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

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SUMMARY

BS 467:PART 21 FIRE RESISTANCE TESTS

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

D.E. Wainman

During the five years 1989-1993 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 sixth report issued as part of that series. It contains a detailed description of the design, instrumentation and construction for a single test assembly, usually referred to as the 'control' shelf angle floor beam, together with the data arising from it. The test was carried out at the Warrington Fire Research Centre.

The serial size for the steel section used was 406 x 178 mm x 54 kg/m UB. The steel grade was BS 4360:Grade 43A (now BS EN 10025 S275). The section was loaded so as to develop a bending stress of 165 N/mm^2, (the maximum likely service stress for such a section), in the lower flange. The performance of the test assembly was judged against the load bearing capacity criterion outlined in Section 5 of BS 476:Part 21:1987. The fire resistance rating for the assembly was found to be 49 minutes.

KEYWORDS

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+BS 5950
+BS 449

Sections (Structural)
Fire Resistance
Load (Mechanical)
Building Floors
Lab Reports

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Cover Pages:	2
Text/Table Pages:	6
Figure Pages:	6
Appendix Pages:	15

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INITIAL CIRCULATION

BS SECTIONS, PLATES & COMMERCIAL STEELS

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- Structural Sections

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BS 476:PART 21, FIRE RESISTANCE TESTS

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

1. INTRODUCTION

Between 1989 and 1993 more than 30 full scale fire resistance tests were carried out on a wide range of structural assemblies. The major features of all the tests were summarised in an earlier Technical Note[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] and
- a single test on a composite slim floor beam[6].

This is therefore the sixth report issued as part of that ongoing series. It contains a detailed description of the design, instrumentation and construction for a single test assembly, together with the data arising from it which are included in Appendix 1. The test assembly was a shelf angle floor beam construction. The test was carried out at the instigation of the 'Steel in Fire Forum', (STIFF), and was designed to check on the accuracy of the various structural models developed by the participating organisations. The assembly is usually referred to as the 'control' shelf angle floor beam. The data are presented in a format which is generally consistent with that of the earlier publications. As before, no analysis of the data is included since this has already been incorporated into other publications dealing with design aspects of this form of construction. The numerical sequence of the data sheets has been maintained, the one in this document being numbered 127. As in the previous compendia and reports the thermal data are reduced to summary values at various times throughout the duration of the test. It should be noted, however, that all the thermal data, usually recorded at one minute intervals, can be made available on a PC disk. (Refer to comments in Appendix 3.) This may be obtained, on request, from British Steel, 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. TEST ASSEMBLY WFRC 46737

The test assembly consisted of a 5 metre length of 406 x 178 mm x 54 kg/m universal beam section and two 5 metre lengths of 125 x 75 x 12 mm hot rolled angle. These were attached, by welding, one each side of the beam, such that the distance between the under-side of the top flange and the inside face of the angle was 210 mm. Furthermore, they were positioned so that the 125 mm long leg was perpendicular to the web of the section. All the 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.

The floor was constructed using 50 pre-stressed concrete slabs supplied by ECC Building Products Ltd. based in Swindon. Each slab had nominal dimensions of 150 x 100 x 1500 mm and contained two steel reinforcing bars running the full 1500 mm length. They were arranged, 25 on each side of the beam, so that they spanned the width of the furnace, resting loosely on the furnace walls and steel angles. The slabs overlapped onto the angles by a distance of 75 mm and were laid such that the thickness of the floor was 100 mm. Each slab was insulated from the adjacent ones by tightly packed 12 mm thick ceramic fibre blanket. The cavity formed between the ends of the slabs and the web of the steel section was filled with fine dry sand which also covered the top flange of the beam to a depth of approximately 30 mm. It was considered that the concrete floor did not provide any additional strength to the beam and therefore was not classed as a composite structure.

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

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

Density:	2260 kg/m^3
Moisture Content:	4.6% w/w

The compressive strength of the lintels was not reported.

The density of the ceramic fibre insulation used in the floor construction, measured on the day of the test, was found to be 97.1 kg/m^3.

3. DIMENSIONS AND SECTION PROPERTIES

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

4. INSTRUMENTATION

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

Thermocouples of the same type were installed by 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.

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

5. ASSEMBLY

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

6. LOADING

A total imposed load of 20.0 tonnes was applied to the steel section by means of two hydraulic rams positioned along the centre line of the web and at points corresponding to $^1/_3$ and $^2/_3$ of the supported span. The applied load, together with the self weight of the system, was intended to develop a bending stress of 165 N/mm^2 in the lower flange of the steel section. This is the maximum allowable bending stress for a BS4360:Grade 43A steel section according to the design rules in BS449:Part 2:1969. The applied load was kept constant for the first 54 minutes of the test, at which time it was removed.

The load to be applied to the test assembly was initially calculated on the basis of the nominal dimensions and section properties for the steel member concerned. These calculations were subsequently repeated to take account of the actual dimensions and mechanical properties of the section. Calculations relating to the applied load level are given in Appendix 2. A comparison of the calculation data to BS5950:Part 1:1985 is also included.

7. FAILURE CRITERIA

The performance of the test assembly was judged against the load bearing capacity criterion outlined in Section 5 of BS476:Part 21:1987. The maximum allowable deflection and the maximum allowable rate of deflection for the test assembly, as specified by the standard, were calculated to be 225 mm, (span / 20), and 5.5 mm/min, (span^2 / 9000 x D), respectively, where D = 405 mm, the measured depth of the section. The allowable rate of deflection criterion is not applicable until the deflection exceeds span / 30, i.e. 150 mm.

