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Shelf-Angle Floor Systems Based on 254 x 146 mm x 43 kg/m Universal Beams

British Steel Technical

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SHELF-ANGLE FLOOR SYSTEMS BASED ON 254 x 146 mm x 43 kg/m UNIVERSAL BEAMS

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SYNOPSIS

There is a significant commercial value to any load bearing subassembly which can achieve a fire resistance time in excess of 60 minutes without the need to apply external fire protection. The shelf-angle floor is one such system and work, at Swinden Laboratories, has concentrated on the provision of easily used design tables to extend its use. The present report deals with shelf-angle floor systems based on 254 x 146 mm x 43 kg/m universal beams.

For room temperature design the presence of the steel angles is ignored and the loads suitable for the 254 x 146 mm x 43 kg/m beams can be readily obtained from safe load tables. In the present report a further design table is developed from which it is possible to read off the fire resistance time of the shelf-angle floor beam as a function of the imposed load and the depth of beam exposed to the flames. This table is based on a mathematical model which has been validated by two standard fire resistance tests. The designer can use the table to adjust either the design load or the floor slab thickness to achieve the level of fire resistance required by the Building Regulations.

Similar design tables will now be determined for shelf-angle floor systems based on 406 x 178 mm x 54 kg/m and 305 x 165 mm x 40 kg/m universal beams.

KEY WORDS

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CONTENTS **PAGE**

SHELF-ANGLE FLOOR SYSTEMS BASED ON 254 x 146 mm x 43 kg/m UNIVERSAL BEAMS

1. INTRODUCTION

When a fire becomes fully developed in a compartment of a multistory building the temperature of the steel beams, supporting the floor above the fire compartment, begins to rise. As the steel temperature rises, its flow stress decreases and for fires of high intensity and long duration there will come a point where the beam is no longer able to support the load imposed on it. The time taken to reach this point can be extended by protecting the steel beam from direct attack by the flames. One economic method of providing this protection is by means of the shelf-angle floor design where precast concrete floor slabs rest on steel angles attached to the web of the beam, Fig. 1, so shielding the upper flange and part of the web from direct attack by the flames. The resulting decrease in heating rate significantly extends the fire resistance time of the steel beam.

An earlier report[1] gave details of standard fire resistance tests carried out on shelf-angle floor systems based on 406 x 178 mm x 54 kg/m universal steel beams. It was shown that it is possible to design shelf-angle floor beams having standard fire resistance times in excess of 1 hour which is the point beyond which they assume substantial commercial significance. The present report describes the results of standard fire resistance tests on shelf-angle floor systems based on 254 x 146 mm x 43 kg/m universal beams. In addition, a mathematical model has been developed and used to illustrate the effect, on fire resistance time, of changes in concrete floor slab thickness and live load. These results have been combined to provide design tables for this particular shelf-angle floor system. In subsequent reports, similar design tables will be developed for shelf-angle floor systems based on 406 x 178 mm x 54 kg/m and 305 x 165 mm x 40 kg/m beams respectively. Interpolation of data between these three beam sizes should cover the majority of medium sections used in floor systems for multistorey buildings.

2. STANDARD FIRE RESISTANCE TESTS

2.1 Steel Supply

All the steel sections were obtained from a local steel stockholder and each test required:

5m 254 x 146 mm x 43 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 and mechanical testing. The chemical compositions are given in Table 1 and the tensile test results in Table 2 which show that the beams satisfied the limits specified in BS4360: Grade 43A while the angles complied with the BS4360: Grade 50B specifications. The compositions of the beams showed that the feedstock used came from different steelmaking/casting routes, one was a balanced steel while the other had been silicon killed and aluminium treated.

2.2 Fabrication of Sections

The angles were positioned back to back on each side of the web of the beam such that the 75 mm leg was adjacent to the web and faced the underside of the top flange of the beam. The angles were continuous and fixed to the web using M20, Grade 8.8 bolts at 600 mm centres. The distances between the underside of the top flange and support angle were 140 and 165 mm for the 100 and 150 mm deep floor slabs respectively. A schematic illustration showing the test assemblies is given in Figs. 1 and 2.

2.3 Concrete Floor Slabs

The 32 concrete floor slabs were cast as 1550 x 550 x 150 mm thick blocks, sixteen of which had one end tapering to 100 mm thick over a distance of 300 mm. Each type of concrete slab contained steel reinforcement as shown in Figs. 3 and 4 and complied with BS8110: Grade 30 compressive strength. Stored indoors and allowed to dry naturally they had an average age of 107 days prior to testing.

2.4 Instrumentation

2.4.1 Temperature Measurement

A total of 36 mineral insulated thermocouples of the chromel/alumel type, each with insulated hot junctions and Inconel sheaths were used to monitor the heating rate of the steel during each test. The thermocouples were located at the positions shown in Fig. 5; in summary, five thermocouples were embedded in the lower flange of the beam, four in the exposed part of the web, four were attached to the protected part of the web and four were attached to the upper flange of the beam.

Twelve thermocouples were attached at the mid-span of the beam in groups of 3 at 4 locations (see Fig. 5) in order to monitor the temperature profile through the depth of the assembly.

Seven thermocouples were embedded in the angles, three on the exposed leg, two on the unexposed leg and two on the root radius.

Thermocouples were also installed after the assembly had been constructed to monitor the furnace gas temperature at six positions along the beam adjacent to the lower flange.

2.4.2 Strain Measurement

Fidicual 500 mm lengths were marked along the edges of the lower flange, exposed angle leg and upper flange to monitor the plastic strain which occured as a result of deformation during the test.

2.4.3 Beam End Movement

Movement due to thermal expansion, rotation and deflection was monitored throughout the test at each end of the beam using two transducers mounted on a stand at the $\frac{1}{3}$ and $\frac{2}{3}$ height position of the assembly (see Fig. 6).

2.5 Assembly

The beam with the angles attached was placed on the floor furnace at the Warrington Fire Research Centre in the standard position to give an effective span of 4.5 m between the roller supports. The concrete floor slabs were fitted and supported between the gap formed by the angles and the upper flange of the beam 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 web of the beam. The opposite ends of the concrete slabs were supported by a brick wall built onto the specimen support frame. 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.

Dried sand was packed into the gap between the web and concrete slab. The support flange was also covered with a 25 mm layer of sand in order to simulate the thermal characteristics of the floor screed which would be used in normal site practice.

Photographs of the assemblies after construction and prior to testing are given in Figs. 7 and 8.

2.6 Loading

The load on the beam was applied through the concrete slabs and angles to simulate service conditions. Four hydraulic rams were positioned at 1/8, 3/8, 5/8 and 7/8 of span on either side of the beam at a distance 500 mm from the centreline. In each test a total load of 176 kN was applied to the beam at 8 points through load spreaders which comprised 1 m lengths of 152 x 152 mm x 25 kg/m universal columns. Details of the loading calculations used in each test are given in Appendix 1.

Deflection measurements were taken at the centre of the beam by the Warrington Fire Research Centre staff using the potentiometric system.

3. Test Results

3.1 Test With 150 mm Thick Floor Slabs

The construction was tested at a design stress of 165 N/mm^2 and achieved a fire resistance of 91 min at which time the L/20 failure criterion in BS476: Part 21 was reached. The L/30 criteria was reached after 66 min. Copies of letters from WFRC confirming the results of each test are presented in Appendix 2.

3.1.1 Deflection Measurements

The vertical deflection measurements made at the centre of the beam are plotted in Fig. 9. During the first 18 min of the test the rate of deflection increased to 5 mm/min but thereafter remained almost constant at 2 mm/min until failure occured.

3.1.2 Temperature Measurements

A summary of steel temperatures and furnace gas temperatures at various stages during the test are presented in Table 3. Table 4 contains individual temperatures measured during the test at the centre of the beam to give a detailed temperature profile through the assembly.

The furnace gas heating curves are compared with the international temperature/time curve in Fig. 10 which shows that the heating rate was generally in accordance with the standard curve throughout the test.

Average heating rates measured at the different locations over the central 2 m of the construction are presented in Fig. 11. At failure (91 min) the lower flange temperatures measured showed little scatter and were within the range (958-976°C) with a mean value of 970°C. The final temperatures in the exposed web were within the range (892-927°C) with a mean of 907°C. The temperatures in the unexposed web were within the range (259-315°C) with a mean of 287°C. At failure the upper flange temperatures were within the range (111-164°C) with a mean of 133°C. The temperatures measured on the angles showed that the exposed angle leg temperatures were within the range (912-937°C) with a mean of 924°C and the unexposed angle leg were within the range (675-690°C) with a mean of 682°C. The mean angle root radius temperature was 808°C.

The temperature profile at the mid-span position through the depth of the assembly is shown in Fig, 12.

3.1.3 Strain Measurements

The 500 mm gauge lengths marked along the lower flange and exposed angle leg were measured after the test and the resuts are given in Table 5. The results indicate that the maximum amount of local plastic strain was 2.6% and it occured on the lower flange of the beam. A maximum strain value of 0.6% was recorded on the exposed leg of the angle. After cooling the shelf-angle floor construction was satisfactorily reloaded before being dismantled and removed from the furnace.

3.1.4 Beam End Measurements

The results obtained form the measurements made at each end of the construction indicated that at the $\frac{1}{3}$ height position the beam and angles expanded/rotated approximately 13.5 mm and at the $\frac{2}{3}$ height position approximately 6 mm.

3.1.5 Observations

Shortly after the test started white fumes were emitted which persisted throughout the test. The angles deflected uniformly with the beam. However, a ripple effect was observed along the length of the angle which was caused by the action of the slab edge (Fig. 13(a)). Some of the slabs suffered vertical edge cracks as shown in Fig. 13(b).

All of the bolts remained intact after the reload test.

3.2 Test with 100 mm Thick Floor Slabs

The construction, tested at a design stress of 165 N/mm^2, failed after 69 min when the L/20 failure criterion in BS476: Part 21 had been reached, deflection of L/30 having been exceeded after 47 min.

3.2.1 Deflection Measurements

The vertical deflection measurements made at the centre of the beam, given in Fig. 9, show that the rate of deflection increased to 5 mm/min during the first 16 min of the test, and then decreased to 2 mm/min for the remainder of the test. However just prior to 'failure' the rate again increased to 5 mm/min.

3.2.2 Temperature Measurements

Summaries of the steel and furnace gas temperatures at various stages during the test are presented in Table 6. Table 7 also contains individual temperatures measured at the centre of the beam during the test to give a detailed temperature profile through the construction.

The furnace gas heating curves are compared with the international temperature/time curve in Fig. 10 which shows that the furnace heating rate was generally in accordance with the standard curve throughout the test.

Average heating curves recorded at different positions across the shelf-angle floor construction are compared in Fig. 14. At failure, after 69 min, there was little scatter between the temperatures measured on the lower flange which were within the range (898-917°C) with a mean of 912°C. The final temperatures in the exposed web were within the range (842-883°C) with a mean of 866°C, the corresponding temperature range in the unexposed part of the web was between 272-310°C with a mean of 294°C. The upper flange reached a mean temperature of 158°C. The final average temperatures of the exposed and unexposed legs of the angle were 843°C and 615°C respectively. The mean angle root radius temperature was 730°C.

The temperature profile at the mid-span position through the depth of the assembly is given in Fig. 15.

3.2.3 Strain Measurements

The 500 mm gauge lengths marked along the lower and upper flanges of the beam and exposed leg of the angle were measured after the test and the results are given in Table 8. The data suggest that the maximum amount of local plastic strain was 1.6% and it occurred on the lower flange of the beam, whereas the upper flange exhibited local strain values of 0.2%. A maximum strain value of 0.6% was recorded on the exposed angle leg. After cooling the shelf-angle floor assembly was satisfactorily reloaded before being dismantled and removed from the furnace.

3.2.4 Beam End Movements

Measurements made at the ends of the beam to monitor movements through thermal expansion and rotation indicated that the beam moved approximately 12 mm at the ¼ height position and approximately 5 mm at the ¾ height position during the test.

3.2.5 Observations

After the test some of the slabs exhibited shear cracks (Fig. 16(a)) which were contained within the load bearing area over the angle. Both the angle and beam deflected uniformly as can be seen from Fig 16(b).

All the bolts remained intact after the reload test.

4. MATHEMATICAL MODELLING

As part of the fire engineering work carried out at Swinden Laboratories a computer package has been devleoped to calculate the fire resistance times of shelf-angle floor systems and thus reduce the need for expensive experimental tests. The package is based on two commercially available finite element programmes, FIRES-T2 and FASBUS II, together with a number of in-house pre and post processor programmes to facilitate data preparation and the extraction of user selected information from the computed results.

4.1 FIRES-T2[2]

FIRES-T2 is a computer programme which evaluates the temperature distribution history of two dimensional structures in fire environments. Transient thermal problems are modelled by the heat conduction boundary problem. These equations are non linear because of the temperature dependence of the thermal properties of structural materials and the heat transfer mechanisms associated with fire environments. The solution technique used in FIRES-T2 is a finite element method coupled with time step integration. The non-linearity of the problem requires an iterative solution process within each time step. The structure is modelled by 4-noded isoparametric quadrilaterals and 3-noded triangles. Fire environments are represented by a non-linear model that includes both convective and radiative mechanisms.

4.2 FASBUS II[3]

FASBUS II is a non-linear structural analysis programme especially written for the analysis of floor systems (of which a shelf-angle floor is a simple example) subjected to both mechanical and thermal loading. It is a programme which accepts a temperature history of the configuration as input and calculates the resulting deflection and stress history. The floor system is modelled using beam finite elements. Element stiffnesses are calculated using temperature dependent non-linear stress-strain curves. The resulting structural stiffness is used in an iterative process to find the deflected shape of the structure which satisfies the non-linear equations of equilibrium for the floor system.

The computer programmes described above were used to simulate the two fire tests. A number of assumptions were made in the calculations.

In FIRES-T2 it was assumed that:-

(a) the screed which covered the universal beam and filled the gaps between the concrete floor slabs and the steelwork had the same thermal properties as the floor slabs.

(b) the thermal properties of Grade 43A steel and concrete were as listed in Tables 9 and 10 respectively.

(c) the furnace gas temperature followed the ISO time-temperature curve

$$T = 20 + 345 \log_{10}(8t + 1)$$

where T = furnace temperature, °C
t = time, min

The temperature of the air above the floor structure was taken to remain at a constant temperature of 20°C throughout the test.

(d) the profiles of the 254 x 146 mm x 43 kg/m universal beam and the 125 x 75 x 12 mm angles used in the construction of the floor systems were at their nominal dimensions.

A schematic diagram of the model used in the two analyses is shown in Fig. 17. The symmetry of the assembly means that only one half of it need be modelled resulting in considerable savings in cpu times.

The structural analysis programme, FASBUS II, also requires certain assumptions. These included:

(a) The following material properties of Grade 43A steel are as listed in Table 11:- Young's Modulus, Yield stress and the coefficient of thermal expansion. Figure 18 shows the stress-strain characteristics used in the model and their variation with temperature

(b) The model assumes that the steelwork consists entirely of one grade of steel.

(c) It is assumed in the model that the shelf-angle is uniformly loaded along its central axis rather than in the manner of the actual fire test. This greatly simplifies the problem and reduces computing time dramatically. The load chosen in each case was that which would produce a maximum stress value of 165 N/mm^2 in the lower flange of a conventionaal 254 x 146 mm x 43 kg/m universal beam with a span of 4.5 m. The presence of the angles bolted to the web would, of course, cause the actual value in the assembly to deviate from this value.

(d) The model assumes a uniform temperature distribution along the length of the steelwork.

A feature of finite element analyses is the vast amount of data which is generated. In a report of this size only a small fraction of the output can be documented and is best presented in diagramatic form. Figures 19 to 32 show comparisons between predicted and measured temperatures at various locations on the two shelf-angle floor assemblies. It can be seen that, bearing in mind the differences between theory and practice discusssed previously, reasonably good agreement has been obtained. The next two diagrams (Figs. 33 and 34) display the calculated and observed vertical displacements of the centre of the floor structure. The horizontal lines indicate the two critical displacements, span/30 and span/20. The figures illustrate the fact that in the case where the shelf-angle supported 150 mm deep floor slabs the predicted and recorded times to reach these displacements are in excellent agreement. For the case of the shallower floor the predicted fire resistance times are both approximately 5 min longer than those recorded in the actual fire test (see Table 12).

However inspection of Fig. 1 shows that the beam used in this particular test was 6 mm deeper than the nominal size and when due allowance is made for this then the actual and predicted values become:

	Measured	Computed
Time to L/30 (min)	47	46
Time to L/20 (min)	69	64

It was also observed that the room temperature yield stress of the beam used in the 100 mm deep floor construction was close to its minimum permissible value of 275 N/mm^2. The value used in the analysis was 292 N/mm^2 which is a typical value for Grade 43A steel rather than the lowest acceptable value. To evaluate the effect of yield stress the analysis was repeated with the previously tabulated values reduced by a factor of 275/292. As a point of interest a third analysis was performed with the room temperature yield stress raised to 360 N/mm^2 - a value within the specifications of Grade 50B steel. The results of these two analyses which are shown in Fig. 35 and listed in Table 13 show that the fire resistance times of the structure are not dramatically affected by these property changes.

Following the successful modelling of the two shelf-angle floor tests it was decided to complete this investigation by analysing the complete range of shelf-angle floors which could be constructed using a 254 x 146 mm x 43 kg/m universal beam as the basis of the floor system. Floor depths of 200 mm, 175 mm, 150 mm, 125 mm and 100 mm were considered, the corresponding values of h being 37 mm, 62 mm, 87 mm, 112 mm, 137 mm respectively. In each case the angles bolted to the web of the beam were 75 x 125 x 12 mm in section. The floors were, in turn, subjected to loads of 70%, 85%, 100%, 115% and 130 % of the design load of a 254 x 146 mm x 43 kg/m universal beam with a span of 4.5 m (i.e. 148 kN).

The location of the angles fastened to the web of the beam obviously affects the section properties of the structure and this, in turn, causes the stress pattern within it to vary when it is loaded. Table 14 lists the section and plastic moduli of the fire configurations under analysis and Table 15 gives the maximum stress values in the upper and lower flanges of the beam when it is initially loaded prior to the commencement of a fire test.

The times taken for the central, vertical deflection of the lower flange to reach the critical values of span/30 and span/20 for each of the load cases and floor configurations are listed in Table 16 and shown in diagramatic form in Figs. 36 and 37.

5. CONCLUSIONS

Standard fire resistance tests, in accordance with BS476: Part 21, on shelf-angle floor systems based on 254 x 146 mm x 43 kg/m universal beams have shown that it is quite feasible to achieve fire resistance times in excess of 60 and even 90 min.

A mathematical model has been developed which is able to predict accurately the behaviour of such systems in the standard fire resistance test.

This model has been used to provide a design table from which the fire resistance time can be read off for any practical combination of load and depth of beam exposed to the flames.

The exercise will now be repeated for shelf-angle floor systems based on 406 x 178 mm x 54 kg/m universal beams.

6. REFERENCES

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TABLE 1
CHEMICAL COMPOSITION OF THE STEEL SECTIONS USED IN THE FIRE TESTS

	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	N	Nb	Sn	V
RS8J052 254 x 146 mm X 43 kg/m UB RS8J053 125 x 75 x 12 mm Angle Tested 9.3.88	0.15 0.13	0.16 0.33	0.79 1.31	0.030 0.013	0.011 0.014	0.03 0.03	<0.005 <0.005	0.04 0.02	0.035 0.042	0.03 0.03	0.0061 0.0097	<0.005 <0.005	<0.005 <0.005	<0.005 0.060
RS8J066 254 x 146 mm x 43 kg/m UB RS8J067 125 x 75 x 12 mm Angle Tested 23.3.88	0.22 0.12	0.03 0.33	1.07 1.32	0.009 0.012	0.028 0.014	0.02 0.03	<0.005 <0.005	0.02 0.02	<0.005 0.043	0.02 0.03	0.0044 0.0086	<0.005 <0.005	<0.005 <0.005	<0.005 0.060
BS4360 Grade 43A Product Analysis	0.30 max.	0.55 max.	1.70 max.	0.06 max.	0.06 max.									
BS4360 Grade 50B Product Analysis	0.24 max.	0.55 max.	1.60 max.	0.06 max.	0.06 max.							0.003/ 0.10		0.003/ 0.10

TABLE 2
TENSILE TEST RESULTS FROM THE BEAMS AND ANGLES USED IN THE FIRE TESTS

Identity	Yield Stress N/mm^2	Tensile Strength N/mm^2	El. %
RS8J052 254 x 146 mm X 43 kg/m UB RS8J053 125 x 75 x 12 mm Angle Tested 9.3.88	301 398	466 544	35 31
RS8J066 254 x 146 mm x 43 kg/m UB RS8J067 125 x 75 x 12 mm Angle Tested 23.3.88	278 395	492 545	34 33
BS4360 Grade 43A Specification	275 (min.)	430/580	20 min.
BS4360 Grade 50B Specification	355 (min.)	490/640	18 min.

