 \text{ kN m}$$

$$= \frac{226.807 \times 4.5}{8} \text{ kN m}$$

$$= \underline{127.579 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 6.495 + 127.579 \text{ kN m}$$

$$= \underline{134.074 \text{ kN m}}$$

and therefore the load ratio given by

$$LR = M_f / M_c$$

$$= 134.074 / 170.0$$

$$= \underline{0.789}$$

A2.3.2.2 Between 18 and 49 minutes

From A2.2.2.2 Total imposed load is 136 261 N.

So $W = 136.261$ kN

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

$$\text{Moment}_2 = (WL) / 8 \text{ kN m}$$

$$= \frac{136.261 \times 4.5}{8} \text{ kN m}$$

$$= \underline{76.647 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 6.495 + 76.647 \text{ kN m}$$

$$= \underline{83.142 \text{ kN m}}$$

and therefore the load ratio given by

$$LR = M_f / M_c$$

$$= 83.142 / 170.0$$

$$= \underline{0.489}$$

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/mm^2 in the lower flange of the steel section an imposed load of 13.96 tonnes was required. However, during the first 18 minutes of the test the section was accidentally overloaded, the actual load applied being 23.12 tonnes. The imposed load was then reduced to 13.89 tonnes. Retrospective calculations using these loads in conjunction with the actual section properties data indicates that:-

1. During the first 18 minutes of the test the bending stress in the lower flange was 251.1 N/mm^2, or 152.2% of the maximum permitted value.

2. For the remainder of the test the bending stress in the lower flange was 155.7 N/mm^2, or 94.4% of the maximum permitted value.

A2.4.2 BS 5950:Part 1:1985

Based on nominal values and the application of the previously calculated imposed loading of 13.96 tonnes the load ratio for the test assembly was found to be 0.53. When the actual load values were used in conjunction with the actual section properties data the load ratio values were 0.789 during the first 18 minutes of the test and 0.489 thereafter. The actual design strength of the steel section was 281 N/mm^2, i.e. only slightly higher than the nominal value of 275 N/mm^2.

APPENDIX 3

LOAD CALCULATION SUMMARY SHEETS

A3.1 TEST NO. WFRC 46386 ON 20 JUNE 1989

The procedures for calculating the loads, load ratios, stress levels etc. for this test were identical to those set out in detail in Appendix 2. It is therefore not proposed to repeat them here but to provide a summary of the important values.

A3.1.1 Geometry

Figure 2 gives 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

		Nominal	Actual
Depth of Section	h (mm)	259.6	260.0
Breadth of Section	b (mm)	147.3	145.0
Thickness of Flange	t (mm)	12.7	12.2
Thickness of Web	s (mm)	7.3	7.05
Area of Section	A (mm^2)	5510	5249
Mass	m (kg/m)	43	41.2
Weight	m (N/m)	422	404
Distance of Neutral Axis from Base of Beam	y (mm)	129.8	130.0
Effective Span of Beam	L (mm)	4500	4500
Moment of Inertia (x-x)	I (cm^4)	6558	6271
Elastic Modulus (x-x)	Z (cm^3)	505.3	482.4
Plastic Modulus (x-x)	S (cm^3)	568.2	549.1
Modulus of Elasticity	E (kN/mm^2)	205	205
Design Strength	p_y (N/mm^2)	275	306
Classification	Class 1, Plastic (Table 7, BS 5950)		

(c) Concrete

The maximum moisture content of the concrete, measured on the day of the test, was found to be 4.1%. The characteristic strength of the concrete was accepted as being 30 N/mm^2 based on the results of the 28 day cube strength tests. The density was reported to be 2350 kg/m^3. The density of normal weight concrete is typically 2400 kg/m^3.

(d) Summary of Nominal and Actual Dimensions and Properties

			Nominal	Actual
Depth	d	(mm)	129	130
Width	w	(mm)	720	720
Area of Section	A_c	(mm^2)	92 880	93 600
Mass	m_c	(kg/m)	222.9	220.0
Weight	m_c	(N/m)	2187	2158
Density	D_c	(kg/m^3)	2400	2350

A3.2 CALCULATIONS BASED ON BS 449:PART 2:1969

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

A3.2.1 Calculations Using Nominal Dimensions and Properties

- bending stress required f = 165 N/mm^2
- load per metre run w = 32 934 N/m
- concrete load per metre run m_c = 2187 N/m
- self weight of beam and concrete slab w_1 = 2609 N/m
- total load to produce required bending stress w_2 = 30 325 N/m
- total imposed load W = 136.46 kN
- point loads required P = 34.12 kN

