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BS 476:Part 21 Fire Resistance Tests Summary of Data Obtained During Tests on Two Floor Beam Assemblies at the Technical Centre for Fire Prevention - TNO, Rijswijk, Holland

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SUMMARY

BS 476:PART 21 FIRE RESISTANCE TESTS

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

D.E. Wainman

During the five years 1989-1993 Swinden Technology Centre carried out more than thirty standard fire resistance tests on hot rolled structural steel sections. Data arising from the tests are being summarised in a series of reports, each one dealing with either a different form of construction or a generic group of test assemblies.

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

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

In the case of the simply supported beam the concrete floor slab was cast in-situ onto the upper flange. In the shelf angle floor beam pre-cast concrete floor slabs were supported from continuous 125 x 75 x 12 mm Grade 50D, (S375J2), hot rolled angles which were welded to the web of the section. Normal weight Grade 35 concrete was used for forming the floor slabs in both cases.

The sections were loaded so as to develop a bending stress of 165 N/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 two assemblies were found to be:

- Test 1
  Simply supported floor beam with concrete topping - 15 minutes
- Test 2
  Simply supported shelf angle floor beam with concrete slabs - 59 minutes

KEYWORDS

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Fire Tests
+BS 5950
+BS 449
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BS 476:PART 21 FIRE RESISTANCE TESTS

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

1. INTRODUCTION

Between 1989 and 1993 more than 30 full scale fire resistance tests were carried out on a wide range of structural assemblies. The major features of all the tests were summarised in an earlier Technical Note(1). Data obtained during the tests are being presented in a series of reports, each of which is concerned with either a different form of construction or a generically similar group of test assemblies. The first report in the series was issued in 1993(2) and included material relating to eight flange plated slim floor beams. Subsequent reports have given details relating to

- five web encased column assemblies(3),
- tests on connections between beams and columns(4),
- a single test on an arched metal deck floor(5)
- a single test on a composite slim floor beam(6)
- the 'control' shelf angle floor beam(7) and
- three composite metal deck shelf angle floor beams(8)

This is therefore the eighth report issued as part of that ongoing series. It contains a detailed description of the design, instrumentation and construction for two test assemblies, together with the data arising from them; see Appendix 1. The test assemblies were a simply supported floor beam with a concrete topping slab cast in-situ onto the upper flange and a shelf angle floor beam supporting pre-cast concrete floor units. The data are presented in a format which is generally consistent with that of the earlier publications. As before, no analysis of the data is included since this has already been incorporated into other publications dealing with design aspects of these forms of construction. The numerical sequence of the data sheets has been maintained, the ones in this document being numbered 131 and 132. As in previous compendia and reports the thermal data are reduced to summary values at various times throughout the duration of the test. It should be noted, however, that all the thermal data, usually recorded at one minute intervals, can be made available on a PC disk. (Refer to comments in Appendix 4.) This may be obtained, on request, from British Steel, Swinden Technology Centre.

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

2. FIRE TESTS ON SIMPLY SUPPORTED FLOOR BEAMS

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

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

2.1 Features Common to Both Test Assemblies

2.1.1 Steel Quality

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

2.1.2 Dimensions and Section Properties

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

2.1.3 Loading

For each of the tests the applied load, together with the self weight of the system, was intended to develop a bending stress of 165 N/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 and 3. A comparison of the calculation data in terms of BS 5950:Part 1:1985 is also included.

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

2.1.4 Fabrication

Both test assemblies consisted of a 5 metre length of 254 x 146 mm x 43 kg/m universal beam section and, in the case of the shelf angle floor beam assembly, two 5 metre lengths of 125 x 75 x 12 mm hot rolled angle. These were attached, by welding, one each side of the beam, such that the distance between the under-side of the upper flange and the inside face of the angle was 165 mm. Furthermore, they were positioned so that the 125 mm long leg was perpendicular to the web of the section. All the welds were 6 mm intermittent fillets. Those along the top edge of the angle were 50 mm in length with 100 mm gaps, whilst those along the lower edge were 25 mm long at 500 mm centres. Welding was by the MMA process using 4 mm diameter basic coated, hydrogen controlled, general purpose welding rods.

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

2.1.5 Instrumentation

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

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

Provision was also made for monitoring the vertical deflections of the assemblies throughout the test. These measurements were made at the geometric centre of the upper surface using a displacement transducer connected to the TNO data logging facility. The deflection values recorded are included in the appropriate Data Sheets in Appendix 1.

2.1.6 Assembly

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

2.1.7 Failure Criteria

The performance of both test assemblies was judged against the load bearing capacity criterion outlined in Section 5 of BS 476:Part 21:1987. The maximum allowable deflection and the maximum allowable rate of deflection for the test assemblies, as specified by the standard, were calculated from 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 both cases heating of the test assembly continued beyond the time at which 'failure' was deemed to have occurred and the load removed from the beam. This was done in order to enable further data concerning the heating rates of the various members of the assembly to be recorded.

2.2 Loaded Test Assemblies

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

2.2.1 Test No. TNO B-89-724A

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

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

- Density 2409 kg/m^3
- Moisture Content 3.8% w/w
- Compressive Strength 42.2 N/mm^2

The thermocouple positions in the steelwork were as shown in Fig. 3, (longitudinal arrangement), and Fig. 4, (transverse arrangement). A load of 13 907 kg was applied to the steel section by means of two hydraulic rams positioned along the centre line of the web and at points corresponding to $^1/_4$ and $^3/_4$ of the supported span. Each ram acted on a load spreader so that the actual points of application of the load to the beam corresponded to $^1/_8$, $^3/_8$, $^5/_8$ and $^7/_8$ of the supported span. The load spreaders were formed from 1.5 metre long pieces of HE200A column section with a weight of 44 kg/m. The general arrangement of the components is shown in Figs. 5-7 which should be viewed in conjunction with the schedule of components given in Table 1.

The maximum allowable rate of deflection was calculated to be 8.62 mm/min based on the actual section depth of 261 mm. In the test this rate was exceeded after 13 minutes. A mid-span deflection of 160 mm was attained after 16 minutes at which time the rate of deflection was 41 mm/min. The load was removed from the beam after 16.5 minutes. Heating of the unloaded assembly continued up to 60 minutes in order to obtain additional thermal data.

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

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

2.2.2 Test No. TNO B-89-724B

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

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

- Density — 2424 kg/m^3
- Moisture Content — 5.6% w/w
- Compressive Strength — 48.8 N/mm^2

The floor was constructed using the sixteen pre-cast slabs which were arranged, eight on each side of the beam, so that they spanned the width of the furnace, resting loosely on the furnace walls and steel angles. The slabs over-lapped onto the angles and walls by distances of 75 mm and 104 mm respectively. They were butted up close to each other, any irregularities at the joints being accommodated within a 12 mm thick compressed ceramic fibre blanket seal. The cavity formed between the ends of the slabs and the web of the steel section was filled with fine dry sand which also covered the top 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 it was not classed as a composite structure. The general arrangement of the components is shown in Figs. 9-11 which should be viewed in conjunction with the schedule of components given in Table 2.

The thermocouple positions in the steelwork were as shown in Fig. 12, (longitudinal arrangement), and Fig. 13, (transverse arrangement). A load of 14 552 kg was applied to the test assembly by means of two hydraulic rams positioned along the centre line of the web and at points corresponding to $^1/_4$ and $^3/_4$ of the supported span. In the test it was required to apply load ONLY to the concrete floor slabs and at a distance of 500 mm on either side of the steel section. In order to achieve this each ram acted on an H-frame which in turn acted on four load spreaders, (see Fig. 14). The H-frames weighed 166 kg each. The eight load spreaders were formed from 1.0 metre long pieces of HE200A column section weighing 44 kg each.

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

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

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

3. CONCLUSIONS

1. Data arising from two standard fire resistance tests carried out at the Technical Centre for Fire Prevention, TNO, Rijswijk, Holland have been collected and reported. The tests were performed on a simply supported floor beam with a concrete topping slab cast in-situ onto the upper flange and a shelf angle floor beam supporting pre-cast concrete floor units. The steel section was 254 x 146 mm x 43 kg/m UB in both cases. Details of the test assemblies are given, together with summaries of the material properties, structural calculations and the thermal data recorded.

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

(a) Simply Supported Beam

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

(b) Shelf Angle Floor Beam

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

(*) Calculated using actual applied loads and section properties

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EJF

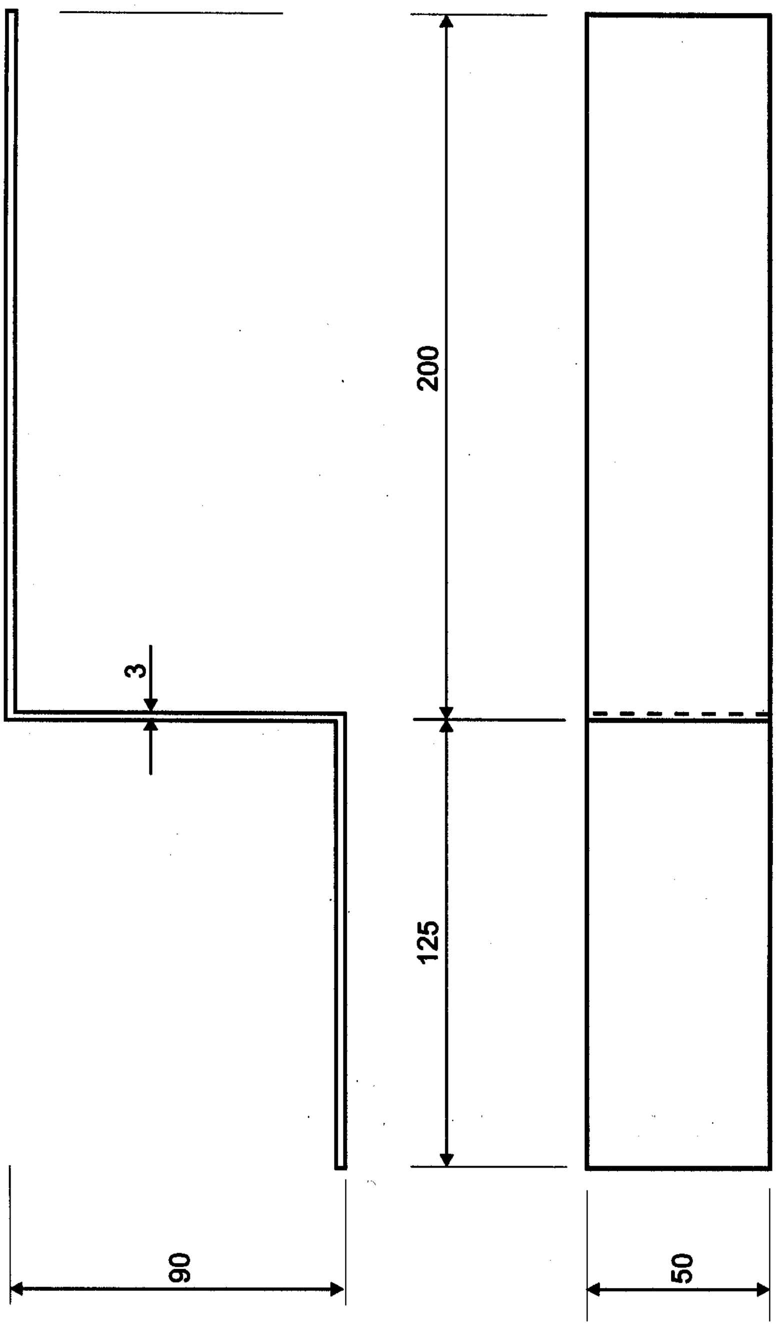
TABLE 1
SCHEDULE OF COMPONENTS FOR TEST NO. TNO B-89-724A
(Refer to Figs. 5-7)

