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The Fire Resistance of a Shelf Angle Floor Construction, a BS476 : Part 8 Fire Test Carried out on 3rd November, 1982

British Steel Corporation
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KEY WORDS

3. Fine Resistance
4. Concrete
5. Floorings
6. Deflection
7. Testing
8. Shelf Angle
9. Lab Reports

4th July, 1983

THE FIRE RESISTANCE OF A SHELF ANGLE FLOOR CONSTRUCTION, A BS476 : PART 8 FIRE TEST CARRIED OUT ON 3rd NOVEMBER, 1982

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 406 x 178 mm x 54 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 68 minutes when the deflection of the beam at its centre reached 150 mm which is the limiting deflection in BS476 : Part 8. This performance was better than expected and it is thought that composite action between the various parts of the construction with the colder ends of the beam may have contributed to the good results.

The use of partial protection of members is clearly beneficial to improve their fire resistance; however the present results of such tests need to be made more general and this could best be achieved by the development of computer based models which can predict both the heating rate and stability of members which exhibit large temperature gradients. The cost benefits of shelf angle floors compared with conventionally protected members require careful evaluation.

1. INTRODUCTION

Attempts have been made in recent years to develop constructional methods utilising unprotected steel members, to achieve fire resistance period of 30 and 60 min[1]. These studies have considered the effect of beam size, steel grade and loading system on the fire resistance and whilst periods approaching 60 min have been achieved the methods investigated to date have demonstrated that unprotected members can only reliably realise fire resistance of 30 min and frequently necessitate 'end restraining moments' to be utilised to improve their inherent fire resistance.

A preliminary test on columns built into masonry walls has shown that this form of construction can achieve a considerable period of fire resistance. The masonry protection to one flange and part of the web, significantly reduces their heating rate and consequently an enhanced fire resistance was measured.

The concept of partial protection can be extended to horizontal members using shelf angle floor systems where precast concrete slabs rest on steel angles attached to the webs of the beam with the upper surface of the slabs below the upper flange of the beam (see Fig. 1). This form of construction has been widely used in the design of multistorey buildings and although expensive it is utilised to reduce the floor/ceiling services void depth which results in cost savings on the area of cladding and partitions which are required.

In this particular test a 406 x 178 mm 54 kg/m BS4360 : Grade 43A beam was utilised along with 125 x 75 x 12 mm BS4360 : Grade 50B angles and 200 mm thick precast concrete slabs to produce a shelf angle floor construction. The section was fully loaded and fire tested at the Warrington Research Centre on 3rd November 1982 and this report describes the construction of the specimen and observations made during and after the test. The report also discusses future testing requirements and the implications of this method of construction for the design of multistorey steel framed buildings where periods of fire resistance up to 1 h are required.

2. THE CONSTRUCTION

2.1 Steel

The steel members used in the test were obtained from local stockholders. Their serial sizes and qualities were as follows:

The beam	406 x 178 mm x 54 kg/m,	BS4360 : Grade 43A
The angles	125 x 75 mm x 12 mm,	BS4360 : Grade 50B

The chemical composition and room temperature mechanical properties of these members are shown in Table 1 and 2.

The flange of the Grade 43A beam had a yield stress of 274 N/mm^2 and tensile strength of 439 N/mm^2 and satisfied both the mechanical and chemical requirements of BS4360.

The longer leg of the BS4360 Grade 50B angle had a yield stress of 384 N/mm^2 and tensile strength of 518 N/mm^2 which satisfied the requirement of BS4360 : Grade 50 B.

2.2 Design of the Construction

Steel

It is usual in shelf angle construction to support the concrete slab on an outer flange of the angle, the angle is then totallly exposed to any fire which occurs underneath the concrete slab. However in this test the configuration was reversed in order to minimise the amount of angle exposed to fire attack.

The 75 mm leg of the angle was bolted to the web of the beam using M20 : Grade 4.6 bolts at 600 mm centres, the bolt holes being drilled at the centre of the 75 mm long leg. The angles were bolted in position at 8 places along their length. The beam used was 5.01 m long, the angles being of the same length. The angles were positioned to leave a 210 mm gap between the upper flange of the beam and the longer leg of the angle. A drawing illustrating the details of the construction is shown in Fig. 2.

Concrete

The concrete slabs used in the test were specially cast in the middle of May 1982, and were stored indoors until the day of the test. During storage the slabs were spaced 75 mm apart to allow a free flow of air between the stacked slabs to aid their drying out. The slabs were 550 mm wide, 200 mm thick and 1550 mm long, this length being selected to permit a gap of 50 mm between the nose of the slab and the web of the beam without interfering with the loading system of the furnace.

The slabs were specially designed to withstand the loading force anticipated during the test and details of the calculations used are shown in Appendix 1 whilst Fig. 3 shows the reinforcement positions within the slab.

The concrete quality used was Grade 30 and the results of cube tests made on similar samples on 4th November 1982 are shown in Table 3.

2.3 Instrumentation

A total of 35 Pyrotenax thermocouples (chromel/alumel with insulated hot junctions) were used to monitor the heating rate and temperature of the steel during the test. The thermocouples were located at the positions shown in Fig. 4 and in summary 5 thermocouples were attached to the exposed lower flange, 4 thermocouples to the exposed part of the web, 4 thermocouples were attached to the protected part of the web and 4 were attached to the upper flange of the section. These thermocouples were located around the central part of the beam. An additional set was positioned (upper flange 2 on webs and lower flange) 100 mm away from the furnace wall. Two additional thermocouples were also located at the flange/web junction on the lower flange of the beam.

The remaining 12 thermocouples were attached to the shelf angles with 4 attached on the exposed flange, 5 on the unexposed flange and 3 on the root of the angle. Figure 5 shows a photograph of some of the thermocouples in position demonstrating the technique used. Three thermocouples were also used to monitor the temperature rise in the concrete slab, i.e. fourth segment at $^{1}/4$, $^{1}/2$ and $^{3}/4$ depths positions, 150 mm away from the web of the beam.

The final six thermocouples were installed once the assembly was constructed to monitor furnace atmosphere temperatures at the locations shown in Fig. 6.

2.4 Assembly

The beam was located in the furnace at the appropriate position and the individual concrete, floor slabs were slotted into the space between the shelf angle and the upper flange to give a load bearing width of 75 mm. A wall was constructed along the long edges of the furnace to support the free ends of the slabs. At the short end of the furnace a small wall was constructed but the slabs did not rest on this wall, the gap being filled using compressible insulating ceramic blanket.

Once all the slabs were located in position the gap between the slab nose and web of the beam was filled with sand to represent the thermal characteristics of a screed. The top flange of the beam was also covered with 25 mm of sand to also represent a screed as used in practice. Photographs showing the construction during assembly is shown in Figs. 7 and 8.

2.5 Loading

In an attempt to represent the type of loading which would be encountered in practice it was considered esssential to apply all the load to the beam and angle through the concrete slabs. High point loads under the ram of the hydraulic loading jacks were avoided by applying the load through 4 sections, each 1 m long, of 152 x 152 mm universal column placed above each side of the beam. These lengths of column acted as load spreaders between the slabs. Furthermore the loads applied were modified to take account of loads carried by the wall along the long edge of the furnace. A total load of 36.9 t was applied at 8 points and details of the loading calculations are shown in Appendix 2. Photographs of the specimen immediately before the test are shown in Fig. 9.

3. THE TEST

The fire resistance of the unit of construction was 68 min, the test being discontinued when the deflection at the centre of the beam reached 150 mm, i.e. the L/30 failure criterion stated in BS476 : Part 8.

3.1 Deflection Measurements

The results of deflection measurements made on the beam and also on the concrete slabs at the centre of the construction are shown in Fig. 10, from which it can be seen that the two curves followed similar patterns. These curves were slightly different from those typically obtained from unprotected steel beams, in that the rate of deflection increased steadily during the test, whereas, normally, the deflection rate is slow at the beginning of the test and then increases rapidly during the final minutes of the test.

3.2 Temperature Measurements

All instrumentation operated satisfactorily and the results of temperature measurement are shown:

Fig. 11 shows temperature data collected from the lower flange.
Fig. 12 shows temperature data collected from the exposed web.
Fig. 13 shows temperature data collected from the concealed web.
Fig. 14 shows temperature data collected from the upper flange of the beam.
Fig. 15 shows temperature data collected from the exposed leg of the shelf angle.
Fig. 16 shows temperature data collected from the concealed leg of the shelf angle.
Fig. 17 shows temperature data collected from the root of the angle.
Fig. 18 shows temperature data collected 100 mm away from the furnace wall.

At the end of the test the following average temperatures were recorded around the centre of the beam:

Lower flange (beam)	915°C
Exposed web (beam)	889°C
Concealed web (beam)	158°C
Exposed leg of angle	824°C
Concealed leg of angle	611°C
Root of angle	722°C

The furnace atmosphere heating curves are compared with the international time temperature curve in Fig. 19, which shows that the heating rate was 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 given in the data sheet.

The temperature rises which were monitored in the fourth concrete cover slab approximately 150 mm from the flange tip at the quarter, half and threequarter depth positions are shown in Fig. 20. The temperature rose steadily after 12 min into the test from 23°C to 53, 105 and 107°C at the 50, 100 and 150 mm depths respectively.

After cooling the shelf angle floor test arrangement was satisfactorily reloaded before being dismantled and removed from the furnace.

3.3 Observations

3.3.1 During The Test

As soon as the test commenced light but dense fumes started to ooze from the concrete cover slabs. These fumes (see Fig. 21) were continually emitted throughout the duration of the test. After about 25 min some hairline cracks appeared in the top surface of the concrete cover slabs in close proximity to the lifting rings. There was also some evidence of spalling in areas along the edges of the slabs.

As the beam deflected the concrete cover slabs developed a stepwise pattern which became more exaggerated towards the ends of the shelf angle arrangement as the test progressed as shown in Fig. 22.

The beam and angle appeared to be deflecting in a uniform manner - in fact very similar to that experienced in a simply supported beam test.

3.3.2 After The Test

Prior to dismantling, inspection of the unit of construction from within the furnace confirmed that the deflection on both the beam and angle was fairly uniform (see Fig. 23) and that there was no evidence of cracking in the underside of the concrete cover slabs.

Figure 24 shows that the slabs had not moved significantly towards the web of the beam. Some of the slabs exhibited cracks which were contained in an area of the slab supported on the shelf angle. There were two types of crack patterns which ran through the slab thickness, one type vertical and the other at an angle of about 45^{o}, as shown in Fig. 25. A closer examination of the steel angle, once all the concrete slabs had been removed, revealed a slight wavey pattern (see Fig. 26) probably caused by the side edge action of the slabs.

Two of the end bolts had sheared, one which was completely outwith the furnace while the other was protected behind the first pair of concrete slabs. It is not known whether this occurred during or after the test but it was noticed during the reload test.

4. DISCUSSION

4.1 Behaviour Of The Construction In The Present Test

The fire resistance time obtained with this construction using the maximum permissible design loads was 68 minutes, easily exceeding a 1 h requirement. Furthermore at the end of the test when the deflection of the assembly had reached the L/30 limit of deflection its rate of deflection of the specimen was very low at 2 mm/min and it is possible that an additional period of fire resistance could have been realised if the test had been extended and a 'rate of deflection' failure criterion utilised. This period of fire resistance is much greater than that observed for fully loaded but totally exposed simply supported beams and clearly the partial protection afforded by the concrete floor slabs had made a considerable contribution towards it fire resistance. This was demonstrated in two ways:

1. The concrete slabs resisted heat flow to the upper flange of the section and this part of the section would therefore retain almost all its original load bearing capacity.

2. There was some evidence that the concrete slabs made a partial contribution to the load bearing capacity of the assembly. (This aspect will be considered in more detail later in this report).

The thermal protection provided by the concrete slabs was very significant in that when the lower flange had been heated to 915^{o}C at the end of the test, the upper flange of the section was only at 94^{o}C. The temperature measurements made indicate that a considerable portion of the beam was maintained at a temperature below 400^{o}C, and hence exhibited load bearing capabilities not significantly reduced from its original load bearing capacity. This considerable temperature gradient did, however, contribute to the deflection of the beam particularly in the early stages of the test due to differential thermal expansion. The lower flange being hotter expands to a greater extent than the upper flange, and hence this differential expansion causes the beam to bow. For instance, the calculations shown in the Appendix 3 model the situation which existed 30 min into the test when the lower flange was heated to 728^{o}C and the upper flange was still at 28^{o}C. This gradient of 700^{o}C would cause bending of the beam and the simple analysis described predicts a central deflection of 52 mm compared with the observed deflection at this time of 79 mm. The underestimate given by these calculations can be explained in part by a reduction in the value of elastic modulus at elevated temperature. The very slow rate of deflection at the end of the fire test is difficult to explain for a simply supported member. One would expect the rate of deflection to increase rapidly towards the end of the test and hence it is thought that other factors such as composite action from the concrete slabs restricted the deflection of the steel member. During the test as the beam deflected the concrete slabs moved independently in a stepwise manner and hence there was some tendency for the slabs to jam-up against each other. This interaction could provide a load bearing memeber in itself provided that the edges of the 'raft' are adequately supported. In this test the ends of the shelf angles were outside the furnace and the upper flange of the beam and the angle leg provided two rigid surfaces to prevent movement of the edge slabs. Hence the loads generated by wedging on these edge slabs were high and subsequently caused bolts which were outside the furnace to fracture by shear. Hence it is concluded that the interaction of the slabs coupled with the cold periphery of the shelf angle provided an additional load bearing member and improved the overall fire resistance of the construction. The significance of this composite action in the application of these results to real structures is difficult to consider. In a fire in a real structure all the shelf angle could be heated and then the degree of restraint which would be provided at the periphery could be significantly lower and hence it is possible that the beam/floor construction would not perform in the same way in real structures in real fires.

4.2 Future Work

The results obtained from the present test only apply to this particular combination of beam size and concrete slab depth, but to extend the commercial utilisation of this construction method system it is necessary to predict the behaviour of other similar floors. This would be best achieved by the development of two models which would simulate:

1. The temperature of the exposed and concealed parts of the section. This could be done using finite element analysis techniques and some work has been completed by James[2] on the development of a model to predict the temperature rise of a column built into a masonry wall.

2. The structural stability of an element which exhibits temperature gradients. Constrado have already developed a preliminary version of a model which can predict the load bearing capacity of a beam which exhibits temperature gradients. Clearly there is scope to utilise and develop both models so that various situations can be examined without the need to perform costly and time consuming fire tests. The first stage would be to establish confidence in the accuracy of these models, by performing a detailed anlaysis on the data generated from the present test to determine the ability of the models to predict for this situation.

4.3 Commercial

The impetus to develop methods of achieving fire resistance in unprotected steel members arises because of the need to reduce or eliminate the costs of applied fire protection. Clearly the cost aspects of this shelf angle floor construction need to be carefully evaluated before extensive further test work is pursued.

The use of shelf angles increases the weight of steel considerably for instance these 125 x 75 x 12 mm angles weigh 17.8 kg/m adding 35.6 kg/m to a beam weighing 54 kg/m.

Using a fabrication cost of £500/t this 'extra steel' would add £77.8/m to the overall cost of the framework. Alternatively the 406 x 178 mm beam would require 1 m^2 of board per metre run to fire protect it and the use of board fire protection could easily achieve the same level of fire resistance (1 h) at the same but most probably lower cost. The spray applied materials would be even less expensive. However the use of shelf angle floors also reduces the surface area of the facade and this factor must be borne in mind in any cost evaluation.