  P = 3.48 tonnes

A3.2.2 Retrospective Calculations Using Actual Dimensions and Properties

- total imposed load W = 13.14 tonnes

  W = 128 903 N
- total load generating the bending stress w_2 = 28 645 N/m
- concrete load per metre run m_c = 2158 N/m
- self weight of beam and concrete slab w_1 = 2562 N/m
- load per metre run w = 31 207 N/m
- resultant bending stress f = 163.8 N/mm^2

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

- moment capacity of beam	M_c	=	156.3	kN m
- dead load	w_1	=	2.609	kN/m
- moment produced by dead load	$Moment_1$	=	6.604	kN m
- total imposed load	W	=	136.463	kN
- moment produced by imposed load	$Moment_2$	=	76.760	kN m
- total moment applied	M_x	=	83.364	kN m
- load ratio	LR	=	0.533	
- shear force	F_v	=	74.10	kN
- shear capacity	P_v	=	312.7	kN

A3.3.2 Calculations Using Actual Dimensions and Properties

- moment capacity of beam	M_c	=	168.0	kN m
- dead load	w_1	=	2.562	kN/m
- moment produced by dead load	$Moment_1$	=	6.485	kN m
- total imposed load	W	=	128.90	kN
- moment produced by imposed load	$Moment_2$	=	72.51	kN m
- total moment applied	M_x	=	78.995	kN m
- load ratio	LR	=	0.470	

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 165 N/mm^2 in the lower flange of the steel section an imposed load of 13.91 tonnes was required. However, in the test the load actually applied was 13.14 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicates that the bending stress in the lower flange was 163.8 N/mm^2, or 99.3% 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 13.91 tonnes the load ratio for the test assembly was found to be 0.53. When the lower actual loading value was used in conjunction with the actual section properties data the load ratio value reduced to 0.47. The factor most effective in bringing about such a reduction is the design strength which at 306 N/mm^2 is higher than the nominal value of 275 N/mm^2. The actual imposed load was approximately 5.5% lower than that required.

APPENDIX 4

LOAD CALCULATION SUMMARY SHEETS

A4.1 TEST NO. WFRC 44176 ON 15 FEBRUARY 1989

A4.2 CALCULATIONS BASED ON BS 449:PART 2:1969

A4.3 CALCULATIONS BASED ON BS 5950:PART 1:1985

A4.4 COMPARISON OF LOADINGS

A4.1 TEST NO. WFRC 44176 ON 15 FEBRUARY 1989

The procedures for calculating the loads, load ratios, stress levels etc. for this test were identical to those set out in detail in Appendix 2. It is therefore not proposed to repeat them here but to provide a summary of the important values.

A4.1.1 Geometry

Figure 5 gives the relevant details

A4.1.2 Material Properties

(a) Steel

Universal Beam - 406 x 178 mm x 54 kg/m
Steel Grade - BS 4360 Grade 43A

(b) Summary of Nominal and Actual Dimensions and Properties

			Nominal	Actual
Depth of Section	h	(mm)	402.6	404
Breadth of Section	b	(mm)	177.6	177
Thickness of Flange	t	(mm)	10.9	10.7
Thickness of Web	s	(mm)	7.6	7.6
Area of Section	A	(mm^2)	6 840	6 785
Mass	m	(kg/m)	54	53.3
Weight	m	(N/m)	530	523
Distance of Neutral Axis from Base of Beam	y	(mm)	201.3	202.0
Effective Span of Beam	L	(mm)	4 500	4 500
Moment of Inertia (x-x)	I	(cm^4)	18 626	18 518
Elastic Modulus (x-x)	Z	(cm^3)	925.3	916.7
Plastic Modulus (x-x)	S	(cm^3)	1 048	1 040
Modulus of Elasticity	E	(kN/mm^2)	205	205
Design Strength	p_y	(N/mm^2)	275	321
Classification	Class 1, Plastic (Table 7, BS 5950)			

(c) Concrete

The maximum moisture content of the concrete, measured on the day of the test, was found to be 4.8%. The characteristic strength of the concrete was accepted as being 30 N/mm^2 based on the results from the 28 day cube strength tests. The density was reported to be 1850 kg/m^3 which is approximately 77.1% of typical normal weight concrete density of 2400 kg/m^3.