Item No.	Description
1	Universal Beam Section (Serial Size 254 x 146 mm x 43 kg/m)
2	Steel Roller, 40 mm dia. x 150 mm
3	Steel Plate, 200 x 150 x 20 mm
4	Concrete Topping Slab (Width 800 mm, Depth 130 mm)
5	Steel Loading Beam, (Load Spreader) (HE200A Section, 44 kg/m)
6	Steel Roller, 30 mm dia. x 200 mm
7	Steel Plate, 200 x 150 x 20 mm
8	Concrete Furnace Topping (Cover Slabs)
9	Steel Bar, 30 mm square x 200 mm
10	Steel Bar, 40 mm square x 150 mm

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

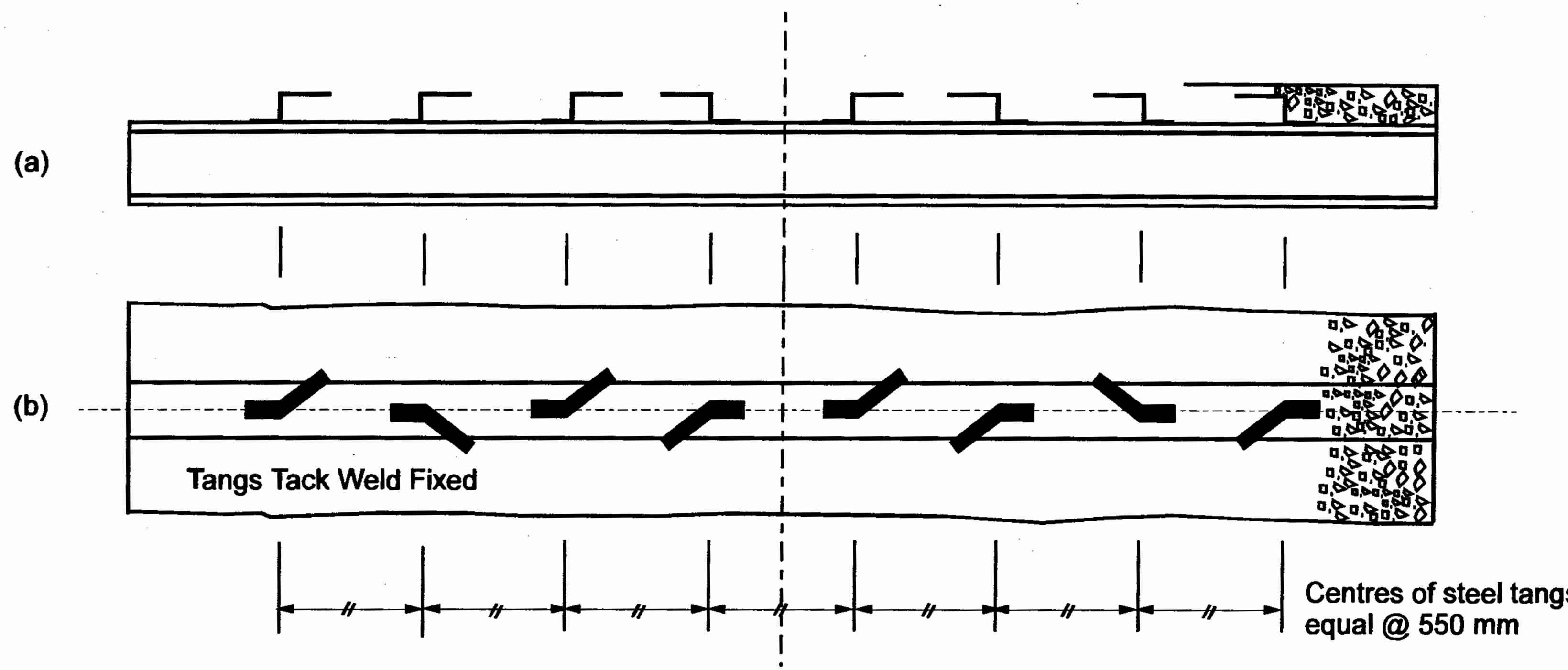
Item No.	Description
1	Universal Beam Section (Serial Size 254 x 146 mm x 43 kg/m with two angles 125 x 75 x 12 mm)
2	Steel Roller, 40 mm dia. x 150 mm
3	Steel Plate, 200 x 150 x 20 mm
4	Pre-cast Concrete Floor Slabs (2050 x 550 x 150 mm)
5	Steel Loading Beam, (Load Spreader) (HE200A Section, 44 kg/m)
6	Steel Plate, 200 x 150 x 20 mm
7	Dish Wheel Support, 80 mm dia.
8	Steel Loading System (H-shape Frame, Weight 166 kg)
9	Fine Dry Sand - Approx. 70 kg/m
10	Rockwool 750, Thickness 50 mm

(D0992C06)



(All Dimensions in mm)

FIG. 1 DIMENSIONAL DETAILS FOR THE MILD STEEL TANGS



(a) Side elevation showing fixing direction of mild steel tangs

(b) Plan showing the tangs splayed out in alternate directions

FIG. 2 PREPARATION OF THE TEST BEAM
TEST NO. B-89-724A (D0992C06)

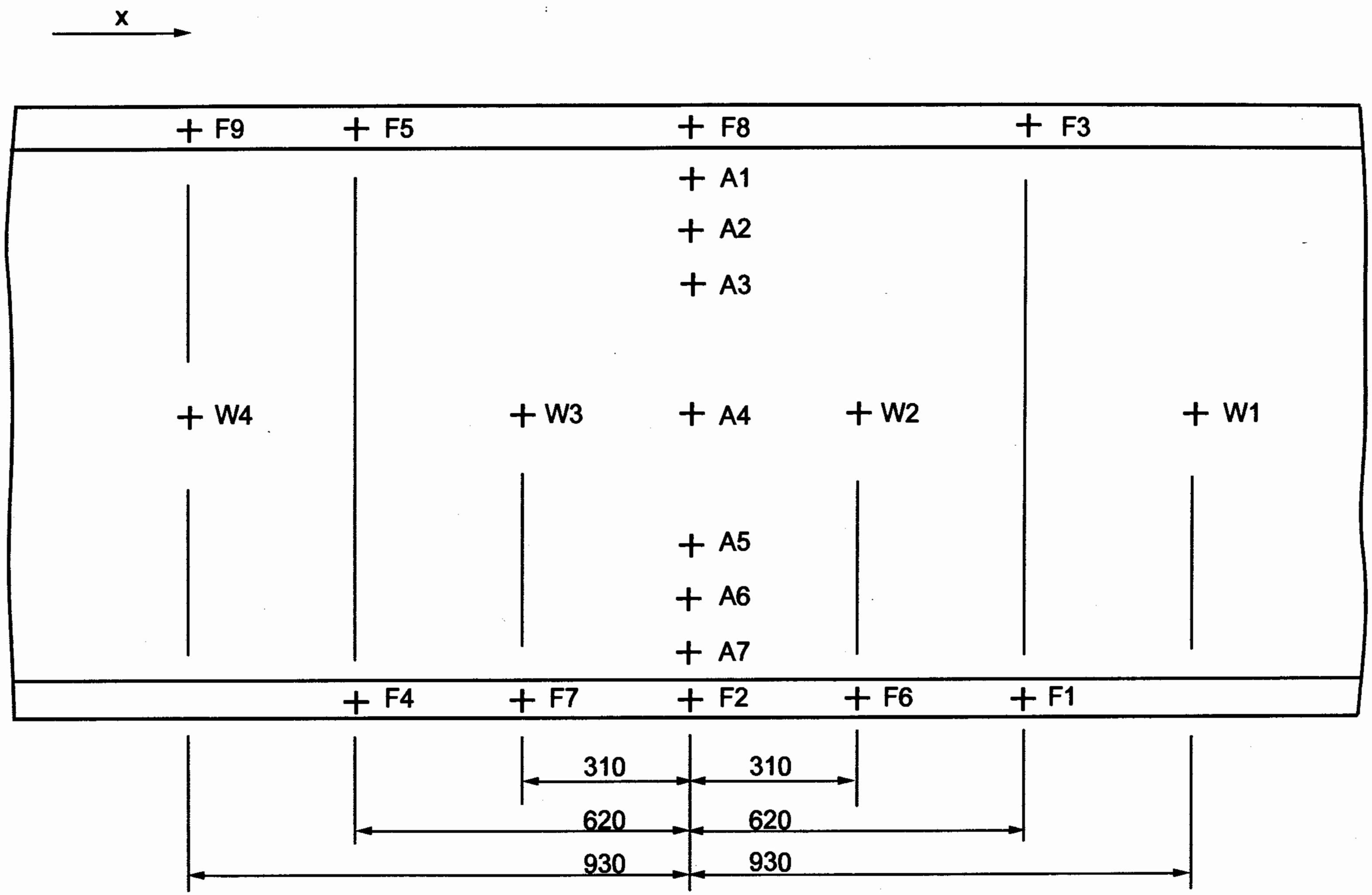
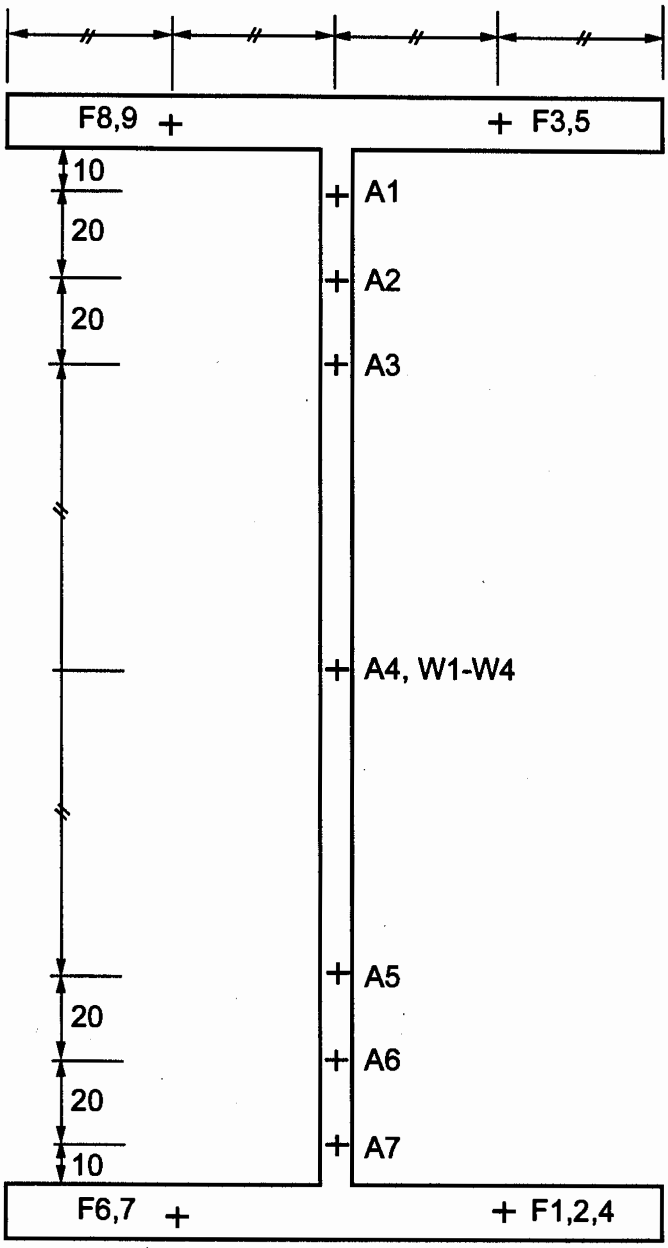


FIG. 3 THERMOCOUPLE POSITIONS IN THE STEELWORK - LONGITUDINAL ARRANGEMENT TEST NO. B-89-724A (D0992C06)



(All Dimensions in mm)

FIG. 4 **THERMOCOUPLE POSITIONS IN THE STEELWORK TEST NO. B-89-724A TRANSVERSE ARRANGEMENT IN DIRECTION OF ARROW 'x' in FIG. 3** (D0992C07)