TABLE 3
TEMPERATURE SUMMARY DATA SHEET

Sections: 254 x 146 mm x 43 kg/m Grade 43A Beam
125 x 75 x 12 mm Grade 50B Angles

Concrete Floor slab: 150 mm deep

Test Date: 9.3.88

Fire Resistance: 66 min(L/30)
91 min(L/20)

Thermocouple Locations		Temperature, °C After Various Times, min																										
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40	45	50	55	60	66	70	75	80	85	91
Lower Flange	F1	108	172	237	309	385	448	504	548	580	607	630	447	661	676	683	716	749	766	789	815	837	863	881	901	919	937	958
	F2	95	162	231	312	390	459	517	560	588	627	651	669	688	702	706	737	772	790	815	838	861	896	903	920	937	955	975
	F4	99	159	226	299	383	450	509	555	593	621	647	668	685	700	707	737	772	789	811	833	854	878	902	916	936	952	975
	F6	85	150	216	290	372	440	499	544	581	621	637	656	673	688	692	724	759	774	796	821	845	871	889	909	928	945	967
	F7	86	153	222	297	383	450	509	555	593	621	646	666	682	697	709	739	770	792	814	834	852	870	913	903	946	945	976
Mean Lower Flange		95	159	226	301	383	449	508	552	589	618	642	661	678	693	699	731	764	782	805	828	850	874	898	910	933	947	970
Exposed Web	W1	67	109	154	204	259	306	352	391	420	450	474	494	512	528	542	598	617	652	679	707	734	763	800	806	852	855	893
	W2	64	103	152	204	258	310	356	395	429	460	483	504	522	538	553	593	634	665	697	728	757	791	814	843	861	890	917
	W3	54	93	140	192	255	313	364	408	447	479	508	532	552	571	589	629	666	695	724	754	784	816	832	859	880	900	927
	W4	62	95	137	183	239	288	339	378	414	446	473	498	520	539	555	598	635	664	691	721	748	779	799	824	844	868	892
Mean Exposed Web		62	100	146	196	253	304	353	393	427	459	484	507	526	544	560	599	638	669	698	727	756	787	811	883	859	878	907
Exposed Flange (Angle)	F10	62	99	142	187	238	284	323	367	404	434	457	481	503	529	553	602	647	680	711	740	767	808	821	856	880	901	937
	F12	64	100	139	175	217	250	284	314	325	332	352	366	403	439	465	526	589	634	673	706	736	768	796	825	855	883	912
Mean Exposed Flange (Angle)		63	99	140	181	227	267	303	340	364	383	404	423	453	484	509	564	618	657	692	723	751	788	808	840	867	892	924
Unexposed Flange (Angle)	W9	17	25	35	49	67	90	115	144	169	191	212	232	251	269	287	331	373	404	444	479	512	550	574	601	626	648	675
	W10	16	24	35	48	65	89	115	143	167	189	209	228	246	262	279	324	373	415	455	491	525	561	585	612	637	660	690
Mean Unexposed Flange (Angle)		16	24	35	48	66	89	115	143	168	190	210	230	248	265	283	327	373	412	449	485	518	555	579	606	631	654	682
Unexposed Web	W5	15	16	17	19	22	27	32	40	46	54	62	69	78	84	91	101	104	107	122	145	168	196	213	231	248	265	285
	W6	15	16	18	21	23	30	37	48	67	84	93	100	104	108	109	119	134	150	171	191	210	232	247	265	283	299	315
	W7	15	17	18	21	25	30	36	44	53	63	73	81	88	93	97	102	106	113	128	148	171	198	214	234	252	273	289
	W8	16	17	18	20	22	27	32	38	46	54	62	70	75	80	85	93	101	102	106	120	142	169	187	206	223	242	259
Mean Unexposed Web		15	16	18	20	23	28	34	42	53	64	72	80	86	91	95	104	111	118	132	151	173	199	215	234	251	270	287
Upper Flange	F3	15	16	15	15	14	15	17	18	19	20	23	27	33	41	49	70	88	97	97	97	97	98	100	102	105	108	114
	F5	15	16	15	15	15	16	18	19	21	24	28	34	43	54	67	97	101	101	103	106	112	116	122	132	141	152	164
	F8	14	15	14	15	15	15	16	17	19	22	24	28	34	40	47	64	80	92	95	96	97	99	103	107	113	106	111
	F9	15	16	15	15	14	15	16	18	19	21	23	26	28	31	34	46	64	93	96	97	99	102	107	114	121	131	142
Mean Upper Flange		15	16	15	15	15	15	17	18	19	22	24	29	34	41	49	69	83	96	98	99	101	104	108	114	120	124	133
Angle Root	F16	21	37	53	74	99	132	165	197	227	257	283	309	332	356	380	433	478	517	555	590	624	661	684	711	741	764	808
	F17	23	40	57	79	102	127	158	190	222	252	279	306	332	355	378	432	482	526	564	599	632	667	691	713	746	761	809
Mean Angle Root		22	38	55	76	100	129	161	193	224	254	281	307	332	355	379	432	480	521	559	594	628	664	687	712	743	762	808
Mean Furnace Gas		474	541	597	656	707	722	747	760	769	779	790	798	807	815	821	843	869	885	903	920	933	950	963	975	990	1004	1011
ISO Curve at 20°C.		444	544	603	645	678	705	728	748	766	781	795	808	820	831	842	865	885	902	918	932	945	959	968	979	988	997	1008
Central Beam Deflection, mm		0	4	9	26	37	47	55	63	68	73	77	81	84	86	89	95	102	111	119	129	138	150	158	169	182	197	224

TABLE 4

TEMPERATURE PROFILE AT MID-SPAN THOUGH A 254 x 146 mm x 43 kg/m SHELF-ANGLE BEAM TEST WITH 150 mm THICK FLOOR SLABS

Thermocouple Positions	Temperature, °C After Various Times, min																										
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40	45	50	55	60	66	70	75	80	85	91
UF8	14	15	14	15	15	15	16	17	19	22	24	28	34	40	47	64	80	92	95	96	97	99	103	107	113	106	111
A1	15	16	15	15	16	18	19	22	26	29	35	42	49	57	64	81	96	102	102	106	113	121	128	137	146	143	154
A2	15	16	16	18	19	23	26	31	37	46	55	66	74	82	88	100	103	108	115	132	149	166	177	189	204	207	219
A3	15	16	16	19	22	27	33	41	53	67	80	90	100	102	102	103	107	113	133	158	183	208	224	241	259	271	286
A7	16	22	30	41	56	75	96	115	134	151	166	183	200	218	237	285	332	372	410	445	478	513	535	564	586	611	640
A8	17	26	36	50	69	93	114	136	158	176	194	213	232	253	273	327	377	418	457	492	526	563	584	612	635	659	686
A9	20	33	47	65	88	112	133	158	180	200	221	243	266	291	317	380	435	481	521	559	593	630	652	679	704	729	759
A10	102	138	173	218	268	313	352	384	410	431	451	474	496	516	535	582	623	659	692	723	751	783	800	830	846	875	899
A11	63	104	150	204	261	316	363	405	437	464	488	511	533	533	573	619	658	690	722	753	784	817	832	862	882	902	930
A4	68	103	137	175	214	257	296	334	363	388	413	435	458	479	500	549	592	628	660	694	725	758	783	808	835	853	885
A12	72	108	167	228	293	353	407	452	486	515	538	559	580	598	617	659	691	718	747	777	807	838	846	884	891	916	946
A5	86	138	181	230	278	333	376	419	452	477	503	523	544	564	583	627	662	693	722	754	785	817	836	859	884	901	928
A6	77	132	183	242	306	371	427	474	511	540	565	585	604	622	639	677	708	730	758	789	818	846	859	881	908	915	946
CE2	95	162	231	312	390	459	517	560	598	627	651	669	688	702	706	737	772	790	815	838	861	886	903	920	937	955	975

TABLE 5
GAUGE LENGTH MEASUREMENTS FROM 150 mm THICK SLAB TEST

Lower Flange Beam			Flange Angle		
Before	After	Strain %	Before	After	Strain %
498	500	0.4	499	499	0
499	502	0.6	499	500	0.2
500	505	1.0	503	505	0.4
501	508	1.4	500	502	0.4
499	512	2.6	501	504	0.6
503	511	1.6	500	502	0.4
499	503	0.8	500	503	0.6
501	503	0.4	500	501	0.2
414	414	0	388	388	0

TABLE 6
TEMPERATURE SUMMARY DATA SHEET

Sections: 254 x 146 mm x 43 kg/m Grade 43A Beam
125 x 75 x 12 mm Grade 50B Angles

Concrete Floor slab: 100 mm deep

Test Date: 23.3.88

Fire Resistance: 47 min(L/30)
69 min(L/20)

Thermocouple Locations		Temperature, °C After Various Times, min																						
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40	47	50	55	60	65	69
Lower Flange	F1	98	164	236	306	377	444	496	540	576	606	630	650	668	684	698	730	750	788	806	832	860	881	898
	F2	116	187	264	337	412	474	526	573	606	634	659	678	697	712	726	752	774	817	834	861	883	901	916
	F4	119	181	254	330	409	478	531	578	613	643	666	696	703	717	730	757	781	822	839	865	886	906	917
	F6	106	174	246	320	393	462	516	563	600	629	654	673	691	707	732	750	771	812	828	854	879	897	914
	F7	112	172	246	326	401	472	529	577	612	644	669	687	706	720	733	755	784	823	841	866	886	904	917
Mean Lower Flange		110	176	249	324	398	466	520	566	601	631	656	675	693	708	722	749	772	812	830	856	879	898	912
Exposed Web	W1	93	135	183	232	288	344	387	427	460	490	516	539	560	579	598	639	674	714	732	759	793	822	842
	W2	103	153	197	254	310	362	409	451	485	517	544	566	590	608	627	665	698	741	760	792	825	850	872
	W3	98	140	197	261	320	381	432	477	514	546	574	596	620	638	655	694	725	763	785	814	844	867	883
	W4	84	132	182	236	297	359	409	453	489	521	549	574	595	613	632	673	706	745	764	796	825	850	867
Mean Exposed Web		95	140	190	246	304	362	409	452	467	519	546	569	591	610	628	668	701	741	760	790	822	847	866
Exposed Flange (Angle)	F10	90	137	180	224	273	321	362	404	439	475	500	526	551	572	591	638	677	725	744	772	802	832	853
	F11	68	107	143	175	223	267	313	356	393	427	459	488	516	539	564	617	660	714	735	764	797	830	852
	F12	65	99	141	177	218	264	304	344	379	410	440	464	490	512	533	581	622	674	695	730	762	796	823
Mean Exposed Flange (Angle)		74	114	155	192	238	284	326	368	404	437	466	493	534	541	563	612	653	704	725	755	787	819	843
Unexposed Flange (Angle)	W9	20	31	47	66	88	110	135	161	186	205	222	241	265	289	313	367	416	473	495	530	561	587	606
	W10	20	33	48	68	93	117	146	176	207	236	263	288	311	334	355	402	445	499	521	552	578	604	623
Mean Unexposed Flange (Angle)		20	32	48	67	91	114	141	169	197	221	243	265	288	312	334	385	431	486	508	541	570	596	615
Unexposed Web	W5	16	18	21	26	33	41	51	61	72	95	102	107	112	117	122	140	170	204	217	237	258	274	288
	W6	15	17	20	25	32	42	52	61	71	82	98	108	116	126	138	156	188	221	234	256	283	299	310
	W7	16	17	21	26	32	41	50	59	70	80	91	104	118	130	138	146	186	218	231	252	276	295	307
	W8	16	17	20	24	31	39	54	92	98	101	102	103	107	111	117	127	138	171	187	212	232	254	272
Mean Unexposed Web		16	17	21	25	32	41	52	68	78	90	98	106	113	121	128	142	171	204	217	239	262	281	294
Upper Flange	F3	15	15	14	15	16	17	20	23	26	30	34	40	46	54	63	88	97	101	105	110	119	131	144
	F5	15	15	15	16	17	19	20	23	27	30	34	39	45	51	59	81	98	110	117	130	142	158	170
	F8	15	15	16	16	17	19	21	24	28	31	37	43	52	63	76	98	102	109	111	115	110	127	148
	F9	16	16	16	16	17	19	21	24	28	31	37	42	50	61	72	100	105	113	124	136	148	181	171
Mean Upper Flange		15	15	15	16	17	19	21	24	27	31	36	41	48	57	68	92	101	110	114	123	130	144	158
Angle Root	F16	28	44	63	88	118	150	187	223	260	293	325	356	384	412	436	492	538	593	615	649	630	707	727
	F17	29	47	68	92	123	155	190	225	259	290	321	352	380	406	431	490	538	596	619	654	684	711	732
Mean Angle Root		29	46	66	90	121	153	189	224	260	292	323	354	382	409	434	491	538	595	617	652	682	709	730
Mean Furnace Gas		517	557	612	650	689	716	728	750	757	762	774	785	792	801	809	829	850	873	885	900	918	931	945
ISO Curve at 20°C.		445	544	603	645	678	705	728	748	766	781	796	809	820	832	842	865	885	909	918	932	945	957	966
Central Beam Deflection, mm		6	13	22	32	42	52	61	69	75	81	87	93	98	103	108	120	133	150	157	170.5	185	206	226

TABLE 7
TEMPERATURE PROFILE AT MID-SPAN THOUGH A 254 x 146 mm x 43 kg/m SHELF-ANGLE BEAM TEST WITH 100 mm THICK FLOOR SLABS

Thermocouple Positions	Temperature, °C After Various Times, min																					
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40	47	50	55	60	69
UF8	15	15	16	16	17	19	21	24	28	31	37	43	52	63	76	98	102	109	111	115	110	146
A1	15	15	17	19	21	26	29	34	41	51	67	85	94	99	102	115	128	141	145	153	154	193
A2	16	16	19	21	27	32	38	46	61	93	102	102	103	105	106	110	124	166	181	201	226	259
A3	16	20	25	32	42	53	67	80	97	114	128	141	153	163	173	203	238	278	292	315	332	373
A7	19	26	39	55	76	100	126	154	181	206	230	253	275	296	317	366	407	458	477	507	529	569
A8	21	32	46	66	89	116	146	174	203	228	254	279	303	326	349	401	445	501	522	555	581	623
A9	24	39	58	80	105	132	162	192	224	253	282	312	339	365	389	444	491	548	570	604	632	677
A10	106	143	189	238	284	330	375	415	447	476	504	528	554	573	592	638	674	720	741	770	801	850
A11	95	144	197	252	306	359	409	452	485	517	544	568	593	610	629	673	707	750	771	803	835	880
A4	105	153	206	254	308	361	411	454	489	519	547	571	595	615	634	675	708	752	772	805	835	879
A12	77	134	193	254	318	375	429	476	512	545	574	597	621	639	657	696	726	768	790	822	850	891
A5	198	241	298	325	378	426	469	508	544	568	591	613	634	651	668	707	734	777	797	826	854	894
A6	73	135	203	270	339	404	460	508	546	578	606	628	648	667	683	717	740	785	805	836	862	899
LF2	116	187	264	337	412	474	526	573	606	634	659	678	697	712	726	752	774	817	834	861	883	916

TABLE 8
GAUGE LENGTH MEASUREMENTS FROM THE 100 mm THICK FLOOR ASSEMBLY

Lower Flange Beam			Flange Angle			Upper Flange Beam		
Before	After	Strain %	Before	After	Strain %	Before	After	Strain %
503	505	0.4	502	502	0	500	501	0.2
502	505	0.6	499	500	0.2	498	499	0.2
521	526	0.9	521	522	0.2	500	500	0
501	508	1.4	502	504	0.4	500	500	0
498	506	1.6	502	504	0.4	500	500	0
500	507	1.4	499	502	0.6	500	500	0
500	505	1.0	500	502	0.4	503	503	0
503	505	0.4	504	504	0	498	498	0

TABLE 9
THERMAL PROPERTIES OF GRADE 43A STEEL

Temperature °C	Thermal Conductivity W/m K	Specific Heat J/kg C	Density Kg/m^3
20	52.0	440	7850
50	51.7	450	7840
100	51.0	480	7830
150	50.0	505	7810
200	48.8	530	7800
250	47.5	550	7780
300	46.0	565	7770
350	44.5	585	7750
400	42.7	610	7730
450	41.0	640	7710
500	39.2	675	7700
550	37.5	715	7680
600	35.5	760	7660
650	33.8	820	7640
700	32.0	1010	7620
725	31.0	1600	7610
750	28.5	1300	7620
775	26.5	1010	7620
800	26.0	810	7630
825	25.8	730	7630
850	26.0	685	7620
875	26.2	660	7610
900	26.5	650	7600
950	27.0	650	7570
1000	27.5	650	7550

TABLE 10
THERMAL PROPERTIES OF CONCRETE

Temperature °C	Thermal Conductivity W/m K	Specific Heat J/Kg C
20	1.95	916
100	1.77	976
200	1.57	1040
300	1.39	1100
400	1.31	1160
500	1.10	1200
600	0.99	1240
700	0.91	1260
800	0.85	1280
900	0.81	1300
1000	0.80	1300

Density - 2200 kg/m^3

TABLE 11
MATERIAL PROPERTIES OF GRADE 43A STEEL

Temperature °C	Young's Modulus N/mm^2	Yield Stress N/mm^2	Coefficient of Thermal Expansion °C^{-1}
20	210000	292	0.0000112
100	208000	268	0.0000117
200	202000	257	0.0000124
300	195000	230	0.0000131
400	186500	205	0.0000139
500	176000	178	0.0000142
600	165000	110	0.0000148
700	152500	53	0.0000151
800	127000	31	0.0000122
900	117500	25	0.0000135

TABLE 12
COMPARISON OF COMPUTED AND MEASURED FIRE RESISTANCE TIMES

	Floor Depth 150 mm		Floor Depth 100 mm	
	Measured	Computed	Measured	Computed
Time to Reach Span/30, min	66	66.0	47	51.6
Time to Reach Span/20, min	91	90.3	69	73.0

TABLE 13
EFFECT OF YIELD STRESS ON FIRE RESISTANCE TIMES OF A 100 mm SHELF-ANGLE FLOOR

	Yield Stress N/mm^2		
	275	292	360
Time to Reach Span/30, min	50.4	51.6	52.6
Time to Reach Span/20, min	70.7	73.0	77.2

TABLE 14
VARIATION OF SECTION PROPERTIES WITH FLOOR DEPTH

Floor Depth, mm	199.9	174.9	149.9	124.9	99.9
Section Modulus, mm^3 (about principal axis)	509479	487739	483948	502630	499661
Plastic Modulus, mm^3 (about neutral axis)	696316	666820	646189	634425	631527
PM/EM	1.367	1.367	1.335	1.262	1.264

TABLE 15

Stress in outer fibre of beam = $\frac{WL^2y}{8I}$

where w = load/unit length = $\frac{148,000}{4500}$

= 32.889 N/mm

L = span = 4500 mm

y = distance from neutral axis, mm

I = moment of inertia about horizontal axis through centroid, mm^4

Floor Depth, mm	199.9	174.9	149.9	124.9	99.9
Dist. from centroid to lower flange, mm	90.67499	102.01159	113.34820	124.68480	136.02141
Dist. from centroid to upper flange, mm	168.92501	157.58841	146.25180	134.91520	123.57859
Moment of Inertia, mm^4	86063700	76862000	70778200	67812400	67964500
$\frac{WL^2}{8I}$, N/mm^3	0.9673067	1.08311	1.1762096	1.2276516	1.2249042
Max. stress in lower flange, N/mm^2					
70% load	61.4	77.3	93.3	107.1	116.6
85% load	74.6	93.9	113.3	130.1	141.6
100% load	87.7	110.5	133.3	153.1	166.6
115% load	100.9	127.1	153.3	176.0	191.6
130% load	114.0	143.6	173.3	199.0	216.6
Max. stress in upper flange, N/mm^2					
70% load	-114.4	-119.5	-120.4	-115.9	-106.0
85% load	-138.9	-145.1	-146.2	-140.8	-128.7
100% load	-163.4	-170.7	-172.0	-165.6	-151.4
115% load	-187.9	-196.3	-197.8	-190.5	-174.1
130% load	-212.4	-221.9	-223.6	-215.3	-196.8

TABLE 16
VARIATION OF FIRE RESISTANCE TIME WITH DEPTH OF FLOOR

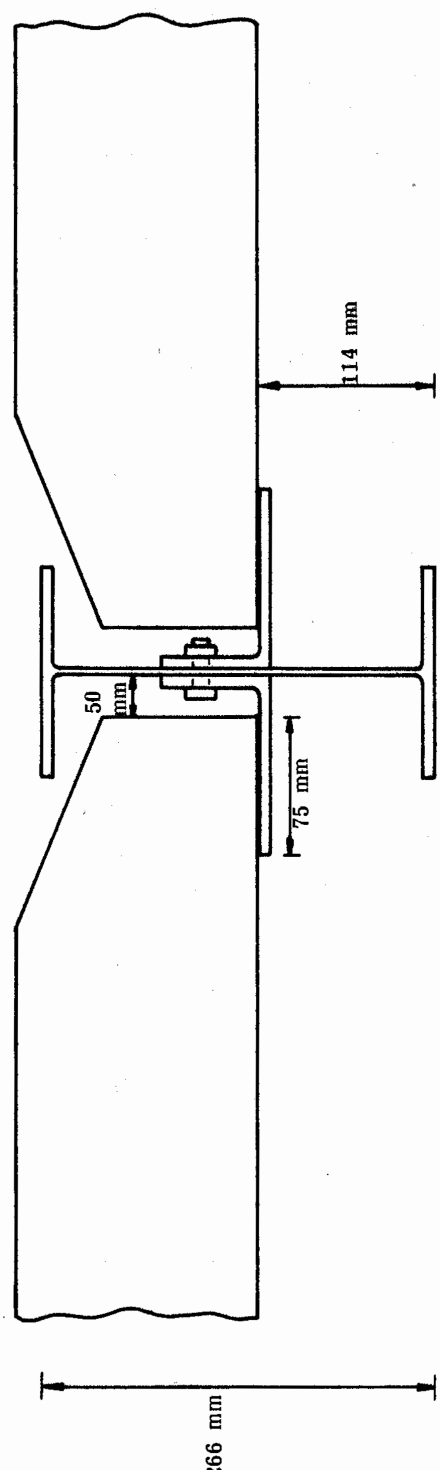
	Total Applied Load (100% = 148 kN)				
	104 kN (70%)	126 kN (85%)	148 kN (100%)	170 kN (115%)	192 kN (130%)
37 mm	122.9[1] 184.0[2]	103.6 152.3	91.0 131.3	82.0 115.8	73.4 101.7
62 mm	97.5 147.1	88.1 123.9	79.5 108.2	72.2 96.1	64.6 85.0
87 mm	78.4 119.5	70.7 100.9	64.0 88.3	58.0 76.8	51.3 66.3
112 mm	56.8 90.9	51.5 77.6	46.9 65.6	41.4 56.1	37.1 48.5
137 mm	43.6 65.9	40.1 56.7	37.0 49.2	32.8 42.6	29.1 37.5