(d) Summary of Nominal and Actual Dimensions and Properties

		Nominal	Actual
Depth Width	d (mm) w (mm)	134 800	135 800
Area of Section Mass Weight	A_c (mm^2) m_c (kg/m) m_c (N/m)	107 200 203.7 1 998	108 000 199.8 1 960
Density	D_c (kg/m^3)	1900	1850

A4.2 CALCULATIONS BASED ON BS 449:PART 2:1969

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

A4.2.1 Calculations Using Nominal Dimensions and Properties

- bending stress required — f = 165 N/mm^2
- load per metre run — w = 60 315 N/m
- concrete load per metre run — m_c = 1 998 N/m
- self weight of beam and concrete slab — w_1 = 2 528 N/m
- total load to produce required bending stress — w_2 = 57 787 N/m
- total imposed load — W = 260.04 kN
- point loads required — P = 65.01 kN

  P = 6.627 tonnes

A4.2.2 Retrospective Calculations Using Actual Dimensions and Properties

- total imposed load — W = 25.09 tonnes

  W = 246 133 N
- total load generating the bending stress — w_2 = 54 696 N/m
- concrete load per metre run — m_c = 1 960 N/m
- self weight of beam and concrete slab — w_1 = 2 483 N/m
- load per metre run — w = 57 179 N/m
- resultant bending stress — f = 157.9 N/mm^2

A4.3 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.

A4.3.1 Initial Calculations Using Nominal Dimensions and Properties

- moment capacity of beam	M_c	=	288.2	kN m
- dead load	w_1	=	2.528	kN/m
- moment produced by dead load	$Moment_1$	=	6.399	kN m
- total imposed load	W	=	260.042	kN
- moment produced by imposed load	$Moment_2$	=	146.274	kN m
- total moment applied	M_x	=	152.673	kN m
- load ratio	LR	=	0.530	
- shear force	F_v	=	135.71	kN
- shear capacity	P_v	=	504.86	kN

A4.3.2 Calculations Using Actual Dimensions and Properties

- moment capacity of beam	M_c	=	333.8	kN m
- dead load	w_1	=	2.483	kN/m
- moment produced by dead load	$Moment_1$	=	6.285	kN m
- total imposed load	W	=	246.133	kN
- moment produced by imposed load	$Moment_2$	=	138.45	kN m
- total moment applied	M_x	=	144.735	kN m
- load ratio	LR	=	0.434	

A4.4 COMPARISON OF LOADINGS

A4.4.1 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/mm^2 in the lower flange of the steel section an imposed load of 26.50 tonnes was required. However, in the test the load actually applied was 25.09 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicates that the bending stress in the lower flange was only 157.9 N/mm^2, or 95.7% of the maximum permitted value.

A4.4.2 BS 5950:Part 1:1985

Based on nominal values and the application of the previously calculated imposed loading of 26.50 tonnes the load ratio for the test assembly was found to be 0.53. When the lower actual loading value was used in conjunction with the actual section properties data the load ratio value reduced to 0.434. The single most effective factor in bringing about such a reduction is the design strength which at 321 N/mm^2 is much higher than the nominal value of 275 N/mm^2. The actual imposed load was approximately 5.3% lower than that required.

APPENDIX 5

PC DISK VERSION OF DATA

As mentioned in the Introduction to this report the data recorded during each of the three 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 A5.1.

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 DSDD, 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 128.DAT to 130.DAT inclusive. This numbering system is consistent with that introduced in reference A5.1. Thus, for example, data from test number WFRC 45520 can be found in data file 128.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.128, which relates to data in file 128.DAT, is shown in Fig. A5.1.

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

A5.1 D.E. Wainman: 'Compendia of UK Standard Fire Test Data - Unprotected Structural Steel Nos. 1 and 2, PC Disk Version', Report SL/HED/R/S2298/1/92/C, British Steel Technical, Swinden Laboratories, 1992.

TABLE A5.1
README FILE ASSOCIATED WITH DATA FILE 128.DAT

Data file 128.DAT contains data recorded during the standard fire resistance test number WFRC 44520 which is described in report number SL/PDE/R/S2442/6/96/C - 'Summary of Data Obtained During Tests on Three Composite Metal Deck Shelf Angle Floor Beams' and should be read in conjunction with that document.

There are 42 items of data which, together with their mean values, are grouped in sets as shown below.

Set Number	Items in Columns
SET001.DAT	TIME, F3, F5, F8, F9, MEAN
SET002.DAT	TIME, W5, W6, W7, W8, MEAN
SET003.DAT	TIME, A1, A2, / A4, W1, W2, W3, W4, MEAN (of 5) / A6, A7
SET004.DAT	TIME, F1, F2, F4, F6, F7, MEAN
SET005.DAT	TIME, W9, W10, W11, MEAN, F10, F11, F12, MEAN, R1, R2, MEAN
SET006.DAT	TIME, ISO, AT1, AT2, AT3, AT4, AT5, AT6, MEAN
SET007.DAT	TIME, DEFLECTION, DEFLECTION RATE