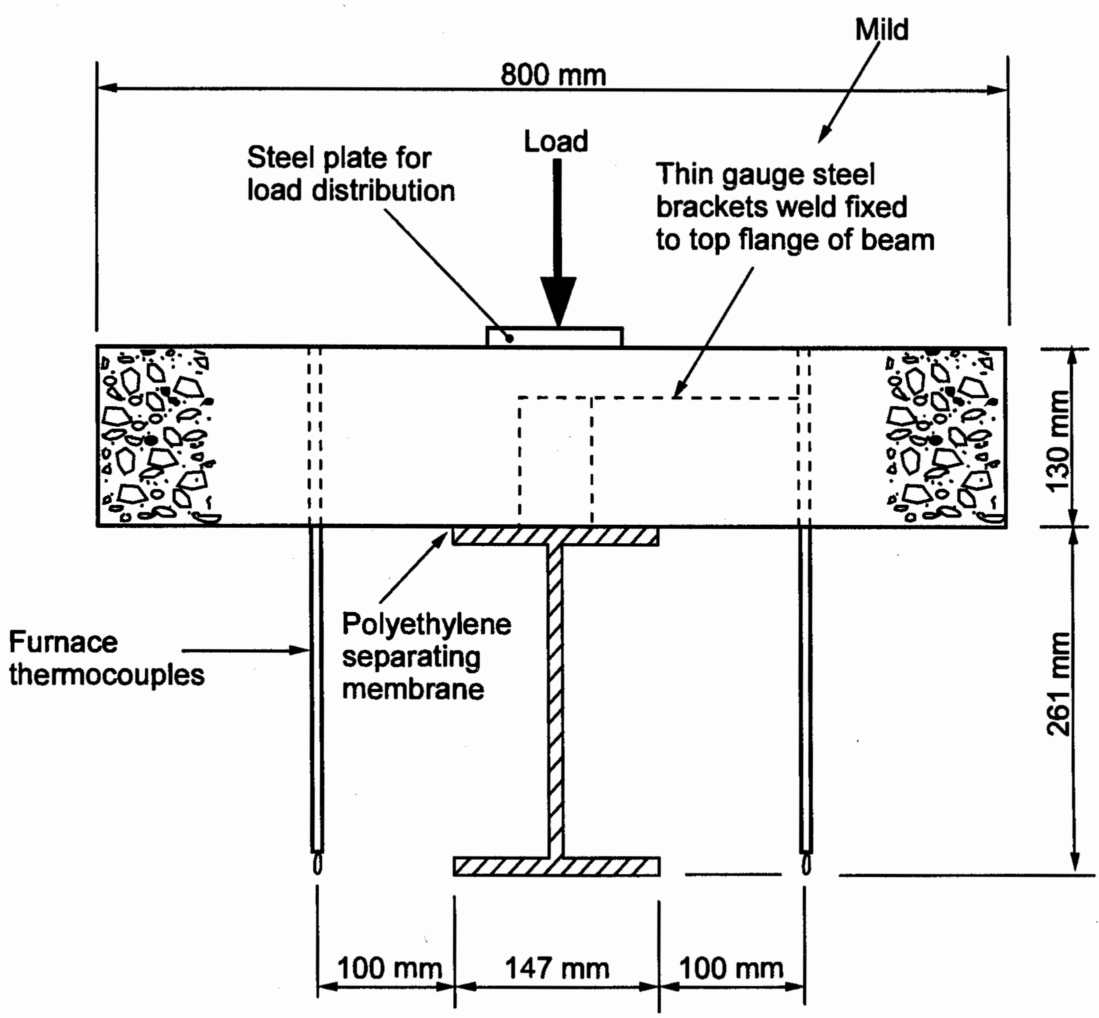
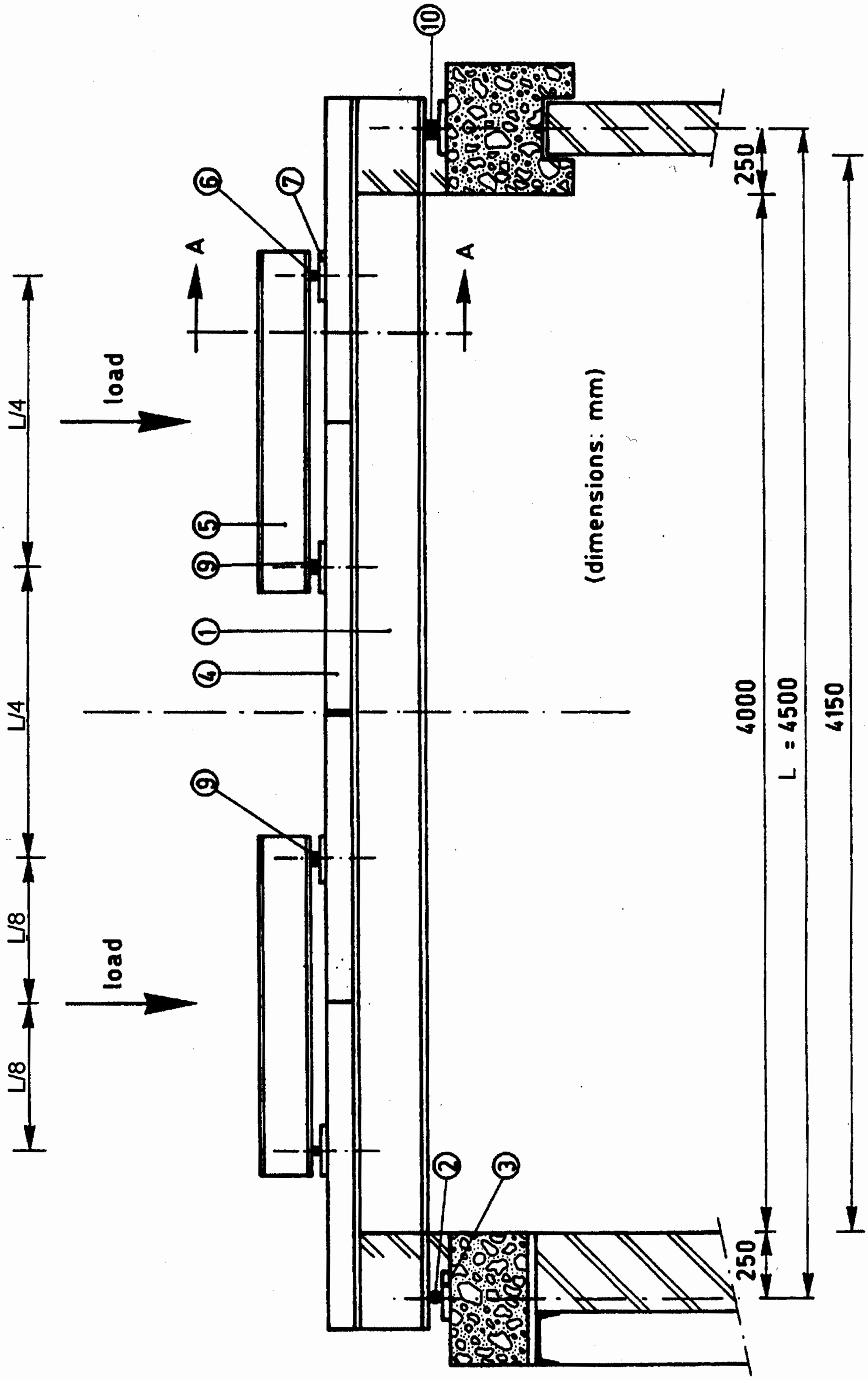


FIG. 5 TYPICAL VERTICAL CROSS SECTION (D0992C07)
TEST NO. B-89-724A



(D0992C08)

FIG. 6 SCHEMATIC ARRANGEMENT OF COMPONENTS, (LONGITUDINAL)
TEST NO. B-89-724A

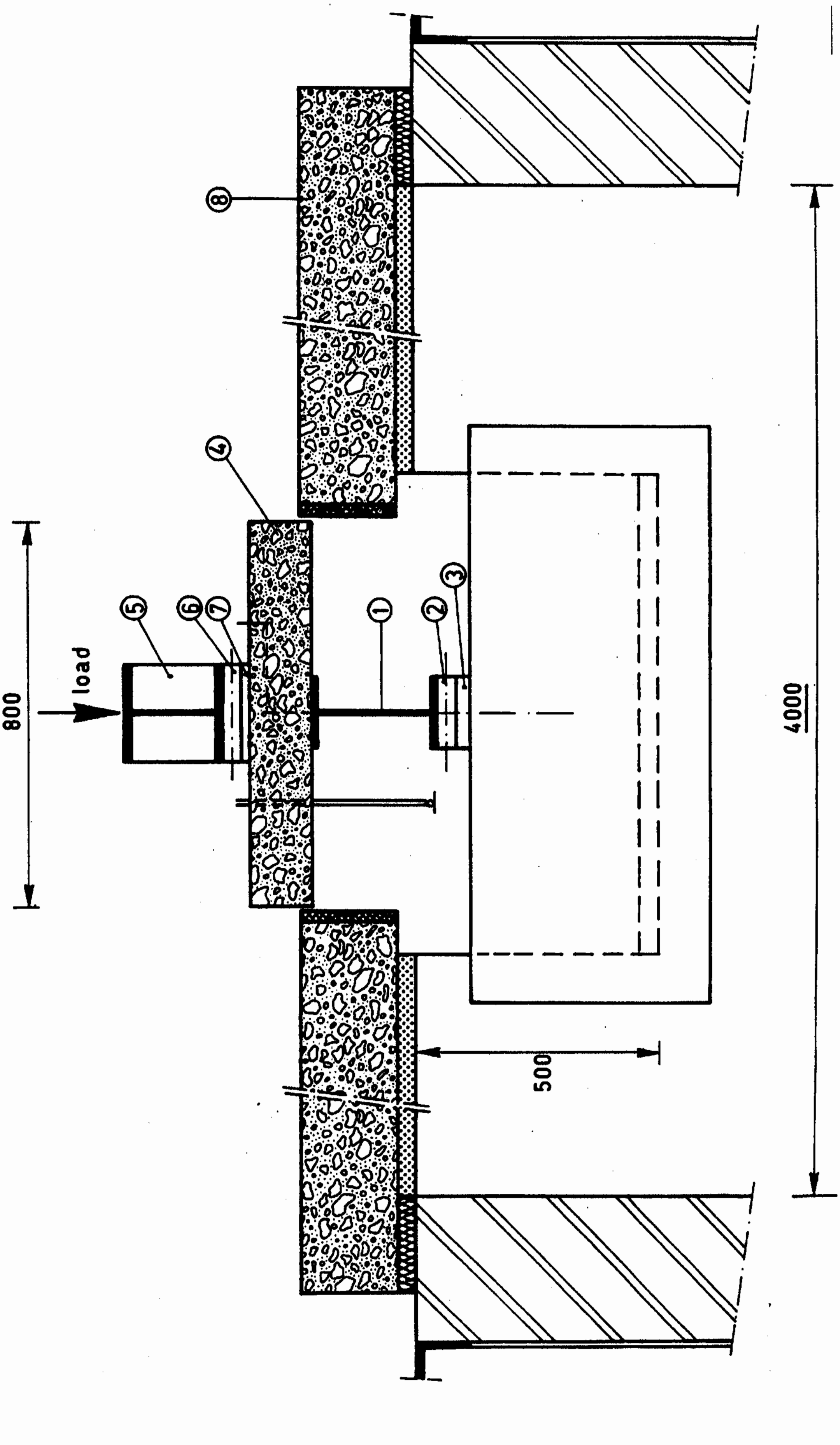
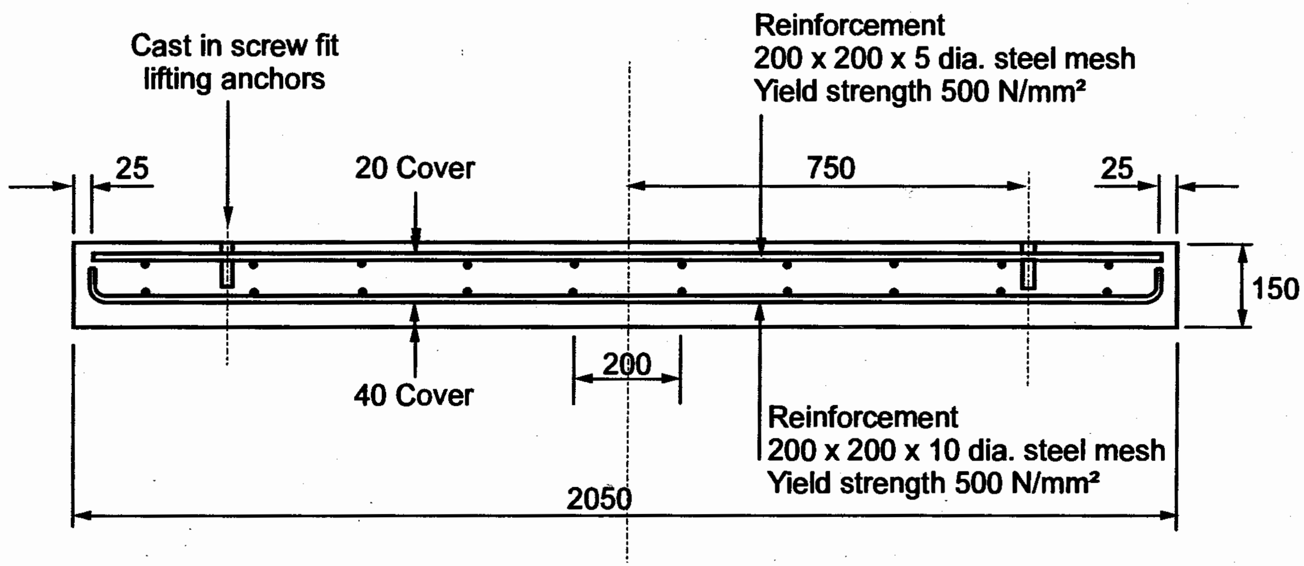
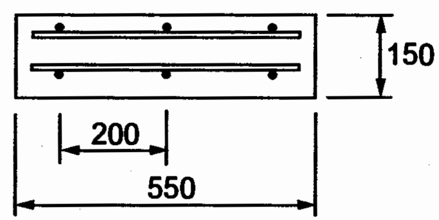