50%
171.326
264.057
121.879
205.618
93.349
162.765
67.116
121.549
50.355
86.035

(1) Time to reach $\frac{\text{span}}{30}$, min

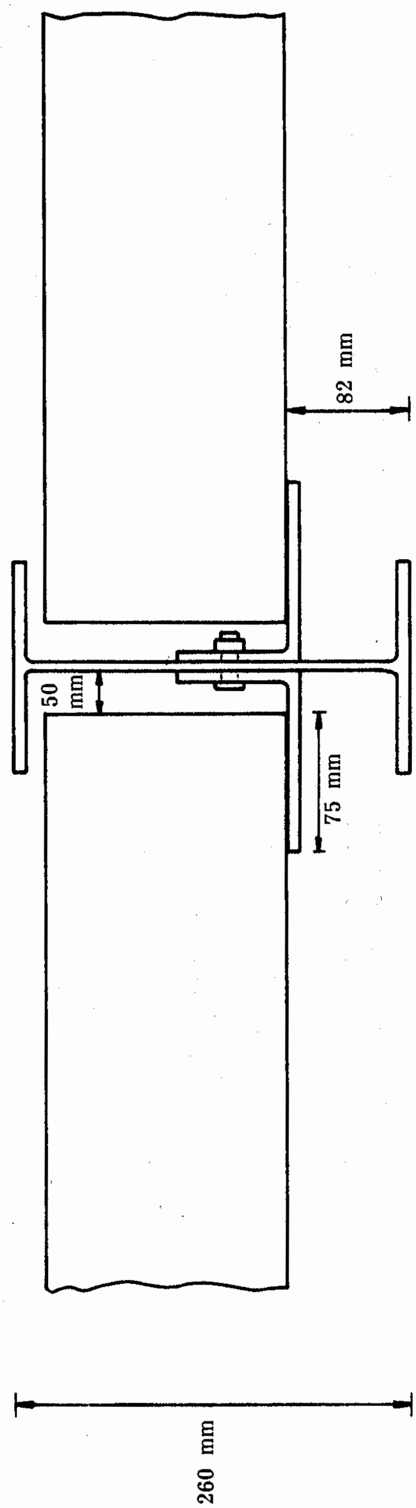
(2) Time to reach $\frac{\text{span}}{20}$, min

~~1059~~	1000	966	942	921	~~896~~
1132	1072	1039	1012	989	964
998	~~956~~	936	914	892	863
~~1033~~	~~1000~~				
1091	1033	1000	975	953	929
947	911	887	860	829	787
1051	995	963	936	907	870
873	822	788	757	721	690



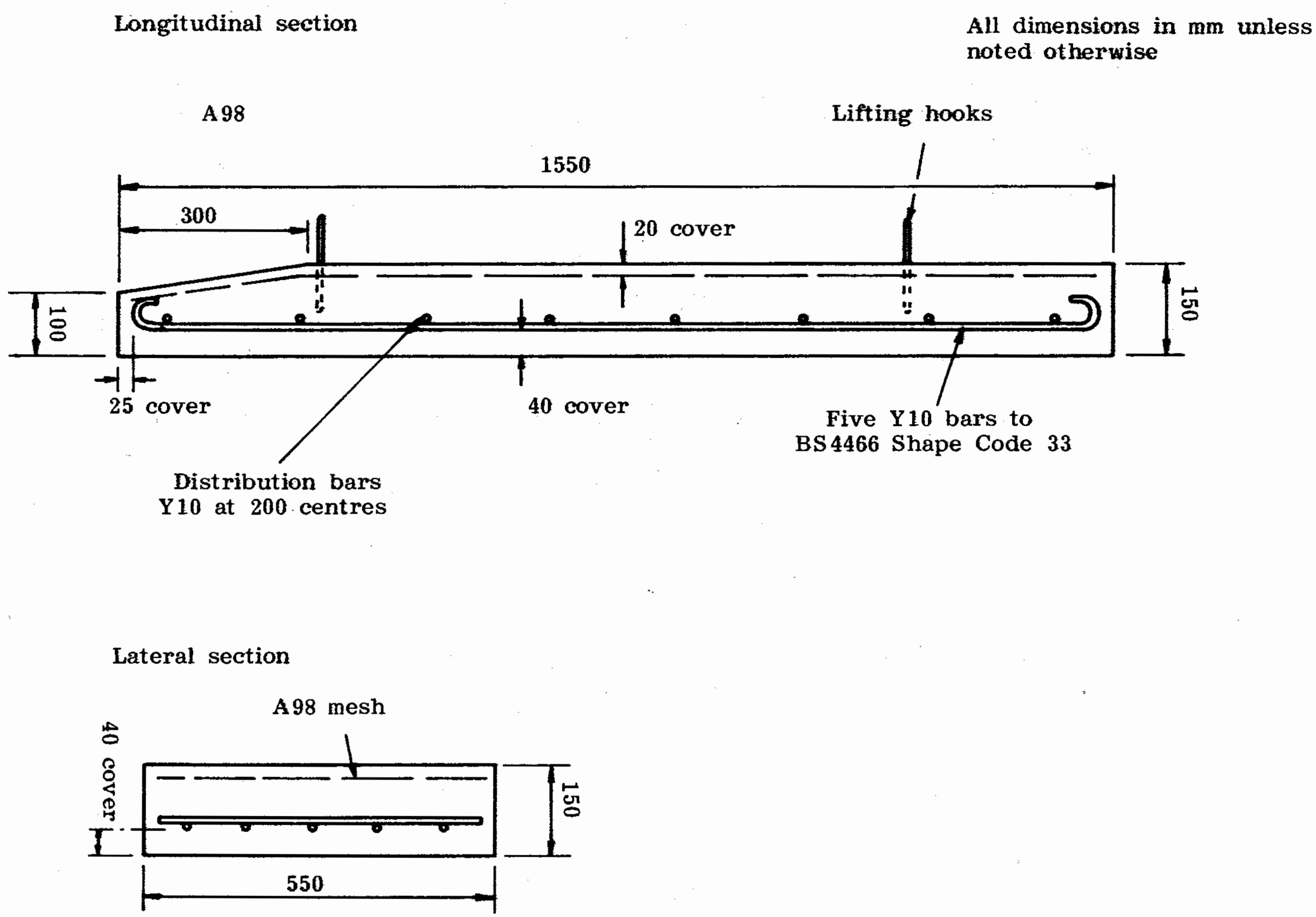
TEST ARRANGEMENT FOR 254 x 146 mm x 43 kg/m BEAM WITH 100 mm THICK FLOOR

FIG. 1
(R3/111O)

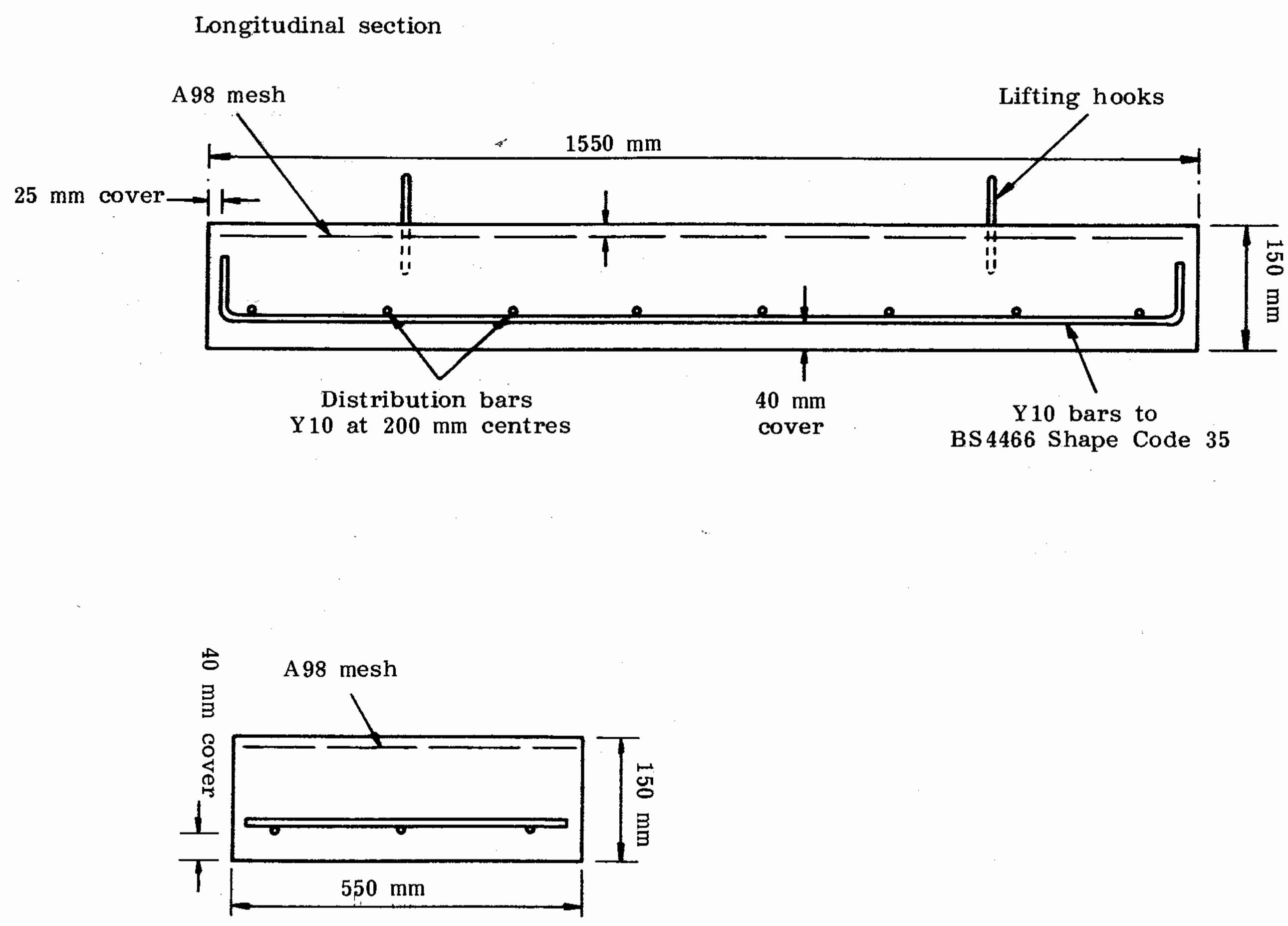


TEST ARRANGEMENT FOR 254 x 146 mm x 43 kg/m BEAM WITH 150 mm THICK FLOOR

FIG. 2
(R3/1111)

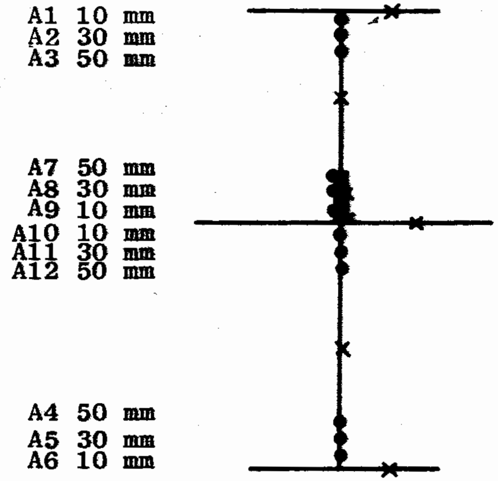


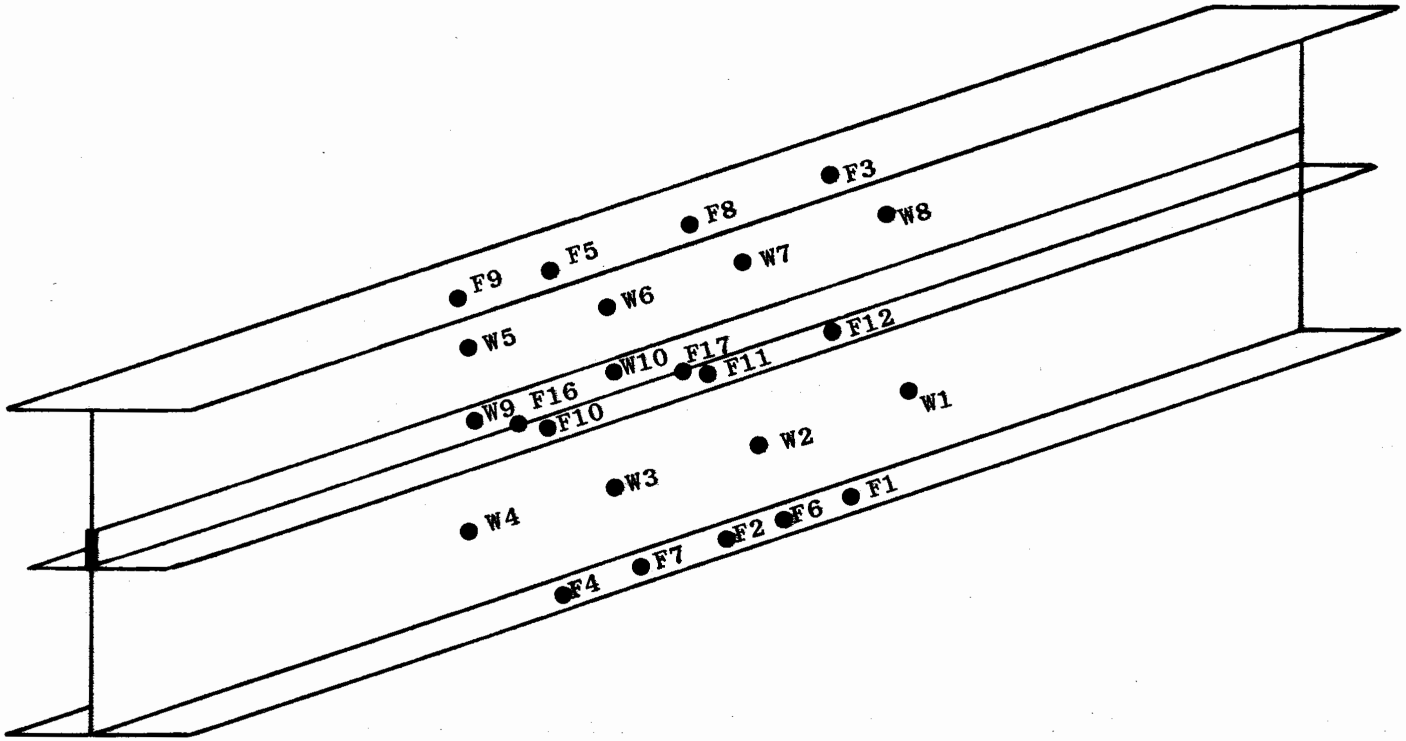
DETAILS OF PRECAST CONCRETE SLAB FIG. 3
(R3/1112)



DETAILS OF PRE-CAST CONCRETE SLABS FIG. 4
(R3/1113)

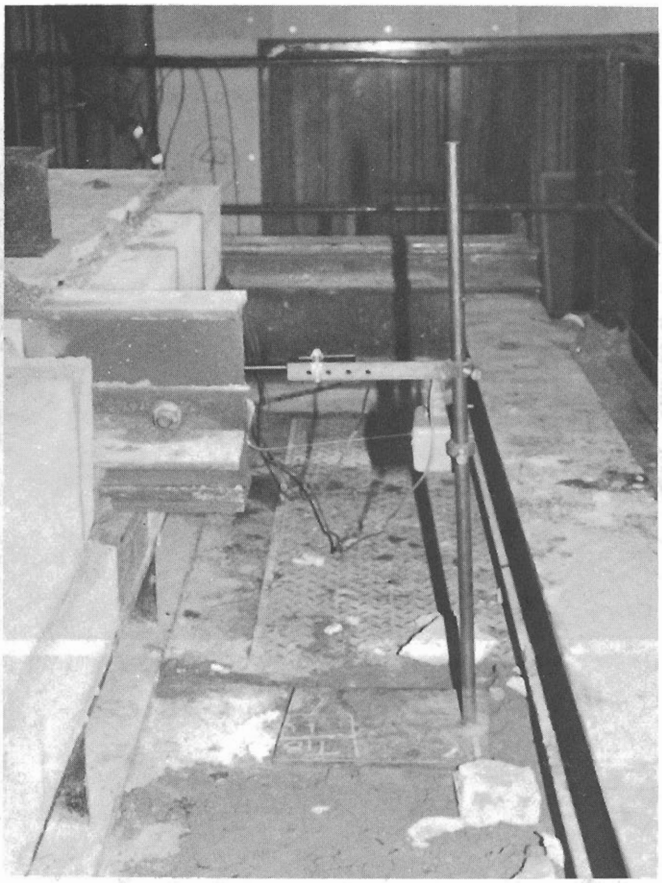
F9, W9, W4, W5 - 1.57 m
W10, F7, W3, W6 - 2.17 m
F6, W2, W7 - 2.80 m
W1, W8 - 3.42 m
F11, F2, F8, F17 - 2.50 m
A1-A12 - 2.50 m
F4, F10, F5, F16 - 1.88 m
F1, F12, F3 - 3.12 m



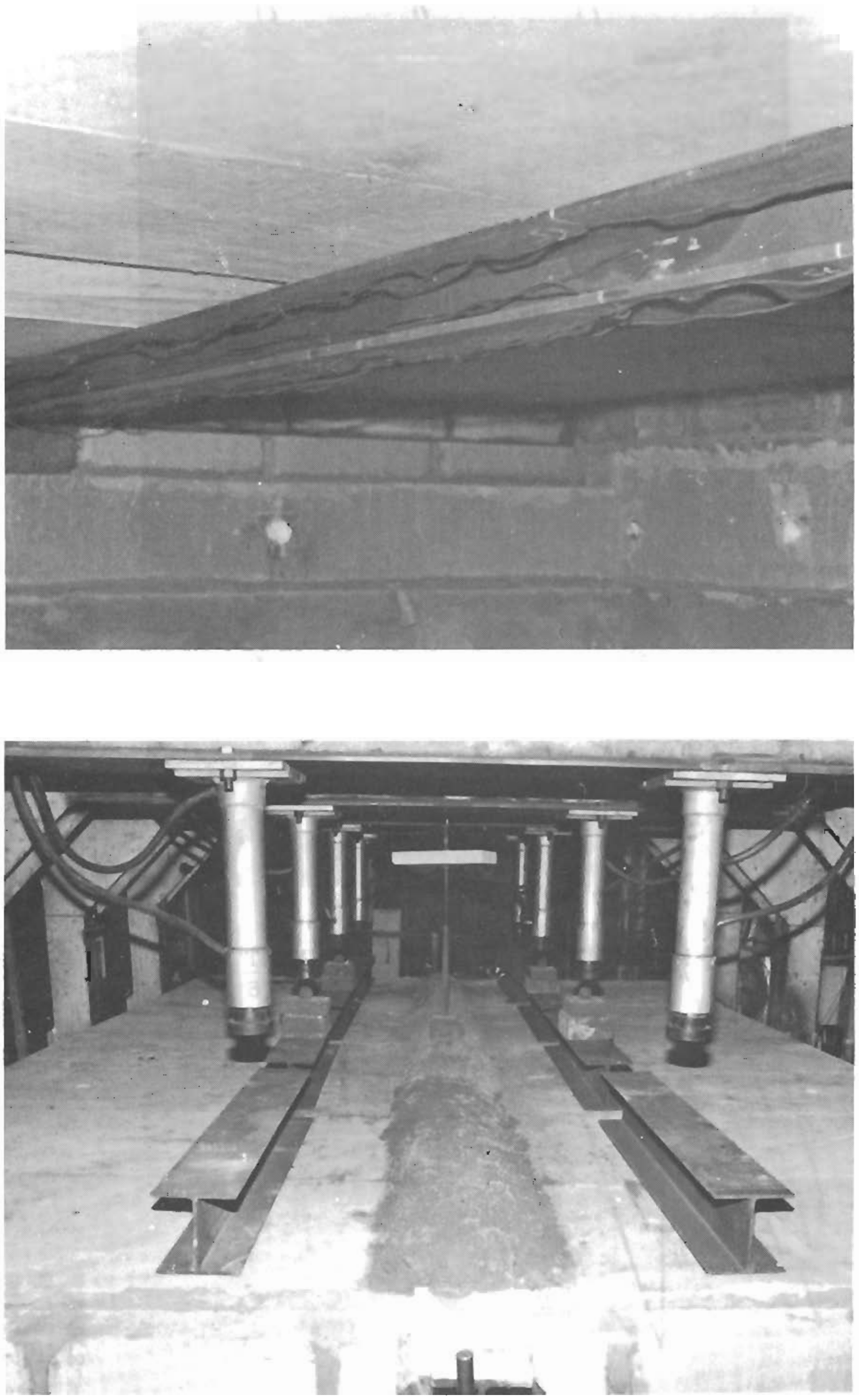


THERMOCOUPLE LOCATIONS USED ON TEST ARRANGEMENT

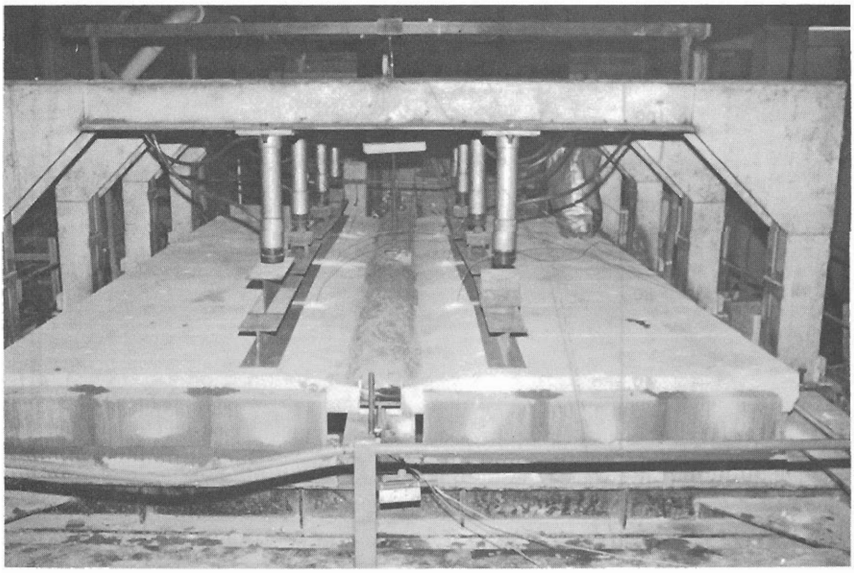
FIG. 5
(R3/1114)