A preliminary exercise, carried out by the Market Development Unit of BSC Sections, has indicated that the use of a shelf-angle floor type of construction could increase the tonnage of steel in a multistorey building by 20% whilst reducing the total building shell cost by 2%.

5. CONCLUSIONS

A shelf angle construction involving a 406 x 178 mm x 54 kg/m beam and 125 x 75 x 12 mm angles supporting 200 mm precast concrete floor slabs has been fire tested following the BS476 : Part 8 requirements and using the maximum design load.

The unit of construction achieved a fire resistance time of 68 min, easily satisfying any Building Regulations requirement for 1 h.

The deflection time graph recorded during the test was different from those of other tests performed on simply supported steel members in that the deflection increased more rapidly in the early stages of the test due to differential thermal expansion and in the later stages the rate of deflection remained relatively constant and 'runaway' did not occur. It is thought that the interaction of the concrete slabs may have produced a load bearing raft and this could have contributed to the enhanced fire resistance observed. Some evidence for this 'raft theory' was observed due to the shear fracture of bolts holding the shelf angle which were outside the furnace. All other bolts remained intact during the test.

The results obtained from the present test apply only to this construction and cannot be made more general without the development of computer based models which should predict both the temperature rise in various parts of the partially protected member and also its stability. Preliminary work has already been performed to develop such models.

The cost benefits of utilising shelf angle floor construction require careful evaluation to show that it does not prove more expensive than conventional fire protection systems.

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TABLE 1 CHEMICAL COMPOSITION OF THE 406 x 178 mm x 54 kg/m UNIVERSAL BEAM AND 125 x 75 x 12 mm ANGLE USED IN THE TEST ARRANGEMENT

Code No.	RS383	BS4360	RS384	BS4360
Section	406 x 178 mm x 54 kg/m	Grade 43A Spec.	0.125 x 75 x 12 mm	Grade 50B Spec.
C	0.24	0.30 max.	0.15	0.24 max.
Si	0.085	0.55 max.	0.24	0.55 max.
Mn	0.93	1.70 max.	1.30	1.6 max.
P	0.013	0.06 max.	0.018	0.06 max.
S	0.029	0.06 max.	0.018	0.06 max.
Cr	<0.01		0.016	
Mo	<0.005		<0.005	
Ni	0.018		0.017	
V	<0.005		0.054	0.003/0.10
Ti	<0.005		<0.005	
Cu	0.017		0.019	
Sn	<0.005		<0.005	
Nb	<0.005		<0.005	0.003/0.10
Zr	<0.0005		<0.005	
B	<0.001		0.001	
Tot. Al	<0.01		<0.01	
N_2	0.0044		0.0058	
O_2	0.0077		0.0086	

TABLE 2 TENSILE TEST DATA FROM THE 406 x 178 mm x 54 kg/m UNIVERSAL BEAM AND 125 x 75 x 12 mm ANGLE USED IN THE TEST ARRANGEMENT

Code No.	Section	Position	Quality	Yield Stress N/mm^2	Tensile Strength N/mm^2	Elongation %
RS383F	406 x 178 mm x 54 kg/m	Flange	BS4360 Grade 43A	274	439	25
RS383W	406 x 178 mm x 54 kg/m	Web	BS4360 Grade 43A	308	477	22
	Specification	Flange	BS4360 Grade 43A	255 min.		
		Web	BS4360 Grade 43A	270 min.	430/540	20
RS384	125 x 75 x 12 mm	Long Leg	BS4360 Grade 50B	384	518	22
RS385	125 x 75 x 12 mm	Short Leg	BS4360 Grade 50B	395	523	21
	Specification		BS4360 Grade 50B	355	490/620	18

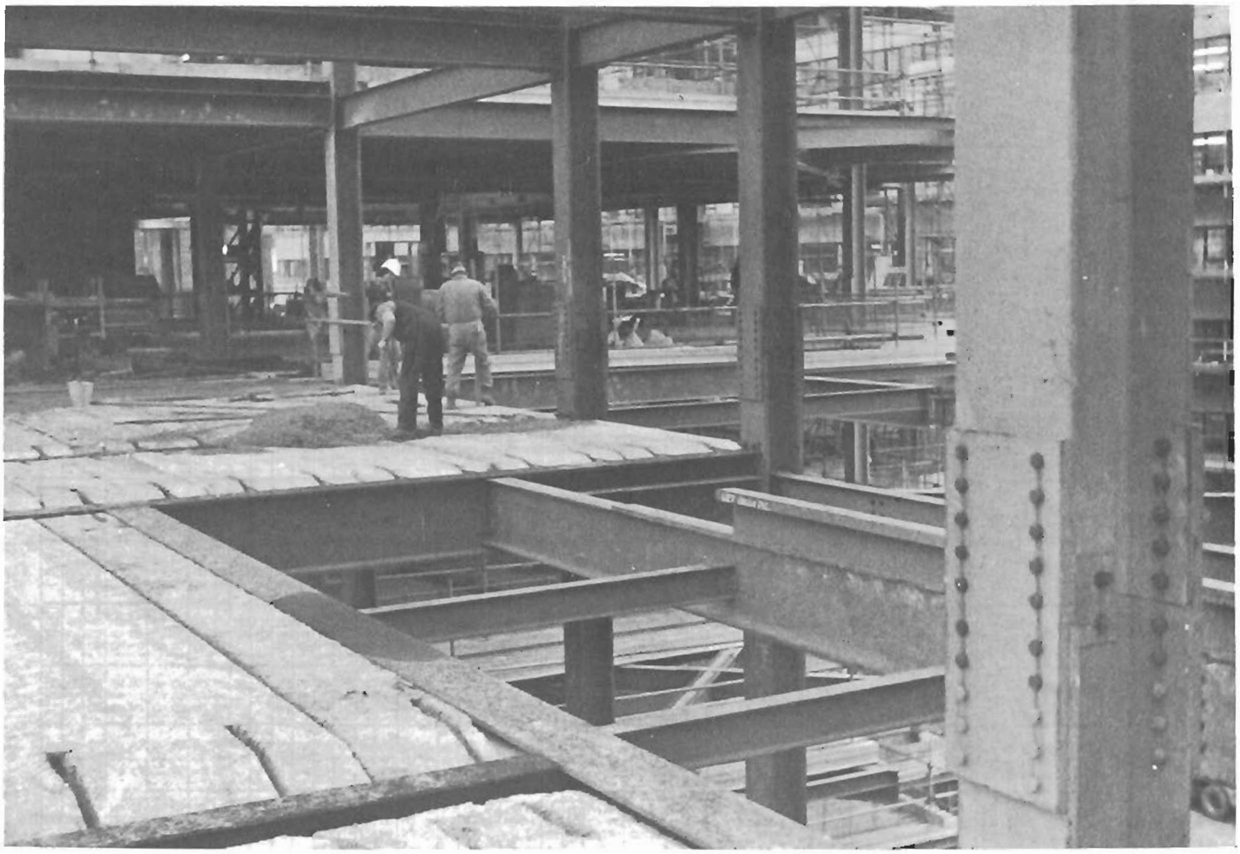
TABLE 3 CONCRETE COMPRESSION TEST RESULTS

Test Date	Age Days	Compressive Strength N/mm^2
4.11.82	145	21.5
4.11.82	143	41.5
4.11.82	142	23.5
4.11.82	141	32.5

TABLE 4 SHELF ANGLE FLOOR TEST - TEMPERATURE DATA SHEET

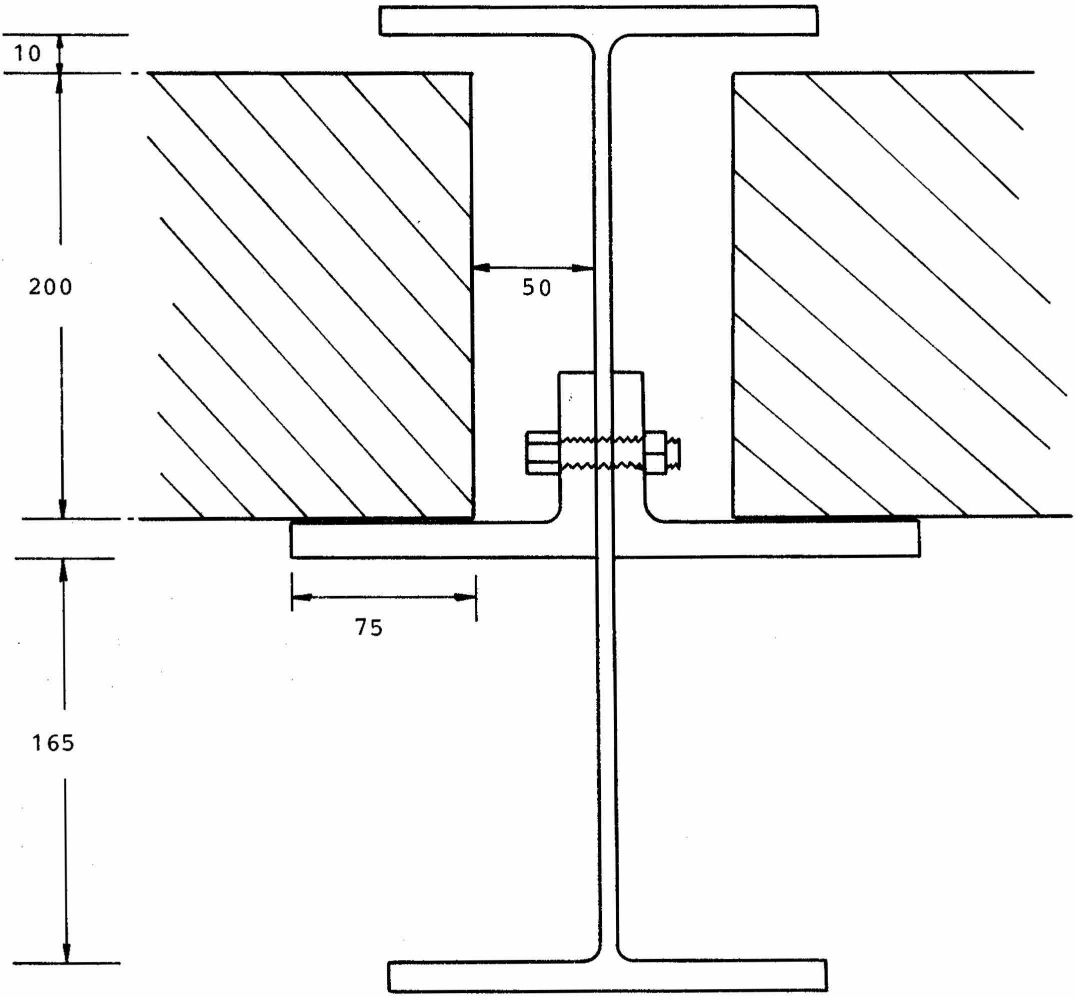
Date 3.11.82 Failure Time: 67.5 min Warrington Research Centre

Thermocouple Location	Temperature (°C) After Various Times (min)															
	3	6	9	12	15	20	25	30	35	40	45	50	55	60	65	67.5
Lower flange F2	88	194	323	442	538	638	690	738	760	792	823	850	875	896	914	922
F4	87	188	308	415	503	602	656	708	737	759	790	817	843	867	885	894
Lower flange F6	86	187	314	434	532	592	690	740	762	794	824	853	878	899	918	927
F7	90	189	310	424	516	610	674	727	748	778	810	838	865	888	916	916
Mean lower flange	88	187	314	429	522	610	677	728	752	781	812	839	865	887	908	915
Web 1/4 position W1	122	220	325	414	492	581	633	689	724	749	780	810	839	863	884	894
exposed W2	131	229	337	433	515	602	655	708	742	767	798	827	855	878	898	907
Web 1/4 position W3	117	216	321	416	495	583	633	688	722	747	781	810	838	862	883	893
exposed W4	145	231	326	400	471	553	603	655	691	722	749	776	803	830	851	864
Mean exposed web	129	224	327	416	493	580	631	685	720	746	777	806	834	866	879	889
Mean lower flange and web	108	205	320	422	508	595	654	707	736	863	794	823	849	877	894	899
Web 3/4 position W5	25	27	30	36	44	58	72	94	109	113	121	130	141	153	164	170
unexposed W6	26	27	31	37	45	60	74	98	112	119	127	137	148	162	175	182
Web 3/4 position W7	25	27	31	36	45	60	76	104	112	115	117	120	124	130	143	155
unexposed W8	26	27	30	35	43	57	70	93	107	109	109	110	112	116	121	127
Mean unexposed web	25	27	30	36	44	59	73	97	110	114	118	124	131	140	151	158
Upper flange F3	23	23	23	24	24	25	27	30	35	41	49	58	68	77	85	89
F8	25	25	25	25	33	27	29	33	37	44	52	60	70	81	93	98
Upper flange F9	25	25	25	26	26	27	29	32	36	40	46	55	67	77	89	94
Mean upper flange	24	24	24	25	28	26	28	32	36	42	49	58	68	78	89	94
Flange/web junction 19	89	134	298	402	490	592	646	701	733	750	783	811	838	683	882	893
beam 20	83	180	299	412	505	610	664	718	743	767	801	830	858	881	900	910
Exposed flange (angle) F10	115	175	233	284	343	430	492	564	613	653	692	718	746	773	792	805
F11	71	121	182	243	308	403	468	547	601	646	689	722	753	779	807	822
Exposed flange (angle) F12	93	150	208	266	338	429	496	575	624	666	709	744	776	801	830	845
Mean exposed flange (angle)	93	149	208	264	330	421	485	562	613	655	697	728	758	784	810	824
Unexposed flange (angle) W9	32	47	72	101	135	195	246	316	367	410	449	484	517	547	576	590
W10	32	50	80	115	155	227	282	356	409	453	492	528	560	591	618	631
Unexposed flange (angle) W11	31	46	71	102	139	212	269	340	380	422	468	508	544	577	607	621
W12	31	48	74	108	148	216	268	339	389	431	467	501	532	562	590	602
Mean unexposed flange (angle)	31	48	74	106	144	212	266	338	386	429	469	505	538	569	598	611
Angle root F16	38	64	101	142	187	269	331	413	470	519	561	597	631	662	690	702
F17	39	66	107	156	208	296	359	442	500	551	594	632	666	697	723	736
Angle root F18	39	65	104	146	198	284	349	432	490	539	582	620	656	686	714	727
Mean angle root	39	64	104	148	198	283	346	429	487	536	579	616	651	682	709	722
Lower flange F13	57	108	173	240	303	392	449	515	557	593	625	654	680	706	726	736
1/4 web exposed W13	81	138	199	255	310	386	436	496	537	573	608	640	670	699	726	737
Exposed flange (angle) F14	74	109	143	180	220	280	326	389	435	475	515	551	584	616	648	662
Unexposed flange (angle) W14	31	43	60	81	107	154	192	247	289	326	362	396	427	456	484	498
Unexposed flange web W15	27	28	31	35	40	52	62	79	95	111	125	139	152	163	174	179
Upper flange F15	26	26	17	28	30	34	38	44	49	55	61	68	75	83	93	98
Atmosphere 1	507	637	691	711	747	782	802	832	843	870	887	909	923	938	953	959
2	491	616	675	691	734	759	786	813	823	858	874	896	913	930	953	958
Atmosphere 3	481	627	704	732	776	806	835	855	881	896	916	931	944	964	976	983
4	487	630	698	722	760	786	816	834	860	874	893	908	924	943	959	963
Atmosphere 5	482	593	660	684	720	748	769	779	798	806	849	858	871	905	895	915
6	478	605	656	682	723	751	769	787	809	825	852	863	880	903	907	923
Average atmosphere	488	618	681	704	743	772	796	817	836	855	878	894	909	930	940	950
ISO curve RT 23°C	505	606	666	708	741	784	818	845	868	888	905	921	935	948	960	966
Central beam deflection, mm	4	12	24	34	45	57	68	79	89	99	106	115	123	132	142	149