FIG. 7 SCHEMATIC ARRANGEMENT OF COMPONENTS - VERTICAL CROSS SECTION ON A-A (FIG. 6)
TEST NO. B-89-724A

(D0992C09)

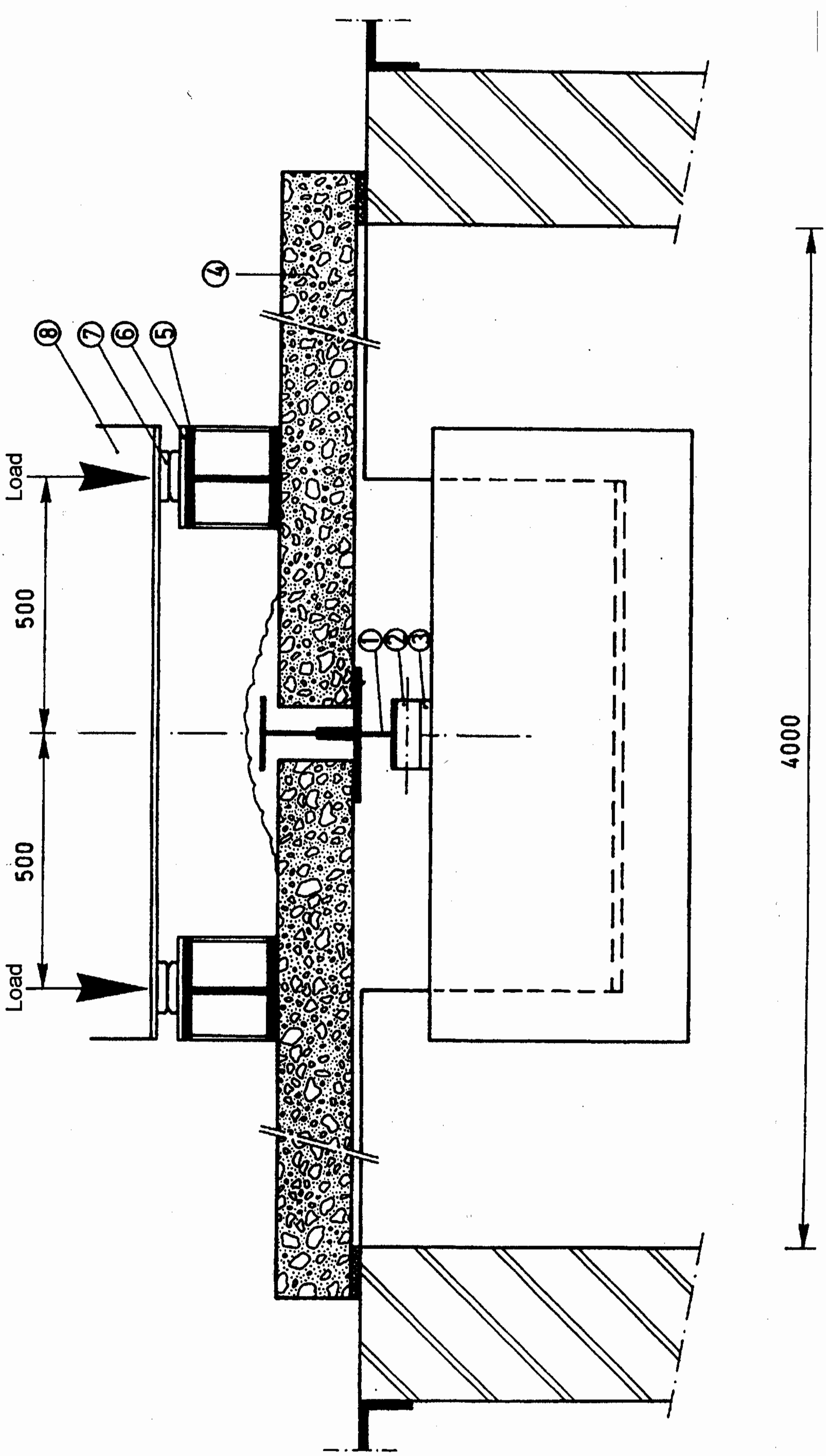


(a) Longitudinal Section (D0992C06)



(b) Transverse Section (D0992C06)

FIG. 8 DESIGN DETAILS OF THE REINFORCED CONCRETE FLOOR UNITS FOR USE WITH THE SHELF ANGLE FLOOR BEAM TEST NO. B-89-724B (D0992C06)



(D0992C10)

SCHEMATIC ARRANGEMENT OF COMPONENTS, (TRANSVERSE SECTION)
TEST NO. B-89-724B

FIG. 9

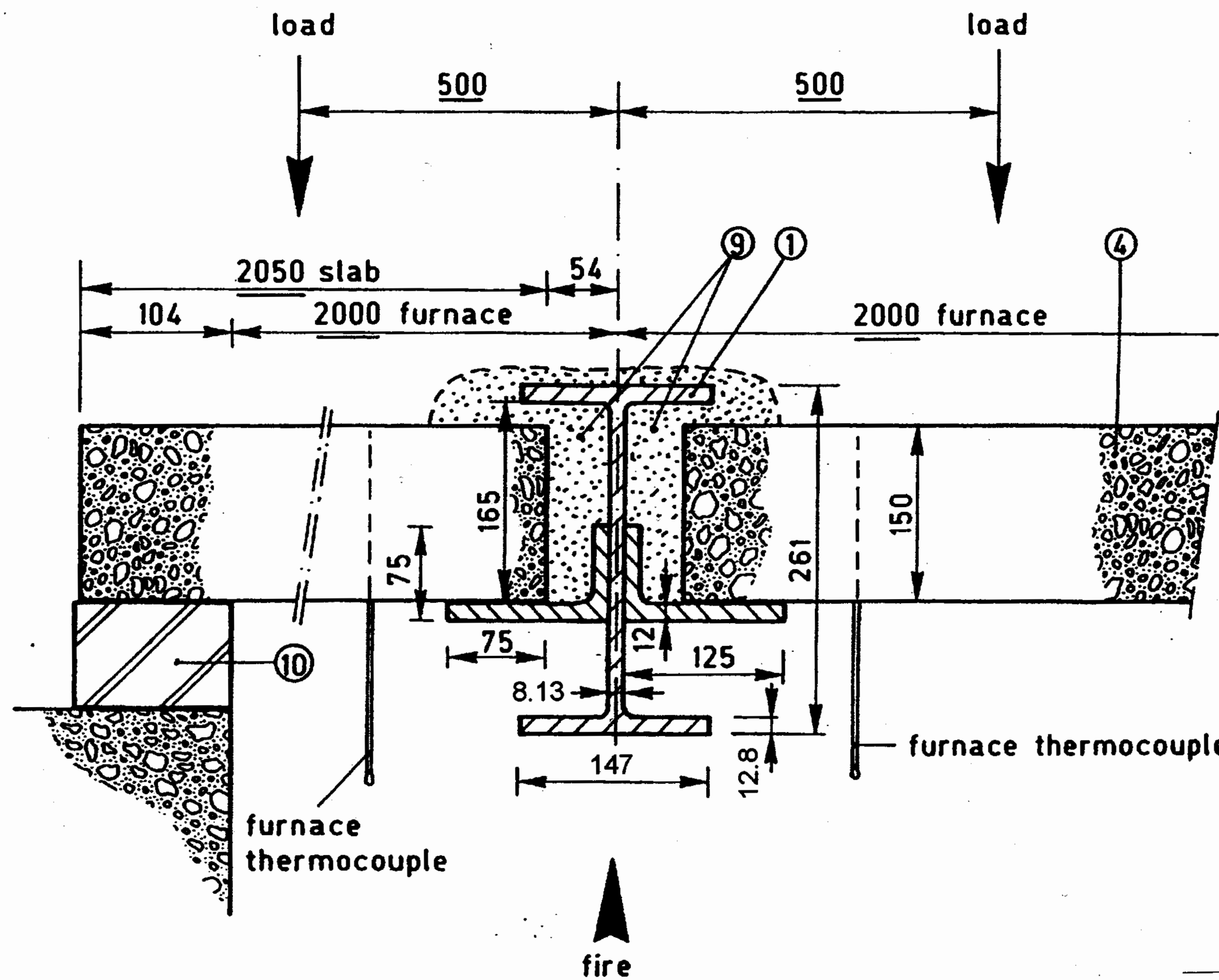


FIG. 10

SECTION THROUGH BEAM AND SLABS
TEST NO. B-89-724B
(BASED ON ACTUAL DIMENSIONS, mm)

(D0992C11)