MONITORING BEAM END MOVEMENT
FIG. 6



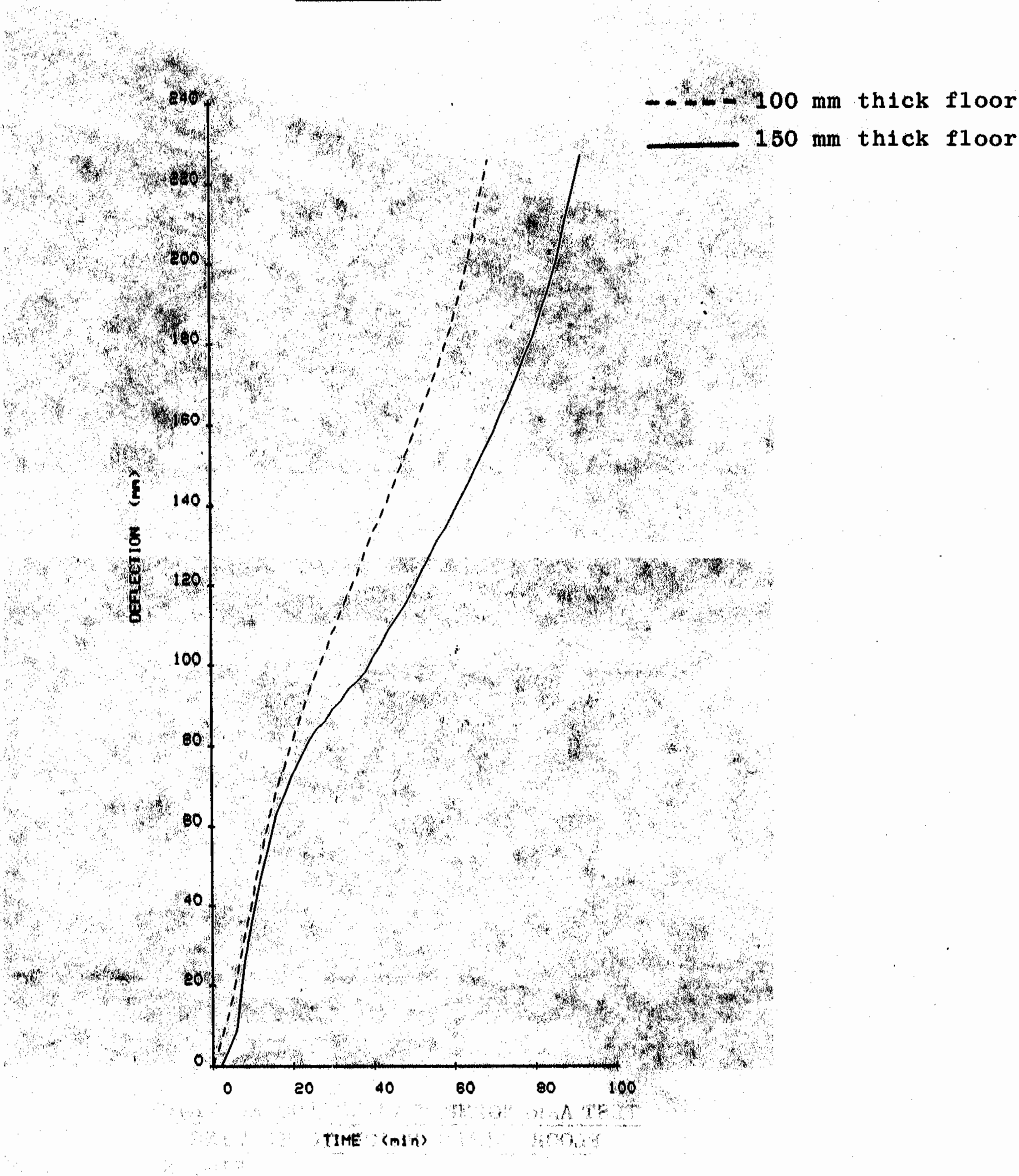
TEST ARRANGEMENT WITH 150 mm THICK
FLOOR SLABS PRIOR TO TESTING
FIG. 7



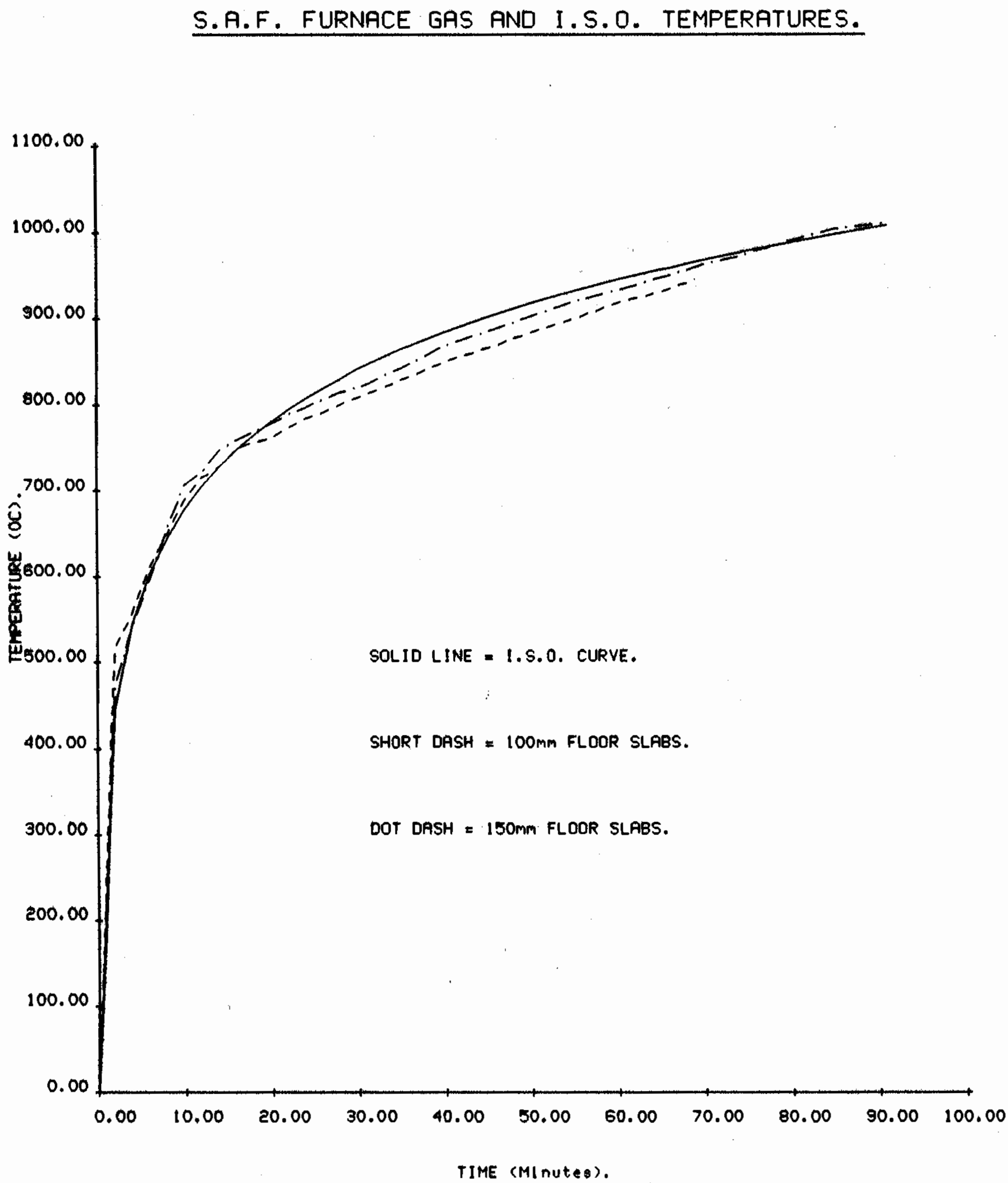
TEST ARRANGEMENT USING 100 mm THICK FLOOR SLABS PRIOR TO TESTING

FIG. 8

DEFLECTION

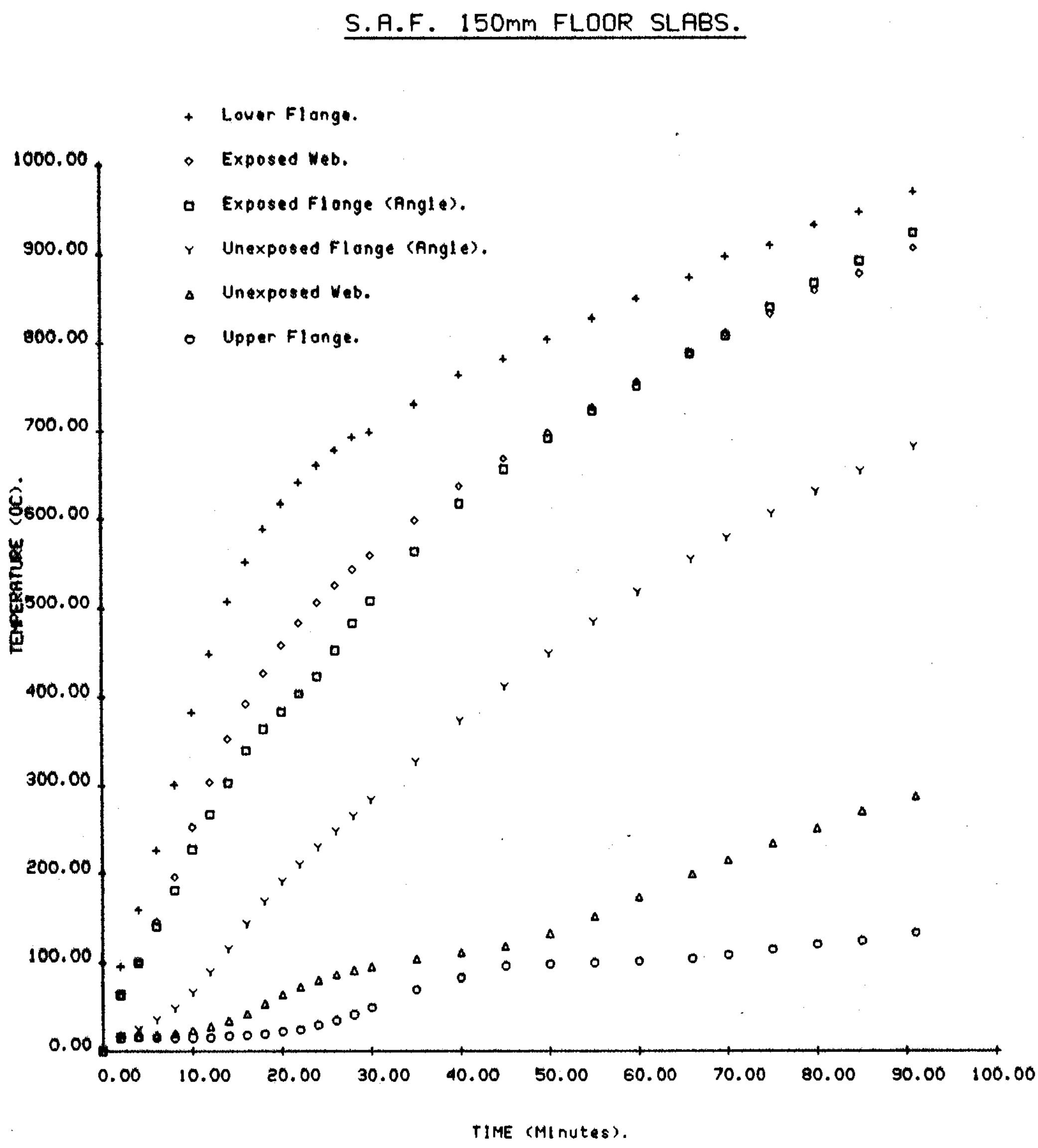


VERTICAL DEFLECTION MEASURED AT THE CENTRE OF THE BEAMS DURING THE TEST   FIG. 9



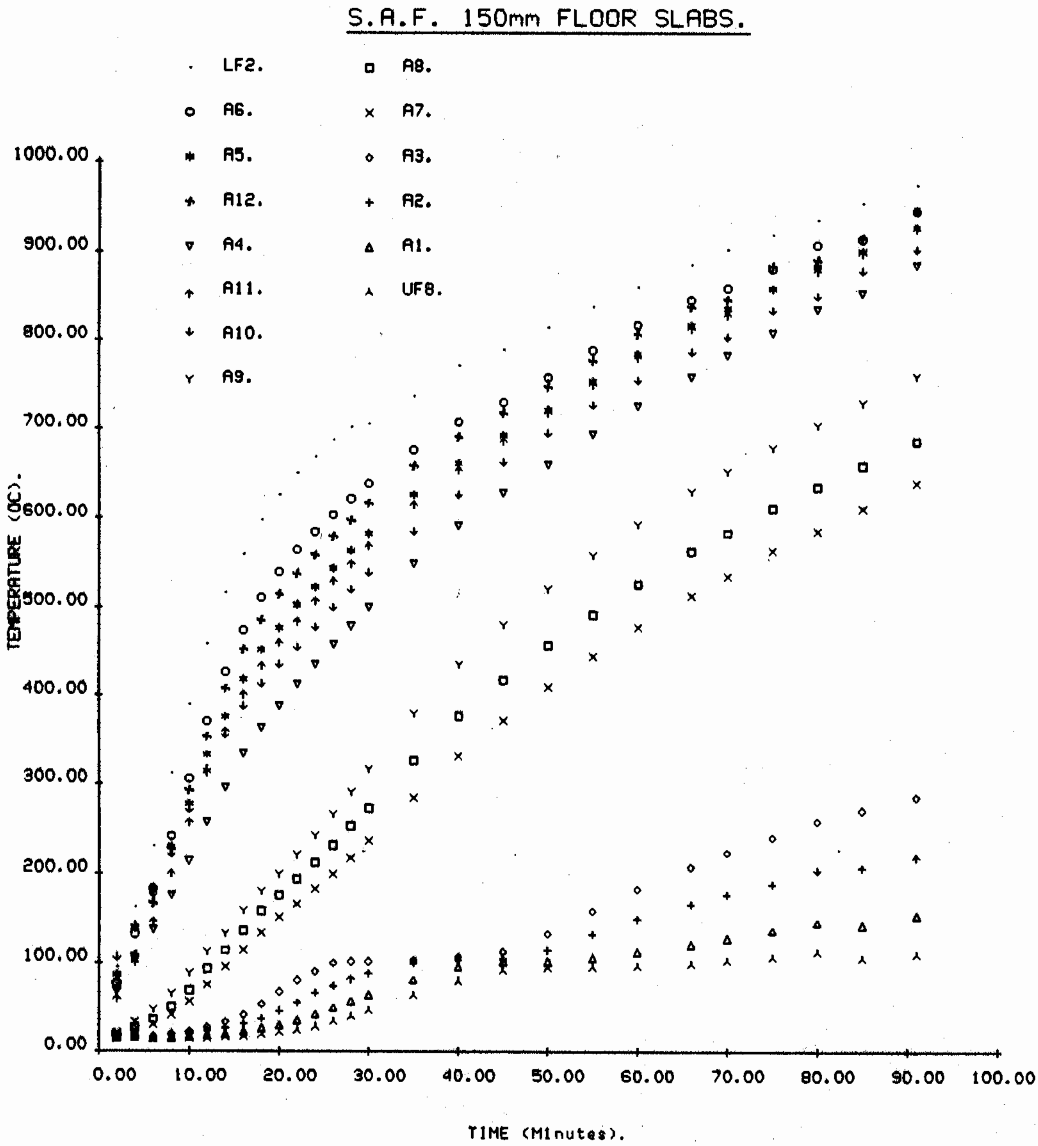
COMPARISON OF FURNACE GAS HEATING RATES WITH THE INTERNATIONAL TEMPERATURE/TIME CURVE

FIG. 10



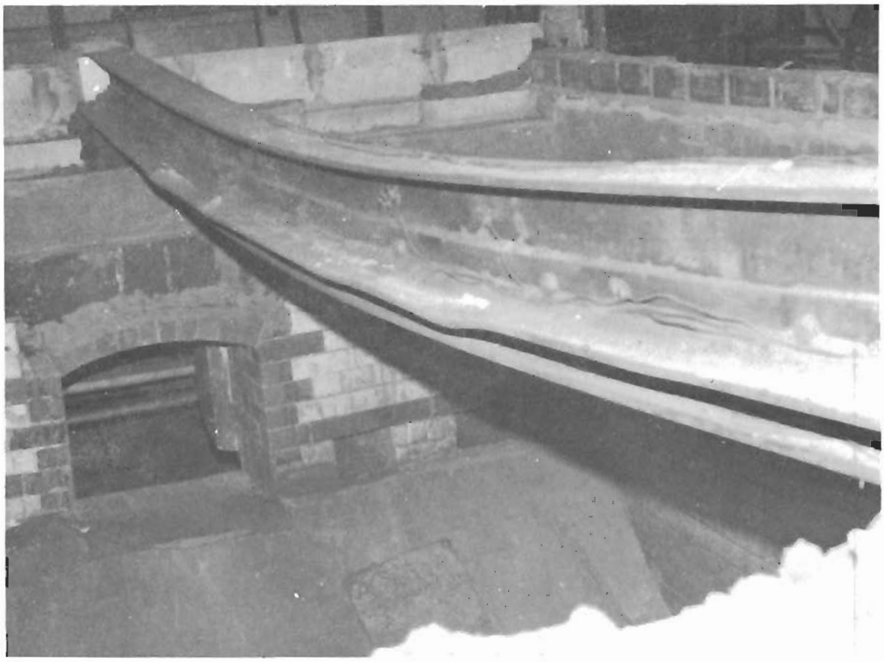
AVERAGE TEMPERATURES RECORDED ACROSS A 254 x 146 mm x 43 kg/m SHELF-ANGLE BEAM WITH 150 mm CONCRETE FLOOR SLABS

