Swinden Laboratories

Report No:	SH/RS/3664/5/84/B
Date:	18 JUNE 1984
Classification:	RESTRICTED

The Fire Resistance of a Shelf Angle Floor Construction - A BS476:Part 8 Fire Test Carried Out on 30th November 1983

British Steel Corporation

Research Organisation

CONTENTS PAGE

1. INTRODUCTION 1
2. DETAILS OF CONSTRUCTION 2
3. TEST RESULTS 3
4. DISCUSSION 4
5. CONCLUSIONS 5
6. REFERENCES 6

APPENDICES

KEY WORDS

3. Fire Resistance
4. Concrete
5. Floorings
6. Deflection
7. Testing
8. Shelf Angles
9. +BS 476 Part 8
10. Lab Reports

18th June, 1984

THE FIRE RESISTANCE OF A SHELF ANGLE FLOOR CONSTRUCTION - A BS476:PART 8 FIRE TEST CARRIED OUT ON 30TH NOVEMBER 1983

SYNOPSIS

The report presents the results of a BS476:Part 8 fire test carried out on an unprotected BS4360:Grade 43A beam of serial size 305 x 165 mm x 40 kg/m which was used as part of a shelf angle floor construction. Precast concrete floor slabs 200 mm deep and 550 mm wide were supported on 125 x 75 x 12 mm angles bolted to the web of the beam. The construction was fully loaded during fire testing and the test was discontinued after 83 mins when the limiting deflection of the beam at its centre reached 150 mm. This performance was much better than could be expected from the steel section tested alone, and was influenced by both the partial fire protection of the beam provided by the concrete slabs and a degree of composite action between the various parts of the construction.

Preliminary work to predict mathematically the heating rate of the steel beam in a shelf angle floor construction shows some promise, but an improved knowledge of the boundary conditions between the different elements of the assembly is required to improve the accuracy of prediction of the temperature field in the protected area of the beam.

1. INTRODUCTION

When a fire breaks out in an enclosure the initial period of growth culminating in 'flashover' is followed by a rapid increase in the air temperature. In time, the temperature of any steel section within the enclosure will rise at a rate depending upon the ratio of its exposed perimeter (H_p) to its cross sectional area (A). Sections with high H_p/A ratios heat up much faster than those possessing low ratios. If, as a consequence of design the steel section is not fully exposed to the fire, then its H_p/A ratio is effectively reduced resulting in an increase in its fire resistance time. Steel members, such as perimeter columns or shelf angle floor beams fall into this category of partially protected elements.

A number of BS476:Part 8 fire tests have shown the advantages to be gained from this approach with regard to perimeter columns. The concept of partial protection can be extended to shelf angle floor systems which are used in the design of multi-store buildings to reduce the floor/ceiling void depth resulting in cost savings in the overall area of cladding and partitions required. One BS476:Part 8 fire test was carried out on an unprotected BS4360:Grade 43A beam of serial size 406 x 178 mm x 54 kg/m which was used as part of a fully loaded shelf angle floor construction[1]. The results suggested that the use of such a design might satisfy the requirements of the Building Regulations for '1 hour' buildings; however as this result applied only to a particular combination of beam size and concrete slab depth it was necessary to determine the behaviour of other similar floors.

The present report describes a second BS476:Part 8 fire test on a shelf angle floor construction, comprising a 305 x 165 mm x 40 kg/m BS4360:Grade 43A, 125 x 75 x 12 mm BS4360:Grade 50B angles and 200 mm thick precast concrete slabs. The section was fully loaded to a design stress of 165 N/mm² and fire tested at the Warrington Research Centre on 30th November 1983.

2. DETAILS OF CONSTRUCTION

2.1 Steel Supply

The steel sections used in the present construction were obtained from a local steel stockholder and comprised:-

5 m 305 x 165 mm x 40 kg/m universal beam, BS4360:Grade 43A

2 x 5 m 125 x 75 x 12 mm angles, BS4360:Grade 50B

Samples were taken from each of the sections for chemical analysis. The results are given in Table 1 and show that the chemical composition of the beam was well within the limits specified for BS4360:Grade 43A and the angles were within the compositional tolerances of BS4360:Grade 50B.

2.2 Fabrication of Sections

The angles were positioned on either side of the beam to leave a 210 mm gap between the upper flange of the beam and the 125 mm leg of the angle. The shorter leg of the angle was located within the 210 mm gap. Holes were drilled at 600 mm centres along the mid axis of the 75 mm angle leg to accommodate M20 8.8 grade bolts. In the earlier test M20 4.6 grade bolts had been used, two of which failed at one end of the test arrangement located outside the furnace. A schematic illustration showing the test assembly is given in Fig. 1.

2.3 Concrete Slabs

The concrete slabs were identical to those used in the earlier test[1] and were cast in July 1983 into 1550 x 550 x 200 mm blocks containing a steel reinforcement layout as shown in Fig. 2. The concrete blocks were subsequently stored indoors until the day of the test.

The results from compressive strength tests carried out on 152 mm cubes of the concrete mix at various stages of curing are given in Table 2 and show that the concrete was Grade 30.

2.4 Instrumentation

A total of 33 mineral insulated thermocouples of the chromel/alumel type, each with insulated hot junctions and an Inconel sheath were used to monitor the heating rate of the steel during the test. The thermocouples were located at the positions shown in Fig. 3; in summary 5 thermocouples were embedded in the lower flange of the beam, 4 thermocouples in the exposed part of the web, 4 were attached to the protected part of the web and 4 were attached to the upper flange of the beam. These thermocouples were located around the central part of the beam.

Ten thermocouples were embedded in the shelf angles, 3 on the exposed leg, 4 on the unexposed leg and 3 on the root of the angle.

An additional six thermocouples were located in the beam and angles approximately 100 mm away from the furnace wall in the upper and lower flange, exposed and unexposed web and in the exposed and unexposed legs of the angle.

Thermocouples were also installed after the construction was assembled to monitor furnace atmosphere temperatures at six positions along the beam adjacent to the lower flange.

2.5 Assembly

The beam with the angles attached was placed on the furance in the standard position to give an effective length of 4.5 m between the roller supports. Each slab was then manoevered into position between the shelf angle and the upper flange to utilise a 75 mm load bearing length on the shelf angle. This left a gap of 50 mm between the end of the slab and the web of the beam. The other end of the slab rested on a wall which was built along the edges of the furnace level with the shelf angle. A 12 mm gap was left between the slab and wall at the ends of the beam, thus enabling the slabs to move freely with the beam as it deflected vertically. Ceramic fibre blanket material was used to cover the gaps at both ends.

Once the 16 slabs were in position the 50 mm gap between the slab end and web was completely filled in with dried sand. The upper flange of the beam was also covered with a 25 mm layer of sand in order to simulate the thermal characteristics of a screed which is used in site practice.

Photographs of the construction during assembly are shown in Figs. 4 and 5.

2.6 Loading

The load to the beam was applied through the concrete slabs and angles to simulate service conditions. Four hydraulic jacks were positioned on either side of the beam at a distance of 0.5 m from its centreline. A total load of 18.8 t was applied to the eight points onto the concrete slabs using 1 m lengths of 152 x 152 mm x 23 kg/m universal column as load spreaders. Details of the loading calculations are given in Appendix 1. A photograph of the completed construction is shown in Fig. 6.

Deflection measurements were taken at the centre of the beam by the Warrington Research Centre staff using their potentiometric system. Additional measurements were also taken from the central concrete slab using a theodilite system.

The strains developed as a result of deformation were measured after the test at intervals of 500 mm along the lower and upper flange of the test beam and along the exposed flange of the angle.

3. TEST RESULTS

The test construction achieved a fire resistance period of 83 min, at which time the $^{L}/30$ failure criterion in the BS476:Part 8 fire test was reached. A copy of the letter received from the WRC confirming the general results is given in Appendix 2.

3.1 Deflection Measurements

The deflection measurements made on the beam and on the concrete slabs at the centre of the construction are shown in Fig. 7. In both cases the rate of deflection was greater in the first 30 min of the test but thereafter remained constant until failure occurred. This behaviour was similar to that observed in the previous shelf angle floor test but different from that experienced in fire tests on simply supported, unprotected beams where the deflection rate progressively increases.

3.2 Temperature Measurements

The results of the temperature measurements are given in Figs. 8-14. Figure 8 shows the heating curves of the central bottom flange positions on the test beam. At failure there was very little scatter between the five temperatures which were within the range 916-935°C with a mean of 924°C. The heating curves recorded for the exposed and unexposed part of the web are given in Figs. 9(a) and (b) and the final temperatures in the exposed web were within the range 852-869°C with a mean of 864°C. The temperatures in the unexposed part of the web were within the range 130-176°C with a mean of 146°C. At failure the upper flange temperatures as shown in Fig. 10 were within the range 88-99°C with a mean of 92°C. The mean lower flange and exposed web temperature at failure was 897°C.

The heating rates of the exposed and unexposed angle flanges are given in Figs. 11(a) and 11(b) respectively. These show that the exposed flange temperatures were within the range 873-882°C with a mean of 878°C, whereas the unexposed flange temperatures were within the range 594-630°C with a mean of 617°C. Fig. 12 gives the angle root heating rates which exhibited final temperatures within the range 727-753°C with a mean of 738°C.

The heating rates recorded by the additional thermocouples used to measure temperature approximately 100 mm away from the furnace wall on the lower and upper flange of the beam and exposed and unexposed parts of the web and angles are given in Fig. 13.

The furnace atmosphere heating curves are compared with the international temperature/time curve in Fig. 14 which shows that the heating rate was generally in accordance with the standard curve throughout the test. A summary of steel temperatures and furnace atmosphere temperature at various stages during the test is presented in Table 3.

3.3 Strain Measurements

The 500 mm gauge lengths marked along the lower and upper flanges of the beam and exposed flange of the angle were measured after the test and the results are given in Table 4. The data suggest that the maximum amount of local plastic strain was 1.4% and it occurred on the exposed lower flange of the beam. Whereas the upper flange exhibited local strain values from -0.4 to +0.4%. A maximum strain value of 0.8% was recorded on the exposed angle leg. After cooling the shelf angle floor construction was satisfactorily reloaded before being dismantled and removed from the furnace.

3.4 Observations

3.4.1 During the Test

Five minutes after the start of test white fumes were emitted from the concrete slabs and these were present throughout the test (see Fig. 15). Only one concrete slab showed evidence of severe spalling when a 300 mm area approximately 10 mm deep became detached from the central left hand segment after 27 min.

As in the previous test the concrete slabs developed a stepwise pattern as the beam deflected, shown in Fig. 16. The angles deflected uniformly with the beam.

3.4.2 After the Test

Figure 17 shows that the slabs had not moved towards the web of the beam. Some of the slabs exhibited vertical edge cracks which were contained within the lower half of the slab see Fig. 18.

Figure 19 confirms that the deflection of both the beam and angle was uniform, with a slightly rippled pattern along the exposed flange of the angle caused by movement of the concrete slabs.

All the bolts remained intact after the reload test.

4. DISCUSSION

The serial size of beam used in the present experiment is one of the lighter steel sections used for shelf angle floor construction incorporating 200 mm thick concrete slabs. It had not previously been subjected to a BS476:Part 8 fire test in the unprotected form, but, with an $^{H}p/A$ value of 209 m^{-1} for 3-sided exposure, the beam would be expected to have a fire resistance time less than 20 min in the fully loaded, simply supported condition.