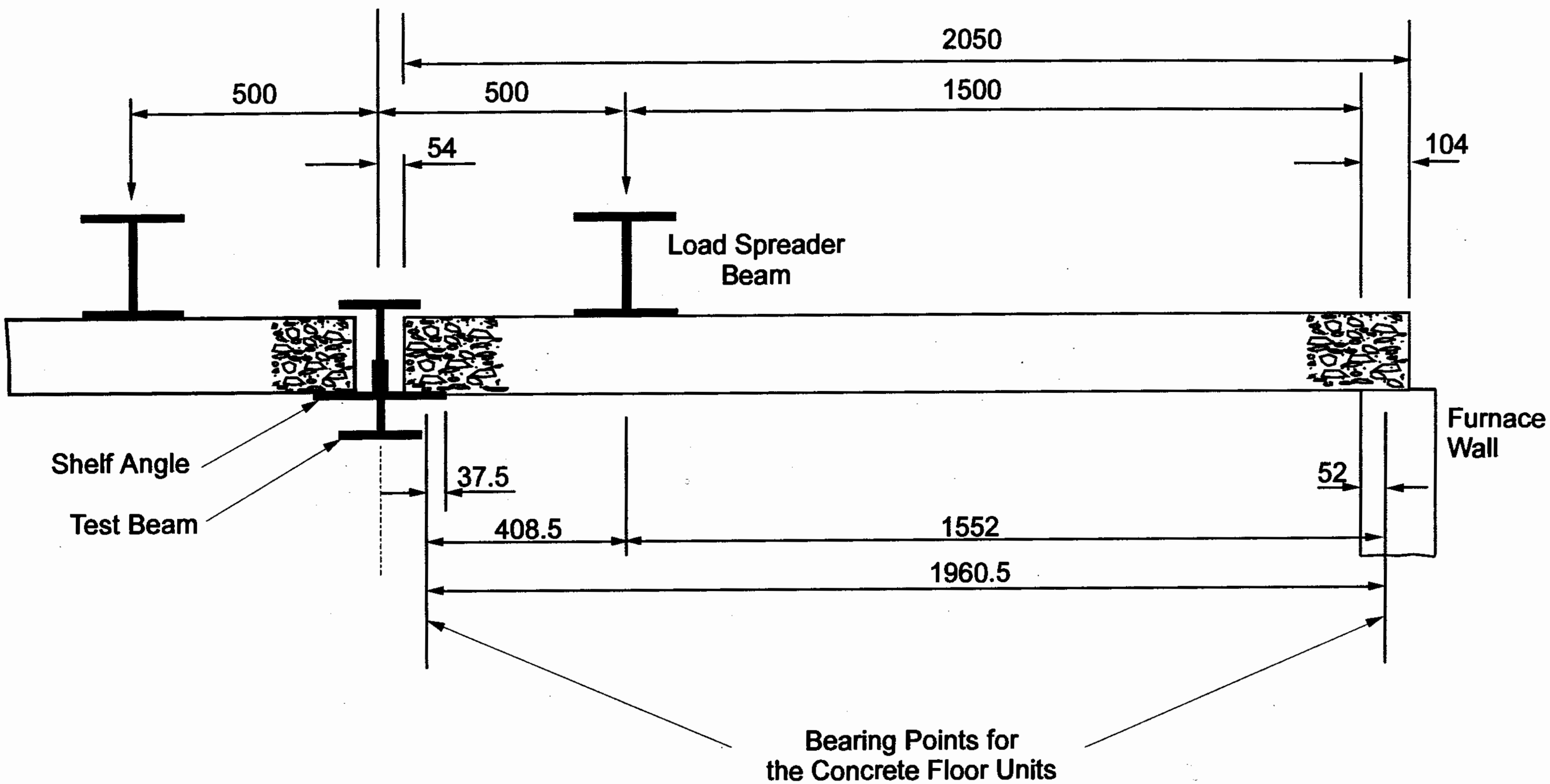


FIG. 11 DESIGN DETAILS FOR LOADING THE SHELF ANGLE FLOOR BEAM ASSEMBLY
TEST NO. B-89-724B (D0992C06)

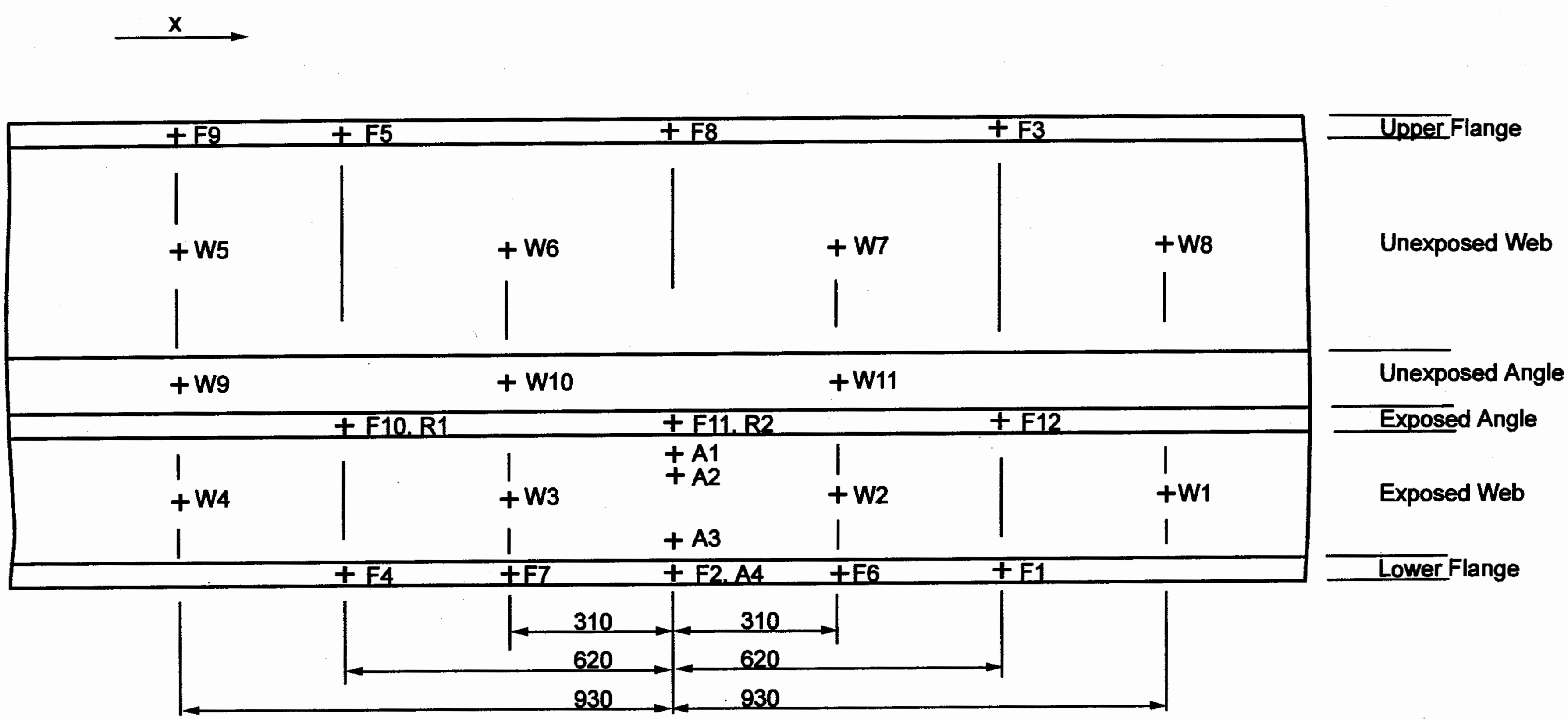
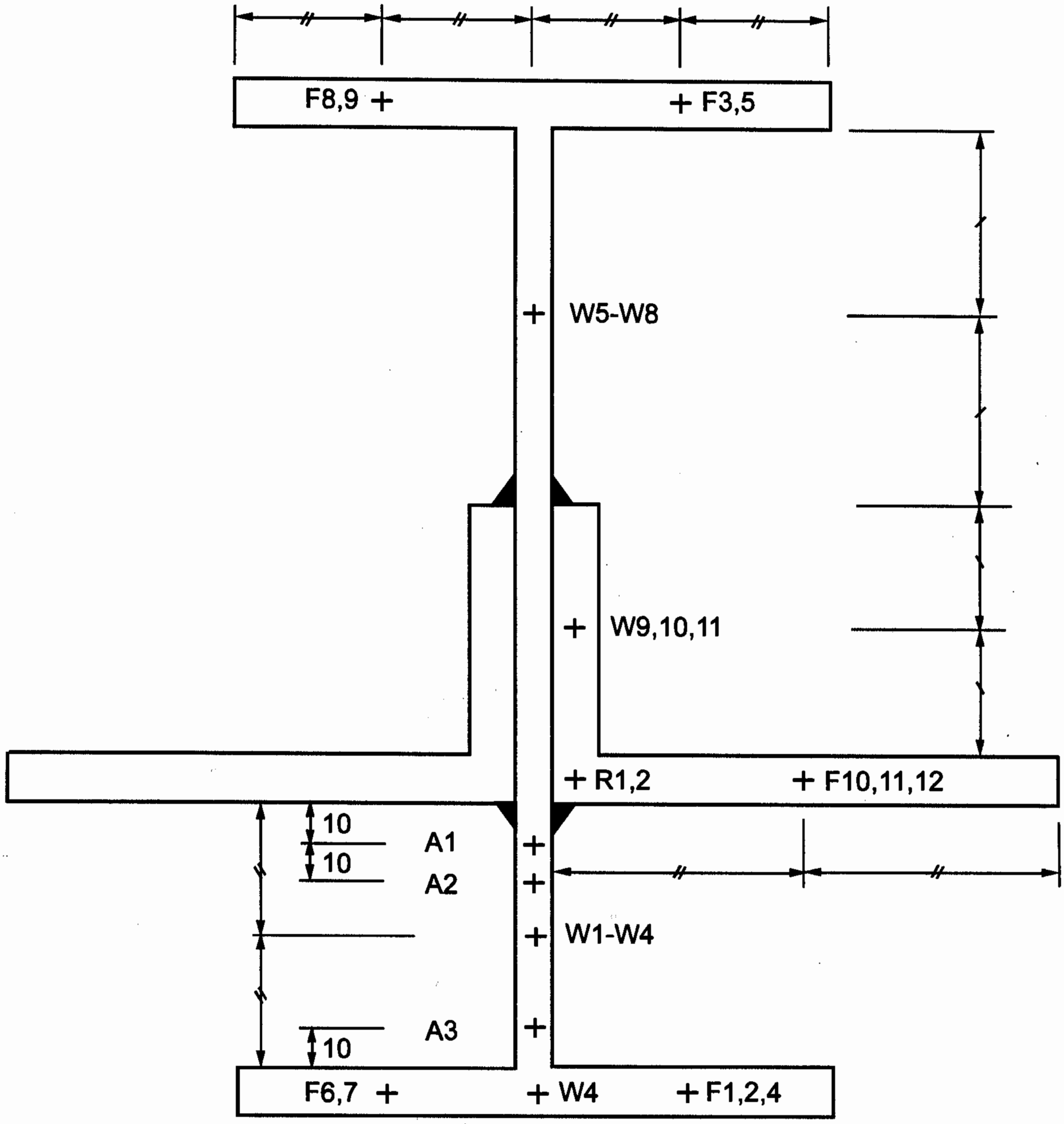


FIG. 12 THERMOCOUPLE POSITIONS IN THE STEELWORK - LONGITUDINAL ARRANGEMENT
TEST NO. B-89-724B (D0992C06)



(All Dimensions in mm)

FIG. 13 THERMOCOUPLE POSITIONS IN THE STEELWORK (D0992C07)
TEST NO. B-89-724B
TRANSVERSE ARRANGEMENT IN DIRECTION OF
ARROW 'x' IN FIG. 12