FIG. 11

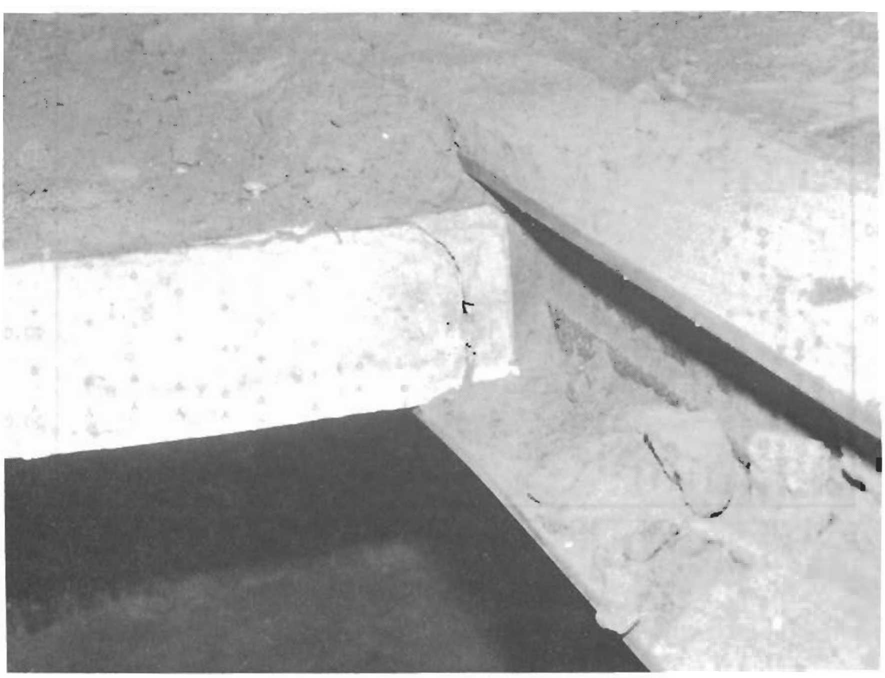


TEMPERATURE PROFILE AT MID-SPAN THROUGH THE 254 x 146 mm x 43 kg/m SHELF-ANGLE BEAM TEST WITH 150 mm THICK FLOOR SLABS

FIG. 12

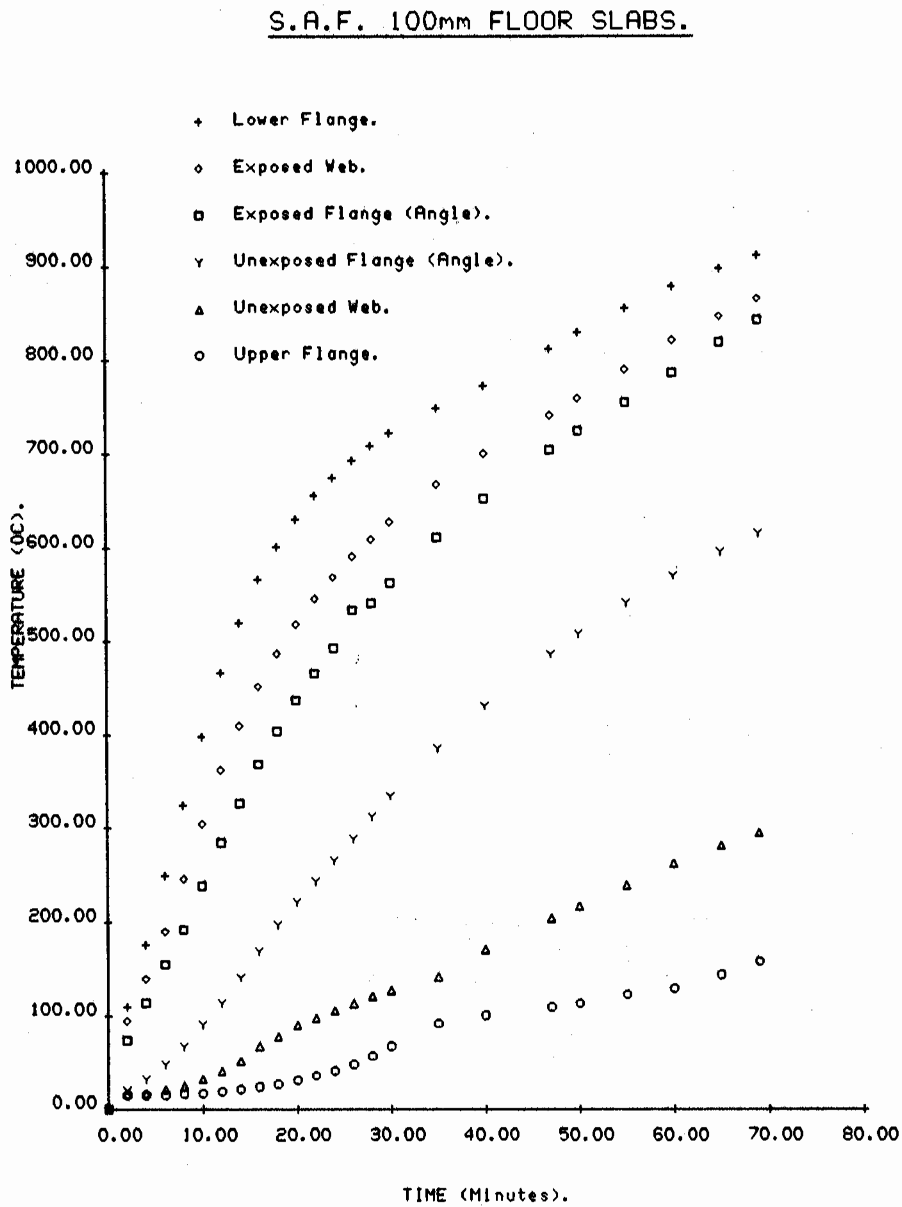


Ripple effect along angle length (a)



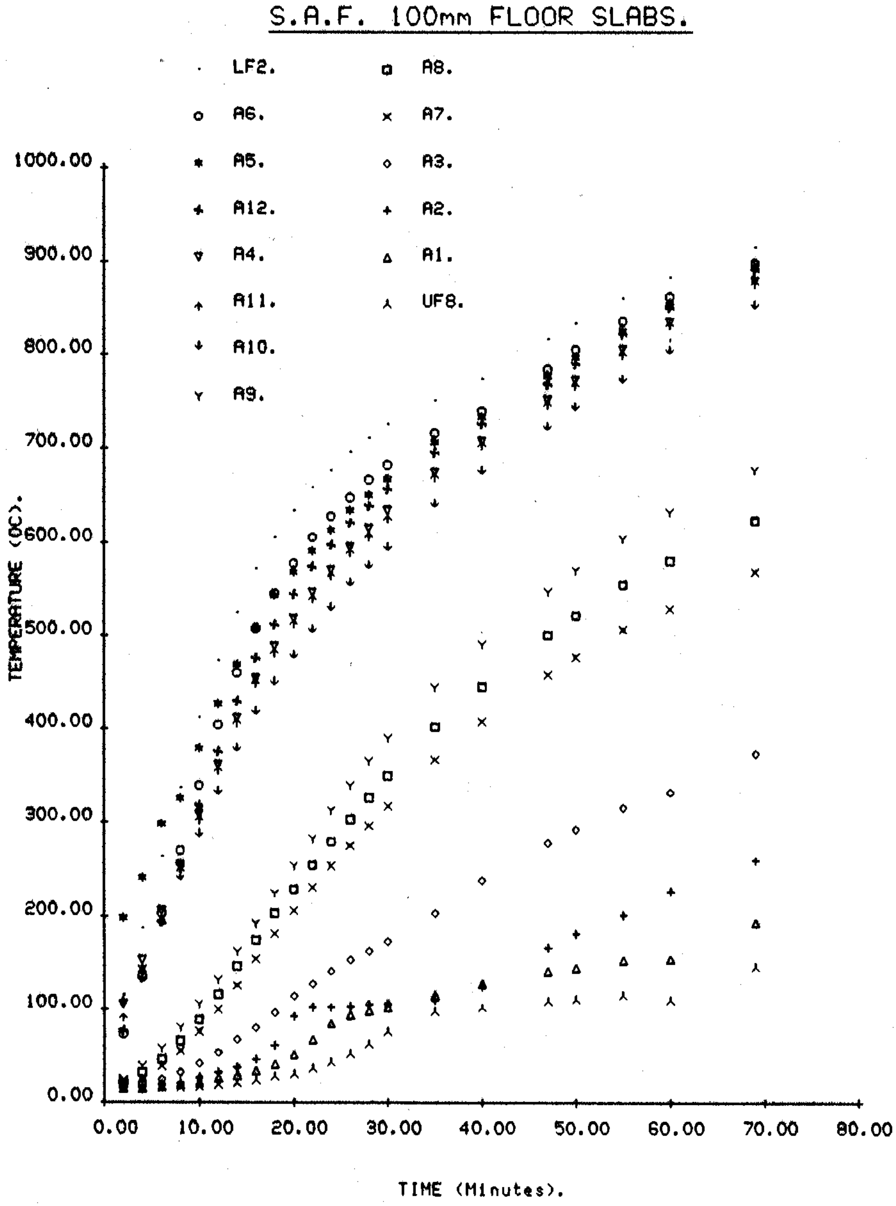
Vertical cracks in concrete slabs (b)

150 mm SHELF-ANGLE FLOOR CONSTRUCTION AFTER TESTING FIG. 13



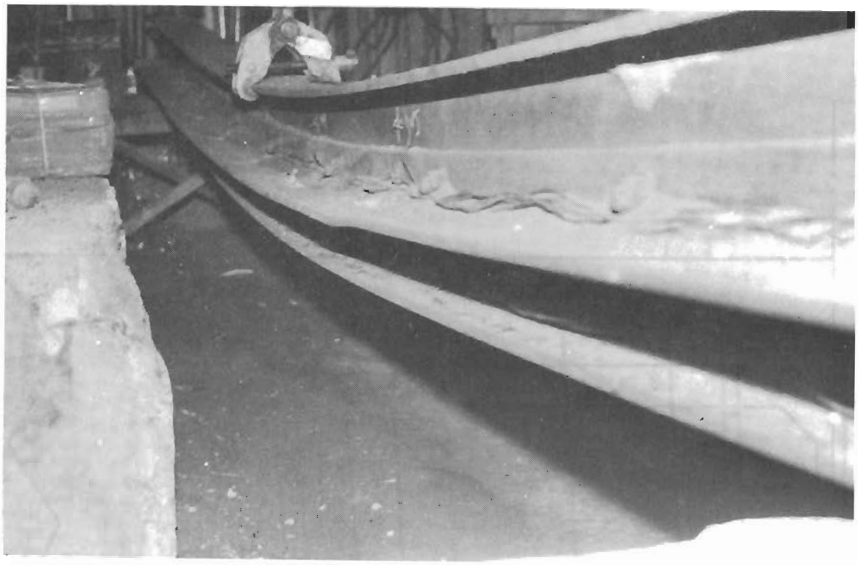
AVERAGE TEMPERATURES RECORDED ON A 254 x 146 mm x 43 kg/m SHELF-ANGLE BEAM TEST WITH 100 mm THICK FLOOR SLABS

FIG. 14

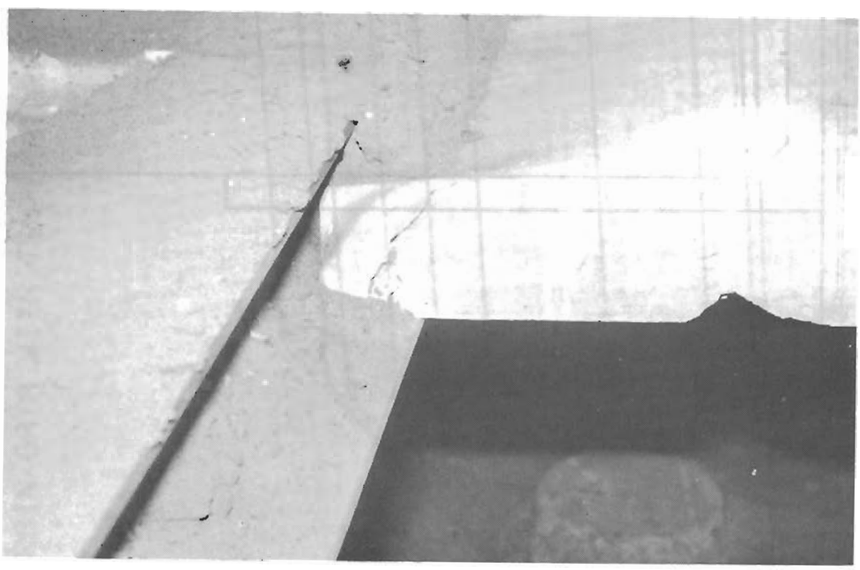


TEMPERATURE PROFILE AT MID-SPAN THROUGH THE 254 x 146 mm x 43 kg/m SHELF-ANGLE BEAM TEST WITH 100 mm THICK FLOOR SLABS

FIG. 15

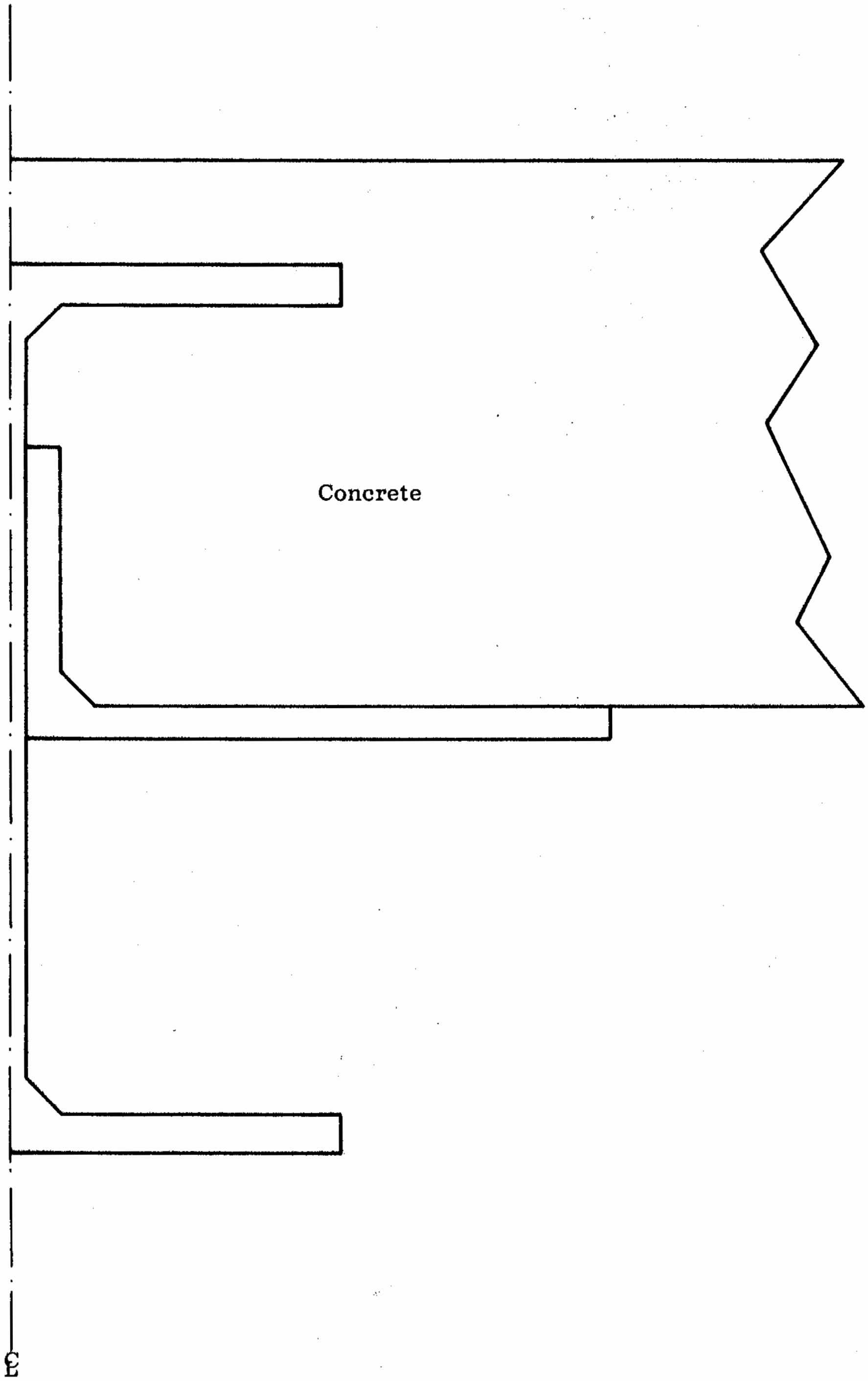


Uniform deflection of angle and beam (a)



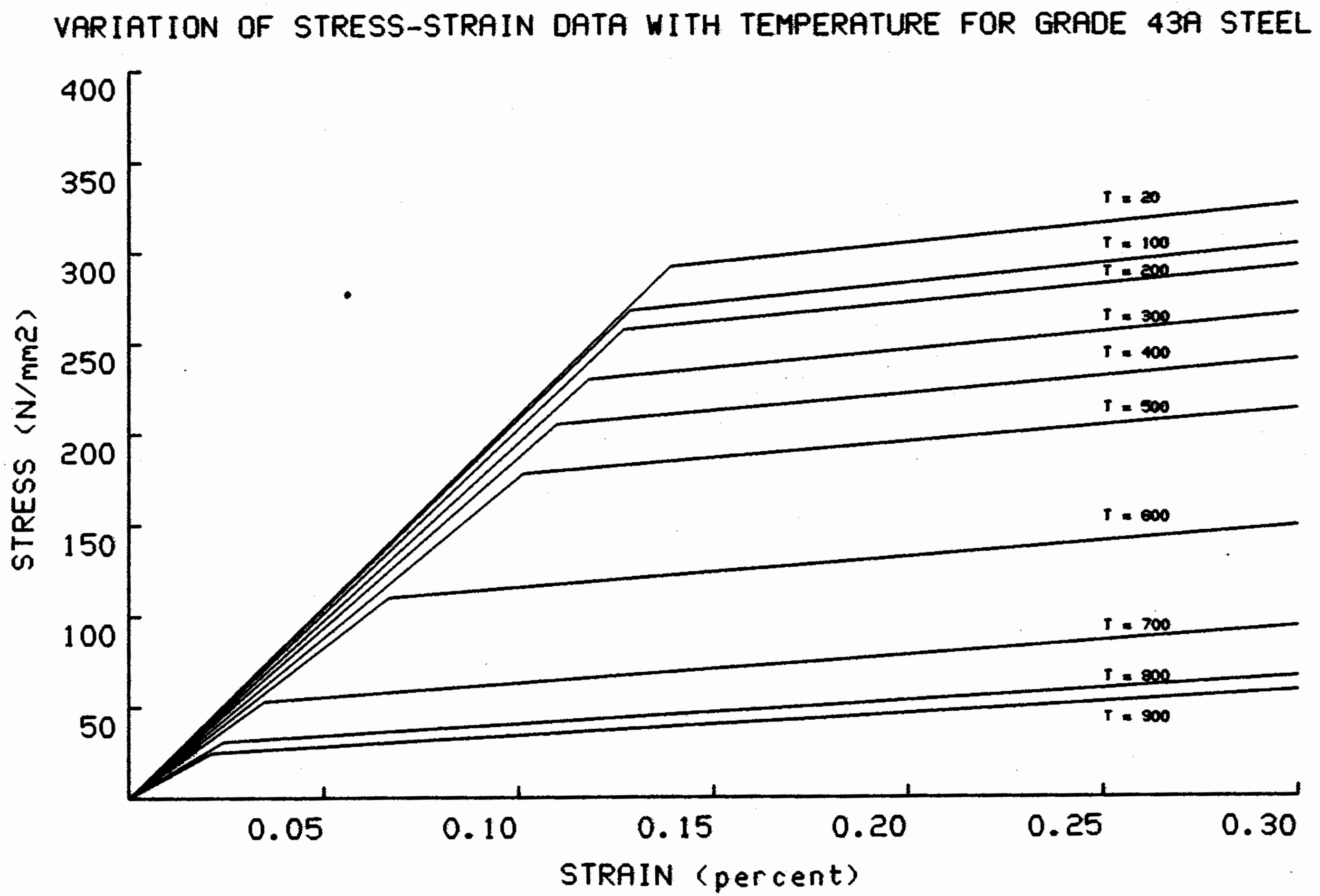
Shear cracks contained in some of the concrete slabs (b)

100 mm SHELF-ANGLE FLOOR CONSTRUCTION AFTER TESTING FIG. 16

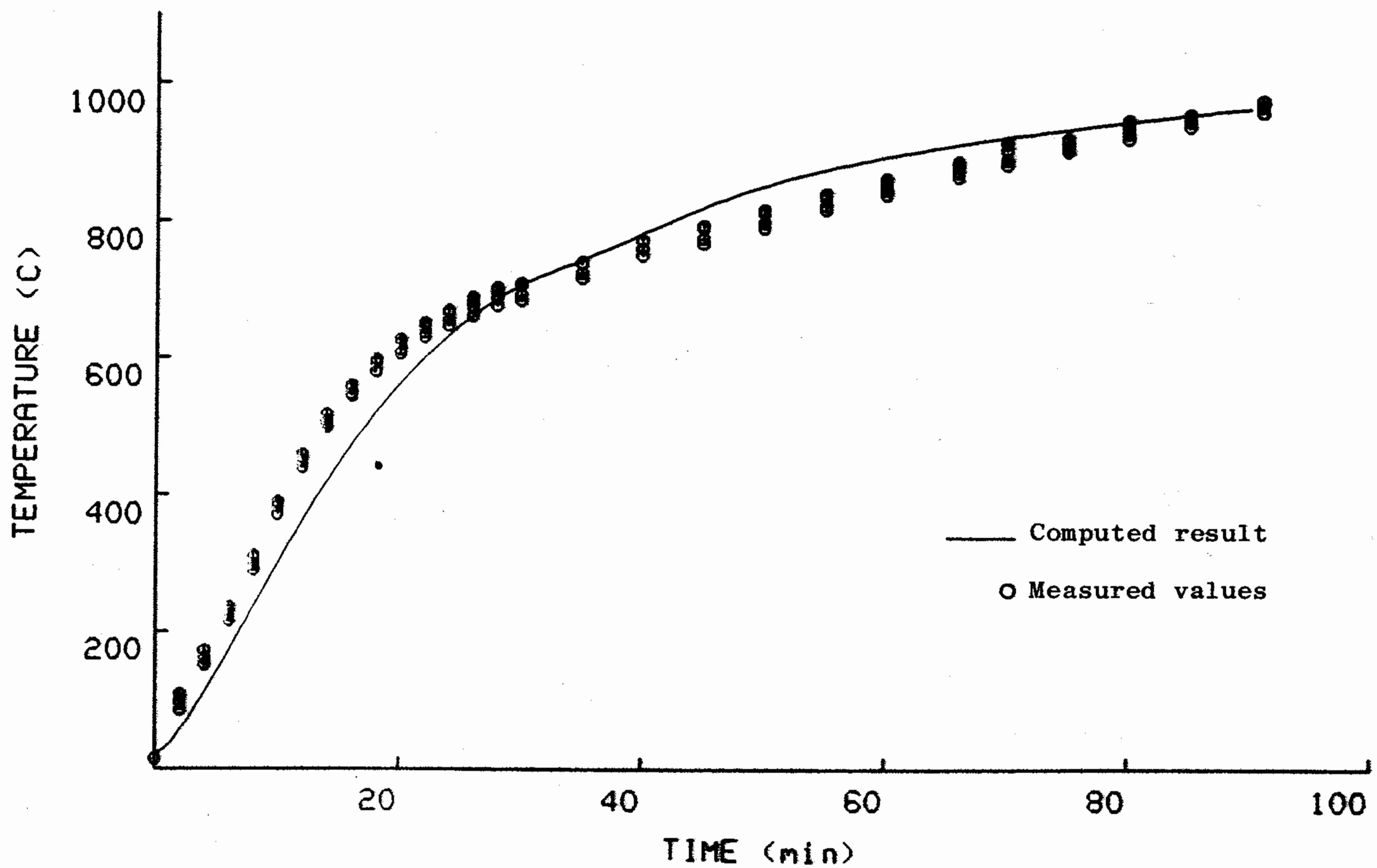


SCHEMATIC MODEL OF SHELF-ANGLE FLOOR STRUCTURE USED IN FE ANALYSIS

FIG. 17
(R3/1115)