SHELF ANGLE FLOOR DESIGN BEING USED IN THE CONSTRUCTION OF A MULTISTOREY BUILDING — FIG. 1

Beam size	406 x 178 mm x 54 kg/m
Angle size	125 x 75 x 12 mm
Bolts	M20 Grade 4.6

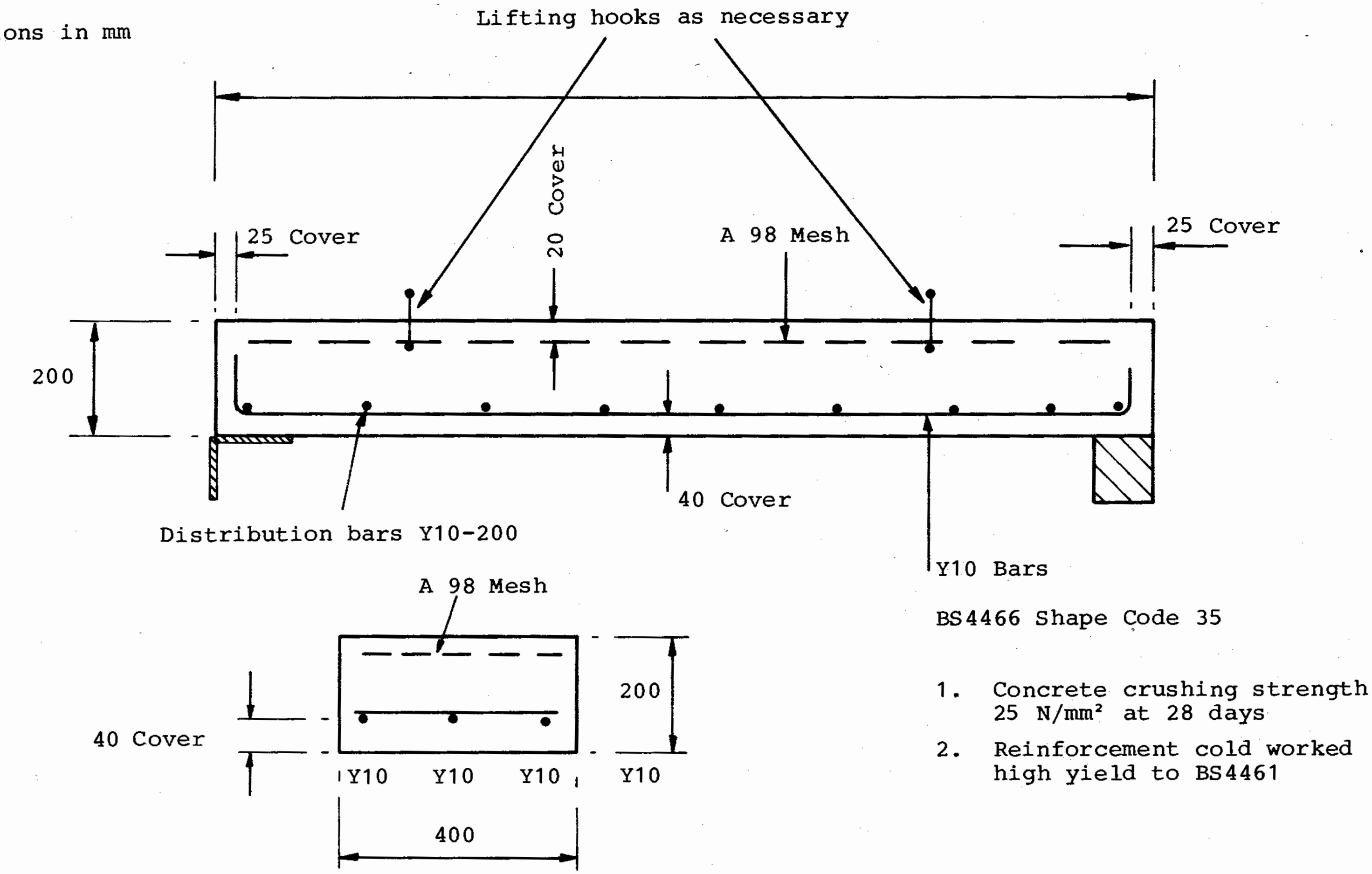


Dimensions in mm

SCHEMATIC ILLUSTRATION OF TEST ARRANGEMENT

FIG. 2
(R1/8766)

All dimensions in mm



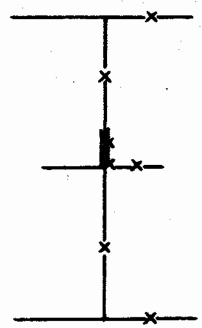
BS4466 Shape Code 35

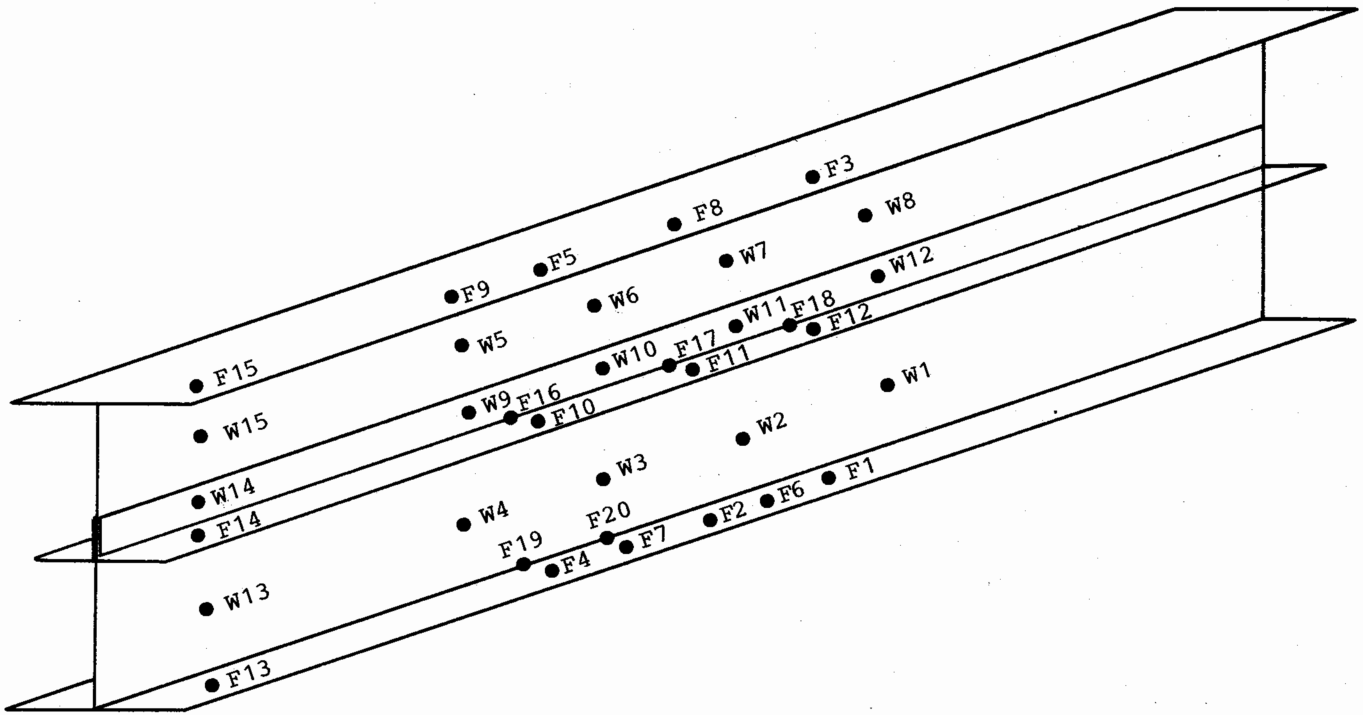
1. Concrete crushing strength 25 N/mm² at 28 days
2. Reinforcement cold worked high yield to BS4461

PRECAST CONCRETE SLAB DESIGN USED IN TEST

FIG. 3
(R1/8767)

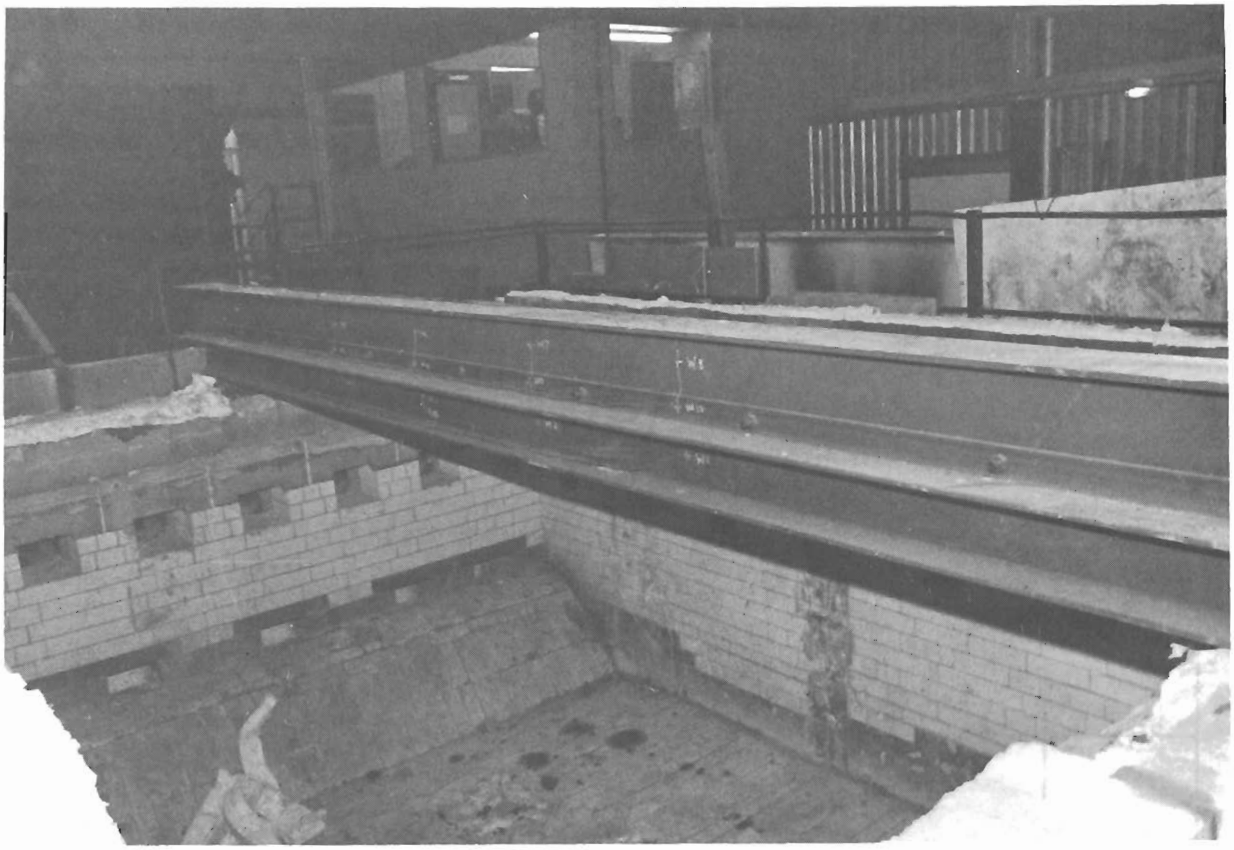
F9, W9, W4, W5	-	1.57 m
W10, F7, W3, W6	-	2.17 m
W11, F6, W2, W7	-	2.80 m
W12, W1, W8	-	3.42 m
F11, F2, F8	-	2.50 m
F4, F10, F5	-	1.88 m
F1, F12, F3	-	3.12 m





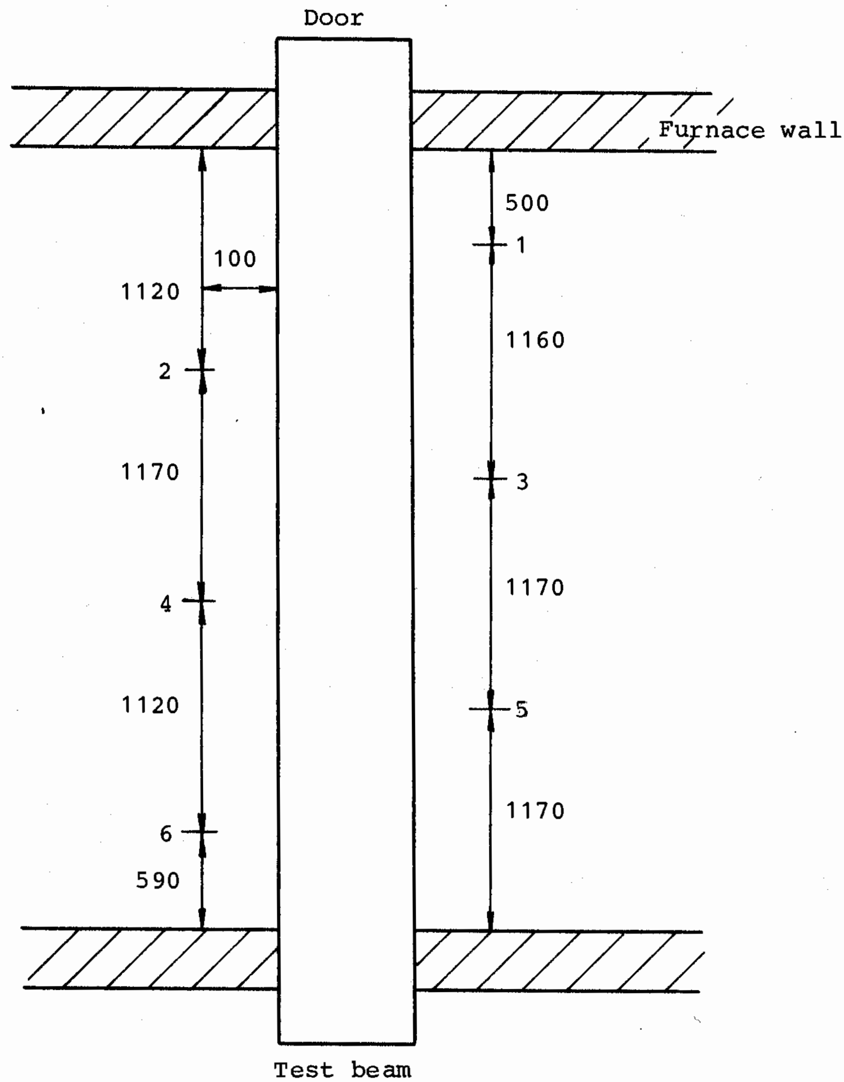
<u>THERMOCOUPLE LOCATIONS USED ON TEST ARRANGEMENT</u>

FIG. 4
(R1/8768)