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

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

8. CONCLUSIONS

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

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

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Investigator

D.M. Martin
Manager
Product Design & Engineering

REFERENCES

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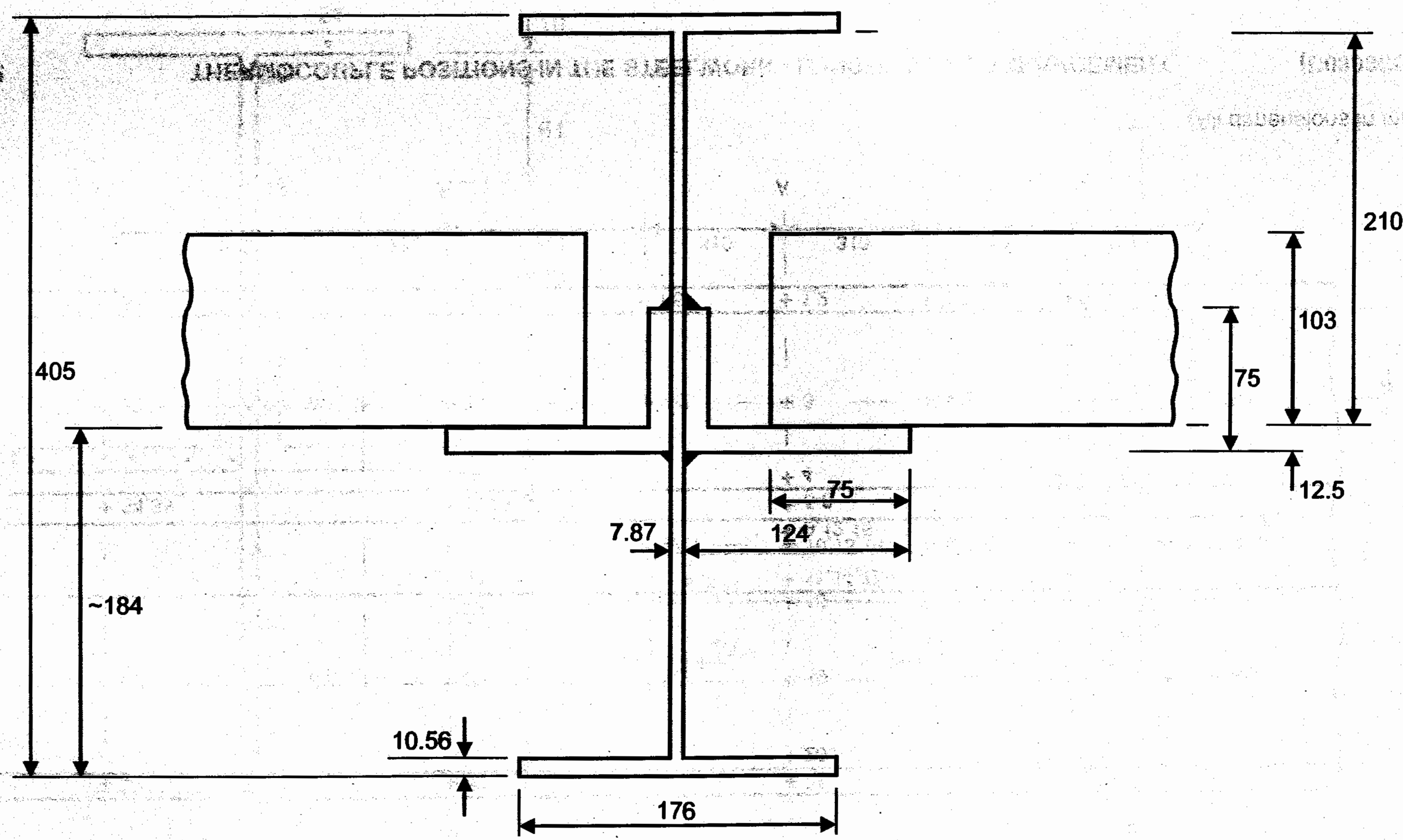
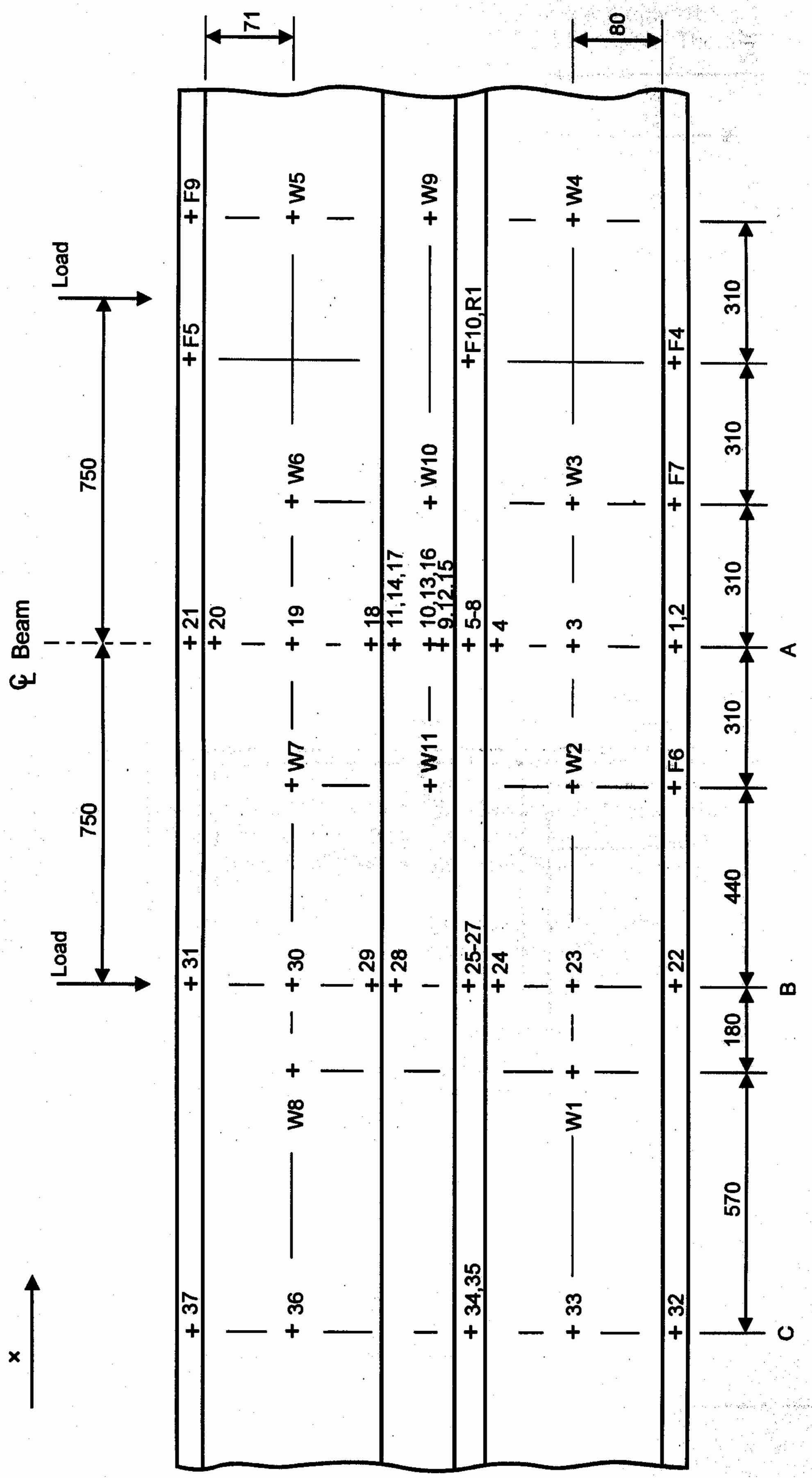
EJF