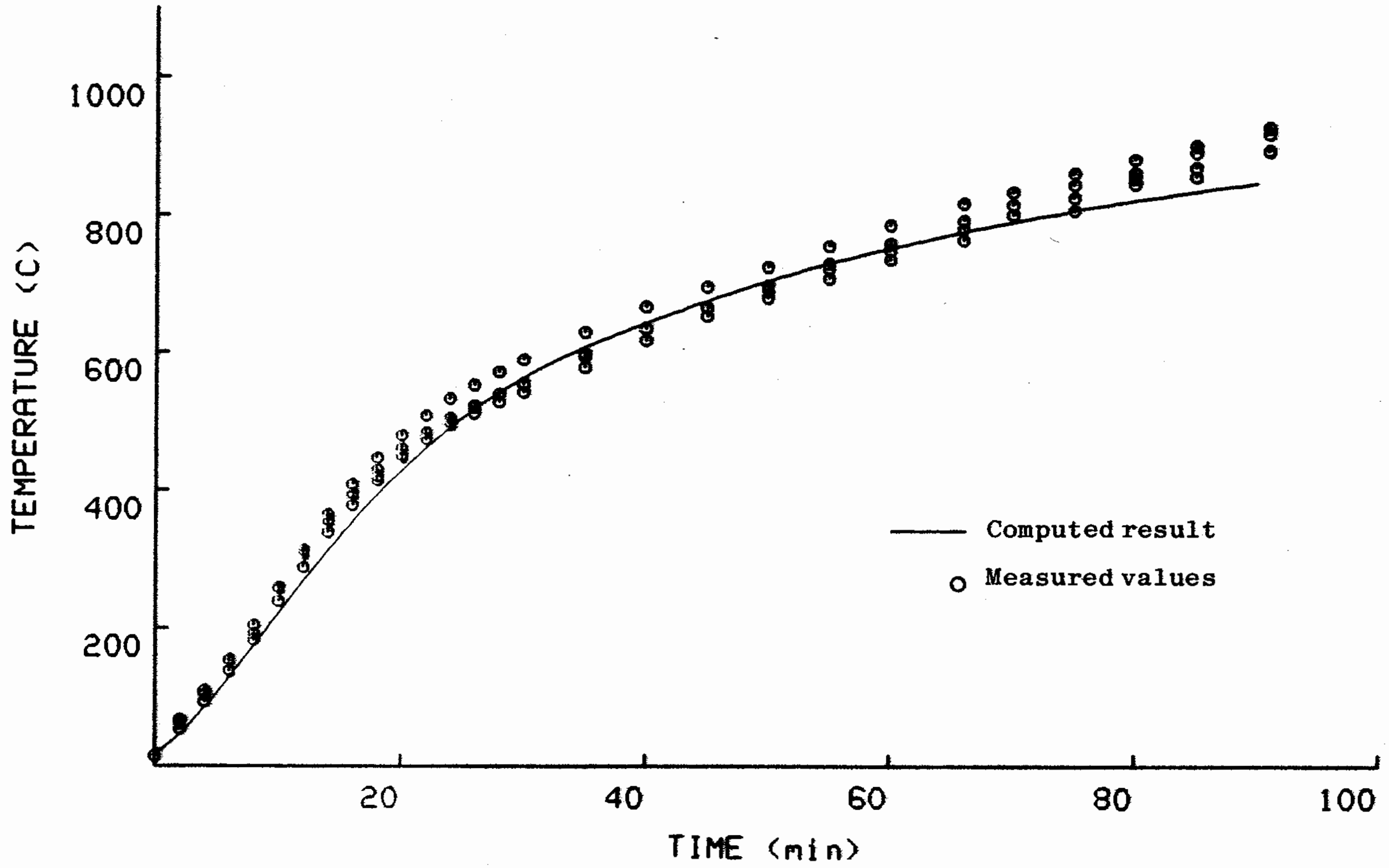


VARIATION OF STRESS-STRAIN DATA WITH TEMPERATURE FOR GRADE 43A STEEL FIG. 18



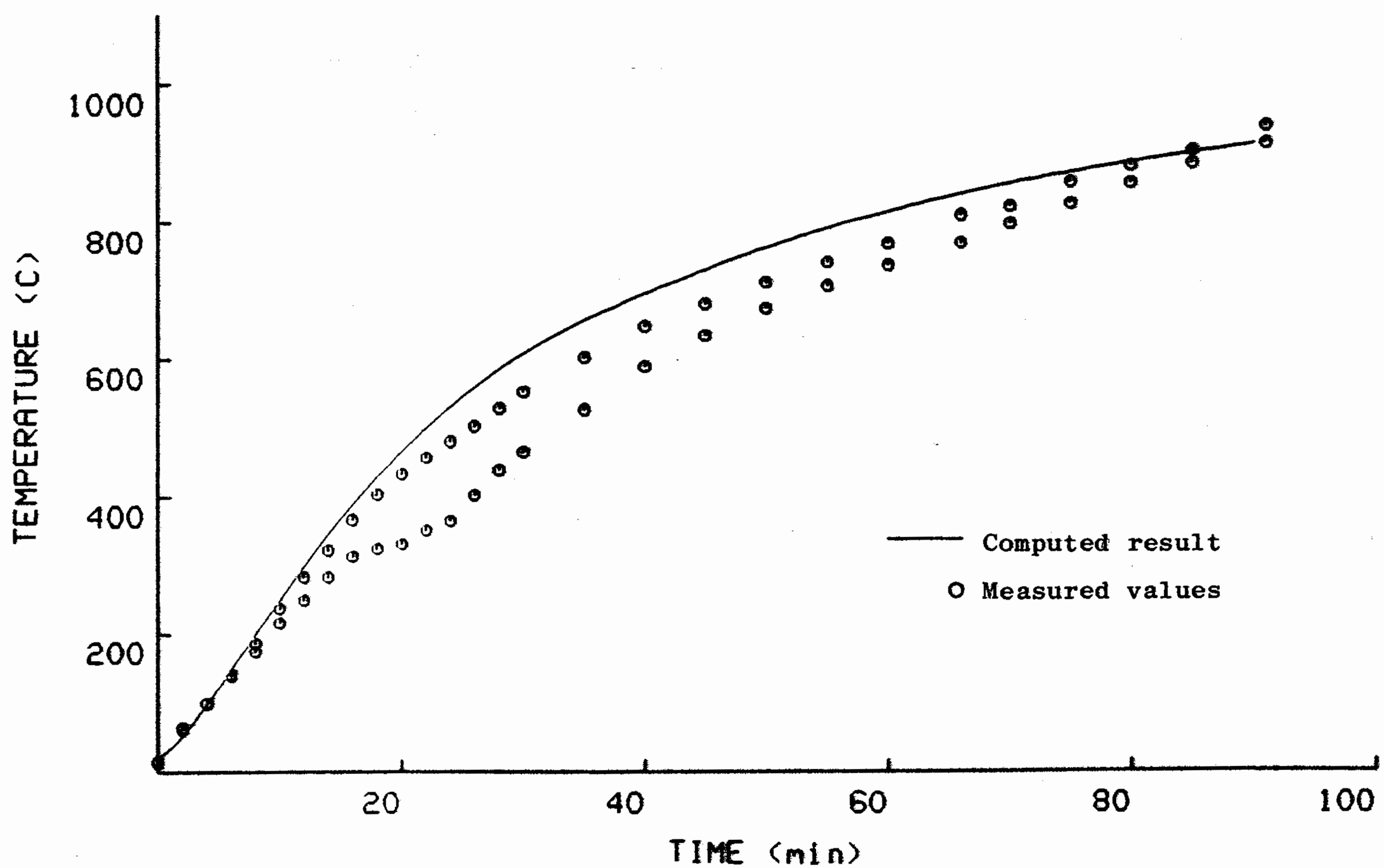
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm
LOWER FLANGE TEMPERATURE

FIG. 19



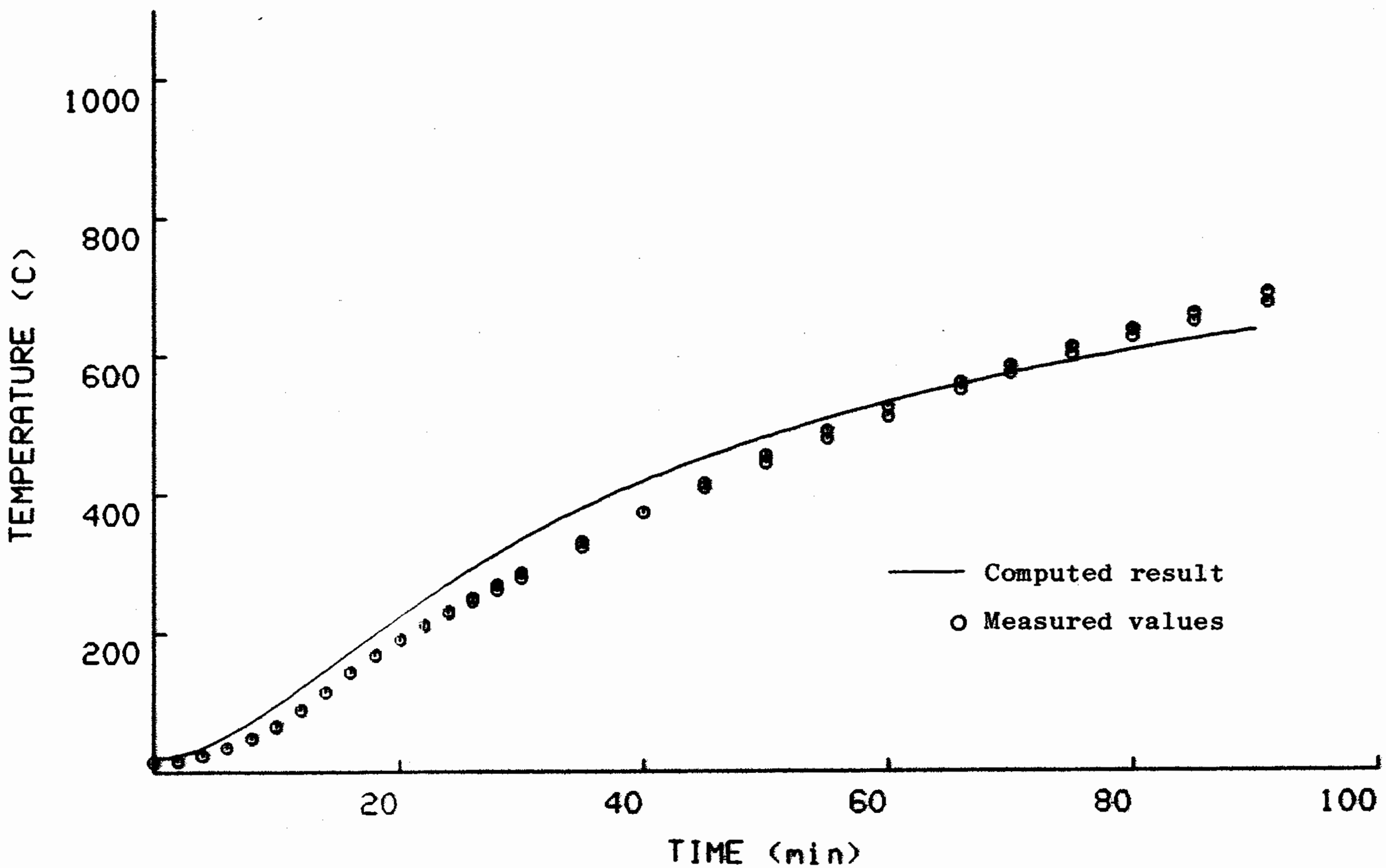
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm   FIG. 20

EXPOSED WEB TEMPERATURE



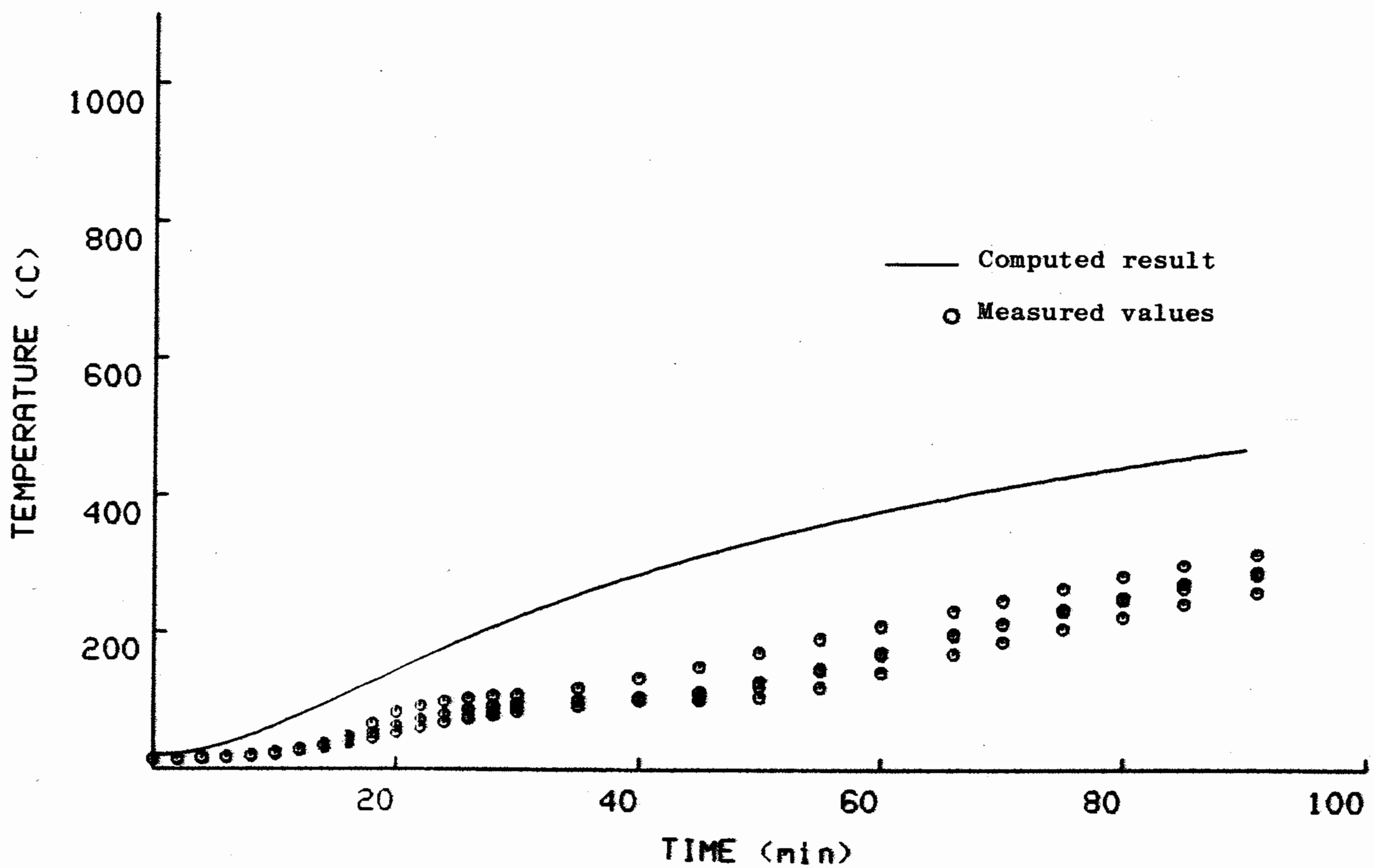
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm FIG. 21

EXPOSED FLANGE (ANGLE) TEMPERATURE



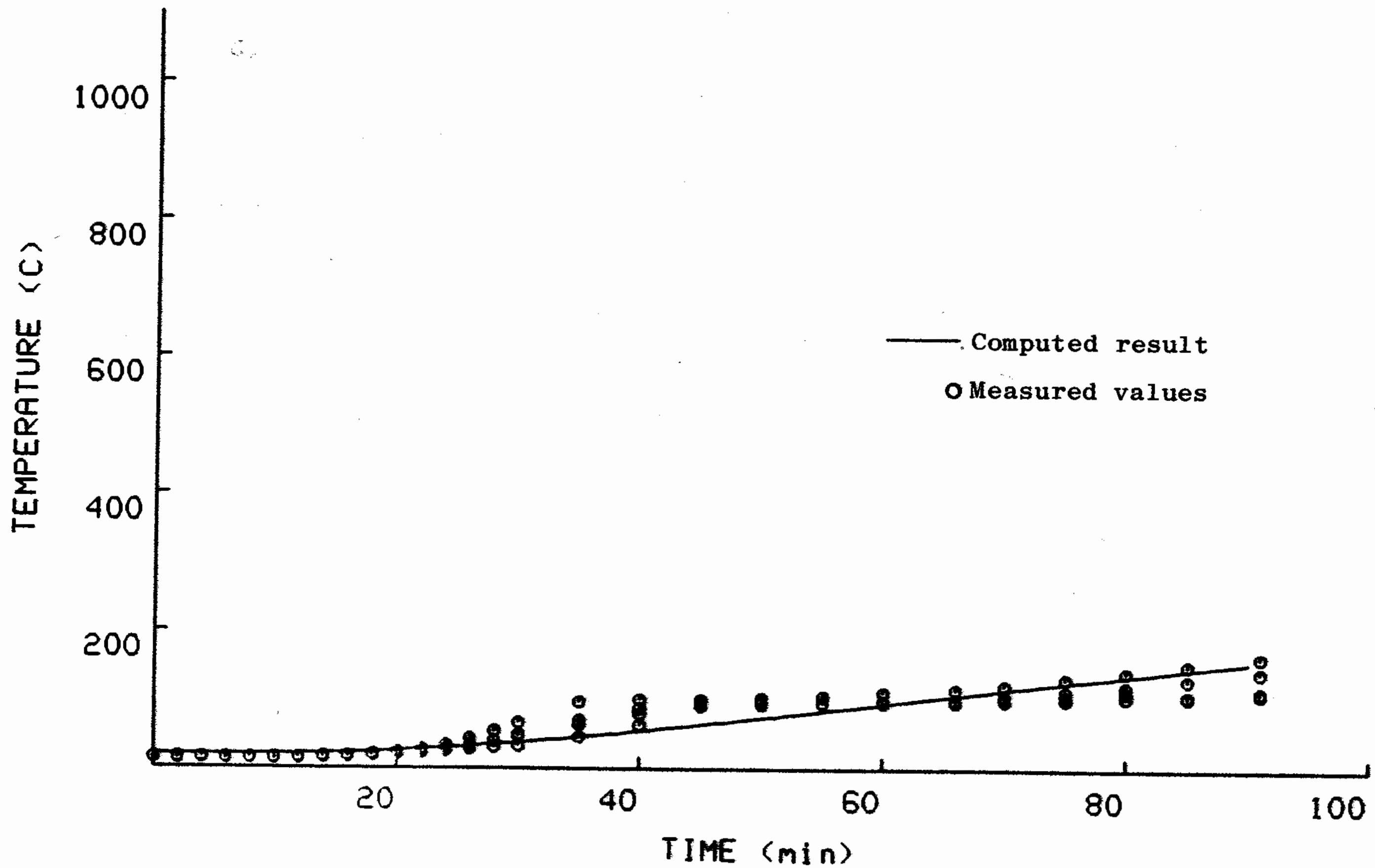
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm FIG. 22

UNEXPOSED FLANGE (ANGLE) TEMPERATURE



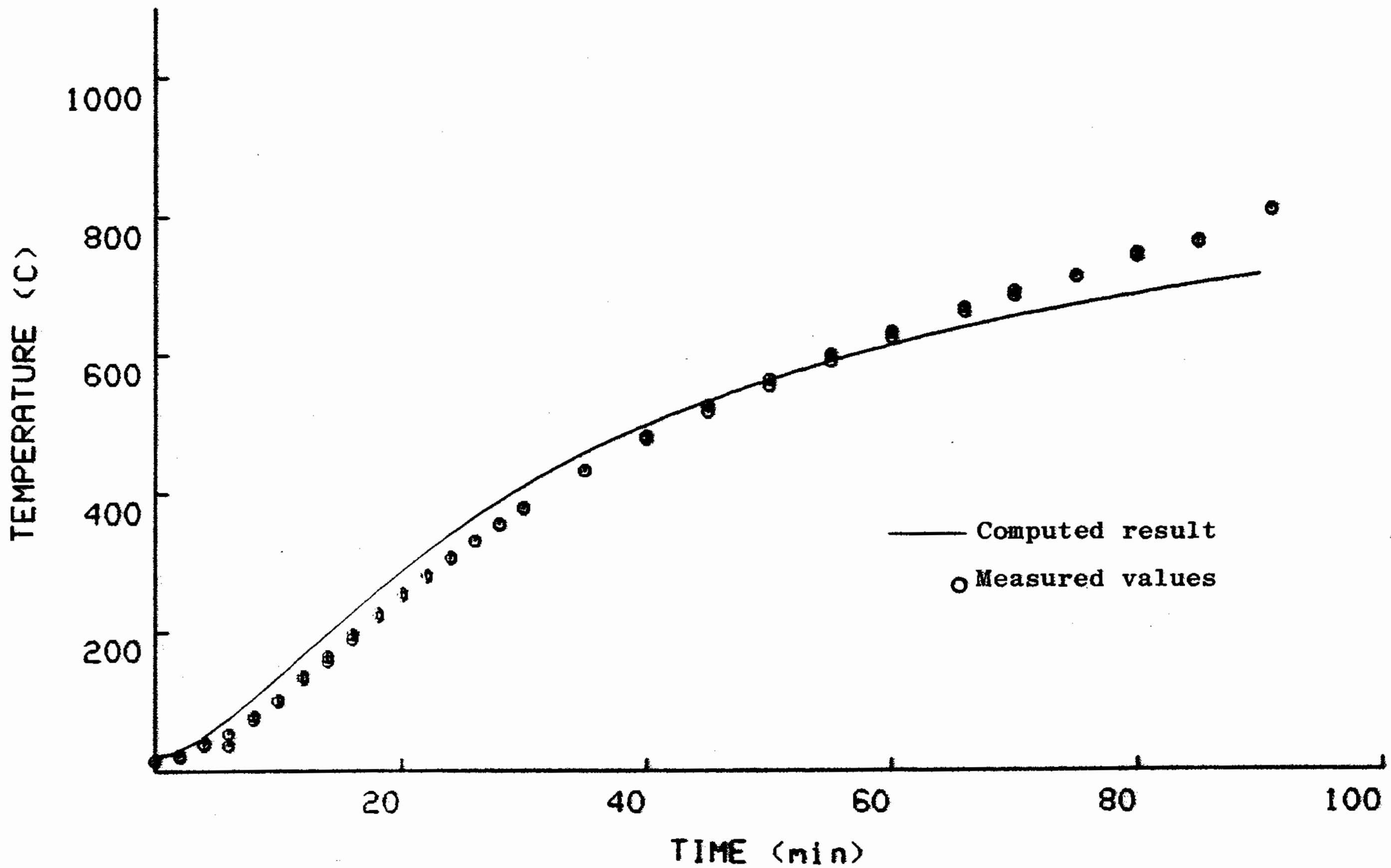
<u>254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm</u> FIG. 23