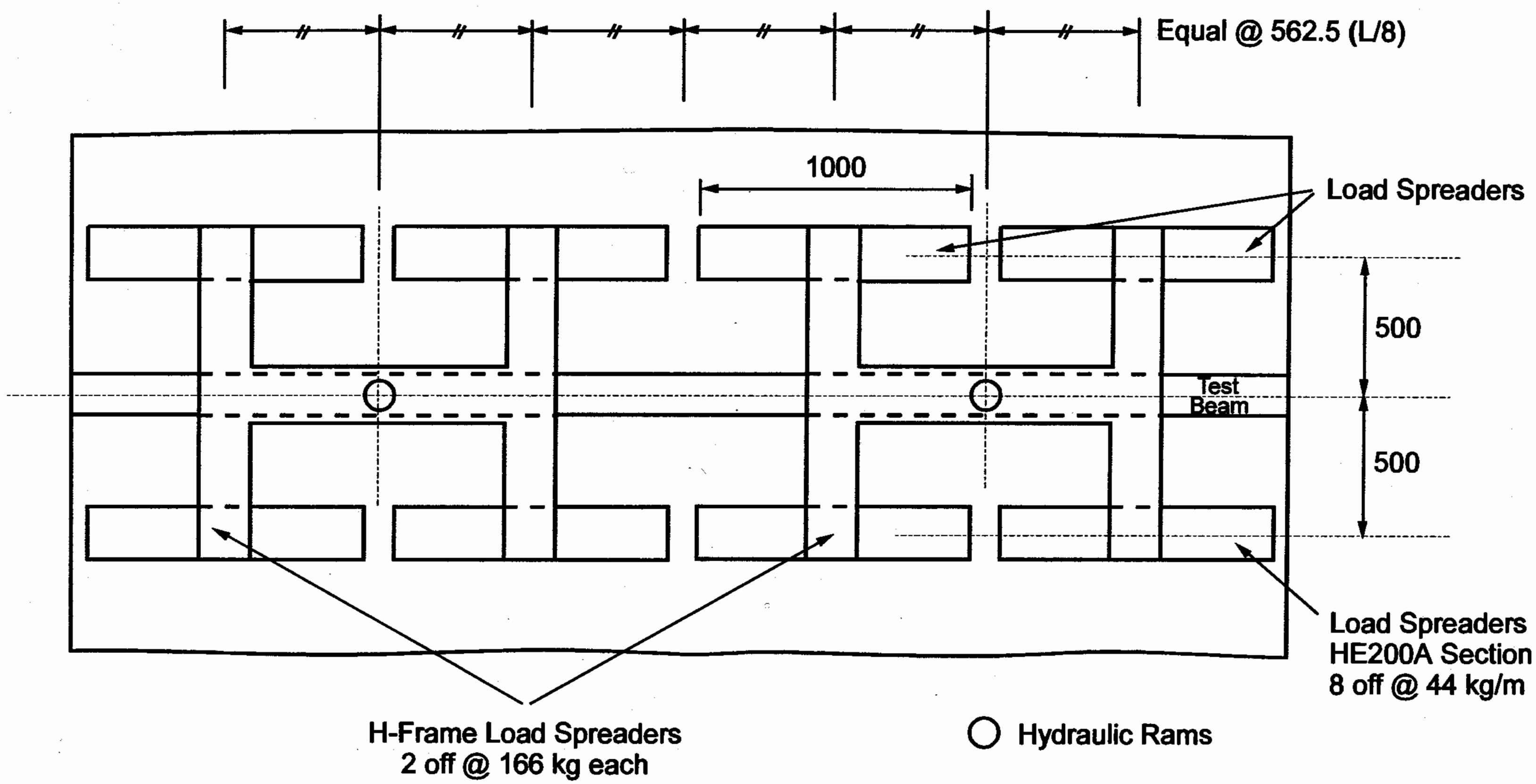


FIG. 14 **SCHEMATIC ARRANGEMENT OF COMPONENTS FOR LOADING THE SHELF ANGLE FLOOR BEAM TEST NO. B-89-724B** (D0992C06)

APPENDIX 1

DATA SHEET NOS. 131/132

DATA SHEET NUMBER	131A

SIMPLY SUPPORTED 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 45	259.6 261.0	147.3 147.0	7.3 8.13	12.7 12.8	505.3 517.3	92.0 92.4	568.2 585.4	141.2 142.5	6558 6751	677 678.9

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	1.23	0.015	0.015	0.02	0.006	0.03	<0.005	0.04	<0.005	<0.005	0.0059

ROOM TEMPERATURE TENSILE PROPERTIES

Position	LYS (N/mm^2)	UTS (N/mm^2)	Elongation (%)
Beam	294	452	34.0

NOTES

(a) Initial ambient temperature = 24°C.

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

TEST CONDITIONS

TEST CENTRE	: IBBC-TNO, Delft
TEST DATE	: 5th October 1989
TEST NUMBER	: B-89-724A

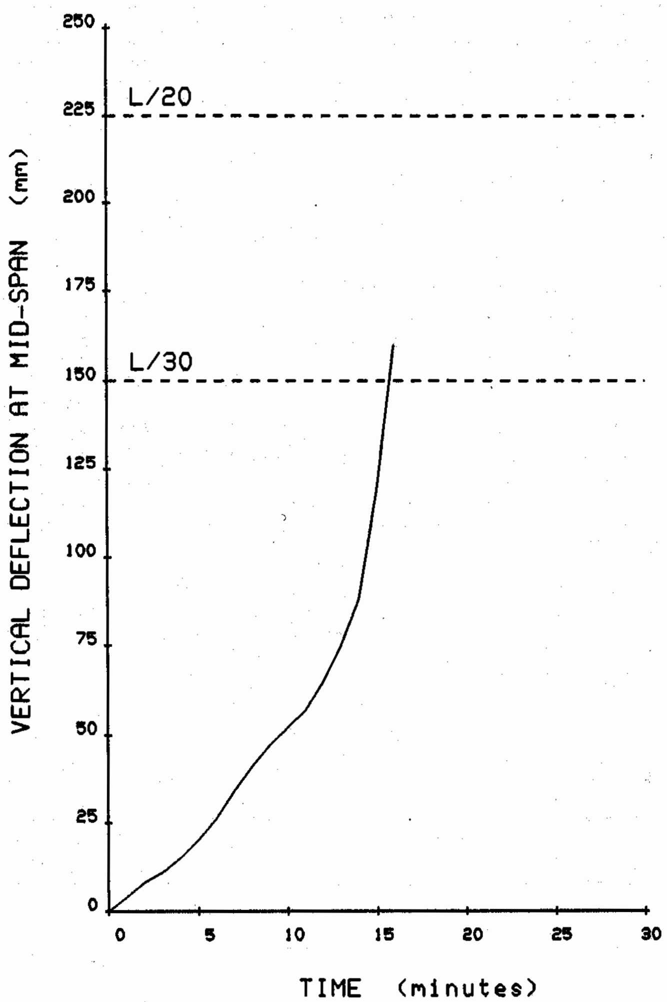
BS 476:PARTS 20 & 21: 1987
RESULTS

Time to L/30	: 15 minutes
Time to $L^2/9000$ D	: 13 minutes
Time to L/20	: Not attained
Reload Test	: Not carried out
Load Bearing Capacity	: 15 minutes
Fire Resistance	: 15 minutes

DATA SHEET NUMBER **131B**

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																
		3	6	9	12	15	16	18	21	24	27	30	35	40	45	50	55	60
<u>Upper Flange</u>	F3	90	151	213	280	355	385	420	472	515	546	586	657	710	750	792	832	865
	F5	94	159	228	301	376	407	466	545	579	616	664	713	740	766	798	834	881
	F8	107	162	221	287	353	374	418	483	537	585	624	673	710	743	770	806	839
	F9	95	161	239	315	389	426	493	561	609	645	675	722	754	794	830	863	897
	Mean	97	158	225	296	368	398	449	515	560	598	637	691	729	763	798	834	871
<u>Exposed Web</u>																		
10 mm Below UF	A1	135	208	281	356	424	445	488	548	595	639	673	719	754	787	813	844	875
30 mm Below UF	A2	175	265	351	432	502	524	563	616	655	692	720	763	795	825	849	876	902
50 mm Below UF	A3	175	281	382	471	543	565	602	651	686	717	742	786	814	841	866	890	914
Mid-Height	A4	194	322	440	539	610	629	661	702	728	752	779	815	838	863	885	906	928
	W1	176	316	450	551	624	646	682	721	747	775	800	836	861	884	907	928	946
	W2	186	326	452	550	621	642	678	718	742	770	796	831	855	879	902	922	942
	W3	189	327	451	554	627	647	682	719	742	770	793	827	850	874	896	917	938
	W4	204	350	486	590	663	683	720	753	787	809	828	861	879	902	922	942	962
	Mean	190	328	456	557	629	649	685	723	749	775	799	834	857	880	902	923	943
50 mm Above LF	A5	165	287	403	503	580	601	637	678	705	726	749	782	805	829	849	868	888
30 mm Above LF	A6	143	258	372	475	557	581	619	662	693	714	738	774	800	824	845	864	884
10 mm Above LF	A7	123	235	350	454	538	562	599	644	677	702	721	759	789	812	833	852	873
<u>Lower Flange</u>	F1	157	291	433	549	631	655	694	730	764	794	818	855	879	902	923	942	960
	F2	143	252	368	475	559	579	611	657	693	722	741	782	813	837	857	879	902
	F4	185	329	471	589	673	699	731	773	806	831	852	882	898	919	938	956	975
	F6	159	291	427	538	621	645	686	726	751	781	806	842	869	892	915	933	952
	F7	145	271	402	517	604	626	662	703	729	756	782	819	843	868	890	909	931
	Mean	158	287	420	534	618	641	677	718	749	777	800	836	860	884	905	924	944
Mean Furnace Gas	(a)	484	596	658	711	748	755	778	796	816	830	848	869	885	905	922	939	958
Standard Curve	(b)	502	603	663	705	739	748	766	789	809	826	842	865	885	902	918	932	945
Deflection (mm)		11	26	47	65	119	160	-	-	-	-	-	-	-	-	-	-	-
Deflection Rate (mm/min)		3	6	6	8	31	41	-	-	-	-	-	-	-	-	-	-	-

DATA SHEET NUMBER	131C



DATA SHEET NUMBER	132A

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 45	259.6 261.0	147.3 147.0	7.3 8.13	12.7 12.8	505.3 517.3	92.0 92.4	568.2 585.4	141.2 142.5	6558 6751	677 678.9
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	0.11	0.24	1.23	0.015	0.015	0.02	0.006	0.03	<0.005	0.04	<0.005	<0.005	0.0059
Angle	Grade 50D	0.12	0.30	1.34	0.018	0.011	0.03	<0.005	0.02	0.06	0.02	<0.005	0.030	0.0051

ROOM TEMPERATURE TENSILE PROPERTIES

Position	LYS (N/mm^2)	UTS (N/mm^2)	Elongation (%)
Beam	294	452	34.0
Angle	371	520	33.0

TEST CONDITIONS

NOTES

(a) Initial ambient temperature = 27°C.