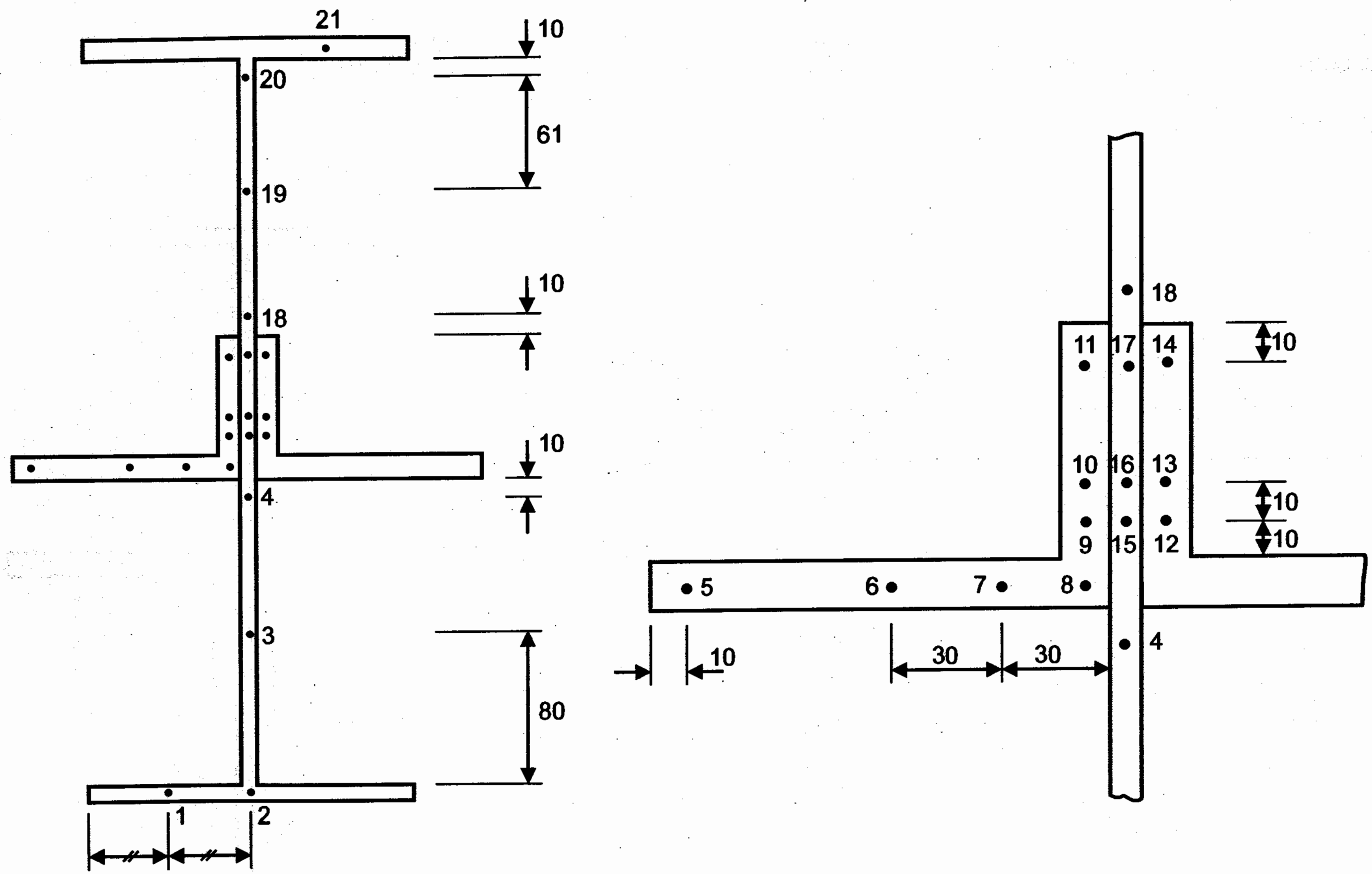
(All dimensions in mm)

FIG. 1 SCHEMATIC ARRANGEMENT OF COMPONENTS - TEST NO. WFRC 46737 (TRANSVERSE SECTION) (D0303C05)
(BASED ON ACTUAL DIMENSIONS)



(All dimensions in mm)

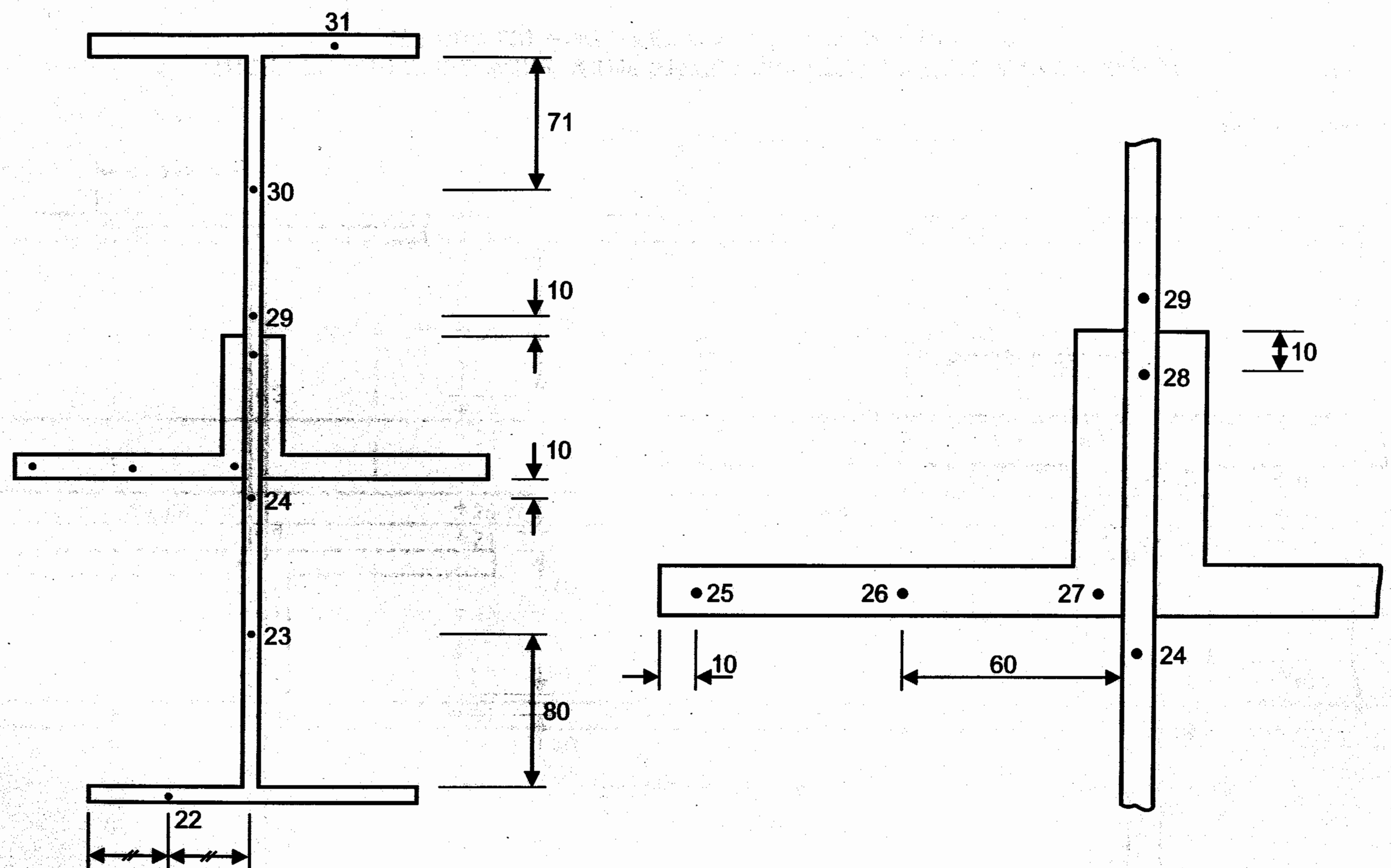
FIG. 2 THERMOCOUPLE POSITIONS IN THE STEELWORK - LONGITUDINAL ARRANGEMENT (D0303C05)