The fire resistance time obtained with the present construction using the maximum permissible design loads was 83 min, well in excess of the requirements of the Building Regulations for '1 hour' buildings. At the $^{L}/30$ failure limit the rate of deflection of the beam was only 1 mm/min. The test was continued for a further 17 min until the concrete slabs made contact with the loading portal frames of the furnace. Even then the rate of deflection was well below the failure cirterion of 12.5 mm/min. The improved fire resistance of the beam was due principally to the partial protection afforded by the concrete floor slabs which reduced its effective $^{H}p/A$ value to 77 m^{-1}.

The concrete cover slabs resisted the heat flow to the upper region of the steel section, such that at the end of the test when the lower flange had a temperature of 927°C, the upper flange was only at 88°C. The marked temperature gradient enhanced the load bearing capacity of the beam during the test above the strength behaviour expected from the unprotected member. The differential thermal expansion influenced the deflection of the beam. For example, after 30 min into the test a temperature gradient of 650°C was recorded across the section. On the basis of simple bending analysis this would result in a central deflection of 64 mm, the observed deflection at this time was 76 mm. The discrepancy between these values is due, in part, to the decrease in elastic modulus at elevated temperature.

During the test the individual concrete slabs made contact as the beam deflected. This interaction could provide a contribution to the load bearing capacity of the assembly as the edges of the slabs were supported. The significance of this composite action is difficult to evaluate but might have contributed to the reduction in the rate of deflection of the beam towards the end of the test.

Both fire tests on shelf angle floors have exceeded a 1 h fire resistance using bare steel beams in the assembly and by extrapolation of the limited data available an effective $^{H}p/A$ value of approximately 90 m^{-1} could be the critical section factor, as shown in Fig. 20.

If the benefits offered by this form of partial protection are to be recognised in design, it is necessary to evaluate the behaviour of the complete range of shelf angle floor systems encountered in practice. The most cost effective approach is to complement a limited number of fire tests on specific assemblies by modelling the behaviour of the remaining sections.

The calculation method involves the development of two models, one to simulate the temperature profiles of both the exposed and concealed parts of the steel beam and the other to determine the structural stability using this temperature data. Progress has been made with the temperature model[2]. Evaluation of the structural stability awaits the computer package 'SNAKES' from Pafec Ltd., or adaptation of FASBUS II, both of which will soon be available.

Before the present shelf angle floor test was carried out the temperature model was used to predict the temperature fields in the steel beam at 20 mm intervals as the test progressed[2]. A comparison between the predicted and measured temperatures is given in Table 5. As the model assumed that the ISO heating curve was adhered to at all stages in the test it was expected to predict higher steel temperatures than were found in practice. Also a constant emissivity factor of $\varepsilon = 0.25$ was taken for the bottom exposed flange, although experience suggests that this value decreases with increasing temperature. In view of these qualifications, the thermal predictions for the lower region of the beam are reasonable. A much greater discrepancy exists for the upper protected area of the beam, where the predicted temperature values are twice as high as those observed. The principal reason for the difference is due to the choice of boundary condition for the model which assumed the presence of an air gap between the concrete slabs and the unexposed web of the beam. In fact the 50 mm clearance was filled with sand, thereby changing the boundary conditions and providing a heat conducting path from the web. The temperature model is currently being modified accordingly.

5. CONCLUSIONS

A shelf angle construction involving a 305 x 165 mm x 40 kg/m beam and 125 x 75 x 12 mm angles supporting 200 mm thick precast concrete floor slabs has been fire tested to the requirements of BS476:Part 8 using the maximum design load. The unit of construction achieved a fire resistance time of 83 min, well in excess of a Building Regulations requirements for 1 h.

The results obtained from the present test together with observations made in an earlier test utilising a 406 x 178 x 54 kg/m beam suggest that the partial protection afforded by the shelf angle floor construction is an important design consideration for improved fire resistance. However, the complete range of floor assemblies encountered in practice must be evaluated before the system can be recognised on this basis.

The use of mathematical modelling complements the more expensive fire tests and is being developed to predict the temperature rise in the shelf angle floor beam and also its stability. Preliminary work on the thermal model has shown promise but required a modification to the theoretical boundary conditions at the concrete/steel interface to reflect more accurately experimental behaviour.

6. REFERENCES

1. Thomson, G., Hogan, G. and Smith, C.I., Sheffield Laboratories Report No. SH/RS/3664/1/83/B.

2. Kay, T.R. and Latham, D.J., Technical Note RS/9/83/B.

G. Thomson
Investigator

G. Hogan
Structural Advisory Engineer

D.J. Latham
Principal Investigator

R.R. Preston
Manager,
Rails and Sections Dept.

J. Lessells
Research Manager,
General Steel Products

JW

TABLE 1 CHEMICAL COMPOSITION OF THE ANGLES AND TEST BEAM

Sample No.	Sample Form	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Sn	Nb	Zr	Al	N_2
RS526B (Beam)	Solid	0.23	0.02	0.88	0.024	0.017	0.02	<0.01	0.03	<0.02	<0.01	0.04	<0.005	<0.005	<0.005	0.008	0.005
BS4360: Grade 43A Product		0.30 max.	0.55 max.	1.70 max.	0.06 max.	0.06 max.											
RS526A (Angle)	Solid	0.15	0.24	1.41	0.02	0.011	<0.02	<0.01	0.02	0.07	<0.01	0.28	<0.005	<0.005	<0.005	0.005	0.0062
BS4360: Grade 50B Product		0.24 max.	0.55 max.	1.6 max.	0.06 max.	0.06 max.				0.003/ 0.10				0.003/ 0.10			

TABLE 2 COMPRESSIVE STRENGTH TEST RESULTS

Test Date	Age Days	Compressive Strength N/mm²
11. 7.83	7	36
1. 8.83	28	41
2.12.83	151	51

TABLE 3 SHELF ANGLE FLOOR TEST - TEMPERATURE DATA SHEET

Sections: 305 x 165 mm x 40 kg/m Grade 43A Beam
125 x 75 x 12 mm Grade 50B Angles

Date: 30.11.83
Failure time: 83 min

Thermocouple Location	Temperature, °C, After Various Times, min																				
	3	6	9	12	15	18	21	24	27	30	35	40	45	50	55	60	65	70	75	80	83
Lower Flange																					
F1	71	166	268	343	409	500	569	613	641	665	698	727	747	774	807	831	860	883	899	917	927
F2	64	160	267	345	412	506	577	621	650	674	708	734	757	784	816	841	869	891	908	926	935
F4	74	169	261	332	393	473	540	587	617	644	681	709	732	752	786	810	841	867	886	905	916
F6	104	222	307	379	446	527	586	625	650	674	704	729	752	777	810	834	860	880	896	912	925
F7	66	163	263	340	404	492	563	609	638	663	696	722	740	762	794	816	847	871	889	906	918
Mean	76	176	273	348	413	500	567	611	639	664	697	724	746	770	803	826	855	878	895	913	924
Web ¼ Position Exposed																					
W1	65	132	197	247	296	363	422	474	507	537	581	621	655	682	719	746	780	812	834	856	869
W2	63	126	181	232	280	340	398	448	484	518	566	608	644	674	713	742	777	807	831	855	868
W3	58	123	187	241	290	356	417	468	504	536	579	614	647	673	708	735	771	804	830	854	868
W4	54	116	180	232	278	339	396	443	477	509	557	596	632	661	692	718	752	784	812	838	852
Mean	60	124	186	238	286	349	408	458	493	525	571	610	644	672	708	735	770	802	827	851	864
Mean lower flange and web	69	153	234	299	356	433	496	543	574	602	641	673	701	726	760	786	817	844	865	885	897
Web ¾ Position Unexposed																					
W5	12	12	16	20	24	28	35	45	52	62	81	97	106	110	121	126	139	151	160	170	176
W6	11	12	15	19	23	27	34	44	51	60	77	88	97	100	107	105	116	126	130	134	135
W7	12	12	15	18	21	24	30	39	45	53	70	82	92	96	106	103	110	116	120	126	130
W8	12	12	16	19	23	26	33	45	55	66	83	94	102	102	107	108	119	129	134	140	143
Mean	12	12	15	19	23	26	33	43	51	60	78	90	99	102	110	111	121	130	136	142	146
Upper Flange																					
F3	11	10	12	12	12	11	12	15	14	16	24	31	39	44	57	61	71	79	82	86	88
F5	9	9	11	12	12	11	12	15	14	16	22	27	34	39	52	58	72	83	89	95	99
F8	9	9	11	11	11	10	11	14	14	18	27	35	43	46	57	60	71	79	83	89	92
F9	9	9	11	11	12	11	12	15	14	16	21	25	31	33	44	48	60	71	77	83	88
Mean	9	9	11	12	12	11	12	15	14	16	23	29	37	40	52	57	68	78	83	88	92
Exposed Flange Angle																					
F10	50	103	147	183	220	276	329	385	429	470	532	582	630	669	712	740	774	807	837	866	882
F11	37	74	120	146	166	230	299	339	390	443	512	571	620	661	705	735	770	808	836	864	880
F12	44	87	133	165	187	230	296	341	388	431	509	573	626	666	707	736	769	803	830	858	873
Mean	44	88	133	165	191	245	308	355	402	448	518	575	625	665	708	737	369	806	834	863	878
Unexposed Flange Angle																					
W9	15	27	45	65	88	115	150	189	223	258	313	359	400	433	470	498	532	563	588	614	628
W10	14	26	45	66	90	116	152	191	214	231	264	299	336	368	409	443	483	520	550	579	594
W11	14	27	47	72	99	128	165	205	238	272	324	367	406	437	475	504	538	569	592	616	630
Mean	14	26	46	68	92	120	156	195	225	254	300	342	381	413	451	482	518	551	577	603	617
Angle Root																					
16	22	42	66	94	122	156	198	240	279	318	380	434	482	521	564	597	634	668	693	719	734
17	21	41	67	95	112	151	201	248	288	327	390	447	498	538	583	617	655	587	713	738	753
18	20	30	63	88	104	129	170	212	248	289	358	418	471	513	558	591	629	662	688	713	727
Mean	21	38	65	92	113	145	173	233	272	311	376	433	484	524	568	602	639	672	698	723	738
Mean atmosphere	462	623	630	653	694	767	786	797	803	811	828	847	866	880	901	913	934	944	959	969	979
ISO curve at 15°C	497	598	658	700	733	761	784	803	821	837	860	880	897	913	927	940	952	963	979	988	994
Central beam deflection, mm	4	13	23	32	40	51	60	66	71	76	84	92	100	106	112	118	124	130	138	145	149