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

TEST CENTRE	: IBBC-TNO, Delft
TEST DATE	: 18th October 1989
TEST NUMBER	: B-89-724B

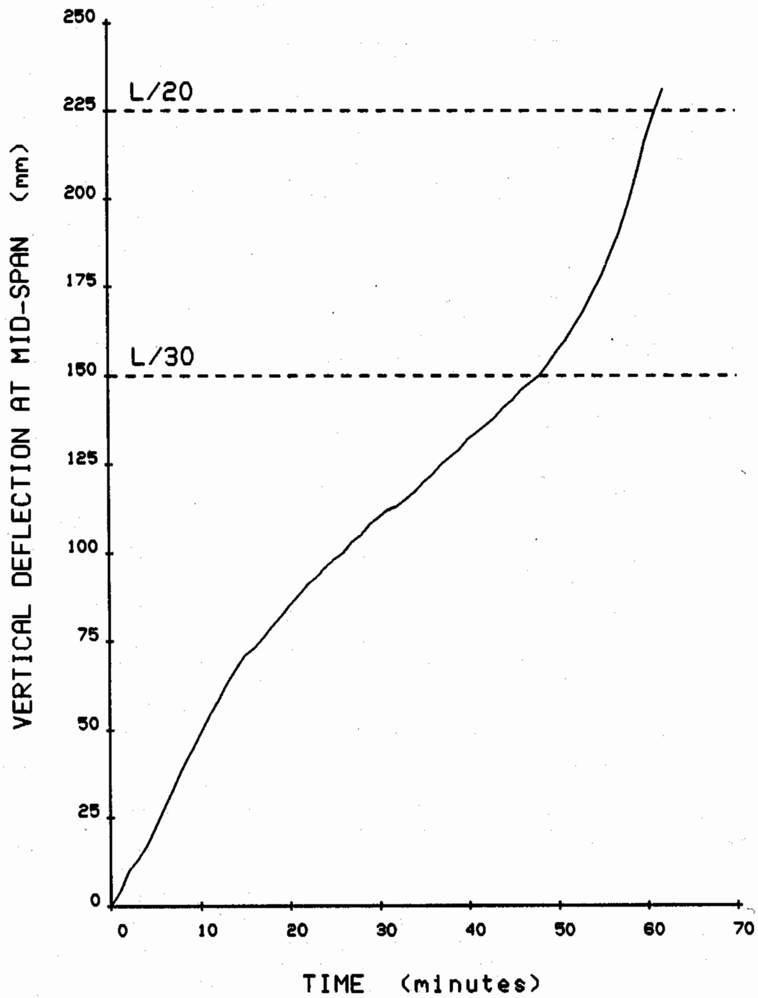
BS 476:PARTS 20 & 21: 1987 RESULTS

Time to L/30	: 48 minutes
Time to L^2/9000 D	: 59 minutes
Time to L/20	: 61 minutes
Reload Test	: Not carried out
Load Bearing Capacity	: 59 minutes
Fire Resistance	: 59 minutes

DATA SHEET NUMBER **132B**

THERMOCOUPLE LOCATION		TEMPERATURE Deg. C AFTER VARIOUS TIMES (MINUTES)																
		3	6	9	12	15	18	21	24	27	30	40	48	55	61	70	80	90
Upper Flange	F3	24	25	25	27	29	33	42	54	65	82	104	120	133	146	168	190	210
	F5	23	23	23	25	29	37	57	69	72	77	98	114	129	141	162	183	204
	F8	24	24	25	27	30	33	38	43	50	61	103	112	122	134	169	204	239
	F9	22	22	23	24	27	31	36	43	51	60	104	125	143	157	176	199	222
	Mean	23	24	24	26	29	34	43	52	60	70	102	118	132	145	169	194	219
Unexposed Web	W5	23	27	36	49	65	83	103	126	147	167	225	262	290	312	343	376	406
	W6	25	29	36	48	62	79	98	120	139	157	204	236	265	286	320	354	385
	W7	26	30	38	49	64	80	99	122	143	161	216	251	279	302	334	368	398
	W8	25	28	36	47	61	77	95	114	135	154	210	245	272	292	324	356	385
	Mean	25	29	37	48	63	80	99	121	141	160	214	249	277	298	330	364	394
Exposed Web	W1	123	202	299	385	467	523	579	625	655	683	770	822	862	889	938	970	996
	W2	131	220	311	395	465	518	571	615	646	674	759	810	850	876	924	957	985
	W3	120	198	288	369	451	508	564	609	638	668	751	803	843	869	916	957	987
	W4	170	246	331	416	490	536	591	632	664	692	778	828	864	890	938	974	1002
	Mean	136	217	307	391	468	521	576	620	651	679	765	816	855	881	929	965	993
Web Profile																		
10 mm Below Angle	A1	101	159	219	282	339	390	441	488	527	562	661	720	764	788	829	871	907
20 mm Below Angle	A2	123	189	256	325	387	438	491	538	575	608	701	757	799	820	859	898	930
10 mm Above LF	A3	123	196	272	348	415	469	523	569	604	636	722	778	817	837	875	911	941
LF/Web Junction	A4	119	205	296	380	454	511	565	610	643	673	750	803	839	856	889	923	951
Lower Flange	F1	164	268	385	488	573	624	675	712	732	759	834	878	909	933	977	1002	1024
	F2	150	248	349	438	513	567	617	658	687	712	785	828	862	871	905	935	962
	F4	166	281	407	511	598	654	705	738	768	797	871	907	937	955	996	1022	1044
	F6	150	265	384	486	565	616	666	705	725	750	826	868	900	920	963	989	1013
	F7	149	249	366	463	553	607	659	698	718	745	817	858	888	906	946	983	1008
	Mean	156	262	378	477	560	614	664	702	726	753	827	868	899	917	957	986	1010
Angle																		
Unexposed Flange	W9	36	61	97	142	191	238	282	325	363	398	500	563	609	644	694	744	789
	W10	34	54	83	122	165	209	253	293	329	360	449	517	570	609	659	710	755
	W11	38	60	94	136	183	229	273	316	356	391	488	552	599	634	681	729	771
	Mean	36	58	91	133	180	225	269	311	349	383	479	544	593	629	678	728	772
Exposed Flange	F10	83	135	201	270	336	388	440	484	523	573	697	767	825	868	926	966	994
	F11	76	125	179	233	280	324	375	425	469	510	625	693	737	763	808	862	903
	F12	97	158	234	303	374	423	482	533	575	612	713	776	831	874	933	967	994
	Mean	85	139	205	269	330	378	432	481	522	565	678	745	798	835	889	932	964
Root	R1	47	78	123	178	239	293	348	397	440	484	604	673	723	764	827	880	919
	R2	50	80	121	167	216	262	309	356	400	440	552	620	669	700	739	790	833
	Mean	49	79	122	173	228	278	329	377	420	462	578	647	696	732	783	835	876
Mean Furnace Gas	(a)	504	598	663	705	744	763	800	821	835	854	903	926	948	951	979	1004	1019
Standard Curve	(b)	502	603	663	705	739	766	789	809	826	842	885	912	932	948	968	988	1006
Deflection (mm)		13	28	44	58	71	79	88	96	103	110	132	150	178	225	-	-	-
Deflection Rate (mm/min)		3	6	5	4	4	3	3	3	3	2	3	2	5	7	-	-	-

DATA SHEET NUMBER	132C



APPENDIX 2

LOAD CALCULATION SUMMARY SHEETS

A2.1 TEST NO. TNO-B-89-724A ON 5 OCTOBER 1989

A2.1.1 Geometry

Figure 6 gives the relevant details

A2.1.2 Material Properties

(a) Steel

Universal Beam - 254 x 146 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	261.0
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	8.13
Area of Section	A	(mm^2)	5510	5727
Mass	m	(kg/m)	43	45
Weight	m	(N/m)	422	441
Distance of Neutral Axis from Base of Beam	y	(mm)	129.8	130.5
Effective Span of Beam	L	(mm)	4500	4500
Moment of Inertia (x-x)	I	(cm^4)	6558	6751
Elastic Modulus (x-x)	Z	(cm^3)	505.3	517.3
Plastic Modulus (x-x)	S	(cm^3)	568.2	585.4
Modulus of Elasticity	E	(kN/mm^2)	205	205
Design Strength	p_y	(N/mm^2)	275	294
Classification	Class 1, Plastic (Table 7, BS 5950)			

(c) Concrete

The mean moisture content of the concrete, measured on the day of the test, was found to be 3.8% w/w. The mean compressive strength of the concrete was reported to be 42.2 N/mm^2, (Range 39.9 to 43.8 N/mm^2), and its mean density was reported to be 2409 kg/m^3, (Range 2405 to 2414 kg/m^3).

(d) Summary of Nominal and Actual Dimensions and Properties

			Nominal	Actual
Depth	d	(mm)	130	130
Width	w	(mm)	800	800
Area of Section	A_c	(mm^2)	104 000	104 000
Mass	m_c	(kg/m)	239.2	250.5
Weight	m_c	(N/m)	2347	2457
Density	D_c	(kg/m^3)	2300	2409

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

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

A2.2.1 Initial Calculations Using Nominal Dimensions and Properties

Maximum allowable bending stress, Table 2, (for steel with a minimum yield stress of 275 N/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 2347 N (based on an assumed density of 2300 kg/m^3).

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

$$w_1 = 422 + 2347 \text{ N/m}$$

$$= \underline{2769 \text{ N/m}}$$

Total load to produce required bending stress

$$w_2 = 32\ 934 - 2769 \text{ N/m}$$

$$= \underline{30\ 165 \text{ N/m}}$$

Therefore total imposed load

$$W = 30\ 165 \times 4.5 \text{ N}$$

$$= 135\ 743 \text{ N}$$

$$= \underline{135.74 \text{ kN}} \qquad \text{(i.e. 13 837 kg)}$$

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:-

$$P = 135.74 / 4 \text{ kN} \qquad \text{(i.e. 13 837 / 4 kg)}$$

$$= \underline{33.935 \text{ kN}} \qquad \text{(i.e. 3459 kg)}$$

Referring to Fig. 6

Loads per hydraulic ram are:-

$$P_{(h)} = (13\ 837 / 2) - \text{load spreader kg}$$

$$= 6918.5 - 66 \text{ kg}$$

$$= \underline{6852.5 \text{ kg}}$$

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

A2.2.2 Retrospective Calculations Using Actual Dimensions and Properties

The required bending moment is given by (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

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

$$= \frac{8 \times f \times 6751 \times 10^7}{130.5 \times 4500 \times 4500} \text{ N/m} \qquad \text{... (A2/1)}$$

The loads actually applied were:-

- by hydraulic rams 2 x 6953.4 kg
- by load spreaders 2 x 66 kg

Total load applied

$$W = 13\,906.8 + 132 \text{ kg}$$

$$= 14\,038.8 \text{ kg}$$

$$= \underline{137\,721 \text{ N}}$$

and therefore the total load generating the bending stress is

$$w_2 = 137\,721 / 4.5 \text{ N/m}$$

$$= \underline{30\,605 \text{ N/m}}$$

The concrete load per metre run is 2457 N (based on the actual density of 2409 kg/m^3).

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

$$w_1 = 441 + 2457 \text{ N/m}$$

$$= \underline{2898 \text{ N/m}}$$

Therefore the load available to generate a bending moment is

$$w = 30\,605 + 2898 \text{ N/m}$$

$$= \underline{33\,503 \text{ N/m}}$$

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

$$33\,503 = \frac{8 \times f \times 6751 \times 10^7}{130.5 \times 4500 \times 4500} \text{ N/mm}^2$$

$$\therefore \quad f = \frac{33\,503 \times 130.5 \times 4500 \times 4500}{8 \times 6751 \times 10^7}$$

$$= \underline{163.93 \text{ N/mm}^2}$$

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

A2.3 CALCULATIONS BASED ON BS 5950:PART 1:1985

In the following calculations any contribution made by the 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 2769 N/m

So $w_1 = \underline{2.769 \text{ kN/m}}$

Moment produced by dead load is given by:

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

$$= \frac{2.769 \times 4.5 \times 4.5}{8} \text{ kN m}$$

$$= \underline{7.009 \text{ kN m}}$$

From A2.2.1, Total Imposed Load is 135 743 N.

So $W = \underline{135.743 \text{ kN}}$

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

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

$$= \frac{135.743 \times 4.5}{8} \text{ kN m}$$

$$= \underline{76.355 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 7.009 + 76.355 \text{ kN m}$$

$$= \underline{83.364 \text{ kN m}}$$

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

$$LR = M_f / M_c$$

$$= 83.364 / 156.3$$

$$= \underline{0.533}$$

(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 $A_v = h \times s$

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

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

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

A2.3.2 Retrospective Calculations Using Actual Dimensions and Properties

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

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

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

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

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

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

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

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 2898 N/m.

So w_1 = 2.898 kN/m

Moment produced by dead load is given by:

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

$$= \frac{2.898 \times 4.5 \times 4.5}{8} \text{ kN m}$$

$$= \underline{7.336 \text{ kN m}}$$

From A2.2.2 Total imposed load is 137 721 N.