(All dimensions in mm)

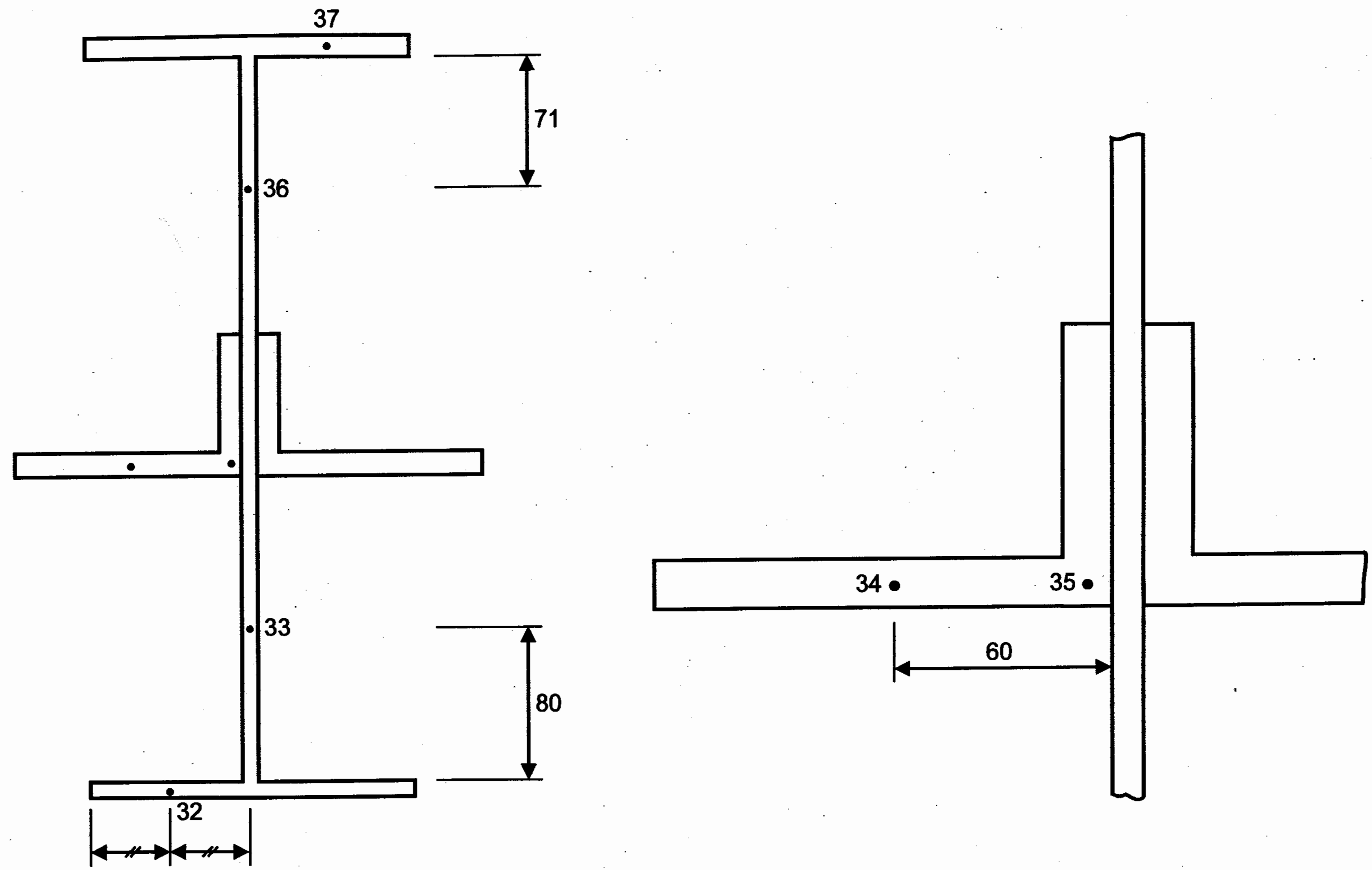
FIG. 3 THERMOCOUPLE POSITIONS IN THE STEELWORK - TRANSVERSE ARRANGEMENT AT POSITION 'A' IN DIRECTION OF ARROW 'x' IN FIG. 2

(D0303C05)



(All dimensions in mm)