<u>UNEXPOSED WEB TEMPERATURE</u>



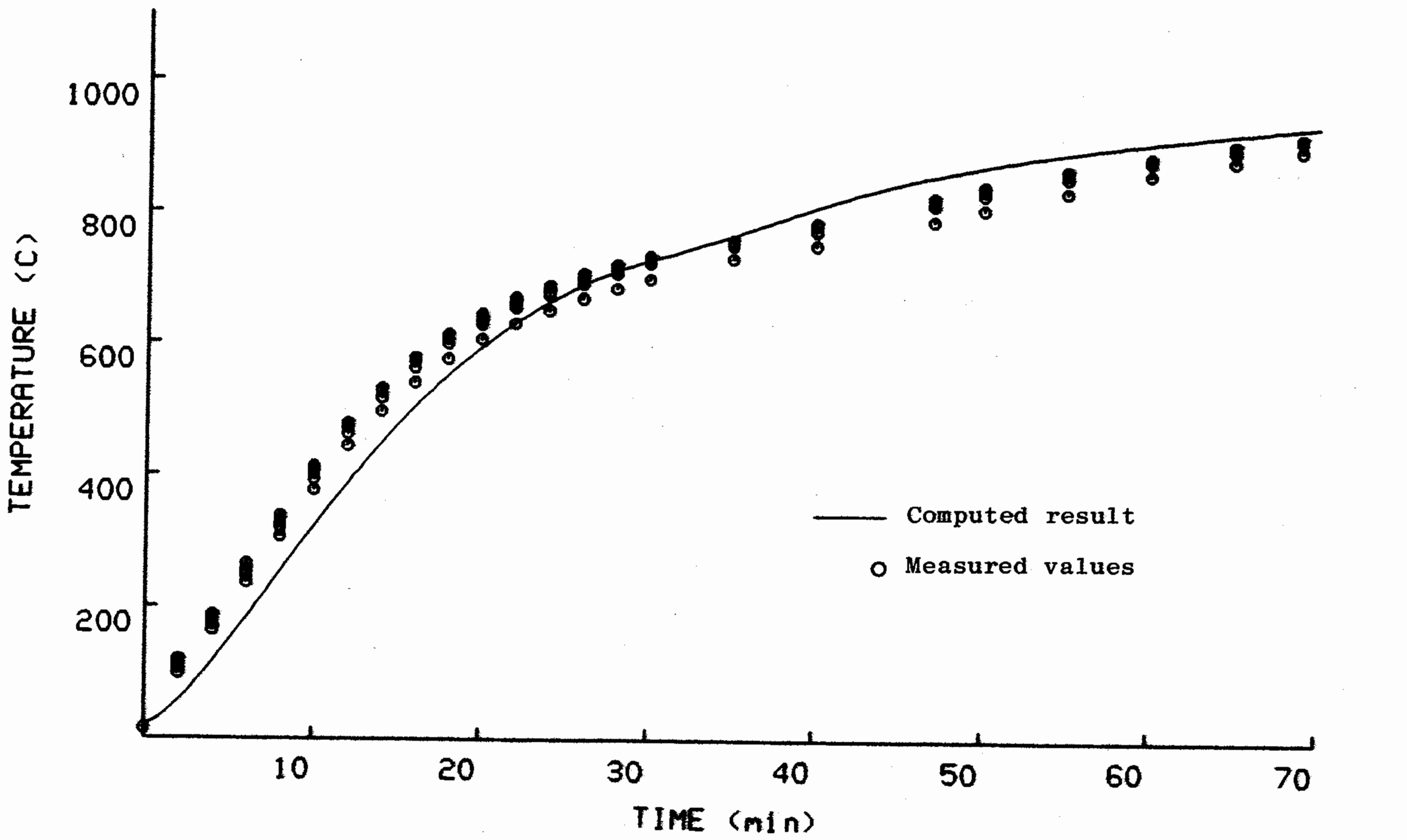
<u>254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm</u> FIG. 24

<u>UPPER FLANGE TEMPERATURE</u>



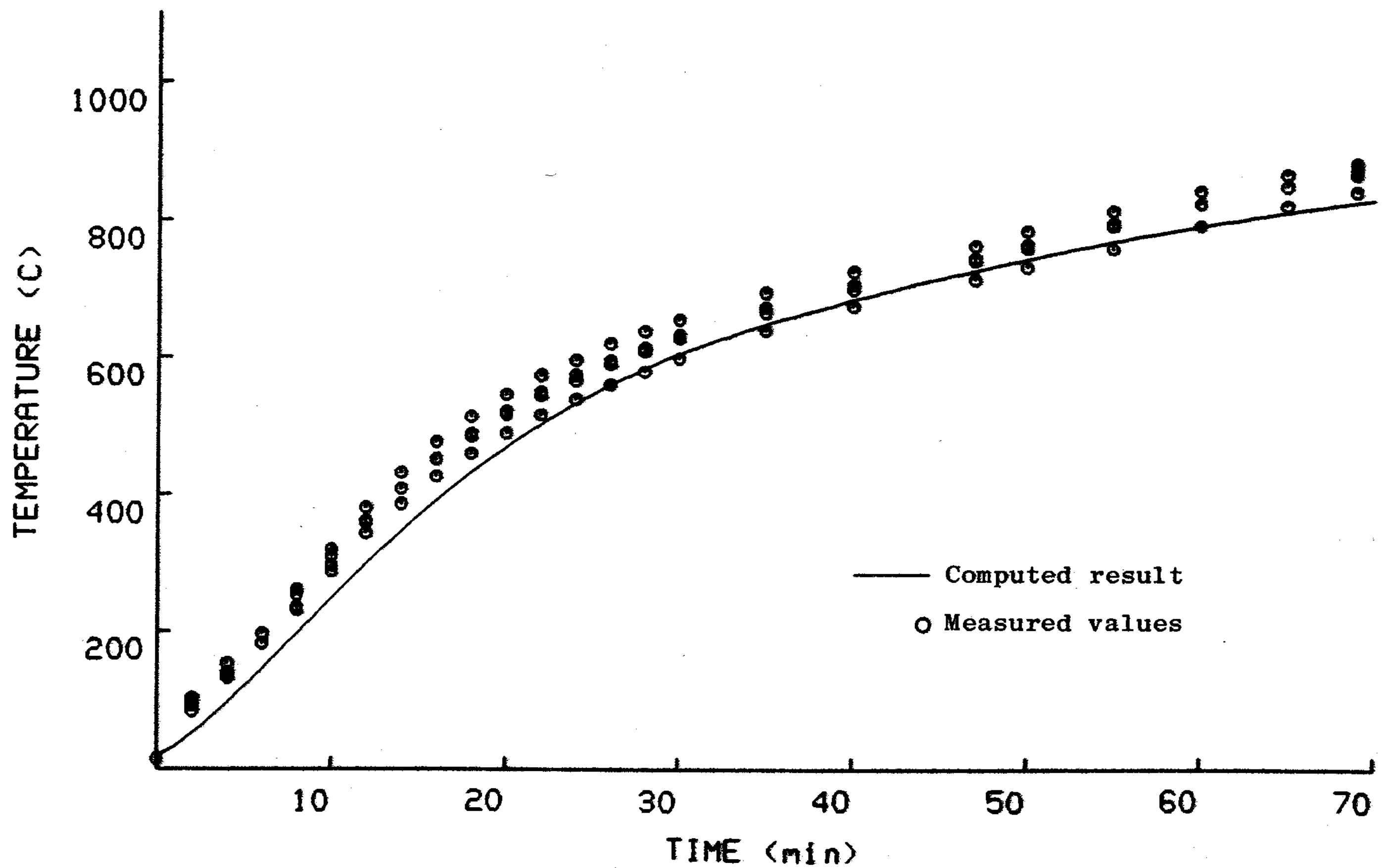
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm   FIG. 25

ANGLE ROOT TEMPERATURE



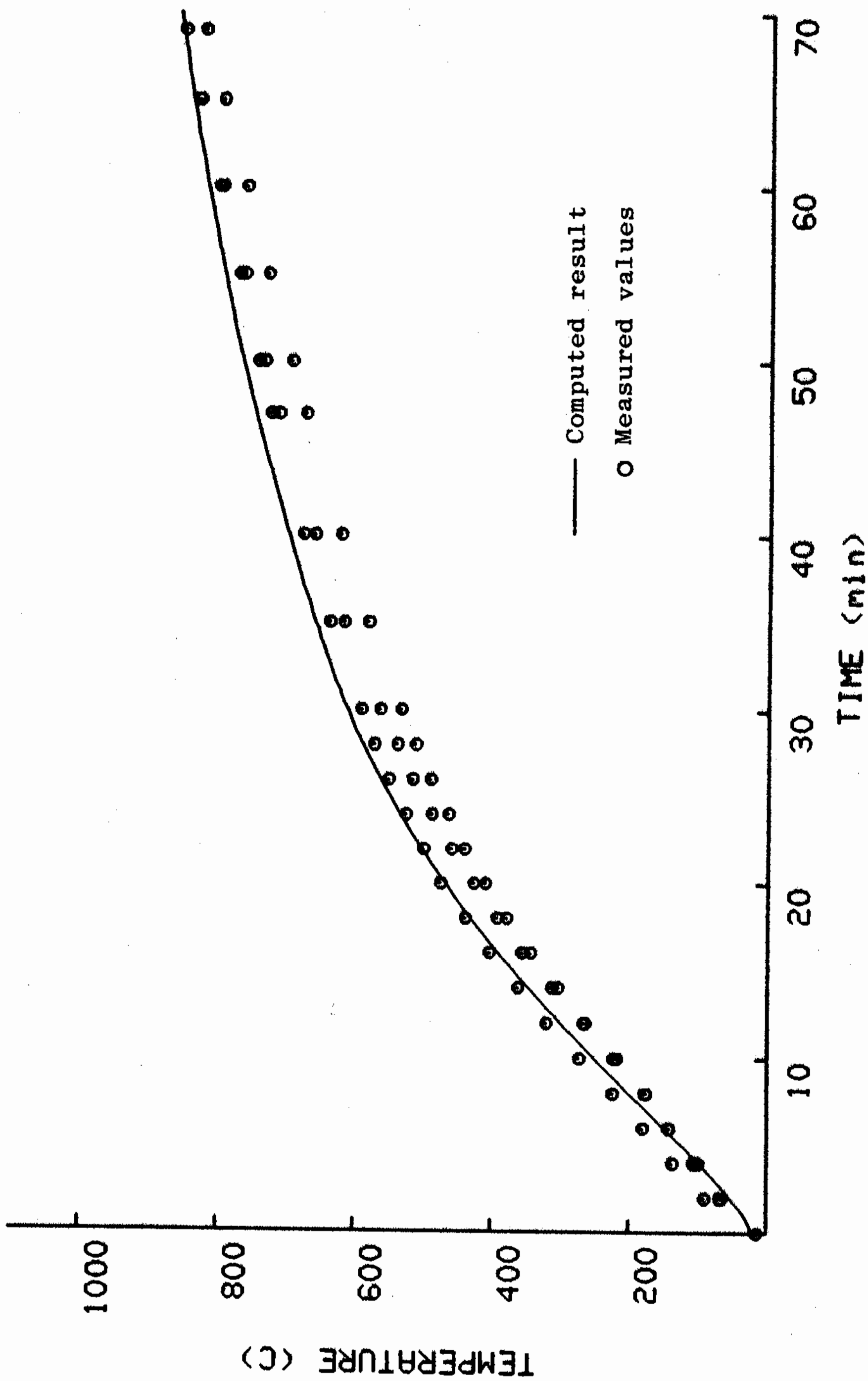
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm FIG. 26

LOWER FLANGE TEMPERATURE



254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm FIG. 27

EXPOSED WEB TEMPERATURE



254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm   FIG. 28

EXPOSED FLANGE TEMPERATURE

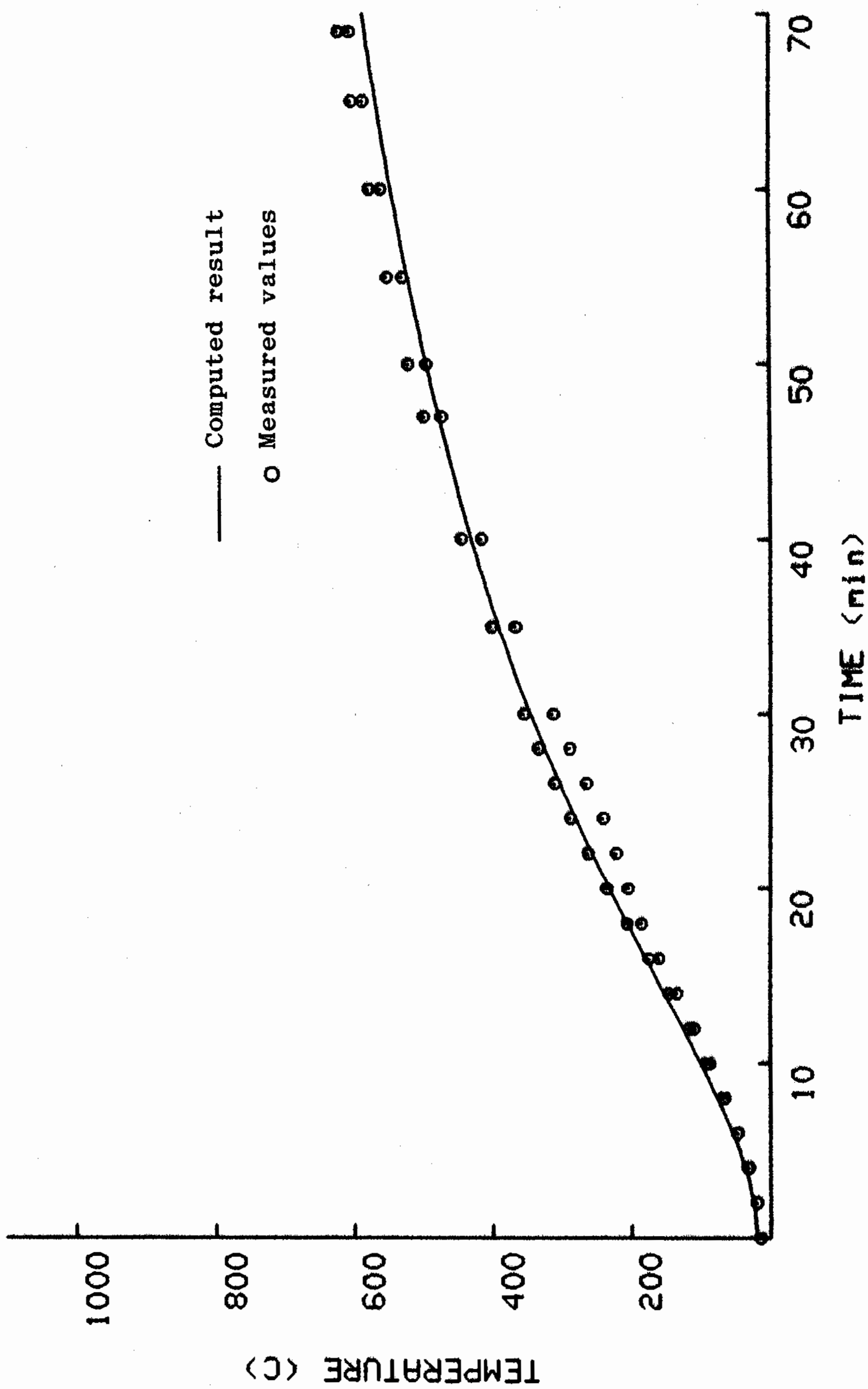
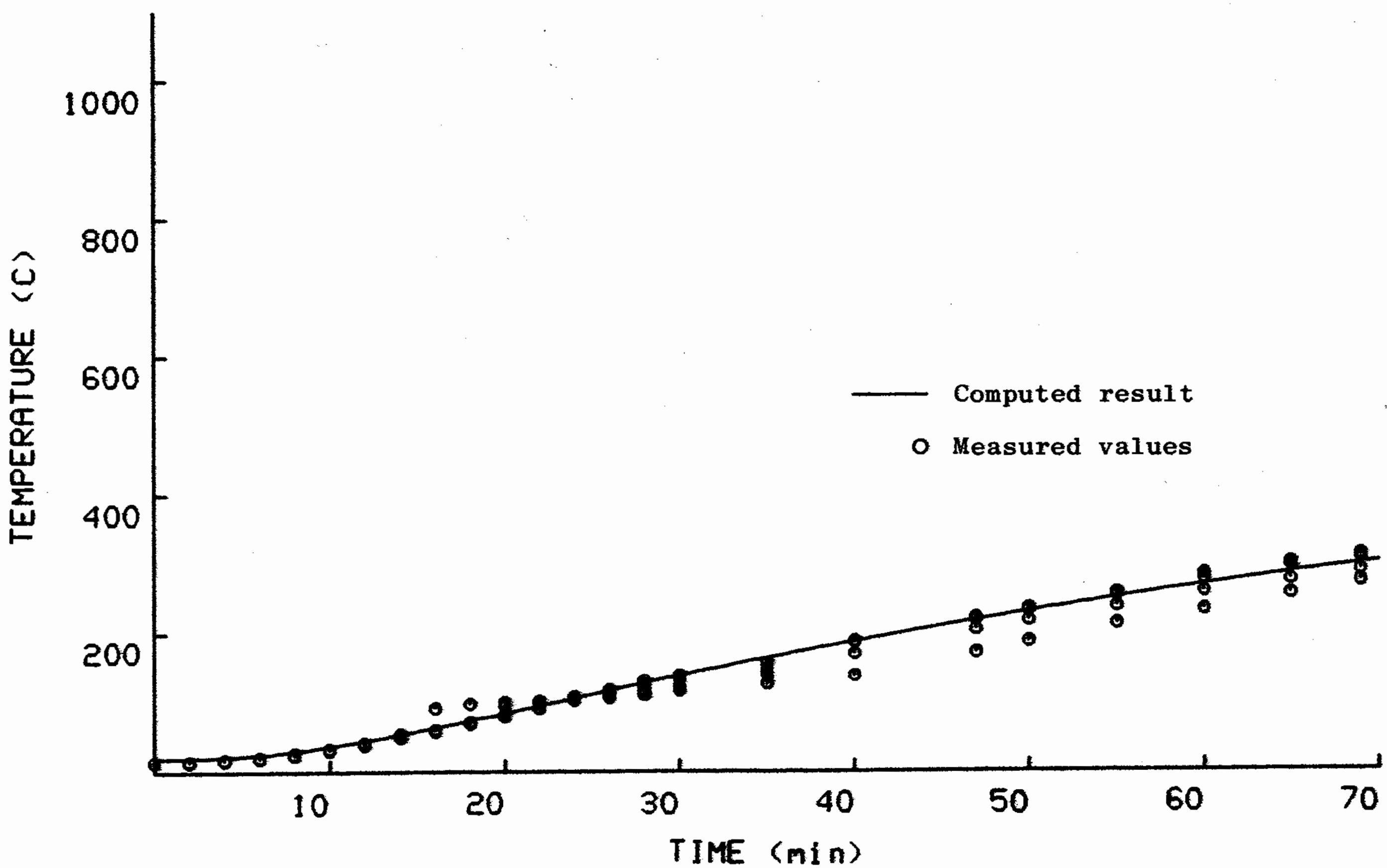