PHOTOGRAPH OF TEST BEAM ON FURNACE SHOWING POSITIONS OF THE ATTACHED THERMOCOUPLES

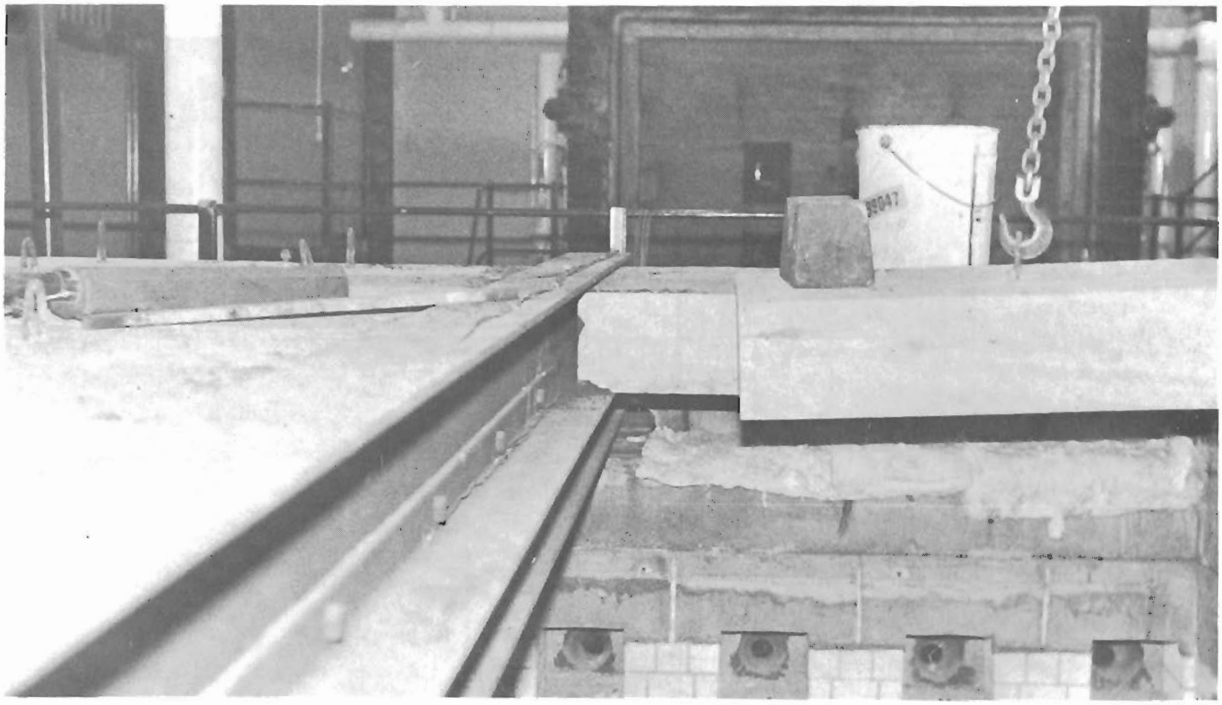
FIG. 5

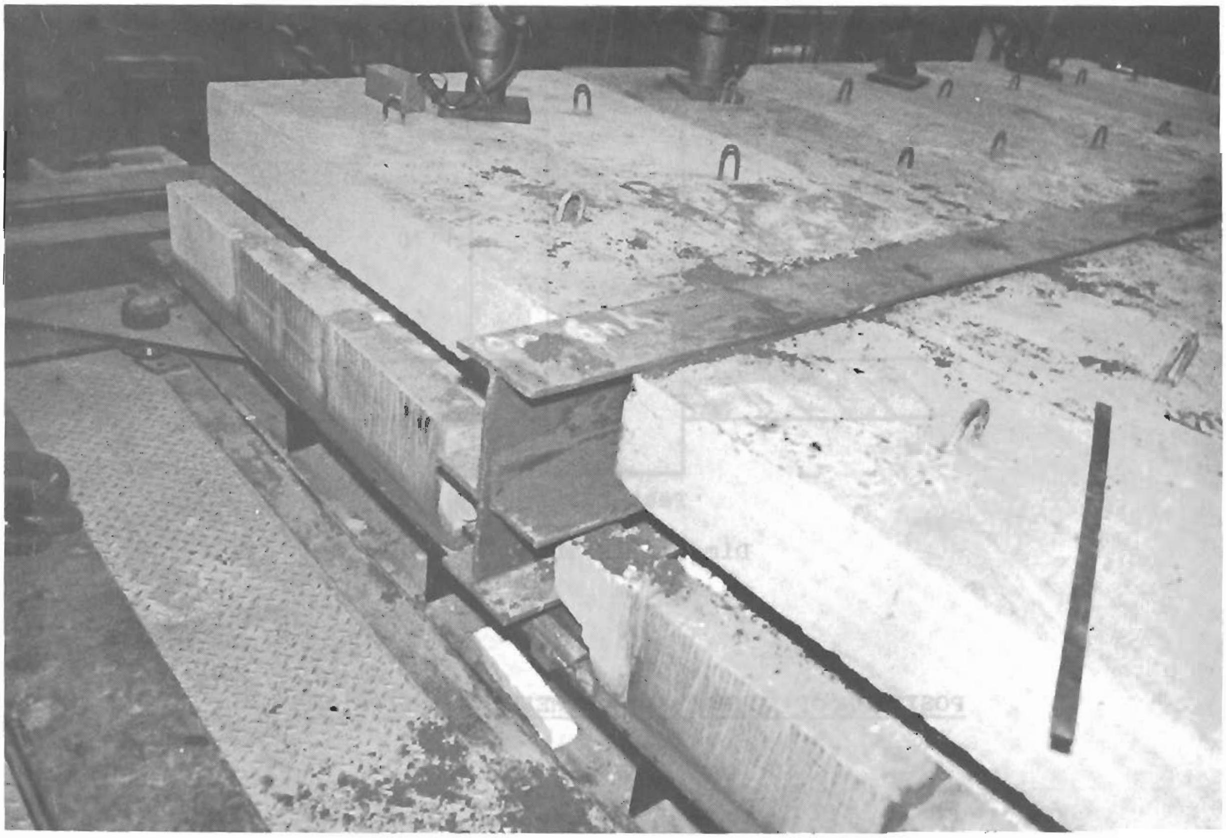


Dimensions in mm

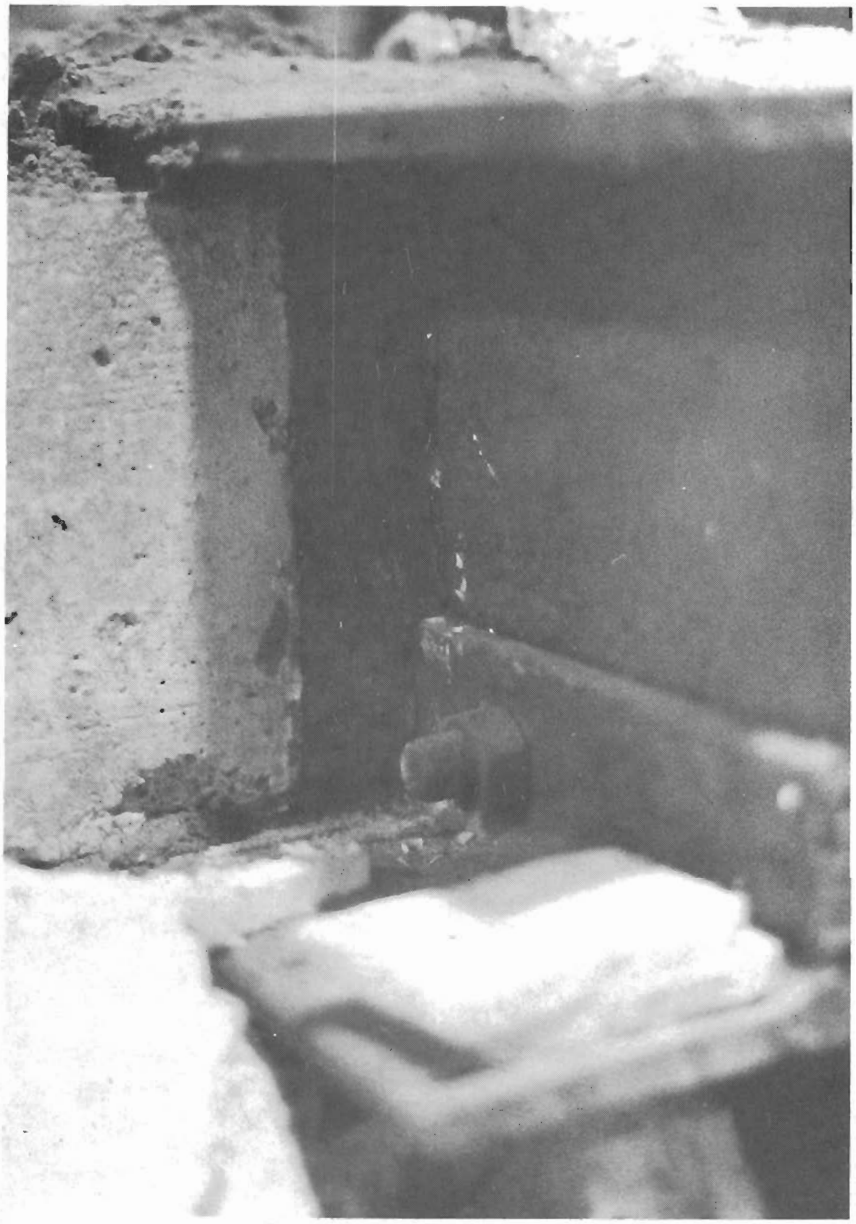
POSITION OF FURNACE ATMOSPHERE THERMOCOUPLES

FIG. 6
(R1/8769)