TABLE 4 GAUGE LENGTH MEASUREMENTS

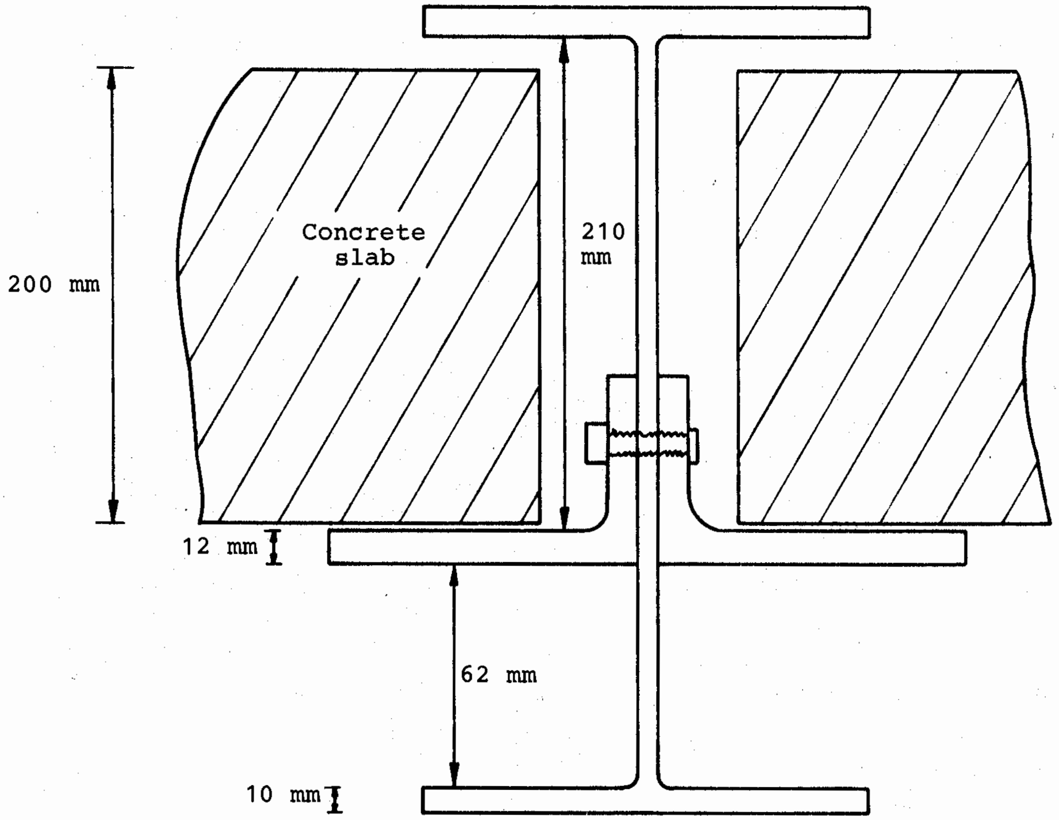
Lower Flange Beam			Flange Angle			Upper Flange Beam		
Before	After	Strain %	Before	After	Strain %	Before	After	Strain %
495	496	-0.2	499	499	0	500	500	0
501	503	0.4	488	486	0.4	501	503	0.4
500	503	0.6	500	501	0.2	500	500	0
500	505	1.0	501	500	-0.2	500	499	-0.2
499	506	1.4	501	505	0.8	500	498	-0.4
500	507	1.4	501	505	0.8	496	496	0
500	506	1.2	500	503	0.6	500	500	0
500	503	0.6	502	503	0.2	501	501	0
505	501	-0.8	498	497	-0.2	501	501	0

TABLE 5 THEORETICAL AND MEASURED TEMPERATURES ACROSS A 305 x 165 mm x 40 kg/m BEAM USED IN A SHELF ANGLE FLOOR CONSTRUCTION

Position	Temperatures, °C	
	Theoretical	Measured (Mean Value)
Upper flange	100	57
Unexposed web	200	110
Unexposed flange (angle)	550	482
Angle root	650	602
Exposed web	800	735
Lower flange	900	826

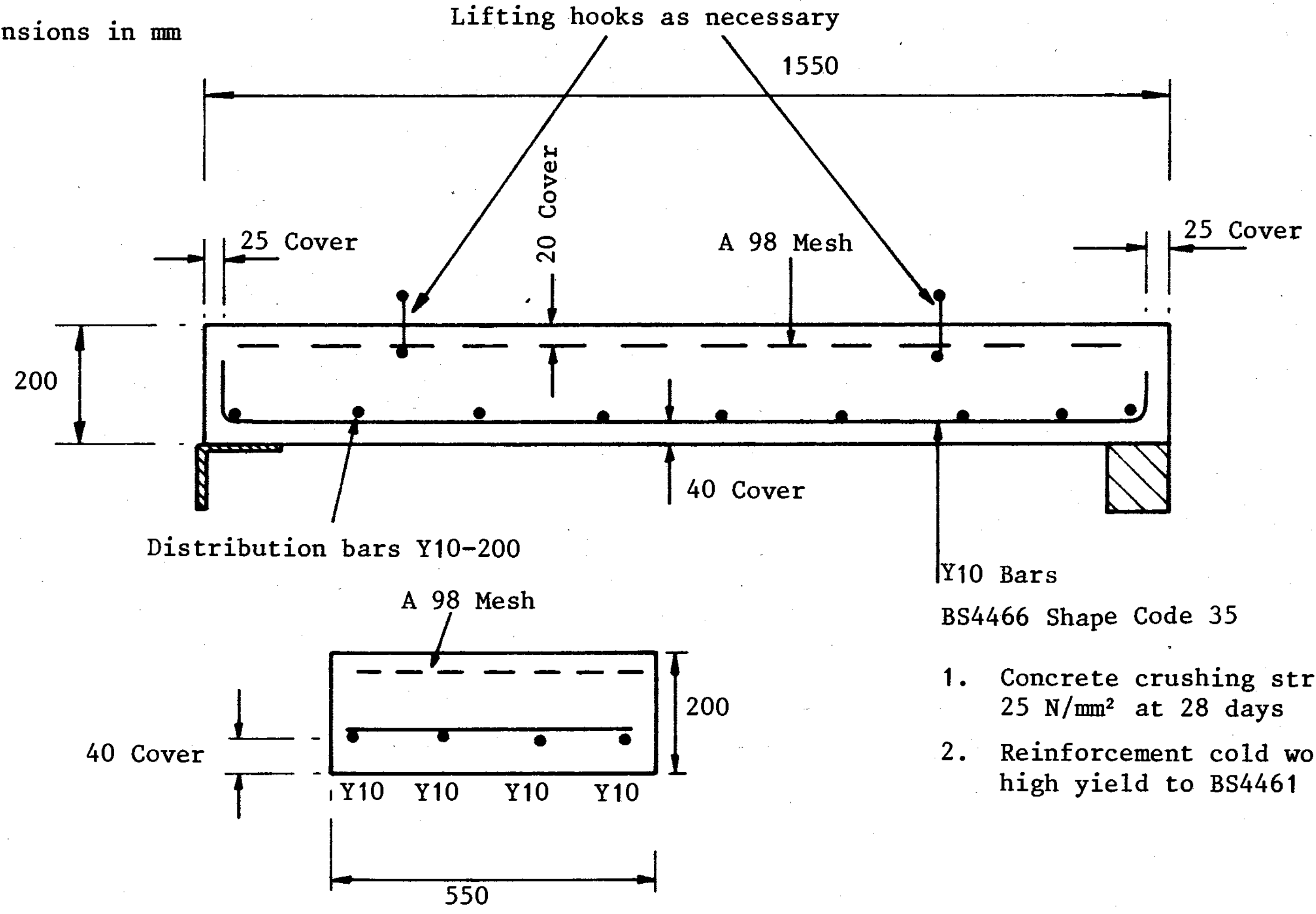
Beam: 305 x 165 mm x 40 kg/m

Angle: 125 x 75 x 12 mm fixed to web using
M20 grade 8.8 bolts at 600 mm centres



TEST ARRANGEMENT FIG. 1
(R2/918)

All dimensions in mm

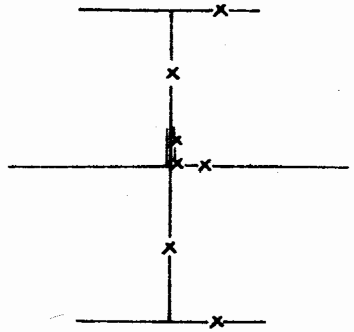


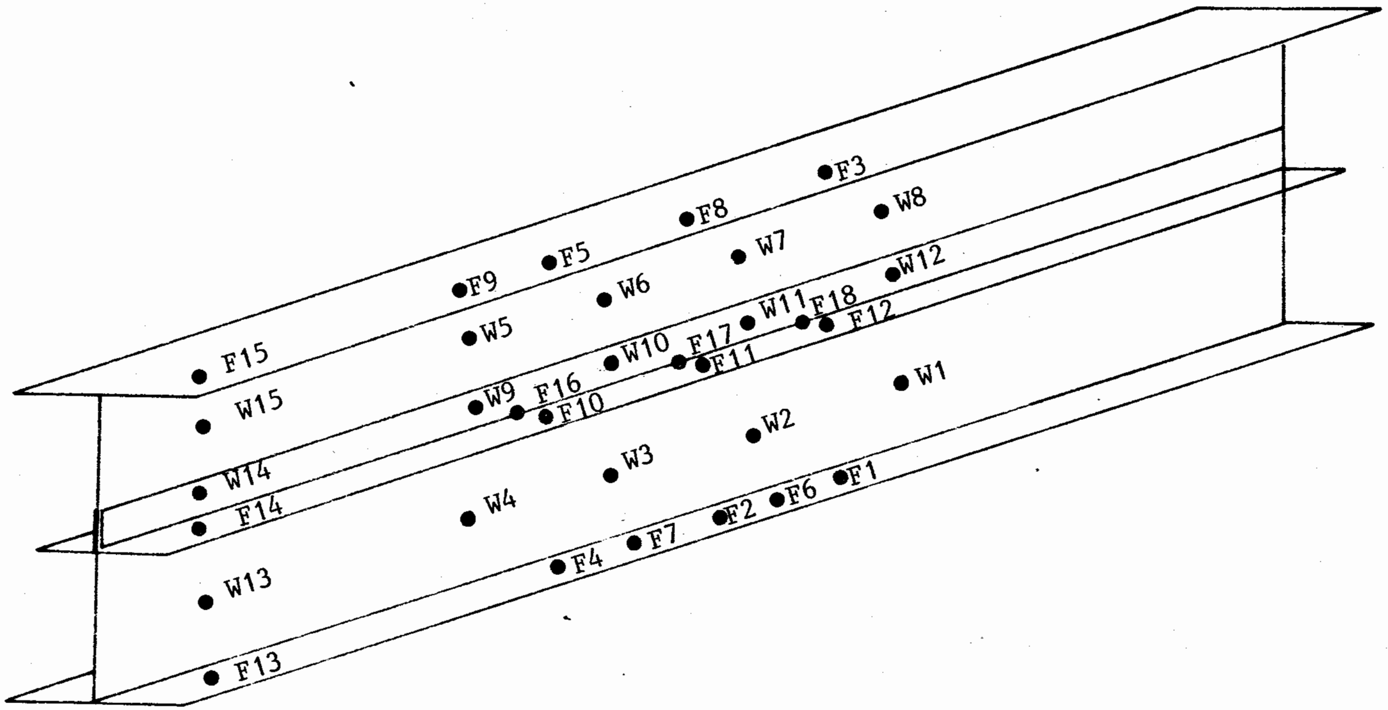
1. Concrete crushing strength 25 N/mm² at 28 days
2. Reinforcement cold worked high yield to BS4461

PRECAST CONCRETE SLAB DESIGN USED IN TEST

FIG. 2
(R2/919)