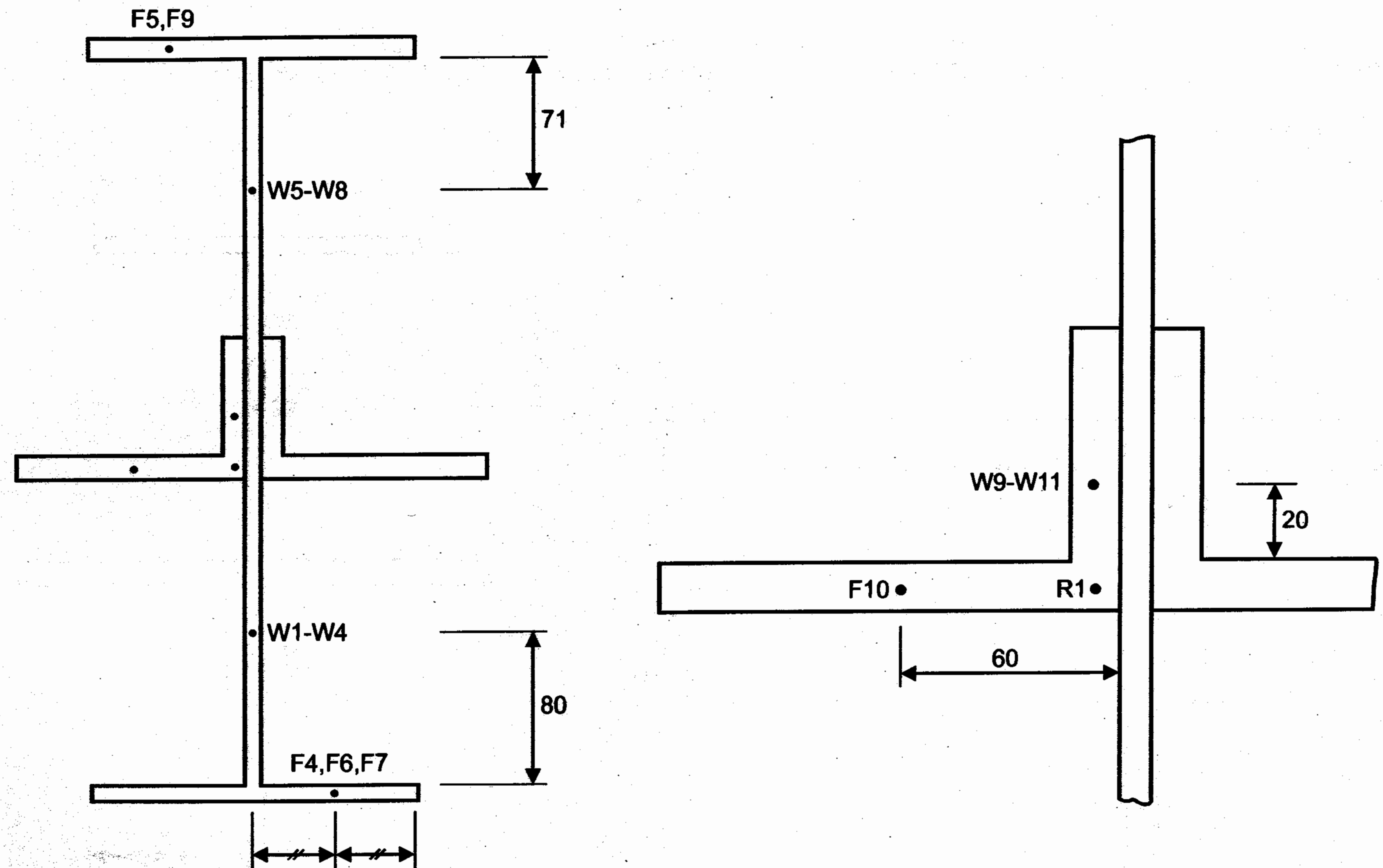
FIG. 4 THERMOCOUPLE POSITIONS IN THE STEELWORK - TRANSVERSE ARRANGEMENT AT POSITION 'B' IN DIRECTION OF ARROW 'x' IN FIG. 2 (D0303C05)



(All dimensions in mm)

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

(D0303C05)



(All dimensions in mm)

FIG. 6 THERMOCOUPLE POSITIONS IN THE STEELWORK - TRANSVERSE ARRANGEMENT AT ALL OTHER POSITIONS IN DIRECTION OF ARROW 'x' IN FIG. 2 (D0303C05)

APPENDIX 1

DATA SHEET NO. 127

DATA SHEET NUMBER	127A

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)
406 x 178 Beam	Nominal Actual	54 53.6	402.6 405	177.6 176	7.6 7.87	10.9 10.56	925.3 913.2	114.5 109.3	1048 1040	177.5 170.1	18 626 18 493	1017 961.4
125 x 75 x 12 Angle	Nominal Actual	17.8 18.4	125 124	75 75	12 12.5	12 12.5	43.2 43.8	16.9 17.6	77.36 79.24	31.42 32.72	354 359	95.5 99.0

CHEMICAL COMPOSITION (PRODUCT ANALYSIS - Wt. %)

Section	Steel Quality	C	Si	Mn	P	S	Cr	Mo	Ni	V	Cu	Nb	Al	N
Beam	Grade 43A	0.11	0.24	1.28	0.017	0.022	0.02	<0.005	<0.02	<0.005	0.03	<0.005	<0.005	0.0047
Angle	Grade 50B	0.11	0.30	1.33	0.016	0.011	0.03	<0.005	0.02	0.060	0.02	<0.005	0.031	0.0052

ROOM TEMPERATURE TENSILE PROPERTIES

Position	LYS (N/mm^2)	UTS (N/mm^2)	Elongation (%)
Beam	355	484	38.5
Angle	367	518	29

TEST CONDITIONS

NOTES

(a) Initial ambient temperature = 25°C.

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

(*) No data recorded.

TEST CENTRE	: Warrington Research
TEST DATE	: 31st May 1990
TEST NUMBER	: WFRC 46737

BS476:PARTS 20 & 21: 1987
RESULTS

Time to L/30	: 47 minutes
Time to L^2/9000 D	: 49 minutes
Time to L/20	: Not attained
Reload Test	: Not carried out
Load Bearing Capacity	: 49 minutes
Fire Resistance	: 49 minutes