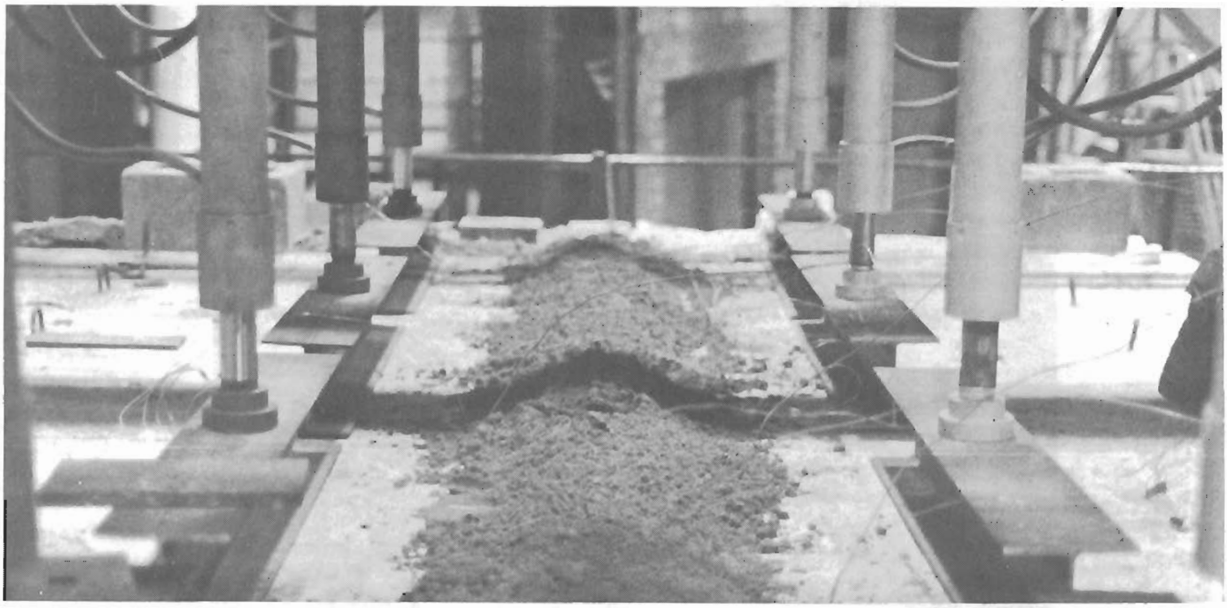


CONSTRUCTION OF TEST ARRANGEMENT FIG. 7

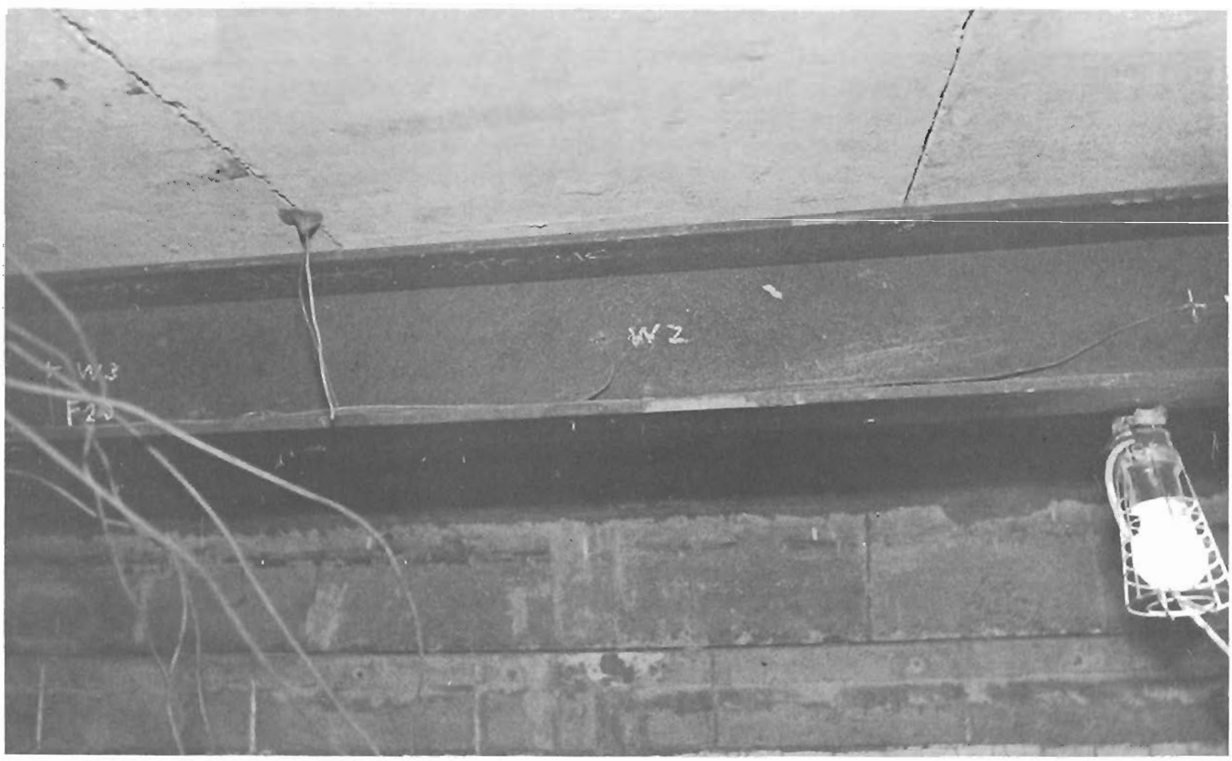


VOID FILLED WITH SAND TO SIMULATE THE THERMAL CHARACTERISTICS OF THE SCREED USED IN SITE PRACTICES

FIG. 8

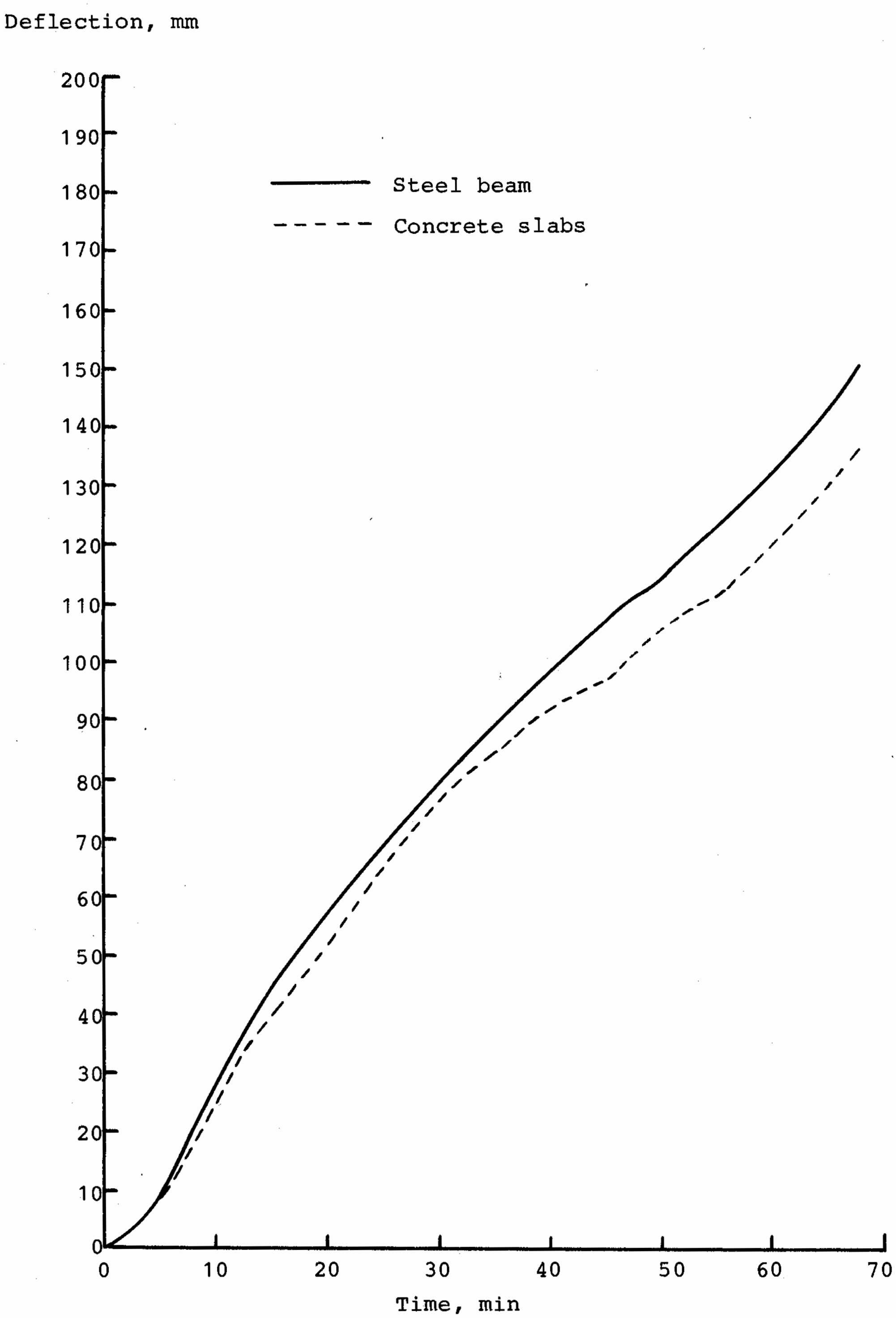


Furnace top side



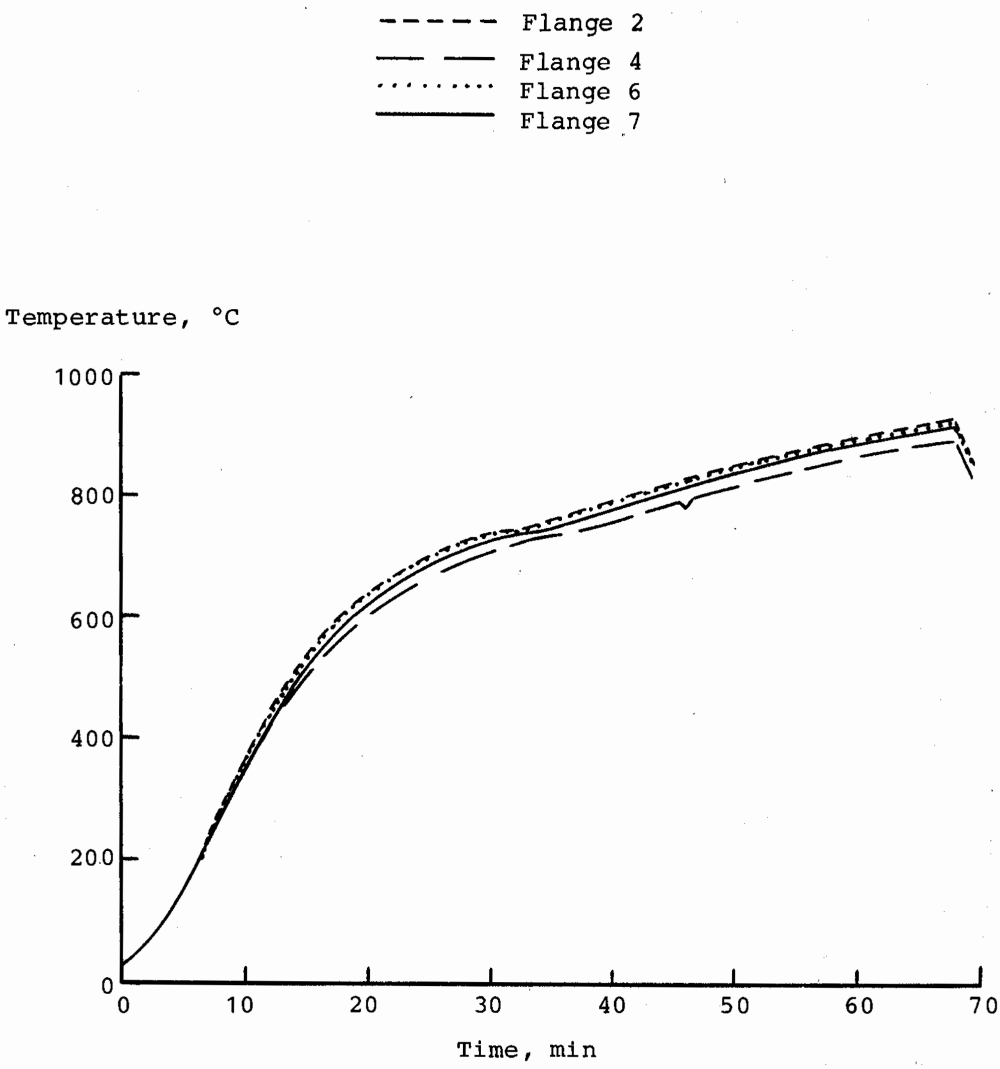
Inside furnace

COMPLETE ARRANGEMENT JUST PRIOR TO TESTING FIG. 9



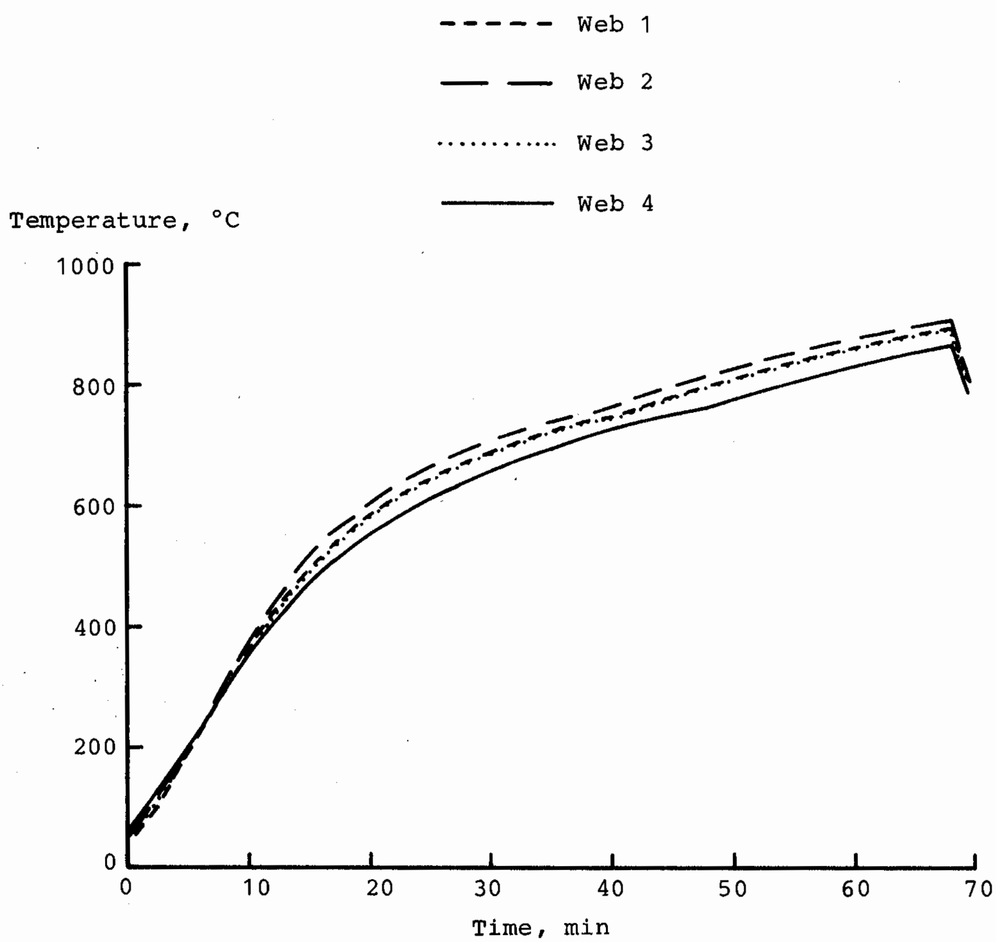
CENTRAL VERTICAL DEFLECTION OF BEAM AND CONCRETE SLABS MEASURED THROUGHOUT THE TEST

FIG. 10
(R1/8770)



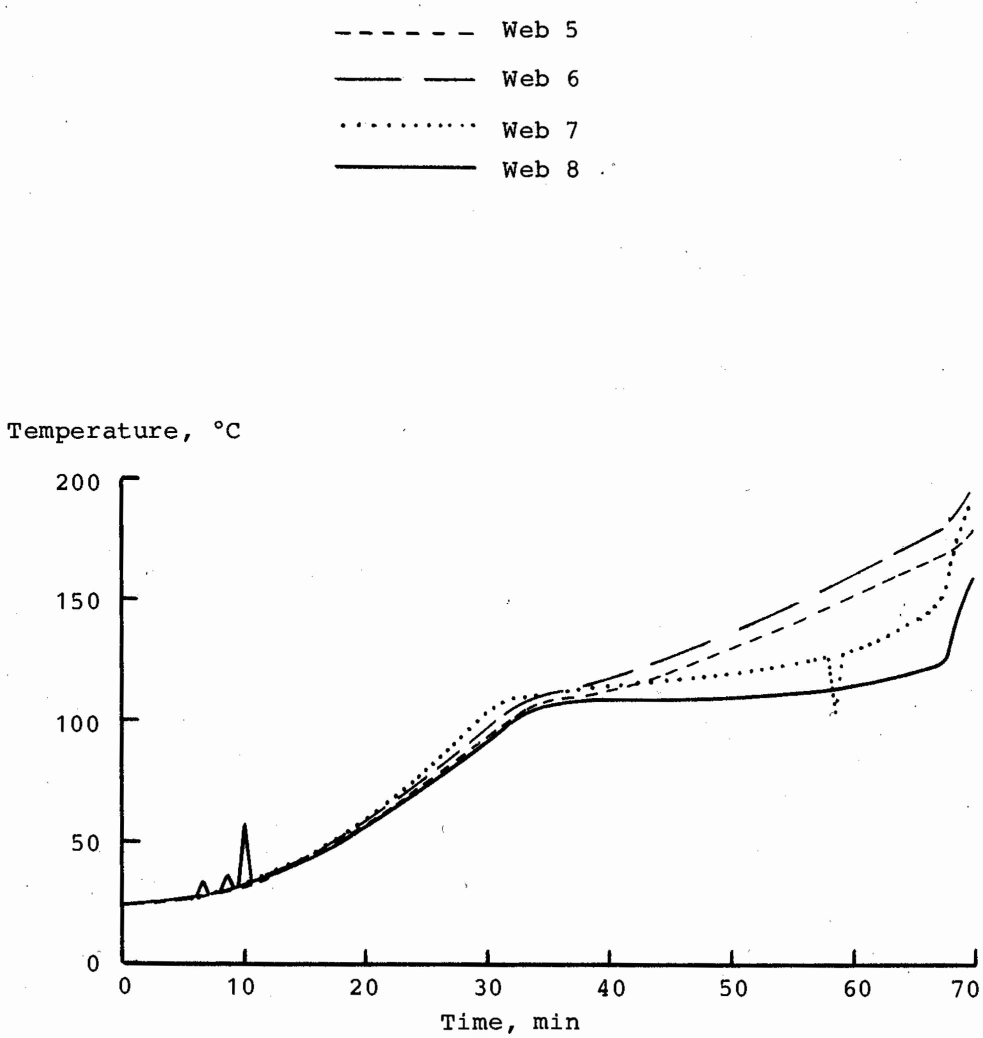
TEMPERATURES RECORDED ON THE LOWER FLANGE OF THE TEST BEAM DURING THE TEST

FIG. 11
(R1/8771)



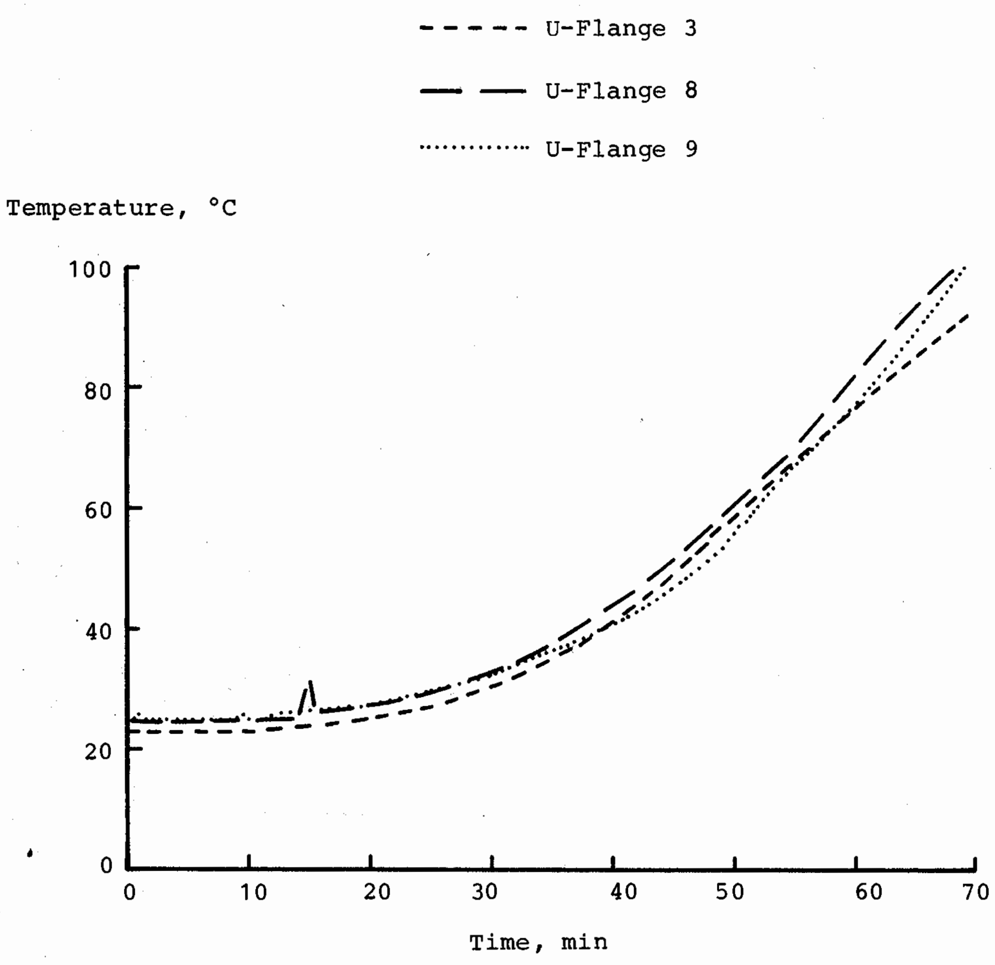
TEMPERATURES RECORDED ON THE EXPOSED WEB OF THE TEST BEAM AT THE QUARTER-WIDTH POSITION