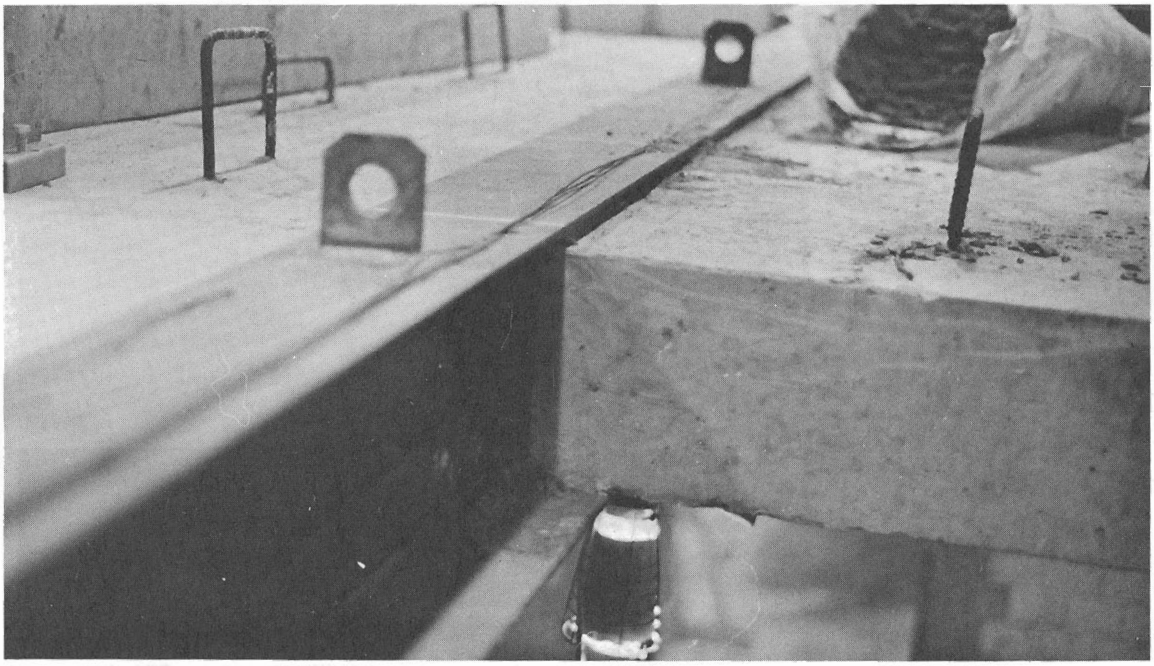
F9, W9, W4, W5 - 1.57 m
W10, F7, W3, W6 - 2.17 m
W11, F6, W2, W7 - 2.80 m
W12, W1, W8 - 3.42 m
F11, F2, F8, F17 - 2.50 m
F4, F10, F5, F16 - 1.88 m
F1, F12, F3, F18 - 3.12 m



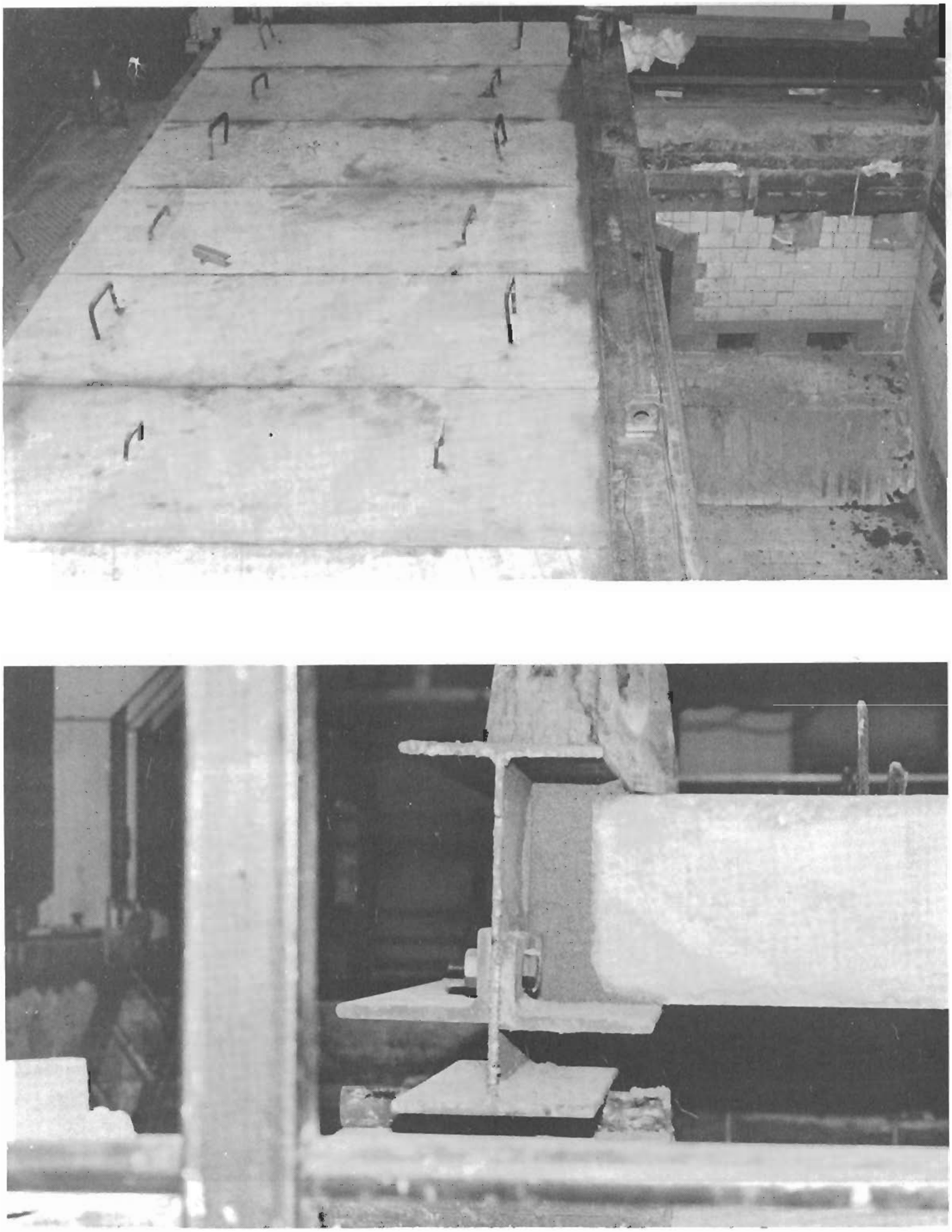


THERMOCOUPLE LOCATIONS USED ON TEST ARRANGEMENT

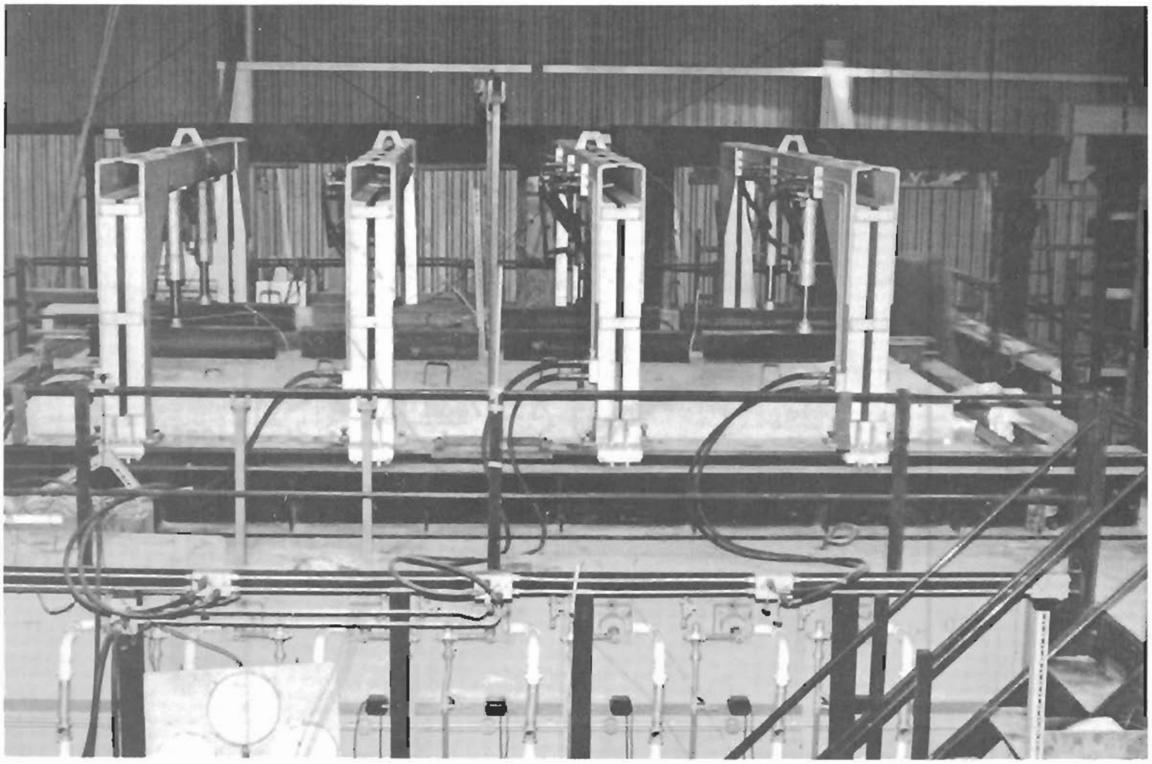
FIG. 3
(R2/920)