DATA SHEET NUMBER **127B**

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																	
		3	6	9	12	15	18	21	24	27	30	35	40	45	49	54	60	65	70
<u>Upper Flange</u>	F9	26	26	26	26	27	27	29	31	33	35	41	48	55	62	72	85	98	109
	F5	25	25	26	26	27	27	29	31	33	36	42	48	56	63	73	88	101	110
	T21	25	26	26	26	27	28	29	31	34	37	44	52	61	69	*	*	*	*
	T31	26	26	27	27	27	28	29	31	33	35	40	47	54	61	*	*	*	*
	Mean	26	26	26	26	27	28	29	31	33	36	42	49	57	64	73	87	100	110
<u>Unexposed Web</u> 10 mm Below U.F.	T20	25	25	26	27	30	33	37	42	47	53	65	77	90	100	115	137	149	161
71 mm Below U.F.	W5	25	27	30	36	44	53	66	79	94	107	133	157	178	194	210	233	250	266
	W6	25	27	30	37	47	59	73	88	105	120	148	173	195	212	231	258	276	292
	T19	25	27	31	38	49	62	77	94	111	127	156	182	206	223	245	270	287	303
	W7	26	27	31	38	48	60	74	89	104	119	146	169	191	206	226	248	266	282
	T30	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	W8	26	28	32	38	47	58	71	86	101	115	142	166	187	202	219	245	262	277
	Mean	25	27	31	37	47	58	72	87	103	118	145	169	191	207	226	251	268	284
10 mm Above Top of Angle	T18	27	35	52	76	105	139	174	208	240	269	319	361	397	422	450	482	506	528
	T29	26	34	47	67	92	120	149	178	206	232	272	303	329	350	376	414	439	461
	Mean	27	35	50	72	99	130	162	193	223	251	296	332	363	386	413	448	473	495
10 mm Below Top of Angle	T17	29	43	68	103	143	184	226	266	305	340	397	446	486	513	544	577	602	627
	T28	30	43	66	97	135	175	215	254	292	326	375	413	444	466	493	546	577	605
	Mean	30	43	67	100	139	180	221	260	299	333	386	430	465	490	519	562	590	616
20 mm Above Inside Face of Angle	T16	32	51	83	124	168	213	259	303	345	382	443	494	535	564	595	628	654	679
10 mm Above Inside Face of Angle	T15	40	68	112	162	214	266	317	366	411	450	513	567	609	638	669	703	730	755
<u>Exposed Web</u> 10 mm Below Angle	T4	80	142	225	294	361	425	479	529	573	609	669	716	751	778	812	846	870	887
	T24	110	176	257	327	391	447	496	543	579	614	669	707	739	762	792	825	849	866
	Mean	95	159	241	311	376	436	488	536	576	612	669	712	745	770	802	836	860	877
80 mm Above L.F.	W4	101	198	309	408	492	560	614	657	691	718	760	798	828	846	870	898	916	924
	W3	113	215	337	441	526	594	642	683	715	740	781	820	844	864	889	913	930	939
	T3	112	210	335	438	524	593	642	684	717	741	786	824	847	866	892	917	933	942
	W2	123	223	344	447	533	600	647	687	719	743	787	825	848	867	891	917	933	942
	T23	117	213	327	429	513	579	628	671	702	729	769	807	831	850	873	900	918	928
	W1	124	219	325	422	504	569	619	663	696	723	762	801	826	845	867	895	913	924
	Mean	115	213	330	431	515	583	632	674	707	732	774	813	837	856	880	907	924	933
Lower F.W. Junction	T2	91	197	332	452	547	618	668	707	735	754	801	837	860	880	901	924	940	950
<u>Lower Flange</u>	F4	103	218	351	465	557	626	673	711	739	759	803	837	860	879	900	922	938	947
	F7	104	222	360	478	570	638	684	721	745	768	813	847	869	887	909	929	945	952
	T1	113	224	367	482	571	637	683	719	743	766	811	843	865	883	904	926	941	950
	F6	107	225	362	479	572	640	686	723	747	771	817	849	872	890	908	930	946	954
	T22	114	217	352	466	555	620	667	705	733	752	796	828	849	867	889	912	928	938
	Mean	108	221	358	474	565	632	679	716	741	763	808	841	863	881	902	924	940	948

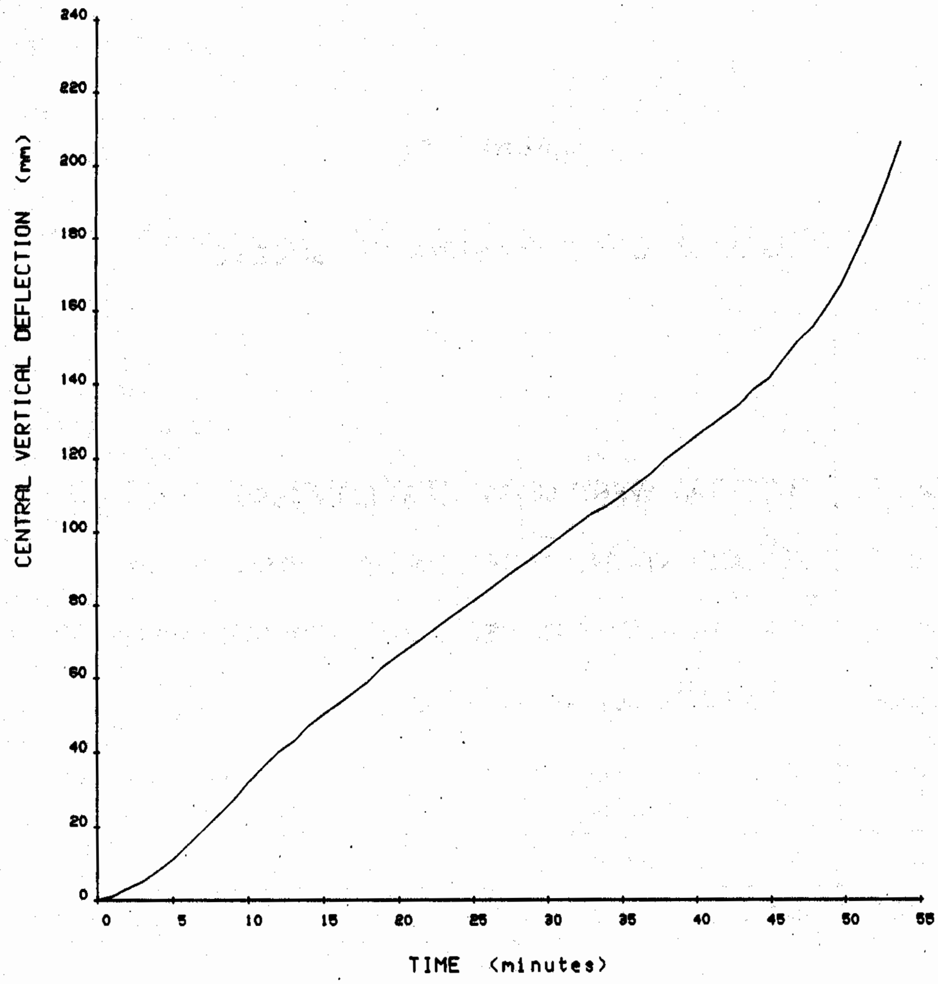
(Cont ...)