FIG. 12
(R1/8772)



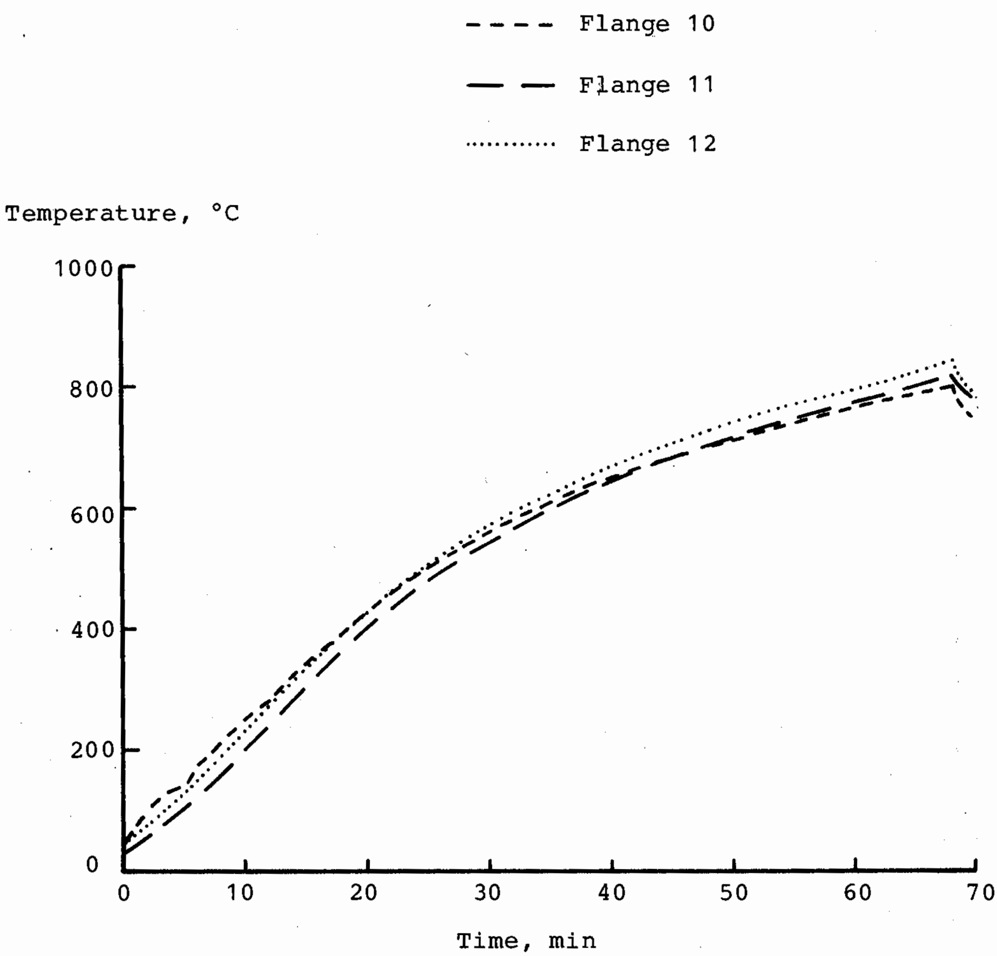
TEMPERATURES RECORDED ON THE UNEXPOSED WEB OF THE TEST BEAM AT THE THREEQUARTER-WIDTH POSITION

FIG. 13
(R1/8773)



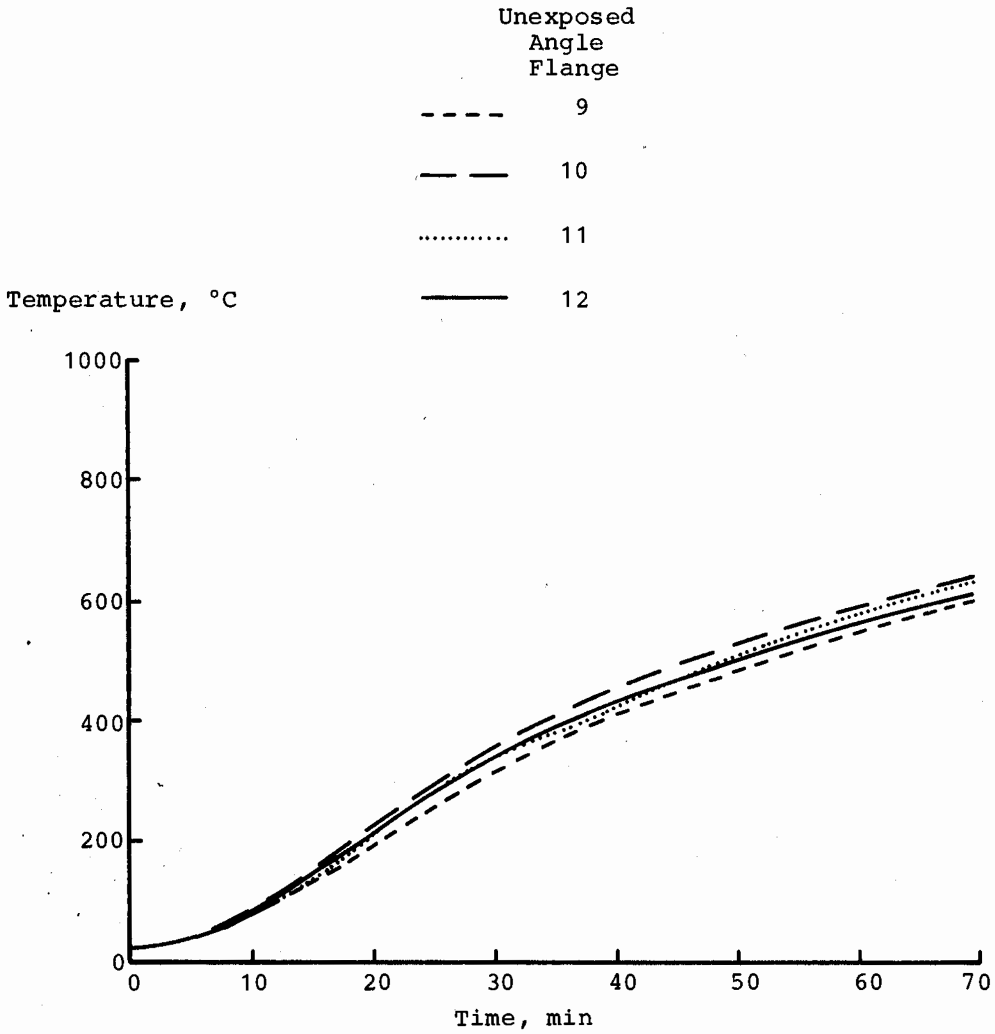
<u>TEMPERATURES RECORDED ON THE UPPER FLANGE OF THE TEST BEAM DURING THE TEST</u>

FIG. 14
(R1/8774)



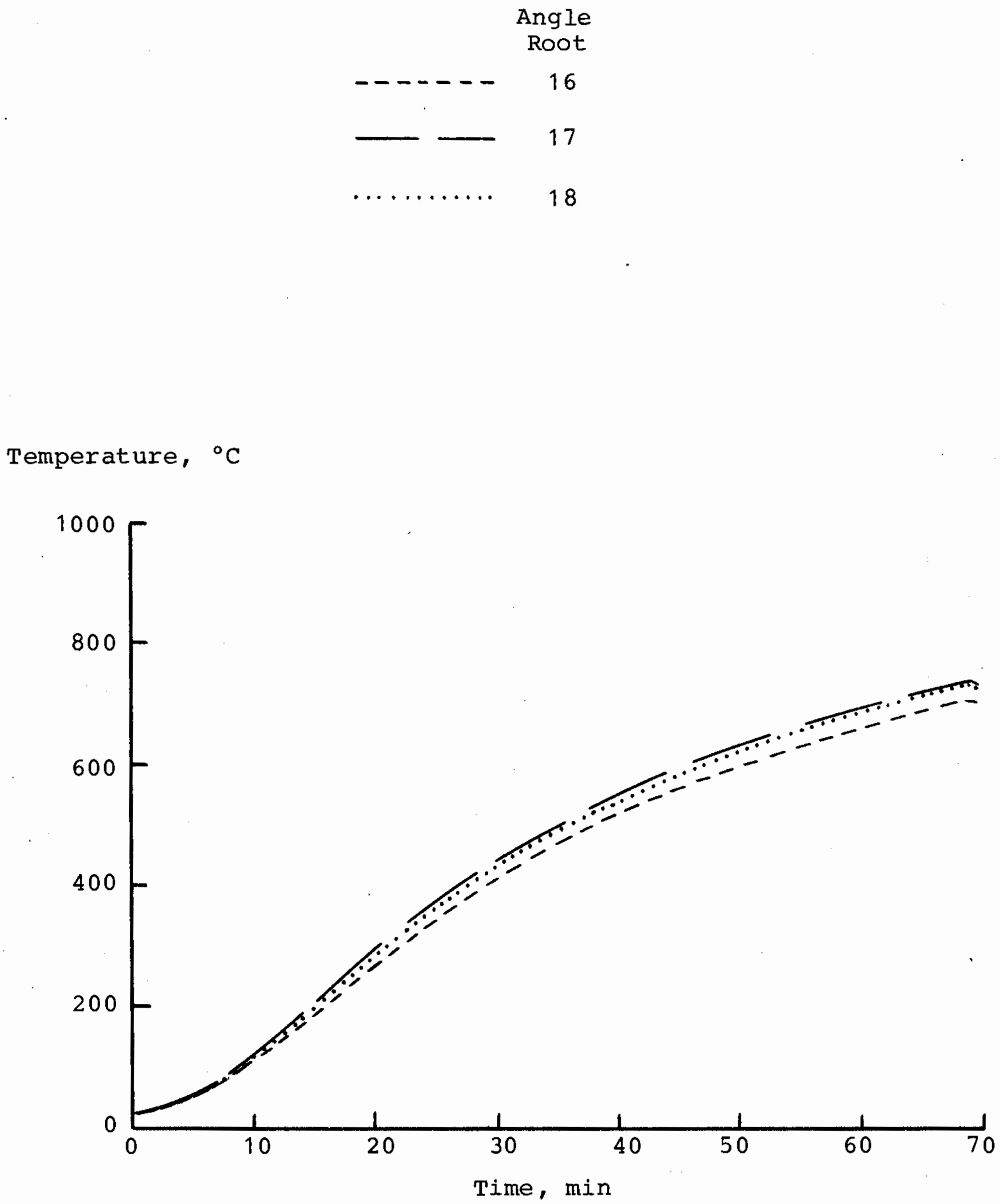
TEMPERATURES RECORDED ON THE EXPOSED FLANGE OF THE ANGLE DURING THE TEST

FIG. 15
(R1/8775)



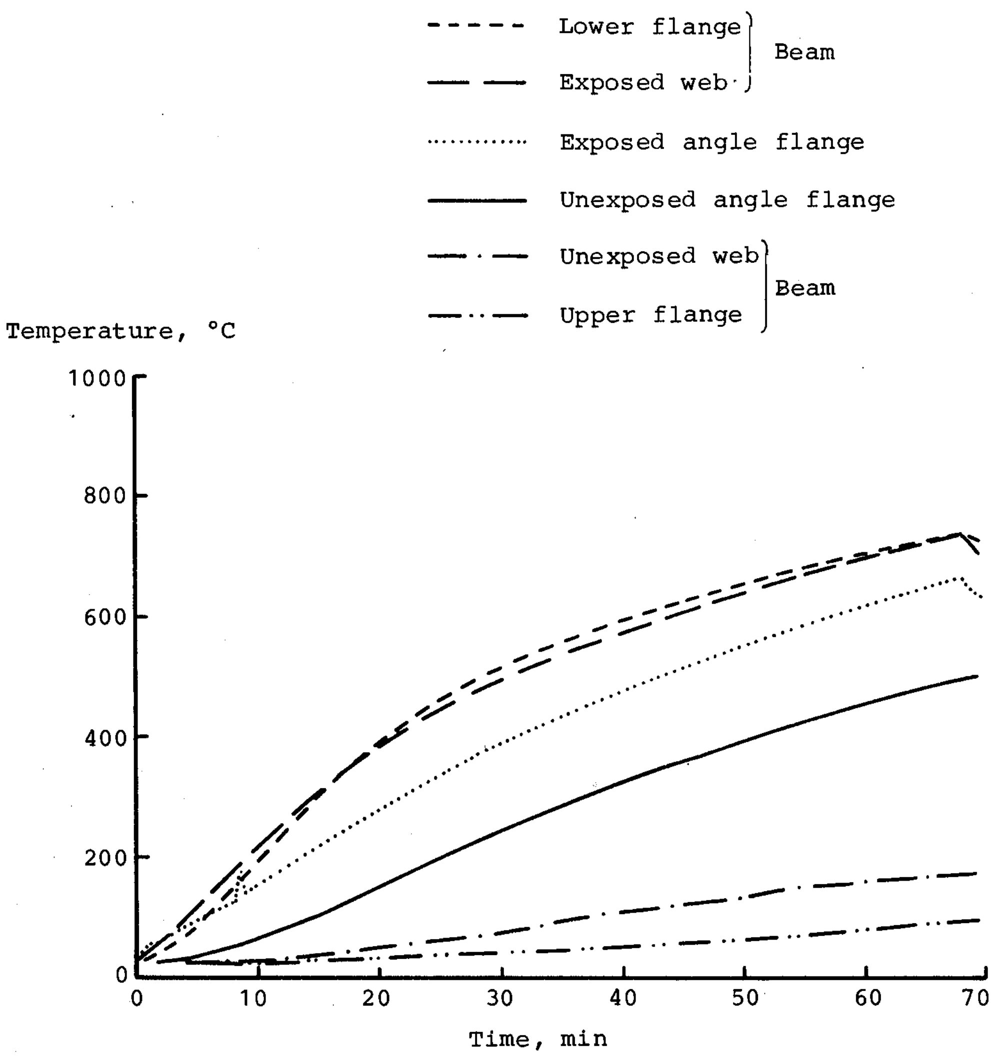
TEMPERATURES RECORDED ON THE UNEXPOSED FLANGE OF THE ANGLE DURING THE TEST

FIG. 16
(R1/8776)