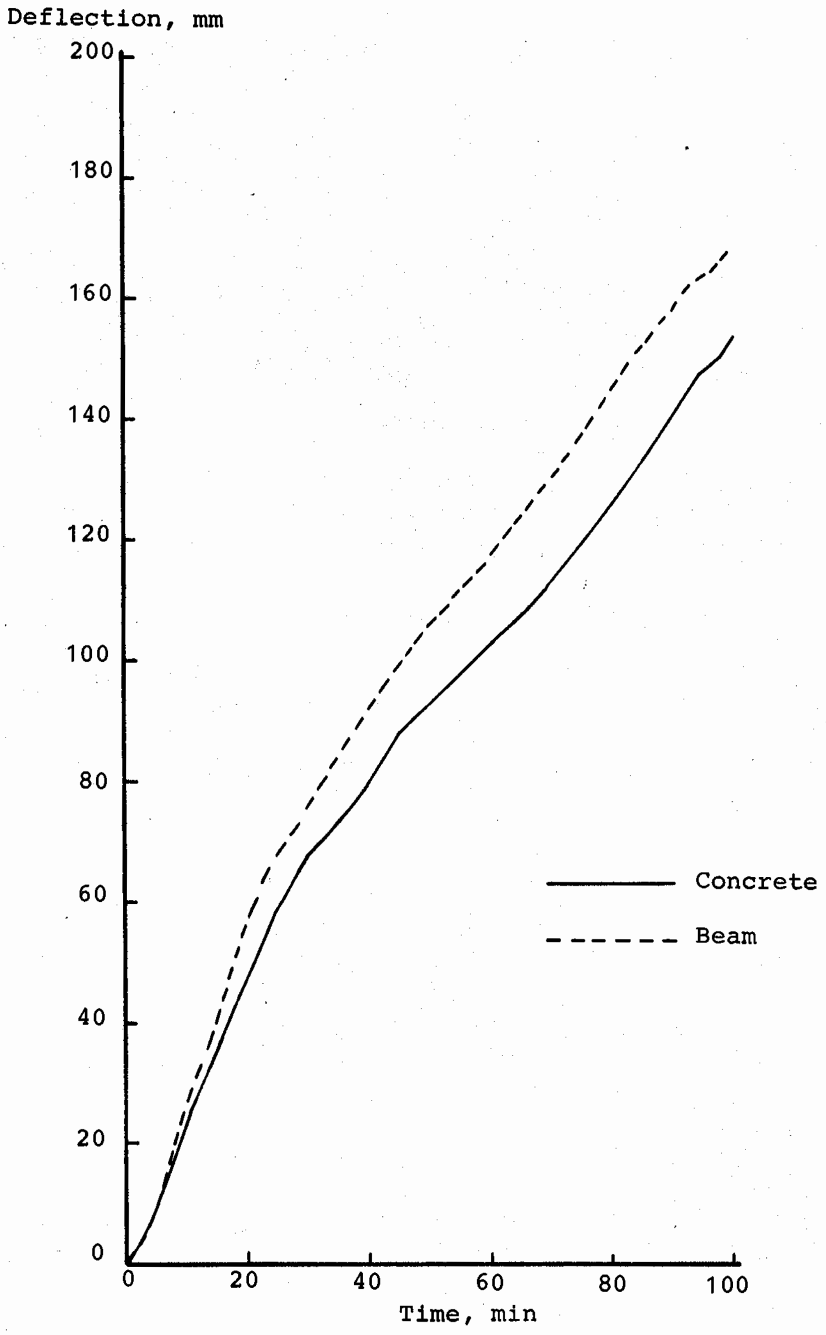
ASSEMBLY OF CONSTRUCTION FIG. 4



ASSEMBLY OF CONSTRUCTION FIG. 5

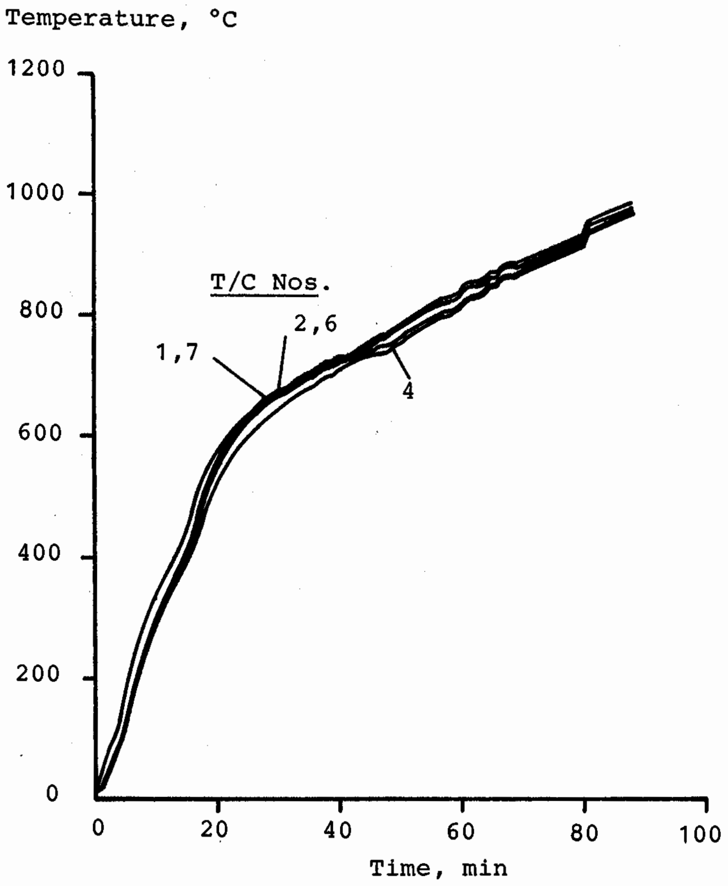


CONSTRUCTION PRIOR TO TESTING FIG. 6



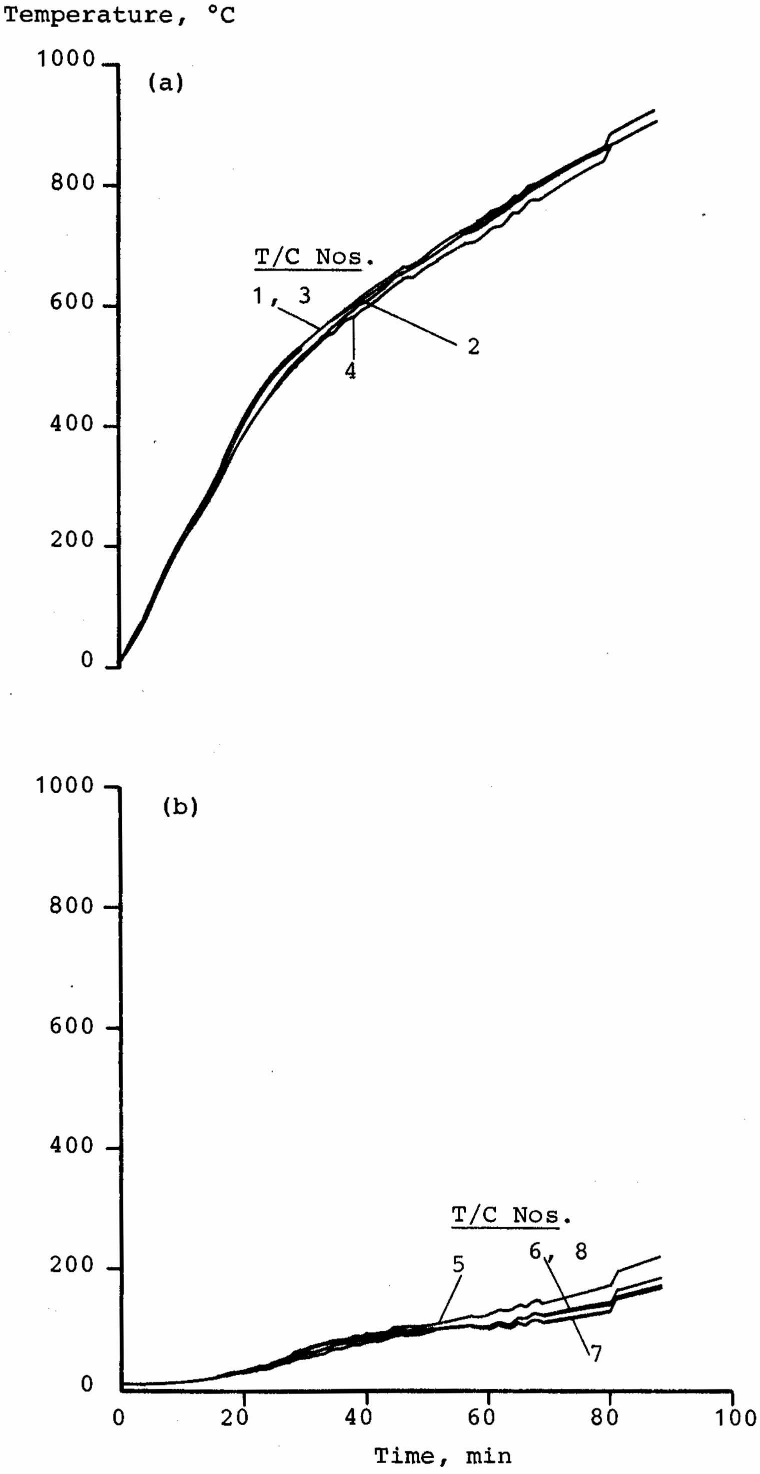
CENTRAL VERTICAL DEFLECTION MEASURED ON THE BEAM AND CONCRETE SLABS DURING THE TEST

FIG. 7
(R2/921)



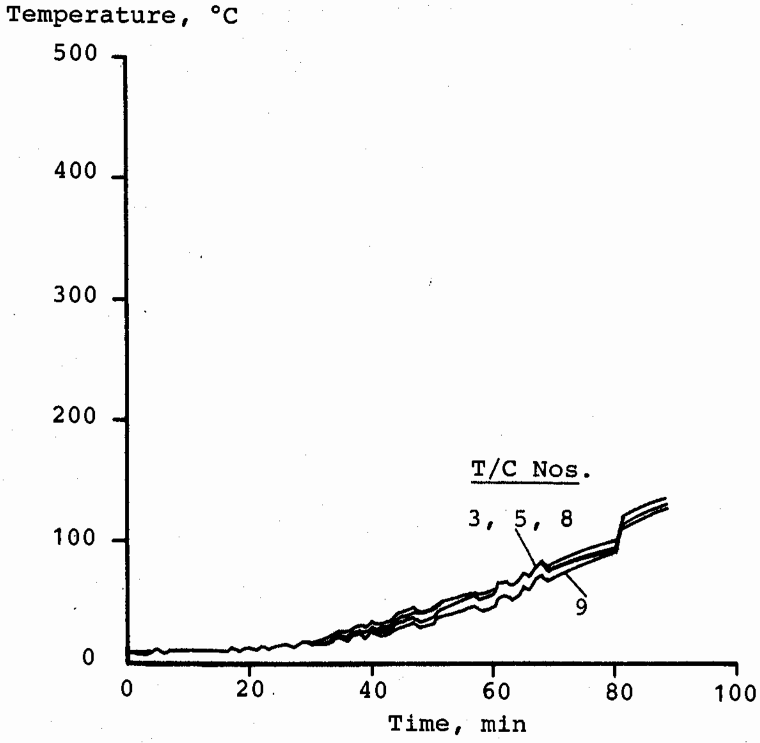
TEMPERATURES RECORDED ON THE LOWER FLANGE OF THE BEAM

FIG. 8
(R2/922)



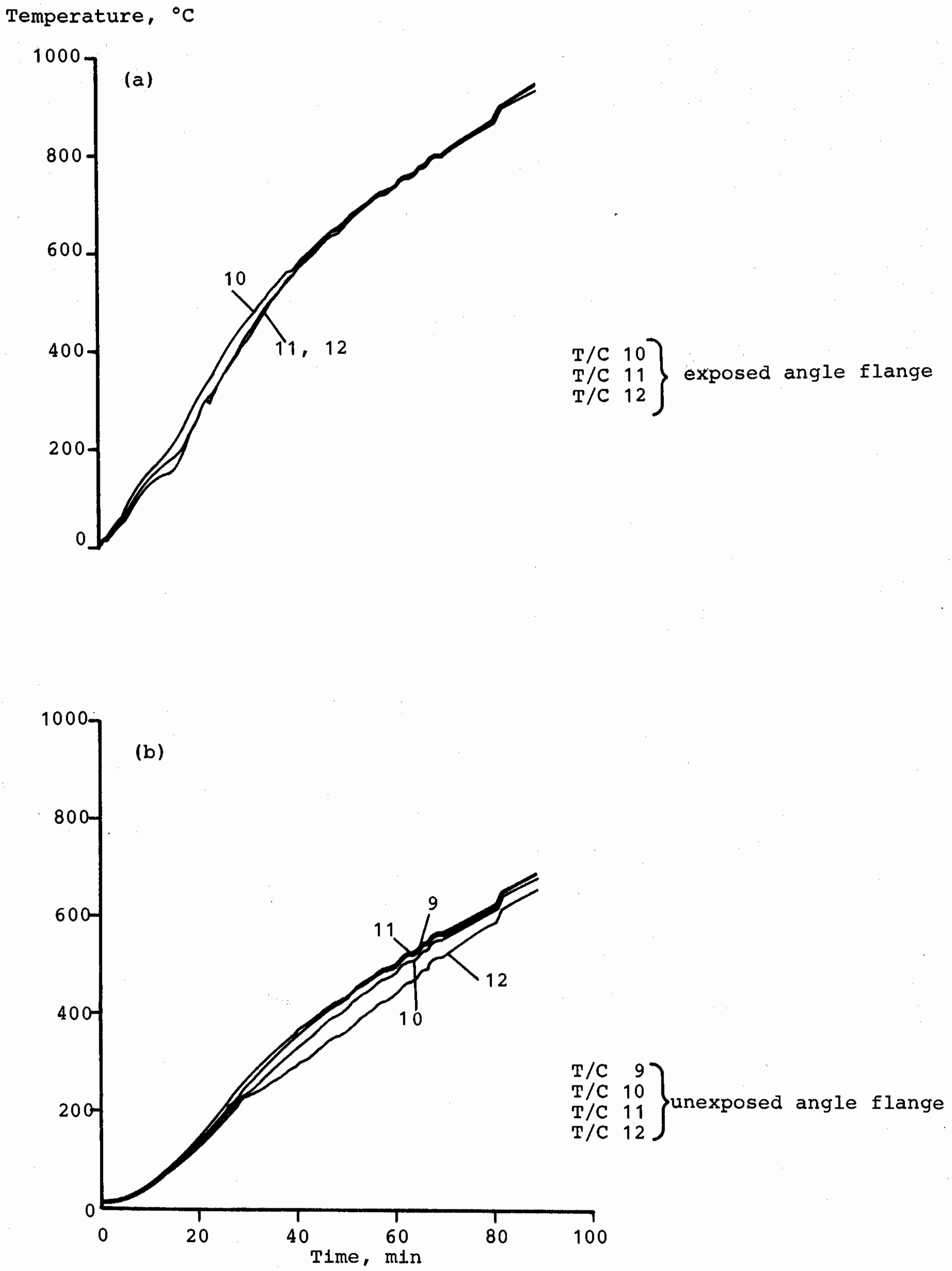
TEMPERATURES RECORDED ON THE EXPOSED AND UNEXPOSED PARTS OF THE WEB OF THE BEAM AT THE QUARTER AND THREE QUARTER POSITIONS