TEST CENTRE	: Warrington Research
TEST DATE	: 31st May 1990
TEST NUMBER	: WFRC 46737

DATA SHEET NUMBER 127B

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																	
		3	6	9	12	15	18	21	24	27	30	35	40	45	49	54	60	65	70
<u>Unexposed Flange of Angle</u>																			
10 mm Below Top	T11	27	38	57	86	121	161	201	240	278	312	369	417	454	480	508	543	571	597
	T14	28	42	66	100	140	181	223	265	304	339	397	446	486	514	544	578	603	627
	Mean	28	40	62	93	131	171	212	253	291	326	383	432	470	497	526	561	587	612
20 mm Above Inside Face	W9	31	47	75	111	152	195	239	283	324	360	419	468	509	538	571	609	635	659
	W10	32	48	77	115	158	203	249	293	335	373	432	481	521	548	580	616	642	668
	T10	32	50	81	121	166	212	258	303	345	383	444	496	538	567	598	632	658	684
	T13	31	49	79	118	162	207	253	297	339	376	437	490	532	561	593	626	651	676
	W11	32	50	79	118	163	209	255	299	342	380	440	491	533	561	593	629	656	680
	Mean	32	49	78	117	160	205	251	295	337	374	434	485	527	555	587	622	648	673
10 mm Above Inside Face	T9	35	57	92	138	188	240	290	339	385	425	490	544	587	616	649	683	711	737
	T12	37	62	101	148	199	251	303	353	400	440	507	562	606	636	668	703	730	756
	Mean	36	60	97	143	194	246	297	346	393	433	499	553	597	626	659	693	721	747
<u>Exposed Flange of Angle</u>																			
10 mm from Tip	T5	65	120	200	276	351	425	488	545	593	633	695	743	773	800	830	867	894	913
	T25	72	123	194	266	338	408	468	525	569	608	667	710	743	764	797	834	862	883
	Mean	69	122	197	271	345	417	478	535	581	621	681	727	758	782	814	851	878	898
60 mm from Web	F10	77	126	182	239	304	370	429	484	532	573	637	687	727	753	784	823	849	871
	T6	64	108	176	242	309	377	438	494	544	583	649	699	736	760	791	832	861	884
	T26	76	117	180	242	307	370	427	481	527	568	630	675	709	734	765	804	837	860
	Mean	72	117	179	241	307	372	431	486	534	575	639	687	724	749	780	820	849	872
30 mm from Web	T7	63	100	157	215	277	340	398	452	501	542	608	661	701	729	759	796	825	849
Angle Root	R1	40	65	103	149	200	255	310	364	414	457	525	580	623	653	687	723	751	779
	T8	42	72	119	171	227	283	339	391	439	480	546	600	643	671	703	737	767	795
	T27	41	65	105	154	207	261	315	366	413	454	519	569	608	635	667	705	734	761
	Mean	41	67	109	158	211	266	321	374	422	464	530	583	625	653	686	722	751	778
<u>At 1500 mm from Mid Span</u>																			
Upper Flange	T37	25	25	25	25	26	26	27	28	30	31	35	40	46	51	*	*	*	*
Unexposed Web, 71 mm Below U.F.	T36	26	27	31	37	44	53	65	77	91	105	130	155	178	195	215	239	258	275
Exposed Web, 80 mm Above L.F.	T33	99	174	263	348	423	490	545	591	629	659	707	744	772	798	825	851	872	889
Lower Flange	T32	90	172	275	373	458	528	582	627	661	687	730	760	791	813	837	863	885	899
Exposed Flange of Angle, 60 mm from Web	T34	51	77	115	157	204	256	309	363	413	457	531	593	641	674	711	749	776	805
Angle Root	T35	36	54	76	110	148	189	234	279	324	365	435	495	544	579	617	657	687	714
Mean Furnace Gas	(a)	509	614	690	723	762	791	811	831	845	866	892	905	922	932	944	972	980	981
Standard Curve	(b)	502	603	662	705	738	765	788	808	826	841	864	884	902	915	929	945	957	968
Deflection (mm)		5	15	27	40	50	59	69	78	87	96	110	126	142	162	207	-	-	-
Deflection Rate (mm/min)		2	4	4	4	3	3	3	3	3	3	3	3	3	6	11	-	-	-

DATA SHEET NUMBER **127C**



APPENDIX 2

LOAD CALCULATION SUMMARY SHEETS

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

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

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

A2.4 COMPARISON OF LOADINGS

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

A2.1.1 Geometry

Figure 1 gives the relevant details

A2.1.2 Material Properties

(a) Steel

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

(b) Summary of Nominal and Actual Dimensions and Properties

			Nominal	Actual
Depth of Section	h	(mm)	402.6	405
Breadth of Section	b	(mm)	177.6	176
Thickness of Flange	t	(mm)	10.9	10.56
Thickness of Web	s	(mm)	7.6	7.87
Area of Section	A	(mm^2)	6 840	6 828
Mass	m	(kg/m)	54	53.6
Weight	m	(N/m)	530	526
Distance of Neutral Axis from Base of Beam	y	(mm)	201.3	202.5
Effective Span of Beam	L	(mm)	4 500	4500
Moment of Inertia (x-x)	I	(cm^4)	18 626	18 493
Elastic Modulus (x-x)	Z	(cm^3)	925.3	913.2
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	355
Classification	Class 1, Plastic (Table 7, BS5950)			

(c) Concrete

The maximum moisture content of the concrete slabs, measured on the day of the test, was found to be 4.6%. Their density was reported to be 2260 kg/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)	100	103
Width	w (mm)	150	150
Length	l (mm)	1 550	1 550
Area of Section	A_c (mm^2)	15 000	15 450
Mass	m_c (kg/m)	36.0	34.9
Weight	m_c (N/m)	353.2	342.5
Density	D_c (kg/m^3)	2 400	2 260

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

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

A2.2.1 Calculations Using Nominal Dimensions and Properties

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

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

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

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

$$f = 165\ N/mm^2$$

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

$$\frac{fI}{y} = \frac{wL^2}{8}$$

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

$$w = \frac{8fI}{yL^2}$$

$$= \frac{8 \times 165 \times 18.626 \times 10^7}{201.3 \times 4500 \times 4500}\ N/m$$

$$= \underline{60\ 315\ N/m}$$

The concrete load per metre run is 353.2 N.

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

$$w_1 = 530 + 353.2\ N/m$$

$$= \underline{883.2\ N/m}$$

Total load to produce required bending stress

w_2 = 60 315 - 883.2 N/m

= <u>59 432 N/m</u>

Therefore total imposed load

W = 59 432 x 4.5 N

= 267 444 N

= <u>267.44 kN</u>

Using two point loads at $^1/_3$ and $^2/_3$ of the supported span, equivalent to W/2.