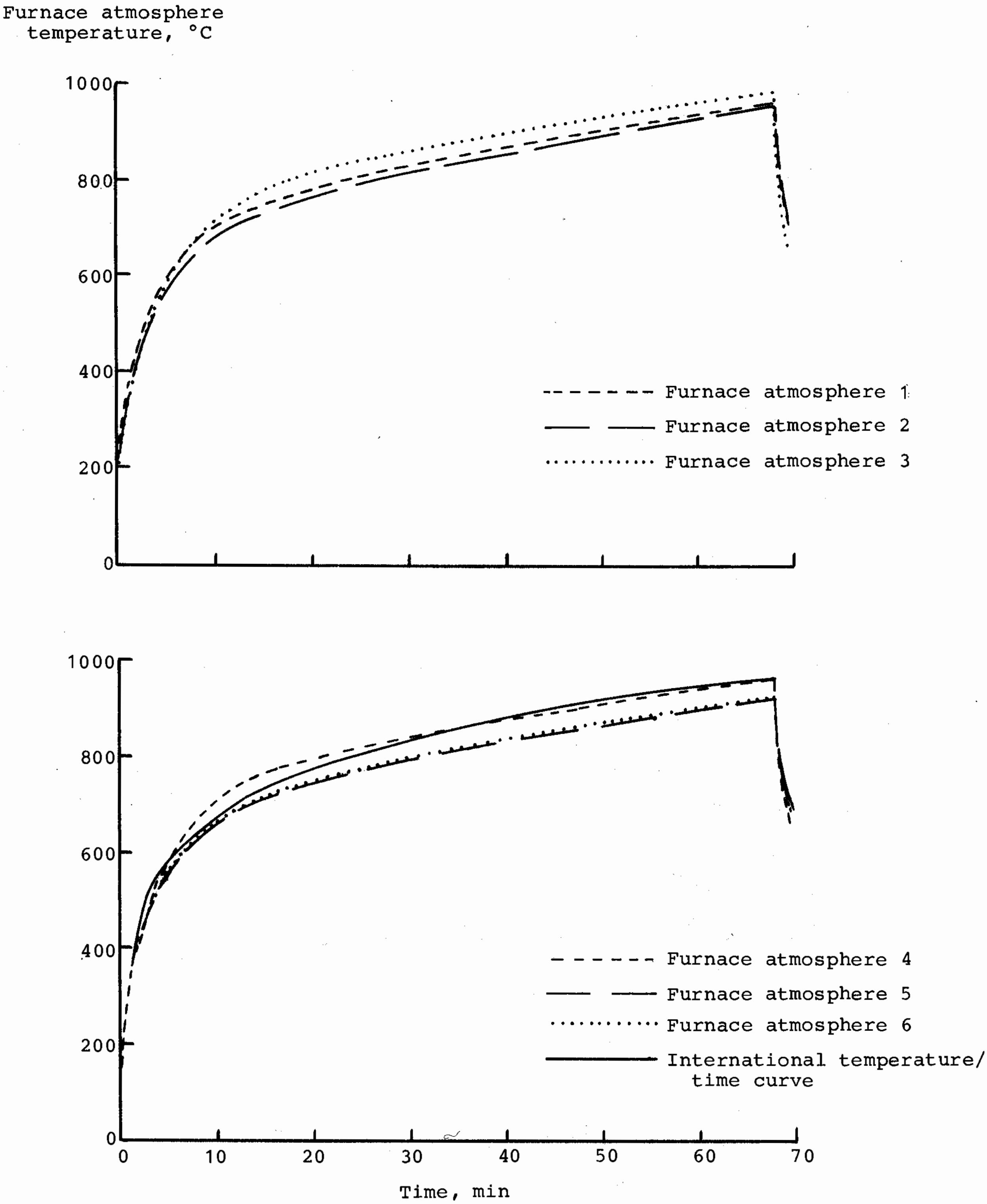
<u>TEMPERATURES RECORDED AT THE ROOT OF THE ANGLE DURING THE TEST</u>

FIG. 17
(R1/8777)



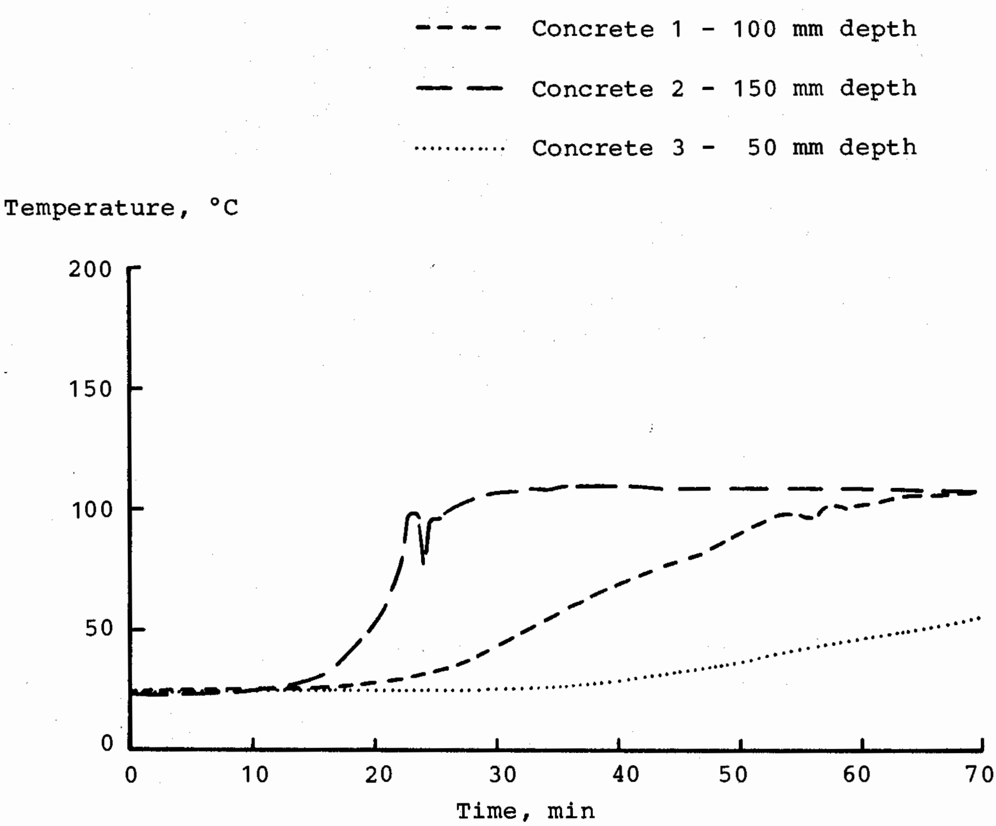
HEATING RATES RECORDED FROM
ADDITIONAL THERMOCOUPLES ON TEST ARRANGEMENT
POSITIONED 100 mm AWAY FROM THE FURNACE WALL

FIG. 18
(R1/8778)



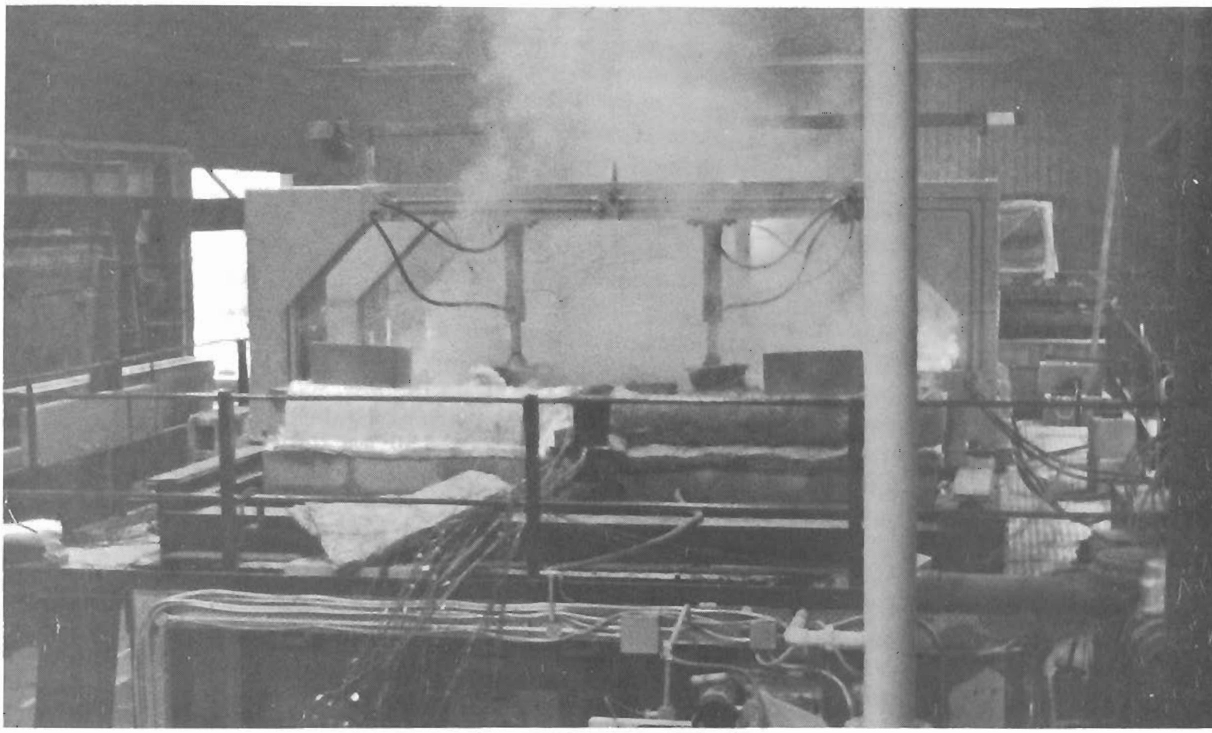
FURNACE ATMOSPHERE TEMPERATURES
RECORDED DURING THE TEST

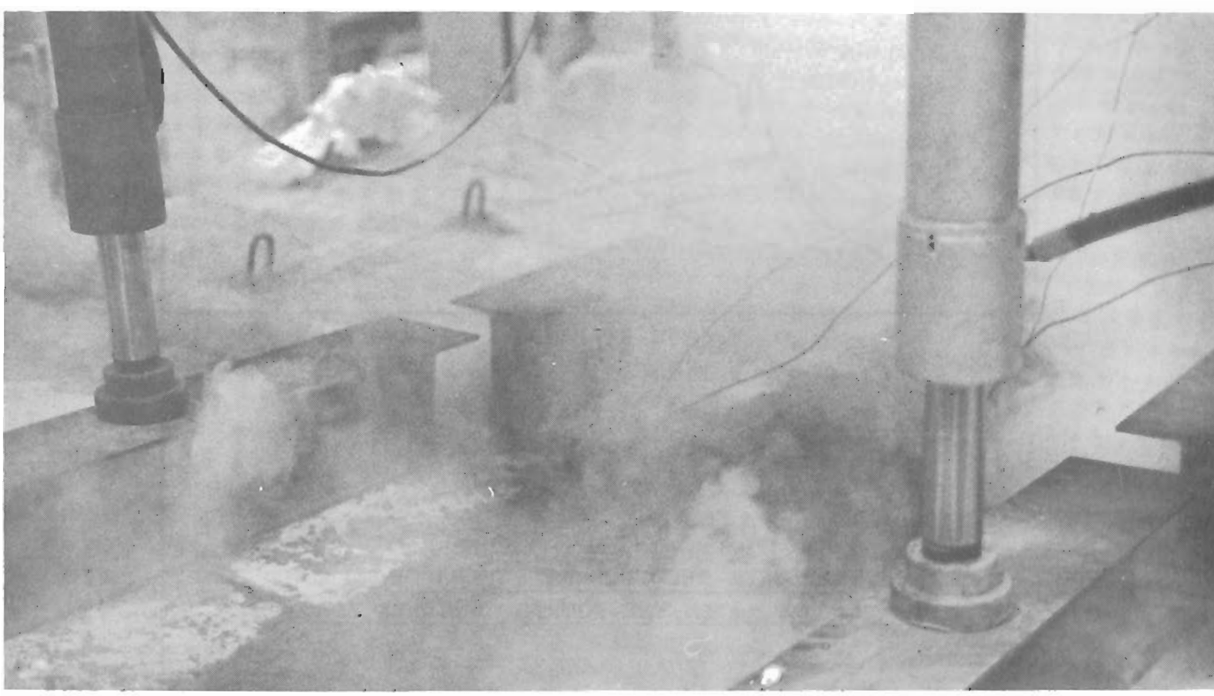
FIG. 19
(R1/8779)



TEMPERATURES RECORDED AT DEPTHS OF
50, 100 AND 150 mm IN THE FOURTH CONCRETE SLAB

FIG. 20
(R1/8786)