FIG. 9
(R2/923)



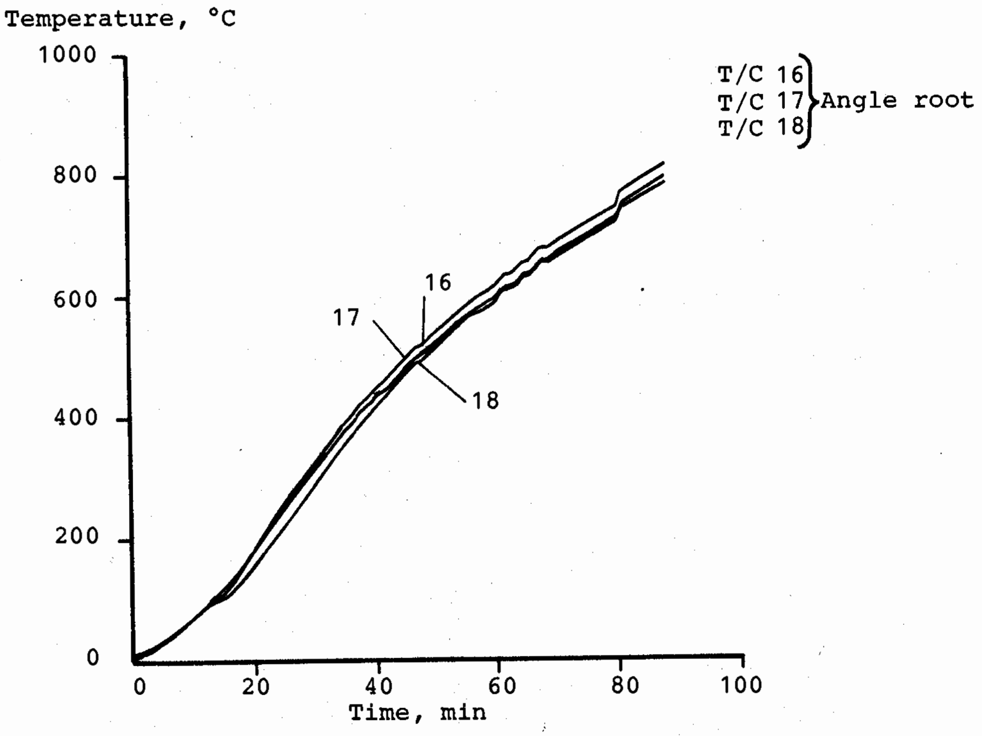
TEMPERATURES RECORDED ON THE UPPER FLANGE OF THE TEST BEAM

FIG. 10
(R/924)

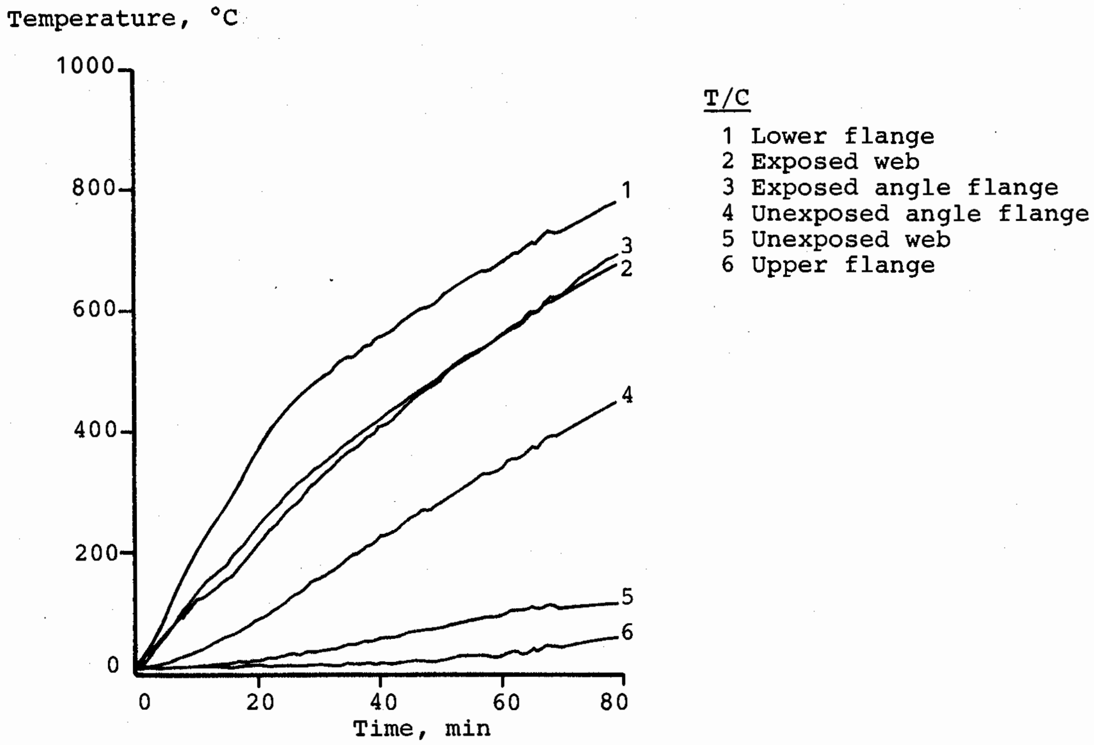


<u>TEMPERATURES RECORDED ON THE EXPOSED AND UNEXPOSED ANGLE FLANGES DURING THE TEST</u>

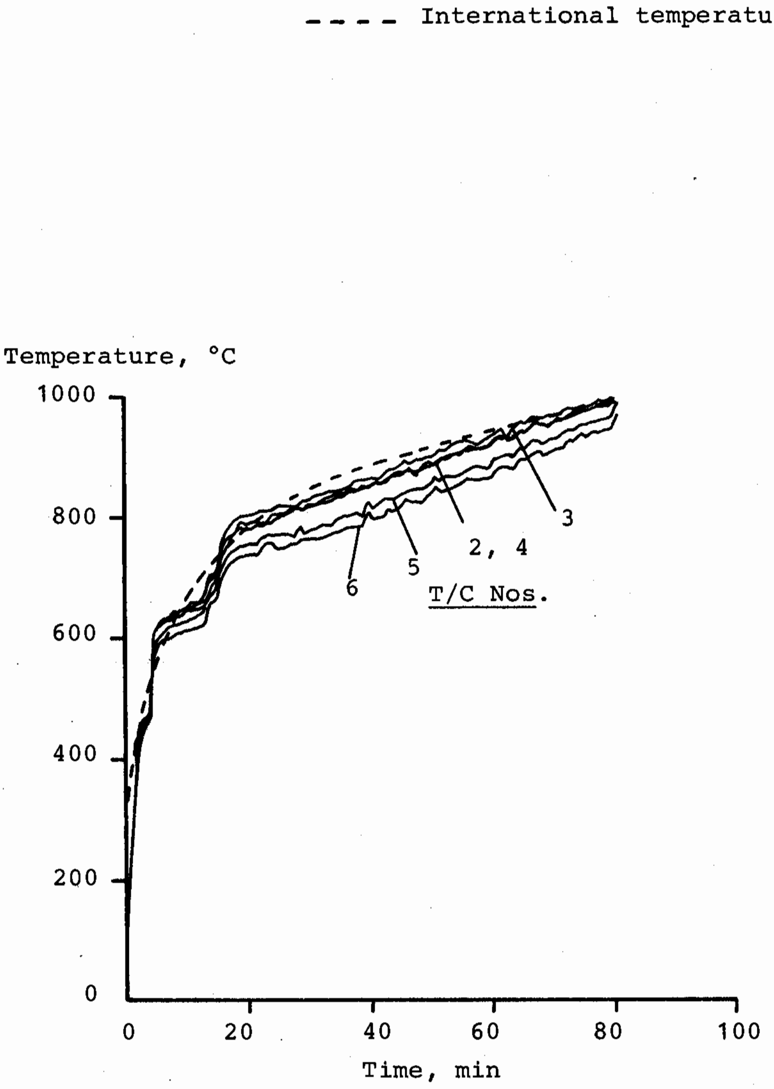
FIG. 11
(R2/925)



TEMPERATURES RECORDED AT THE ANGLE ROOT DURING THE TEST FIG. 12

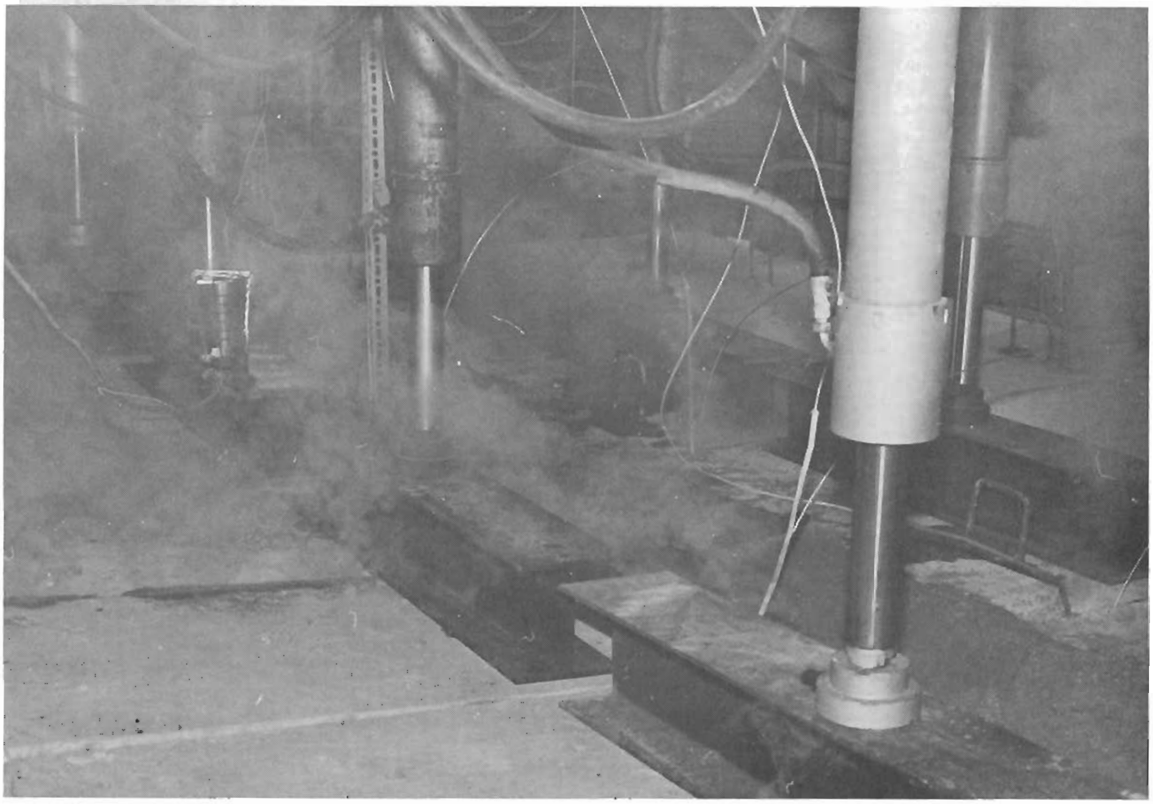


TEMPERATURES RECORDED FROM ADDITIONAL THERMOCOUPLES POSITIONED 100 mm AWAY FROM FURNACE WALL FIG. 13 (R2/926)