So W = 137.721 kN

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

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

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

$$= \underline{77.468 \text{ kN m}}$$

Total Moment Applied, (dead + imposed loads)

$$M_x = 7.336 + 77.468 \text{ kN m}$$

$$= \underline{84.804 \text{ kN m}}$$

and therefore the load ratio given by:

$$LR = M_f / M_c$$

$$= 84.804 / 172.1$$

$$= \underline{0.493}$$

A2.4 COMPARISON OF LOADINGS

A2.4.1 BS 449:Part 2:1969

Based on nominal dimensions and section properties it was calculated that in order to develop the maximum permissible bending stress of 165 N/mm^2 in the lower flange of the steel section an imposed load of 13.84 tonnes was required. However, during the test the actual load applied was 13.91 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicate that the bending stress in the lower flange was 163.93 N/mm^2, or 99.35% 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 13.84 tonnes the load ratio for the test assembly was found to be 0.53. When the actual load value was used in conjunction with the actual section properties data the load ratio value was 0.493. The actual design strength of the steel section was 294 N/mm^2, i.e. 6.9% higher than the nominal value of 275 N/mm^2.

APPENDIX 3

LOAD CALCULATION SUMMARY SHEETS

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

A3.1.1 Geometry

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

A3.1.2 Material Properties

(a) Steel

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

(b) Summary of Nominal and Actual Dimensions and Properties

		Nominal	Actual
Depth of Section	h (mm)	259.6	261.0
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	8.13
Area of Section	A (mm^2)	5510	5727
Mass	m (kg/m)	43	45
Weight	m (N/m)	422	441
Distance of Neutral Axis from Base of Beam	y (mm)	129.8	130.5
Effective Span of Beam	L (mm)	4500	4500
Moment of Inertia (x-x)	I (cm^4)	6558	6751
Elastic Modulus (x-x)	Z (cm^3)	505.3	517.3
Plastic Modulus (x-x)	S (cm^3)	568.2	585.4
Modulus of Elasticity	E (kN/mm^2)	205	205
Design Strength	p_y (N/mm^2)	275	294
Classification	Class 1, Plastic (Table 7, BS 5950)		

(c) Concrete

The mean moisture content of the concrete, measured on the day of the test, was found to be 5.6% w/w. The mean compressive strength of the concrete was reported to be 48.8 N/mm^2, (Range 42.5 to 52.1 N/mm^2), and its mean density was reported to be 2424 kg/m^3, (Range 2389 to 2449 kg/m^3).

(d) Summary of Nominal and Actual Dimensions and Properties

		Nominal	Actual
Depth	d (mm)	150	150
Width	w (mm)	2050	2050
Area of Section	A_c (mm^2)	307 500	307 500
Mass	m_c (kg/m)	707.25	745.38
Weight	m_c (N/m)	6938	7312
Density	D_c (kg/m^3)	2300	2424

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 Initial Calculations Using Nominal Dimensions and Properties

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

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

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

Therefore, bending stress required is 165 N/mm²

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

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

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

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

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

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

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

And therefore W, the operating load, is given by:

$$W = 32\,934 \times 4.5 \text{ N}$$

$$= \underline{148\,203 \text{ N}}$$

Self Weight of Steel Beam = 422 N/m

Self Weight of Sand Filler = 70 kg/m (approx.)

= 687 N/m

Total Self Weight of Beam and Sand

w_1 = 4.5 x (422 + 687) N

= <u>4990 N</u>

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

= <u>61 054 N</u>

Self Weight of Steel Loading System (Refer to Fig. 14)

8 x 1 m long load spreaders @ 44 kg/m	=	352 kg
2 x H frames @ 166 kg each	=	332 kg
Total weight of loading system	=	684 kg
	=	<u>6710 N</u>

Total Self Weight of Concrete and Loading System

w_2 = 61 054 + 6710 N

= <u>67 764 N</u>

Reaction on the angles due to the concrete slabs and loading system

Reaction = w_2 / 2 N

= 67 764 / 2 N

= <u>33 882 N</u>

Imposed force required by the angles to produce the required bending stress in the test beam

w_3 = $W - w_1 - (w_2 / 2)$ N

= 148 203 - 4990 - 33 882 N

= <u>109 331 N</u>

Therefore total load required to be applied by the hydraulic rams to the load spreaders located 500 mm on either side of the test beam.

w_4 = 109 331 x (1960.5 / 1552) N

= <u>138 108 N</u>

And so the load per hydraulic ram

$$P_{(h)} = 138\,108 / 2 \text{ N}$$

$$= 69\,054 \text{ N}$$

$$= \underline{7039 \text{ kg}}$$

The load actually applied was 7276 kg per ram.

A3.2.2 Retrospective Calculations Using Actual Dimensions and Properties

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

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

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

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

$$= \frac{8 \times f \times 6751 \times 10^7}{130.5 \times 4500 \times 4500} \text{ N/m} \qquad \text{... (A3.1)}$$

Self Weight of Steel Beam = 441 N/m

Self Weight of Sand Filler = 70 kg/m (approx.)

= 687 N/m

Total Self Weight of Beam and Sand

$$w_1 = 4.5 \times (441 + 687) \text{ N}$$

$$= \underline{5076 \text{ N}}$$

Self Weight of Concrete Slabs = 16 x 0.55 x 7312 N

= <u>64 346 N</u>

Self Weight of Steel Loading System

= <u>6710 N</u> (unchanged)

Total Self Weight of Concrete and Loading System

$$w_2 = 64\,346 + 6710 \text{ N}$$

$$= \underline{71\,056 \text{ N}}$$

Reaction on the angles due to the concrete slabs and loading system

	Reaction	=	w_2 / 2 N
		=	71 056 / 2 N
		=	<u>35 528 N</u>

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

So	$P_{(h)}$	=	7276 kg

Hence the total applied load

	w_4	=	7276 x 2 kg
		=	14 552 kg
		=	<u>142 755 N</u>
But	w_4	=	w_3 x (1960.5 / 1552) N
Therefore	w_3	=	w_4 x (1552 / 1960.5) N
		=	142 755 x (1552 / 1960.5) N
		=	<u>113 010 N</u>
And	w_3	=	W - w_1 - (w_2 / 2) N
Therefore	W	=	w_3 + w_1 + (w_2 / 2) N
		=	113 010 + 5076 + 35 528 N
		=	<u>153 614 N</u>

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

	w	=	153 614 / 4.5 N/m
		=	<u>34 136 N/m</u>

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

$$34\,136 = \frac{8 \times f \times 6751 \times 10^7}{130.5 \times 4500 \times 4500} \ \text{N/mm}^2$$

Therefore

$$f = \frac{34\,136 \times 130.5 \times 4500 \times 4500}{8 \times 6751 \times 10^7} \ \text{N/mm}^2$$

$$= \underline{167.0 \ \text{N/mm}^2}$$

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

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

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

A3.3.1 Initial Calculations Using Nominal Dimensions and Properties

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

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

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

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

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 A3.2.1

Total Self Weight of Beam and Sand Filler

$$w_1 = 4990 \text{ N}$$

Moment produced by this load is given by:

$$\text{Moment}_1 = (w_1 L) / 8 \text{ N m}$$

$$= (4990 \times 4.5) / 8 \text{ N m}$$

$$= \underline{2807 \text{ N m}}$$

Total Self Weight of Concrete Slabs and Load Spreaders

$$w_2 = 67\,764 \text{ N}$$

Reaction on the angles

$$w_2 / 2 = 33\,882 \text{ N}$$

Moment produced by this reaction is given by:

$$Moment_2 = 0.5 \times (w_2 L) / 8 \text{ N m}$$

$$= (0.5 \times 67\,764 \times 4.5) / 8 \text{ N m}$$

$$= \underline{19\,059 \text{ N m}}$$

Total hydraulic force imposed on the test beam through the angles

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

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

$$= \underline{109\,331 \text{ N}}$$

Moment produced by this force is given by:

$$Moment_3 = (w_3 L) / 8 \text{ N m}$$

$$= (109\,331 \times 4.5) / 8 \text{ N m}$$

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

Total moments applied to the test beam

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

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

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

$$LR = M_f / M_c$$

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

$$= \underline{0.533}$$

(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.

A3.3.2 Retrospective Calculations Using Actual Dimensions and Properties

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

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

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

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

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

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

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

So p_y S is less than 1.2 p_y Z.

(b) From A3.2.2

Total Self Weight of Beam and Sand Filler

$$w_1 = 5076\ \text{N}$$

Moment produced by this load is given by:

$$\text{Moment}_1 = (w_1\ L) / 8\ \text{N m}$$

$$= (5076 \times 4.5) / 8\ \text{N m}$$

$$= \underline{2855\ \text{N m}}$$

Total Self Weight of Concrete Slabs and Load Spreaders

$$w_2 = 71\ 056\ \text{N}$$

Reaction on the angles

$$w_2 / 2 = 35\ 528 \text{ N}$$

Moment produced by this reaction is given by:

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

$$= (0.5 \times 71\ 056 \times 4.5) / 8 \text{ N m}$$

$$= \underline{19\ 985 \text{ N m}}$$

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

So $P_{(h)}$ = 7276 kg

and therefore the total load applied was:

$$w_4 = 142\ 755 \text{ N}$$

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

$$w_3 = 113\ 010 \text{ N}$$

Moment produced by this force

$$\text{Moment}_3 = (w_3 L) / 8 \text{ N m}$$

$$= (113\ 010 \times 4.5) / 8 \text{ N m}$$

$$= \underline{63\ 568 \text{ N m}}$$

Total moments applied to the test beam

$$M_x = 2855 + 19\ 985 + 63\ 568 \text{ N m}$$

$$= \underline{86\ 408 \text{ N m}}$$

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

$$LR = M_f / M_c$$

$$= (86\ 408 \times 10^{-3}) / 172.1$$

$$= \underline{0.502}$$

A3.4 COMPARISON OF LOADINGS

A3.4.1 BS 449:Part 2:1969

Based on nominal dimensions and section properties it was calculated that in order to develop the maximum permissible bending stress of 165 N/mm^2 in the lower flange of the steel section an imposed load of 14.08 tonnes was required. However, in the test the load actually applied was 14.55 tonnes. Retrospective calculations using this load in conjunction with the actual section properties data indicate that the bending stress in the lower flange was 167.0 N/mm^2 or 101.2% of the maximum permitted value.

A3.4.2 BS 5950:Part 1:1985

Based on nominal values and the application of the previously calculated imposed loading of 14.08 tonnes the load ratio for the test assembly was found to be 0.53. When the higher actual loading value was used in conjunction with the actual section properties data the load ratio value reduced to 0.502. The factor most effective in bringing about such a reduction is the design strength which at 294 N/mm^2 is approximately 6.9% higher than the nominal value of 275 N/mm^2. The actual imposed load was approximately 3.4% higher than that required.

APPENDIX 4

PC DISK VERSION OF DATA

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

The data are held on the disks in the form of ASCII text files. This format has been chosen since the majority of commercial software packages can import files of this type. The format allows the data to be referenced either via the screen, (or printer), or read directly by PC based software. The data are initially being made available on 3½ inch 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. 131.DAT and 132.DAT. This numbering system is consistent with that introduced in reference A4.1. Thus, for example, data from test number TNO-B-89-724A can be found in data file 131.DAT. For each individual fire test the thermal data have been sub-divided into 'SETS' which reflect the thermocouple positions in the steelwork, and other materials. Mean temperature values are also included in these data sub-sets where it is considered valid to do so. In order that the columns of data in any particular 'SET' can be related to the corresponding thermocouple positions a 'README' file is associated with each data file. By way of example, README.131, which relates to data in file 131.DAT, is shown in Fig. A4.1.

REFERENCE

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

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

There are 30 items of data which, together with their mean values, are grouped in sets as shown below.

Set Number	Items in Columns
SET001.DAT	TIME, F3, F5, F8, F9, MEAN
SET002.DAT	TIME, A1, A2, A3, / A4, W1, W2, W3, W4, MEAN (of 5) / A5, A6, A7
SET003.DAT	TIME, F1, F2, F4, F6, F7, MEAN
SET004.DAT	TIME, ISO, AT1, AT2, AT3, AT4, AT5, AT6, MEAN
SET005.DAT	TIME, DEFLECTION, DEFLECTION RATE