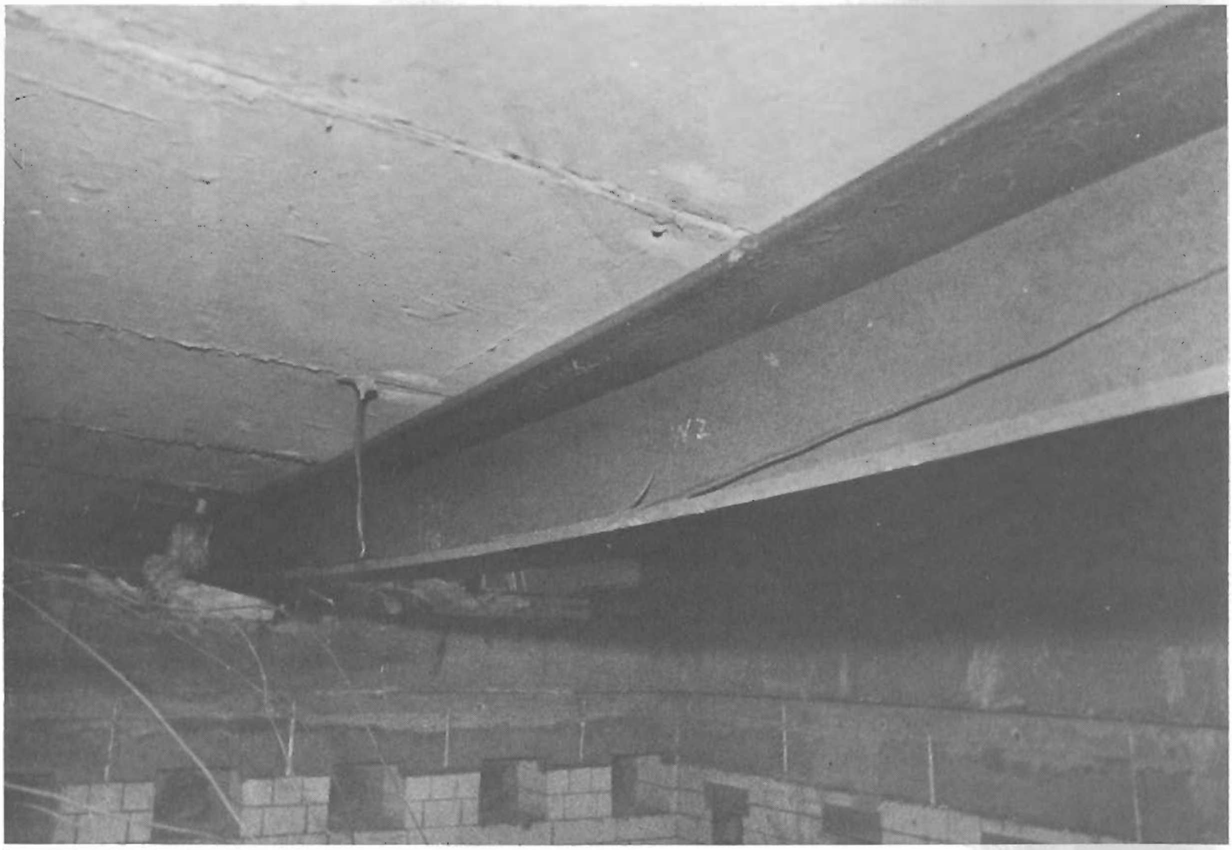


LIGHT DENSE FUMES WHICH WERE CONTINUALLY PRESENT THROUGHOUT THE TEST

FIG. 21

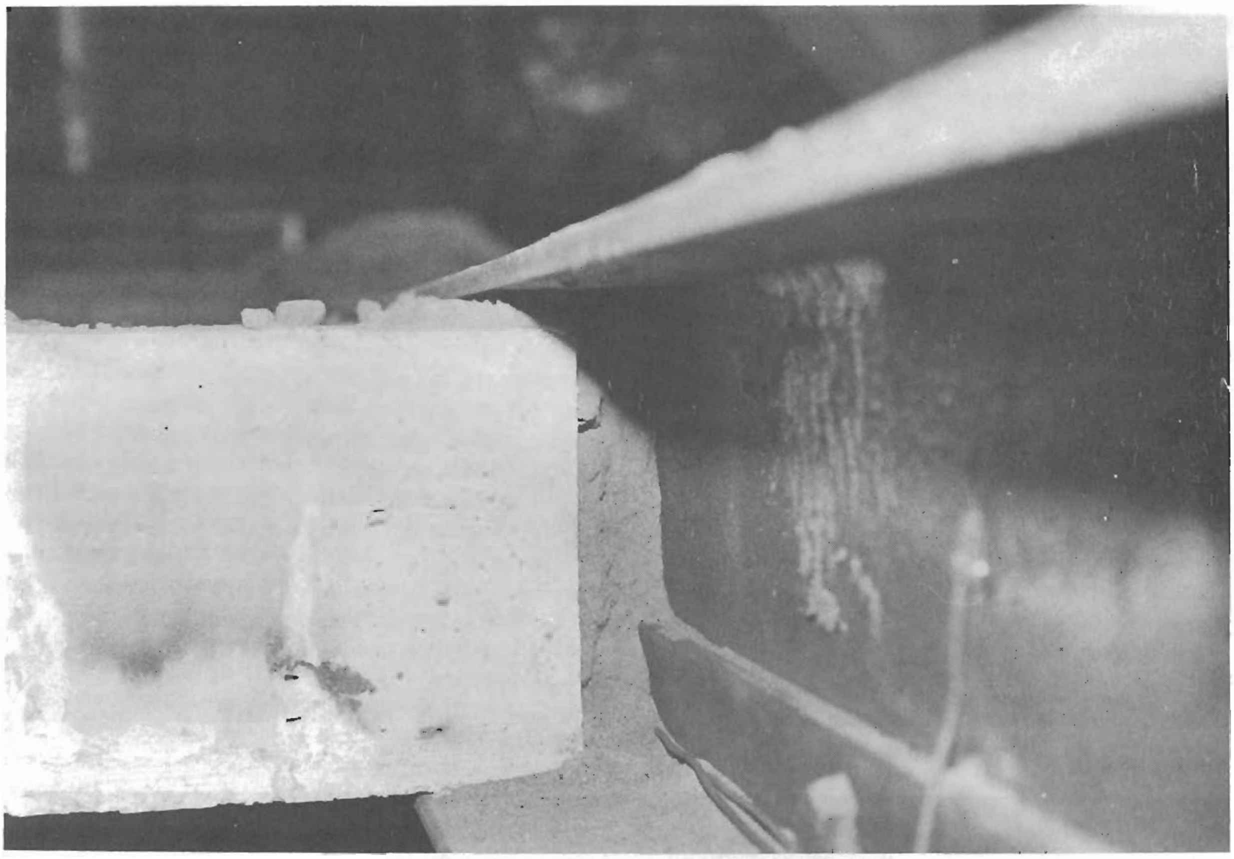
STEPWISE PATTERN FORMED BY THE CONCRETE SLABS AS THE DEFLECTION ON THE BEAM INCREASED

FIG. 22

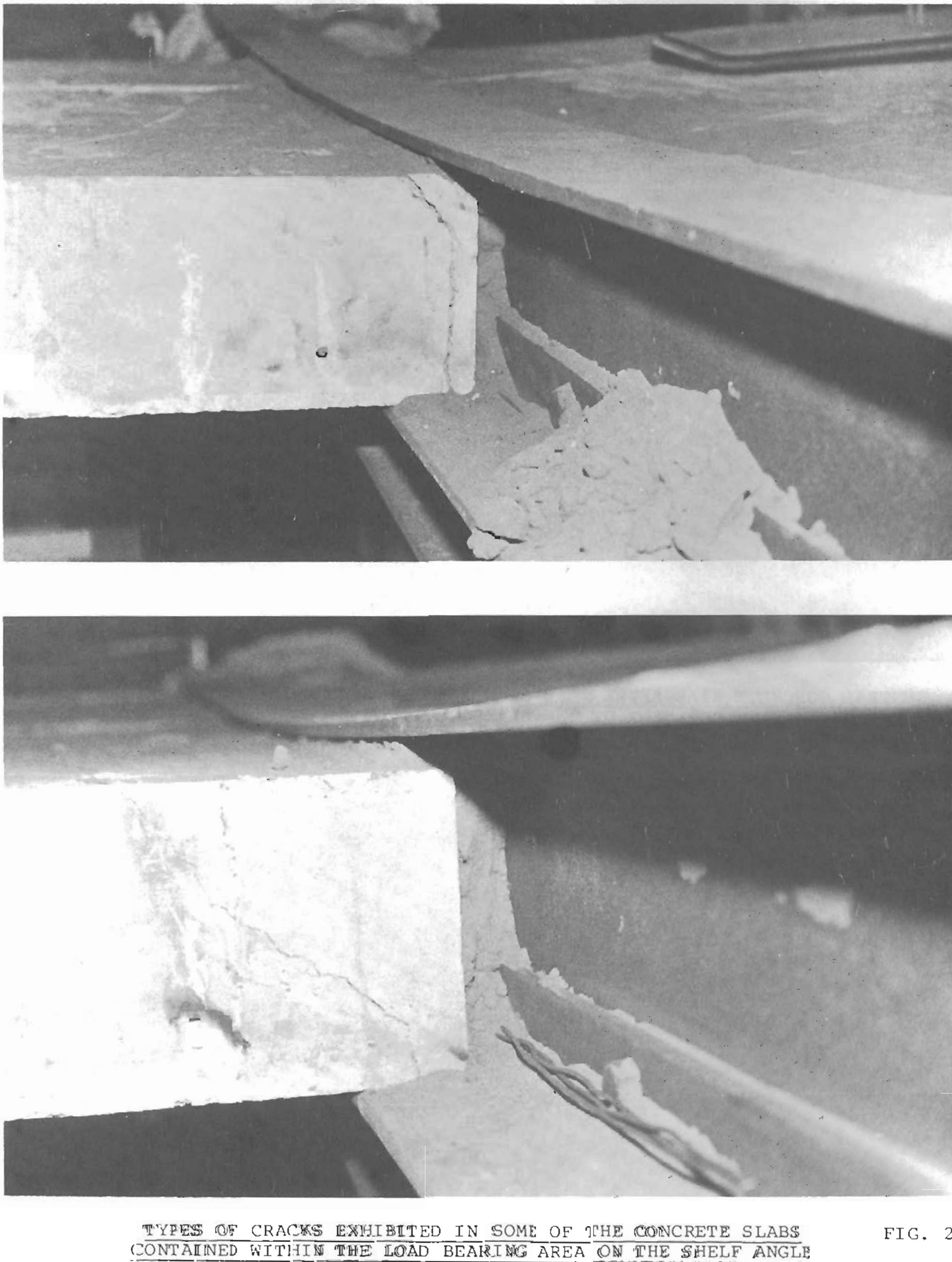


UNDERSIDE OF THE TEST ARRANGEMENT AFTER TESTING SHOWING THE BEAM AND ANGLE HAD DEFORMED UNIFORMLY

FIG. 23



CENTRAL CONCRETE SLAB AFTER TEST SHOWING THAT THERE WAS NO SIGNIFICANT MOVEMENT OF THE SLABS DURING THE TEST FIG. 24



TYPES OF CRACKS EXHIBITED IN SOME OF THE CONCRETE SLABS CONTAINED WITHIN THE LOAD BEARING AREA ON THE SHELF ANGLE

FIG. 25

WAVEY PATTERN FORMED ALONG THE SHELF ANGLE DURING THE TEST FIG. 26

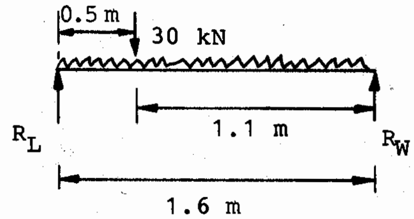
APPENDIX 1 DESIGN CALCULATIONS FOR PRECAST CONCRETE FLOOR SLABS

Floor Slabs

Consider a concrete strength at 28 days = 25 N/mm^2.

Let slab depth = 200 mm
slab width = 1000 mm

Concrete cover to steel ≃40 mm for 4 h resistance.



Consider a load from the loading frame = 30 kN
Self weight of slab = 24 x 0.2 = 4.8 kN/m
Total distributed load = 4.8 x 1.6 = 7.7 kN
Reaction from the shelf angle R_L = 20.6 + 3.85 = 24.45 kN
Reaction from the wall R_W = 9.4 + 3.85 = 13.25 kN
Bending moment at load point = $(24.45 \times 0.5) - (4.8 \times \frac{0.5^2}{2})$

= 11.63 kN m

Effective depth of tensile reinforcement = d_1 = 155 mm
slab width = b = 1000 mm

Resistance moment of section m = k bd_1^2

$$\therefore \frac{M}{bd^2} = \frac{11.63}{1 \times 0.155^2} = 484$$

From graphs of lever arm ratio, j against $\frac{M}{bd^2}$ for the maximum permissible steel stress, then j = 0.90

∴ Lever arm, la = 0.90 x 155 = 139.5

From CP 114 : Part 2 1969

Based on the tensile reinforcement M = A_{ST} P_{ST} la

where A_{ST} = area of tensile reinforcement

P_{ST} = permissible tensile stress in reinforcement = 230 N/mm^2 from Table 11.

la = 139.5 mm

$$\therefore A_{ST} = \frac{11.63 \times 10^6}{230 \times 139.5} = 362.5 \text{ mm}^2$$

∴ Provide 5 off Y10 - 200 bars as tensile reinforcement.

Shear Stress across reinforced concrete slab = $\frac{R_L}{b\ la} = \frac{24.45 \times 10^3}{10^3 \times 139.5}$

= 0.18 N/mm^2
(permissible shear <0.8 N/mm^2)

<u>Bond Stress</u> = $\frac{R_L}{la \times 0}$, where 0 = sum of perimeters of tensile reiforcement

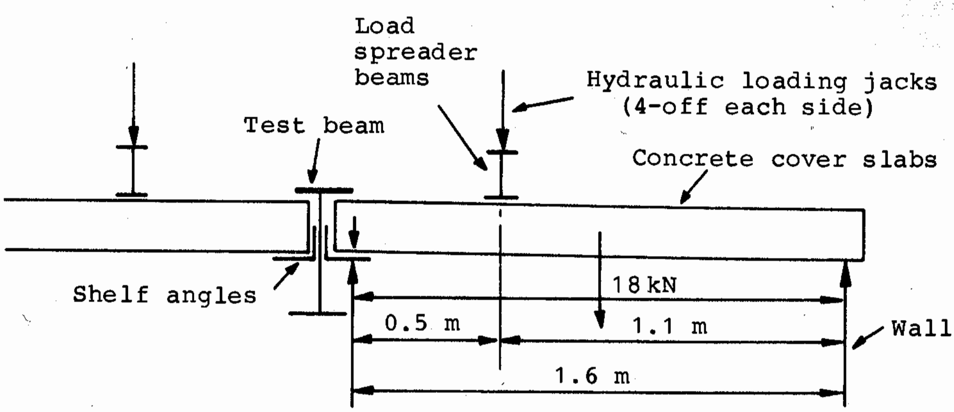
$= \frac{24.45 \times 10^3}{(139.5) \times 5 \times 31.4} = 1.11 \text{ N/mm}^2$ (Permissible local bond stress <1.5 N/mm^2)

<u>Bearing Stress</u> Assume 75 mm of bearing

$= \frac{24.45 \times 10^3}{10^3 \times 75} = 0.326 \text{ N/mm}^2$ (Permissible bearing stress <6.5 N/mm^2)

APPENDIX 2   SHELF ANGLE : CONCRETE FLOOR TEST

Beam 406 x 178 x 54 kg/m
Shelf angles 125 x 75 x 10 (15 kg/m) - 2 off
Distance between beam end supports = 4.5 m
Safe working load uniformly distributed = 271 kN (Assume working stress of 165 N/mm^2)



(i) Self weight of cover slabs and spreader beams - 36 kN
Reaction on each shelf angle due to (i) above $\frac{36}{2} \times \frac{1}{2} = 9$ kN

(ii) Total force required on each shelf angle to produce working stress in test beam = $\frac{271}{2}$ = 135.5 kN - 9 kN (self Wt. cover slabs)

= 126.5 kN

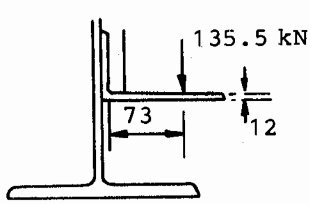
Force required by each set of jacks to produce (ii) above

$= \frac{126.5 \times 1.6}{1.1} = \underline{184}$ kN

∴ Force required at each loading jack = $\frac{184}{4} = \underline{46}$ kN

Total hydraulic forces applied = 46 x 8 $\underline{368}$ kN (36.9 tonf)

TO CALCULATE STRESS IN SHELF ANGLE



Bending moment/m = $\frac{135}{4.5} \times 73$

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

∴ BM stress = $\frac{135 \times 73 \times 6 \times 1000}{4.5 \times 1000 \times 12^2} = 91$ N/mm^2

Shear stress = $\frac{135 \times 1000}{4.5 \times 12 \times 1000} = 2.5$ N/mm^2

i.e. $R\theta = 114.592$

Substituting this value in Equation A3.2 we have:-

$$\frac{4.042 \times 360}{2 \pi \times 2} = \theta R + 0.4060$$

$$0.406 \times \theta = \frac{4.042 \times 360}{4 \pi} - 114.59$$

$$0.406 \times \theta = 115.795 - 114.592$$

$$= 1.203^{o}$$

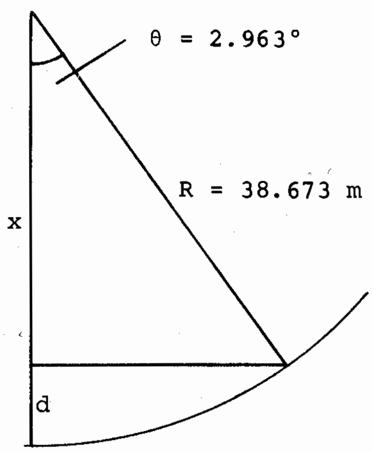
$$\therefore \quad = \underline{2.963^{o}}$$

And using Equation A3.1

$$R = \frac{4 \times 360}{4 \ \theta \pi}$$

$$= 38.673 \text{ m}$$

Using the values of R and θ the value of d = deflection can be determined as follows



$$\text{Now } \cos \theta = \frac{x}{R} \text{ or } x = R \cos \theta$$

$$\therefore x = 38.673 \times 0.9986631$$

$$= 38.6213$$

$$\therefore d = 38.673 - 38.621$$

$$= 0.52 \text{ m} = 52 \text{ mm}$$

Hence a deflection of 52 mm could arise from differential thermal expansion.

INITIAL CIRCULATION

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Standard Circulation

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Mr. G. Thomson

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GENERAL STEELS GROUP

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