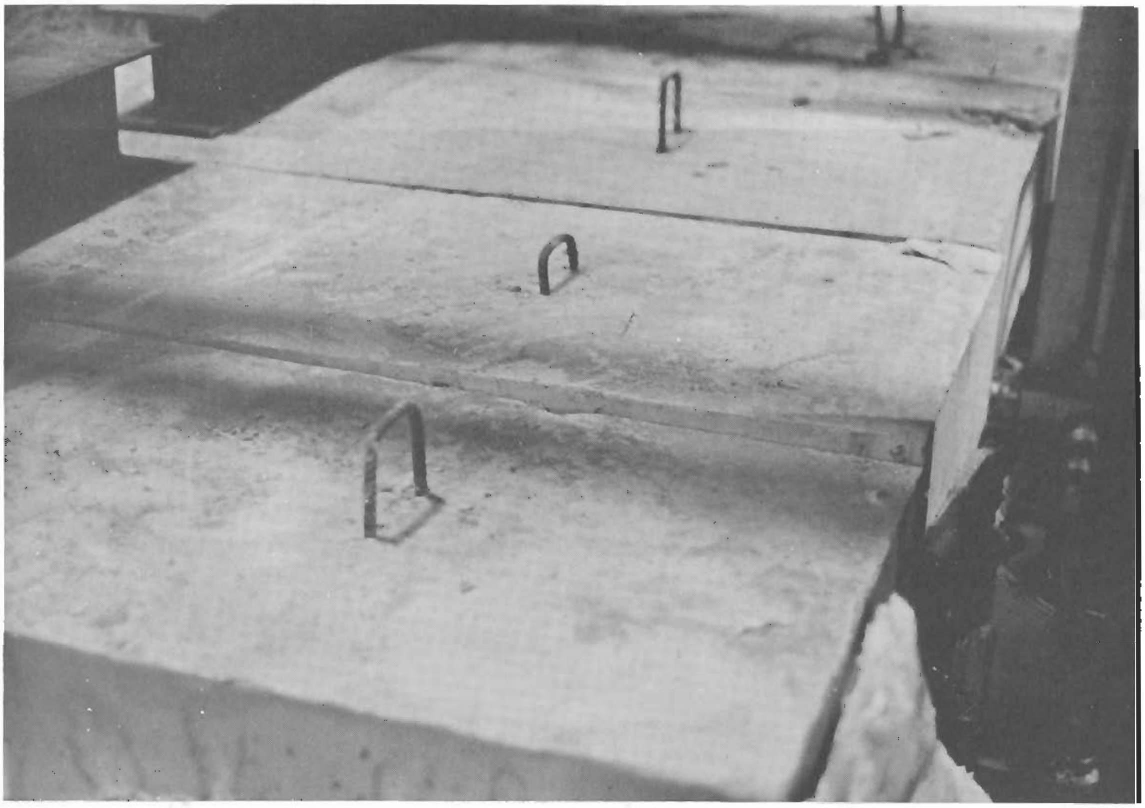
COMPARISON OF FURNACE ATMOSPHERE TEMPERATURES WITH INTERNATIONAL TIME/TEMPERATURE CURVE

FIG. 14
(R2/927)