Point Loads Required are:-

P = 267.44 / 2 kN (i.e. 27 262 / 2 kg)

= <u>133.72 kN</u> (i.e. 13 631 kg)

<u>13.63 tonnes</u>

The total load actually applied was 20.0 tonnes.

A2.2.2 Retrospective Calculations Using Actual Dimensions and Properties

The required bending moment is given by (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

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

$$= \frac{8 \times f \times 18\,493 \times 10^7}{202.5 \times 4500 \times 4500} \text{ N/m} \qquad \text{... (A2/1)}$$

Since the load actually applied was 20.0 tonnes

W = 20 000 kg

= <u>196 200 N</u>

and therefore the total load generating the bending stress is

$$w_2 = 196\,200 / 4.5 \text{ N/m}$$

$$= \underline{43\,600 \text{ N/m}}$$

The concrete load per metre run is 342.5 N.

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

$$w_1 = 526 + 342.5 \text{ N/m}$$

$$= \underline{868.5 \text{ N/m}}$$

Therefore the load available to generate a bending moment is

$$w = 43\,600 + 868.5 \text{ N/m}$$

$$= \underline{44\,468.5 \text{ N/m}}$$

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

$$44\,468.5 = \frac{8 \times f \times 18\,493 \times 10^7}{202.5 \times 4500 \times 4500} \text{ N/mm}^2$$

$$\therefore \quad f = \frac{44\,468.5 \times 202.5 \times 4500 \times 4500}{8 \times 18\,493 \times 10^7}$$

$$= \underline{123.3 \text{ N/mm}^2}$$

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

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

In the following calculations any contribution made by the 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.

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

$$= 275 \times 1048 \times 10^{-3} \text{ kN m}$$

$$= \underline{288.2 \text{ kN m}}$$

Check whether $p_y S \leq 1.2 p_y Z$

$$1.2 p_y Z = 1.2 \times 275 \times 925.3 \times 10^{-3} \text{ kN m}$$

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

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

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

So $w_1 = \underline{0.8832 \text{ kN/m}}$

Moment produced by dead load is given by

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

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

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

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

So $W = \underline{267.444 \text{ kN}}$

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

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

$$= \frac{267.444 \times 4.5}{8} \text{ kNm}$$

$$= \underline{150.437 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 2.2356 + 150.437 \text{ kN m}$$

$$= \underline{152.673 \text{ kN m}}$$

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

$$LR = M_f / M_c$$

$$= 152.673 / 288.2$$

$$= \underline{0.530}$$

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

Maximum Shear Force at the ends

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

$= (60.315 \times 4.5) / 2$ kN

$=$ <u>135.71 kN</u>

Shear Capacity

$$P_V = 0.6\ p_y\ A_v$$

where A_v is the shear area.

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

$\therefore \quad P_V = 0.6 \times 275 \times 402.6 \times 7.6 \times 10^{-3}$ kN

$=$ 504.86 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.

$M_c = p_y S \quad$ but $\leq 1.2\ p_y Z$

$= 355 \times 1040 \times 10^{-3}$ kN m

$=$ 369.2 kN m

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

$1.2\ p_y Z = 1.2 \times 355 \times 913.2 \times 10^{-3}$ kN m

$=$ 389.0 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 slabs, (dead load), is 868.5 N/m.

So $\quad w_1 =$ 0.8685 kN/m

Moment produced by dead load is given by

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

$$= \frac{0.8685 \times 4.5 \times 4.5}{8} \text{ kN m}$$

$=$ 2.198 kN m

From A2.2.2 Total imposed load is 196 200 N.

So W = 196.20 kN

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

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

$$= \frac{196.20 \times 4.5}{8} \text{ kN m}$$

$$= \underline{110.363 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 2.198 + 110.363 \text{ kN m}$$

$$= \underline{112.561 \text{ kN m}}$$

and therefore the load ratio given by

$$LR = M_f / M_c$$

$$= 112.561 / 369.2$$

$$= \underline{0.31}$$

A2.4 COMPARISON OF LOADINGS

A2.4.1 BS449:Part 2:1969

Based on nominal dimensions and section properties it was calculated that in order to develop the maximum permissible bending stress of 165 N/mm^2 in the lower flange of the steel section an imposed load of 27.26 tonnes was required. However, in the test the load actually applied was 20.00 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicates that the bending stress in the lower flange was only 123.3 N/mm^2, or 74.7% of the maximum permitted value.

A2.4.2 BS5950:Part 1:1985

Based on nominal values and the application of the previously calculated imposed loading of 27.26 tonnes the load ratio for the test assembly was found to be 0.53. When the lower actual loading value was used in conjunction with the actual section properties data the load ratio value reduced to 0.31. The factors most effective in bringing about such a reduction are the design strength which at 355 N/mm^2 is much higher than the nominal value of 275 N/mm^2 and the actual imposed load which was approximately 27% lower than that required.

APPENDIX 3

PC DISK VERSION OF DATA

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

The data are held on the disk in the form of ASCII text files. This format has been chosen since the majority of commercial software packages can import files of this type. The format allows the data to be referenced either via the screen, (or printer), or read directly by PC based software. The data are initially being made available on 3½ inch 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 file is identified by reference to the DATA SHEET NUMBER sequence, i.e. 127.DAT. This numbering system is consistent with that introduced in Reference A3.1. The thermal data recorded during the fire test have been divided into 'SETS' which reflect the positions of the thermocouples in the steel section. Mean temperature values are included in the sets where it is considered valid to do so. In order that the columns of data in any particular 'SET' can be related to the corresponding thermocouple positions a 'README' file is associated with the data file. README.127 which relates to data in file 127.DAT is shown in Table A3.1.

REFERENCE

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

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

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

Set Number	Items in Columns
SET001.DAT	TIME, F9, F5, T21, T31, MEAN
SET002.DAT	TIME, T20
SET003.DAT	TIME, W5, W6, T19, W7, T30, W8, MEAN
SET004.DAT	TIME, T18, T29, MEAN, T17, T28, MEAN, T16, T15
SET005.DAT	TIME, T4, T24, MEAN, W4, W3, T3, W2, T23, W1, MEAN, T2
SET006.DAT	TIME, F4, F7, T1, F6, T22, MEAN
SET007.DAT	TIME, T11, T14, MEAN, W9, W10, T10, T13, W11, MEAN, T9, T12, MEAN
SET008.DAT	TIME, T5, T25, MEAN, F10, T6, T26, MEAN, T7
SET009.DAT	TIME, R1, T8, T27, MEAN
SET010.DAT	TIME, T37, T36, T33, T32, T34, T35
SET011.DAT	TIME, ISO, AT1, AT2, AT3, AT4, AT5, AT6, MEAN
SET012.DAT	TIME, DEFLECTION