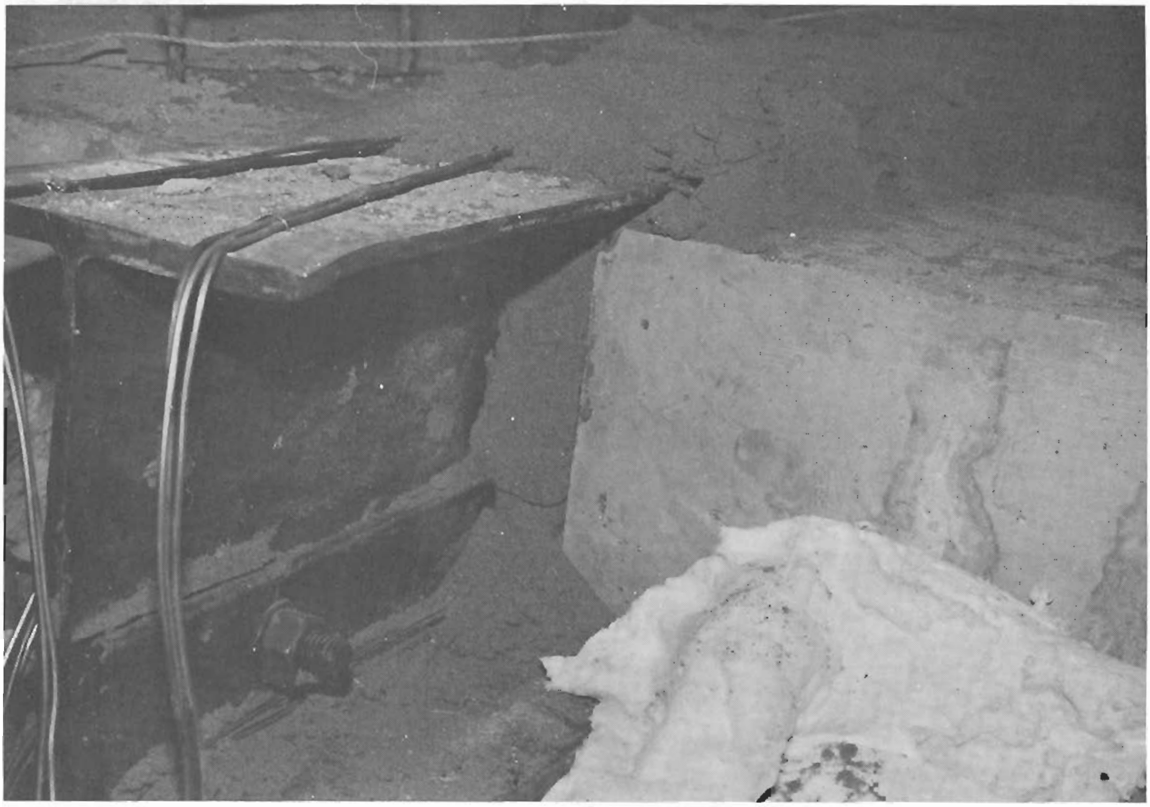


LIGHT FUMES WHICH WERE CONTINUALLY EMITTED FROM THE CONCRETE SLABS THROUGHOUT MOST OF THE TEST

FIG. 15

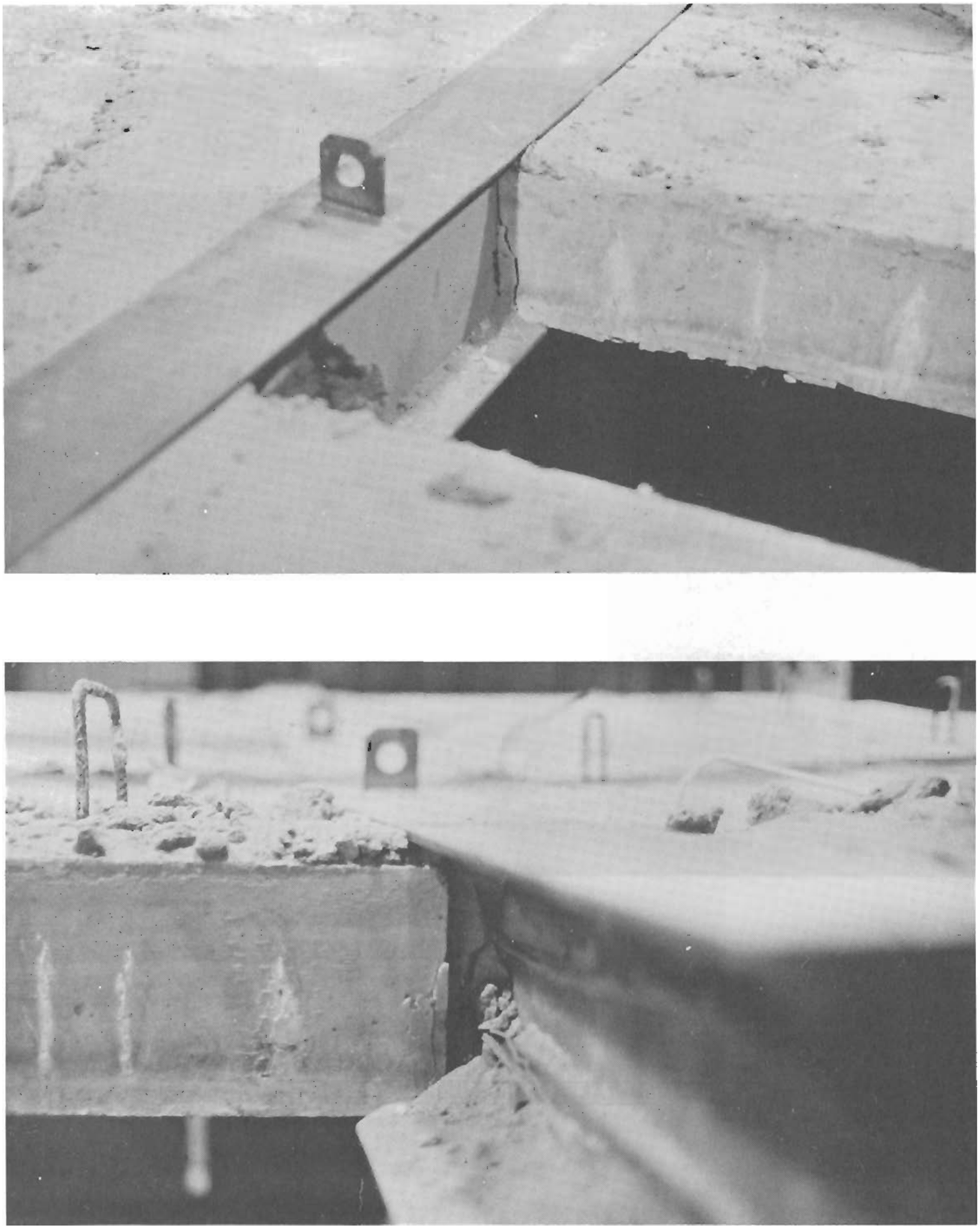


STEPWISE DEFORMATION OF CONCRETE SLABS AFTER THE TEST FIG. 16



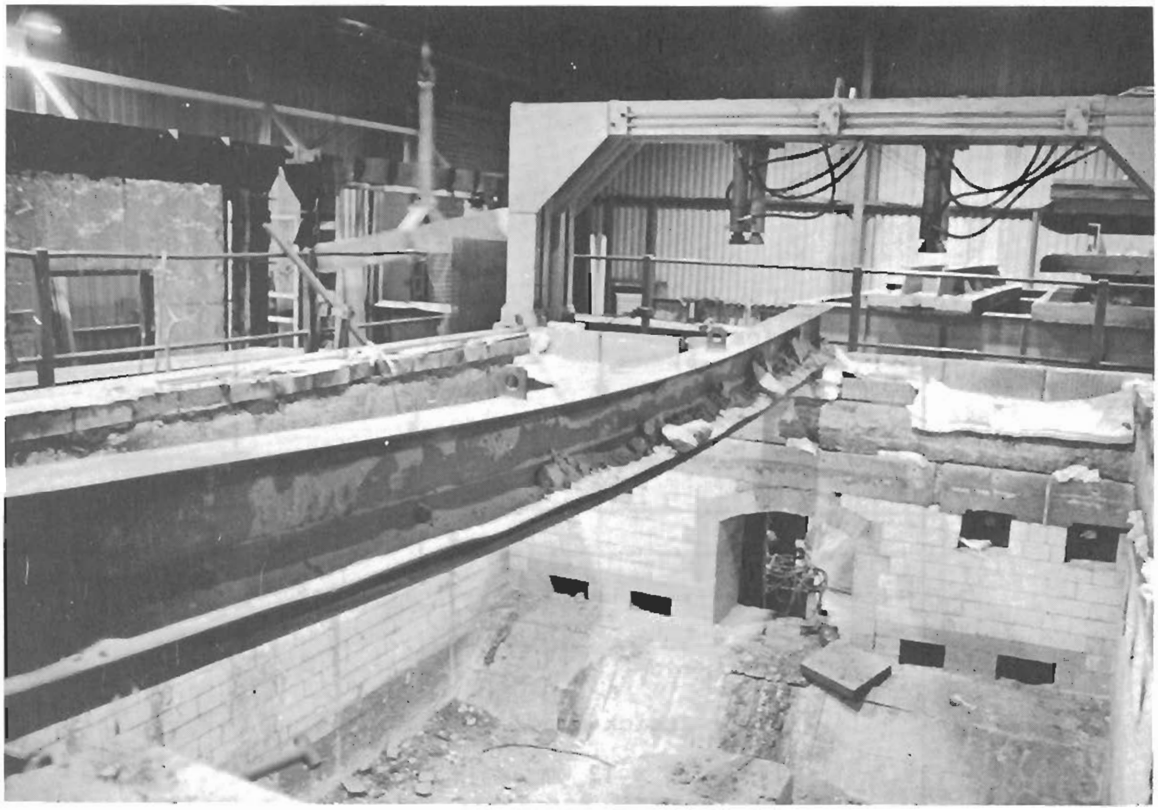
END OF SLAB SHOWING LITTLE OR NO MOVEMENT HAD TAKEN PLACE DURING TEST

FIG. 17



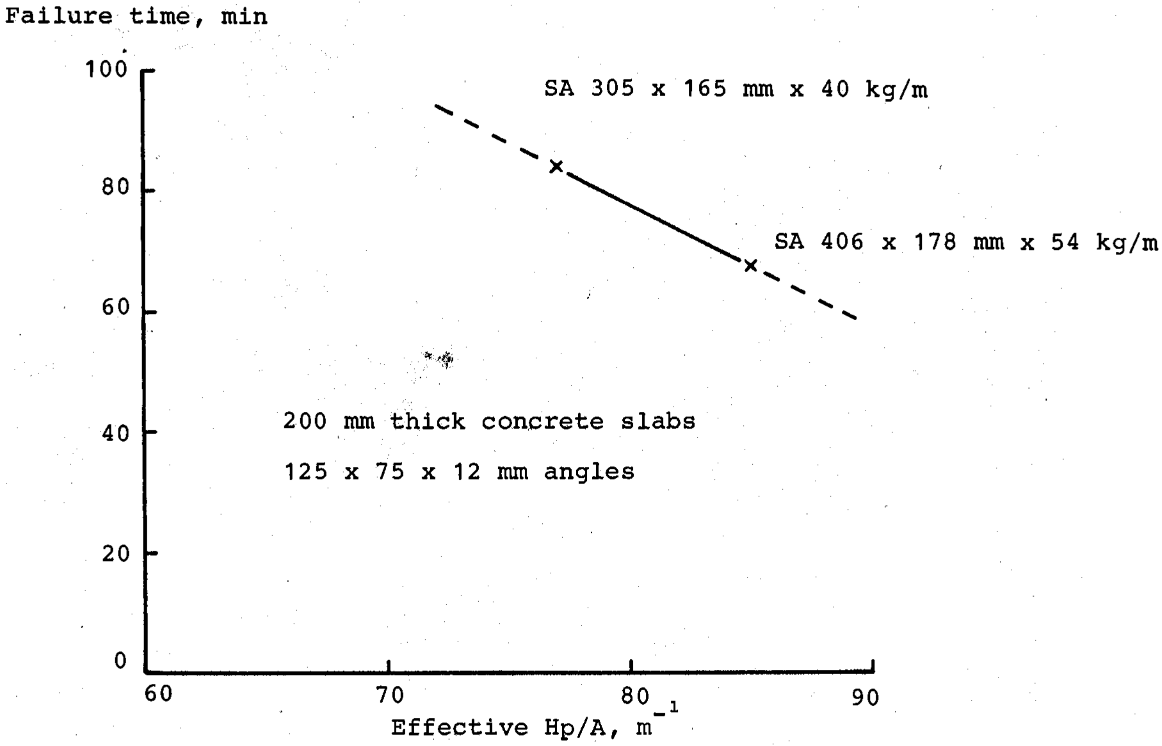
VERTICAL CRACK FORMATION EXPERIENCED BY SOME OF THE CONCRETE SLABS

FIG. 18



BEAM AND ANGLES AFTER TEST SHOWING RIPPLE PATTERN ALONG THE LENGTH OF ANGLE

FIG. 19



<u>EFFECT OF PARTIAL PROTECTION OF STEEL BEAMS BY SHELF ANGLE FLOOR CONSTRUCTION ON FIRE RESISTANCE</u>

FIG. 20
(R2/928)

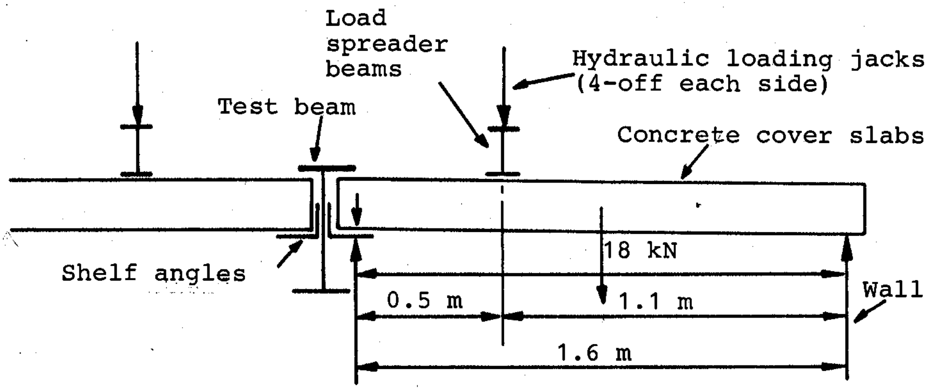
APPENDIX 1 SHELF ANGLE - CONCRETE FLOOR TEST LOADING CALCULATIONS

Beam:- 305 x 165 mm x 40 kg/m BS4360:Grade 43A

Shelf Angles:- 125 x 75 x 12 mm (2 off) BS4360:Grade 50B

Distance between beam end supports = 4.5 m

Safe working load uniformly distributed = 165 kN
(Working stress 165 N/mm²)



(a) Total dead weight of cover slabs and spreader beams = 72 kN

Reaction on each shelf angle $= \frac{72}{2} \times \frac{1}{2} = 18$ kN

(b) Total force required on each shelf angle to produce working stress in test beam load ?

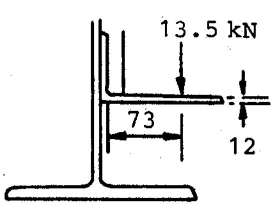
$= \frac{165}{2} = 82.5$ kN $- 18$ kN $= 64.5$ kN

Force required by each set of jacks $= \frac{64.5 \times 1.6}{1.1} = 93.8$ kN

Forge required by each loading jack $= \frac{93.8}{4} = 23.45$ kN

Total hydraulic forces applied $= 23.45 \times 8 =$ ~~18.8 kN~~ 187.6

Stresses in shelf angle:-



Bending moment/m $= \frac{64.5 \times 73}{4.5}$

82.5 / 4.5 = 18.33

Section modulus of angle leg/m $= \frac{1000 \times 12^2}{6}$

64.5 / 4.5 = 14.33

$\therefore$ BM Stress $= \frac{64.5 \times 73 \times 6 \times 1000}{4.5 \times 1000 \times 12^2} = 43.6$ N/mm²

Shear Stress $= \frac{64.5 \times 1000}{4.5 \times 12 \times 1000} = 1.19$ N/mm²

(R118780B)

APPENDIX 2 LETTER OF CONFIRMATION

WRC
WARRINGTON RESEARCH CENTRE
Fire Research, Testing and Consultancy

Warrington Research
Consultants (Services) Limited
Holmesfield Road
Warrington WA1 2DS
Tel: Warrington (0925) 55116
Telex: 627110 or 628702
CHACOM G WARRES

W.R.C.S.I. No. 33721

2nd December 1983

Mr. G. Thompson,
British Steel Corporation,
Sheffield Laboratories,
Swindon House,
Moorgate, Rotherham.

Dear Sir,

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf in accordance with B.S. 476: Part 8: 1972, on a steel beam of serial size 305 mm x 165 mm x 40 kg/m, Grade 43A, which supported precast reinforced concrete slabs of overall size 1550 mm long by 550 mm wide by 200 mm deep on each side of the beam. The concrete slabs were supported on a continuous mild steel angle of serial size 125 mm by 75 mm by 12 mm thick, Grade 50B, on each side of the web of the beam. A total load of 188 kN was applied to the concrete slabs at 1/8, 3/8, 5/8 and 7/8 span positions. The loading was applied at a distance of 500 mm away from the centre line of the beam on each side of the beam. The ends of the concrete slabs being supported by the steel beam, were bedded in a sand and cement mortar mix. The steel beam was unprotected. The test results were as follows:

Stability : 83 minutes
Re-load test : Satisfied

Date of test : 30th November 1983.

Our full report will follow in due course.

Yours faithfully,

L Healey

(L. HEALEY)
Warrington Research Centre

INITIAL CIRCULATION

Swinden Laboratories	Teesside Laboratories
General Steel Products Group Standard Circulation Mr. T.R.Kay Dr. B.R. Kirby Dr. D.J. Latham Mr. G. Thomson Mr. D.E. Wainman	Dr. R. Baker

GENERAL STEELS GROUP

BSC Sections and Commercial Steels

Steel House

Mr. N.J. Cavaghan
Mr. G. Hogan
Mr. R.A.C. Latter
Dr. M.J. Pettifor
Mr. J.T. Robinson

CONSTRADO

Mr. G.M. Newman

EXTERNAL CIRCULATION

Mr. F.C. Adams - Fire Research Station
Mr. G.M.E. Cooke - Fire Research Station
Mr. A. Porter - Greater London Council