FIG. 29

254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm

UNEXPOSED FLANGE TEMPERATURE



<u>254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm</u> FIG. 30

<u>UNEXPOSED WEB TEMPERATURE</u>

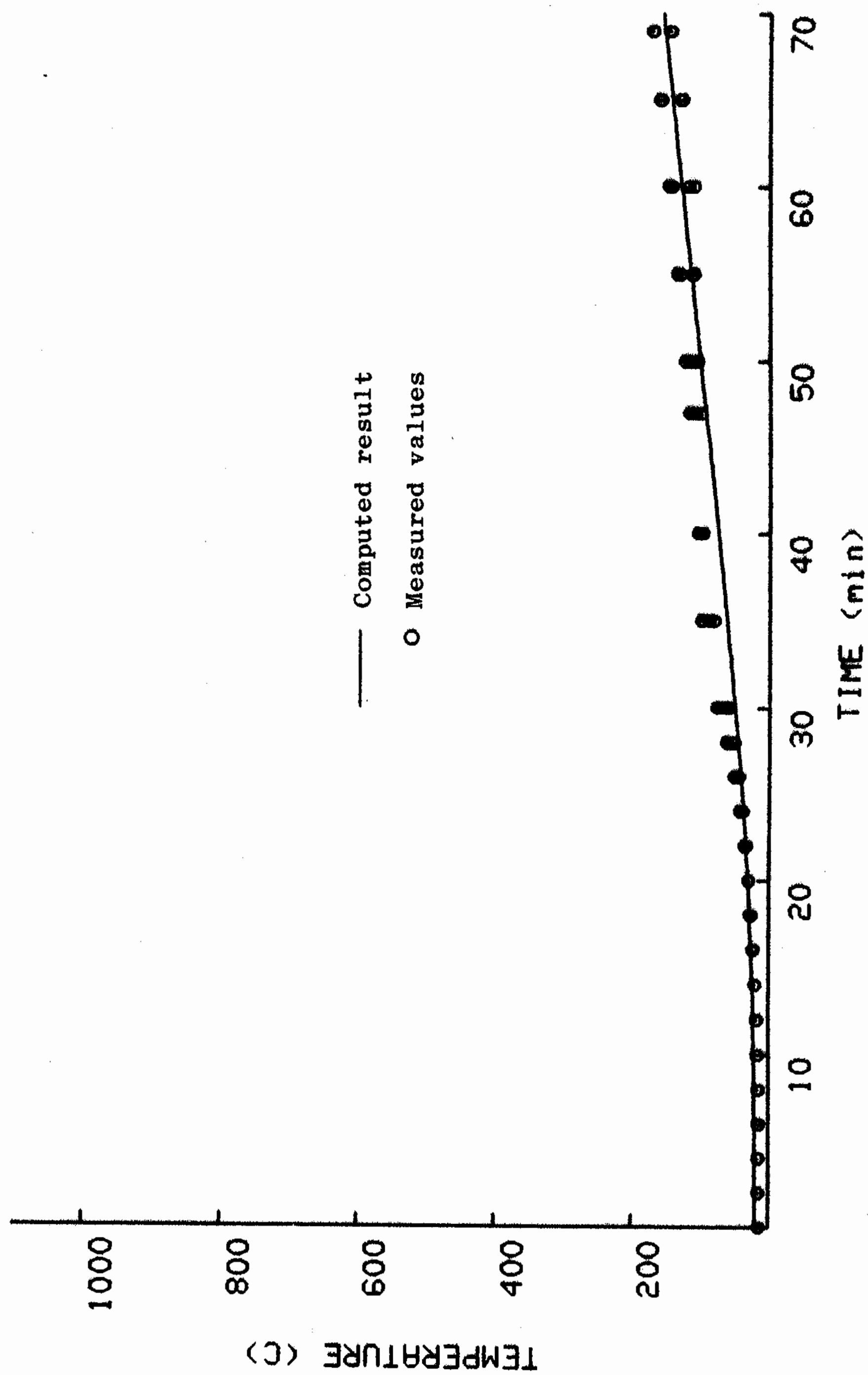


FIG. 31

254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm

UPPER FLANGE TEMPERATURE

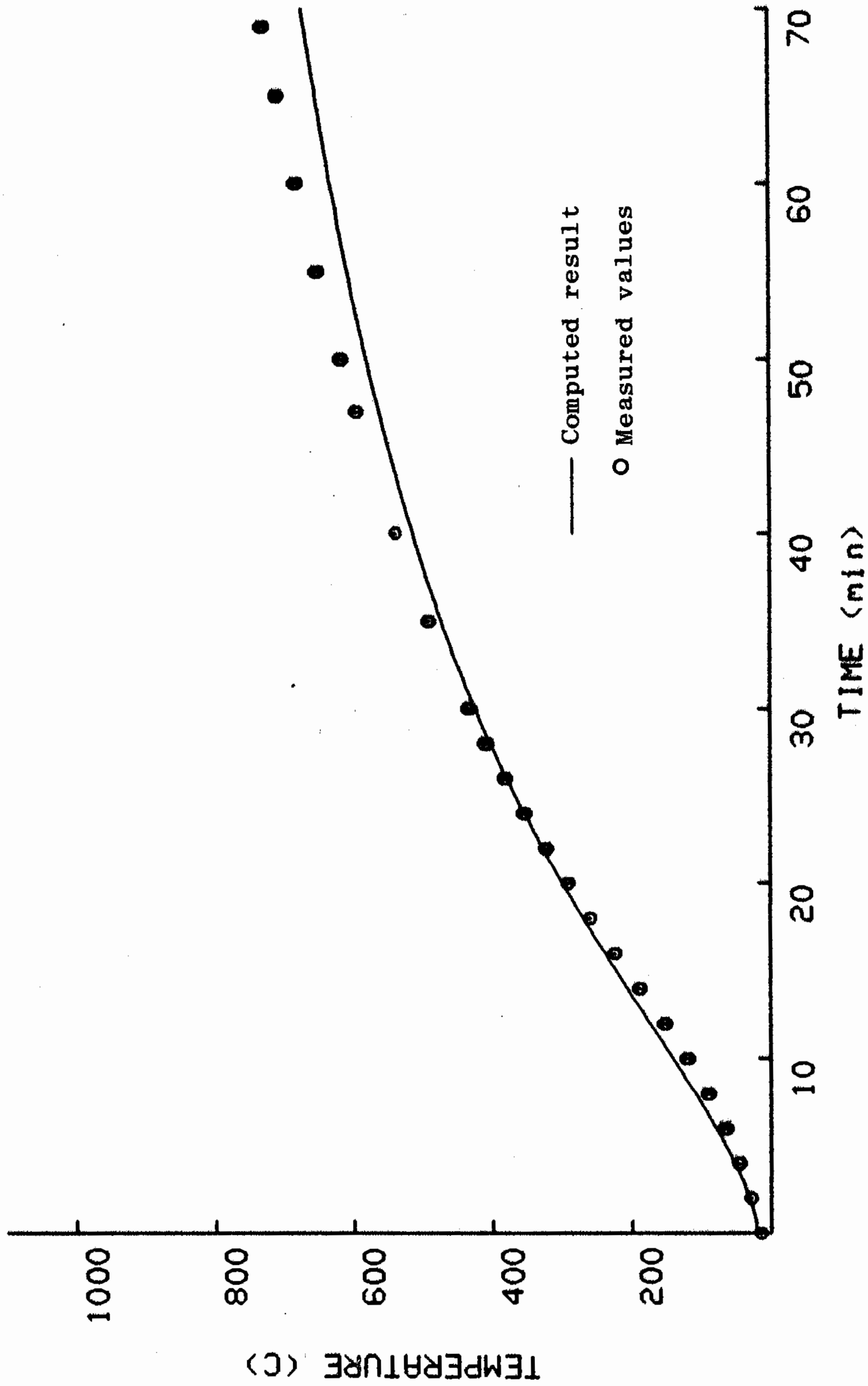
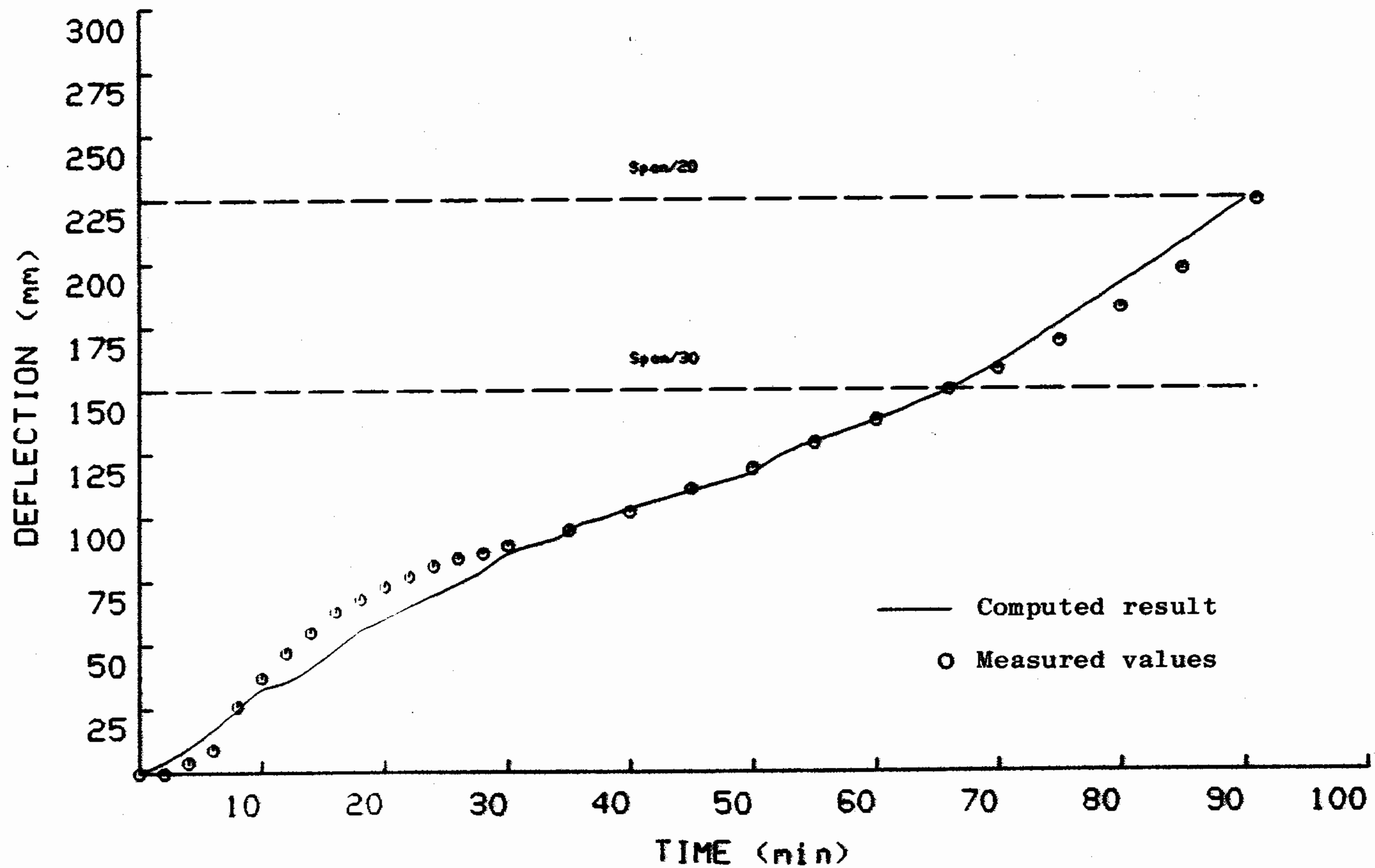


FIG. 32

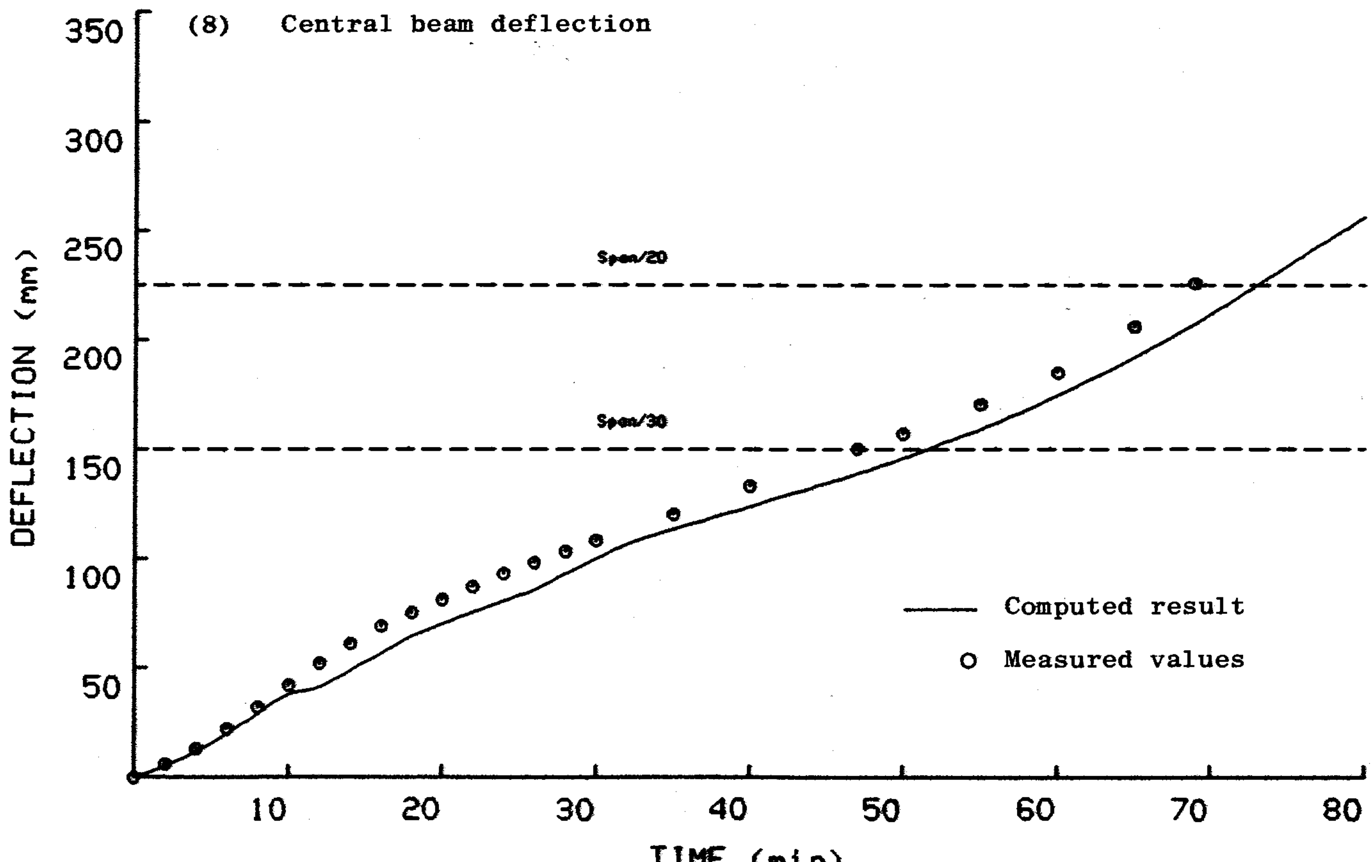
<u>254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm</u>

<u>ANGLE ROOT TEMPERATURE</u>



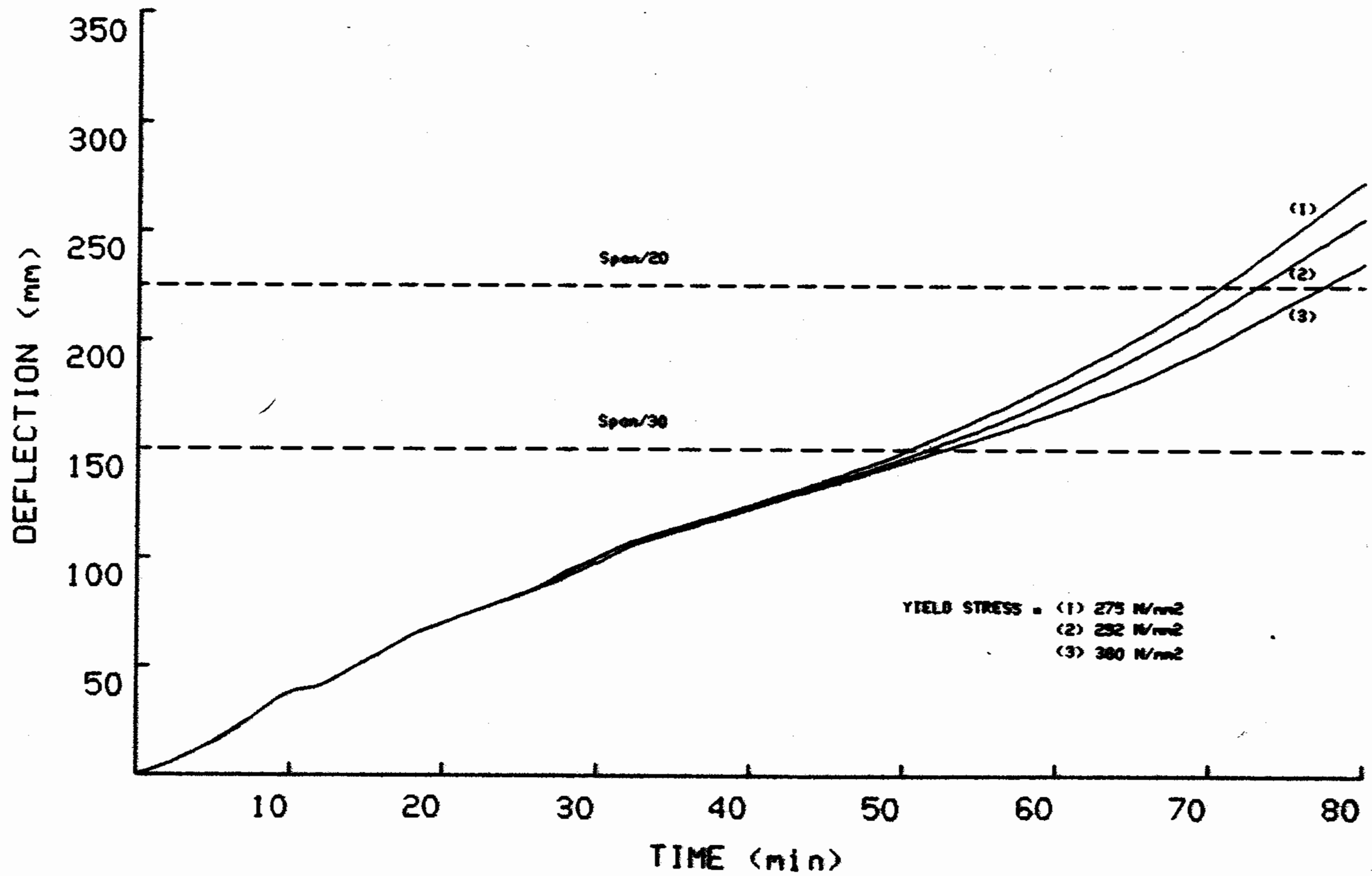
254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 150 mm FIG. 33

CENTRAL BEAM DEFLECTION



254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm FIG. 34

CENTRAL BEAM DEFLECTION



<u>254 x 146 x 43 kg/m SHELF-ANGLE FLOOR - DEPTH = 100 mm</u> FIG. 35

<u>EFFECT OF YIELD STRESS ON FIRE RESISTANCE TIMES</u>

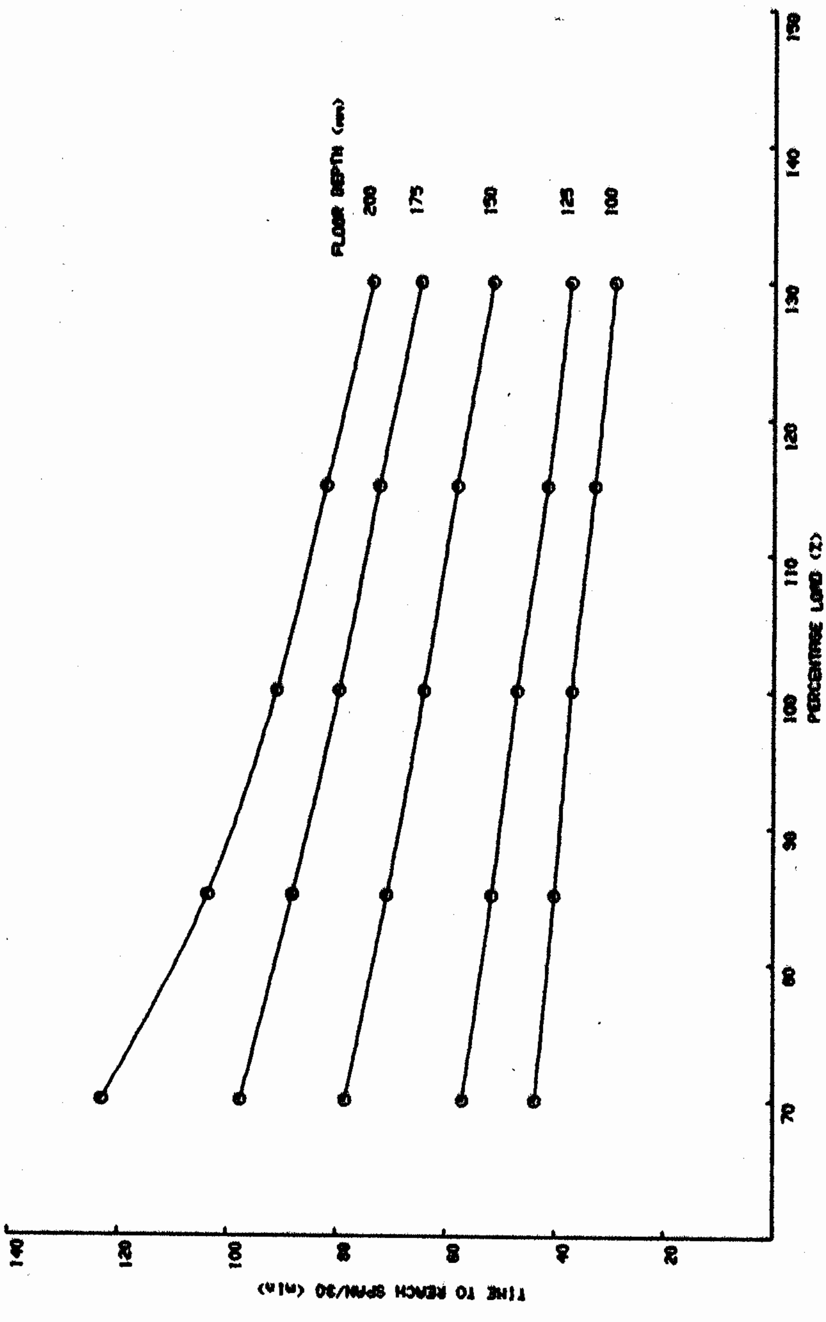
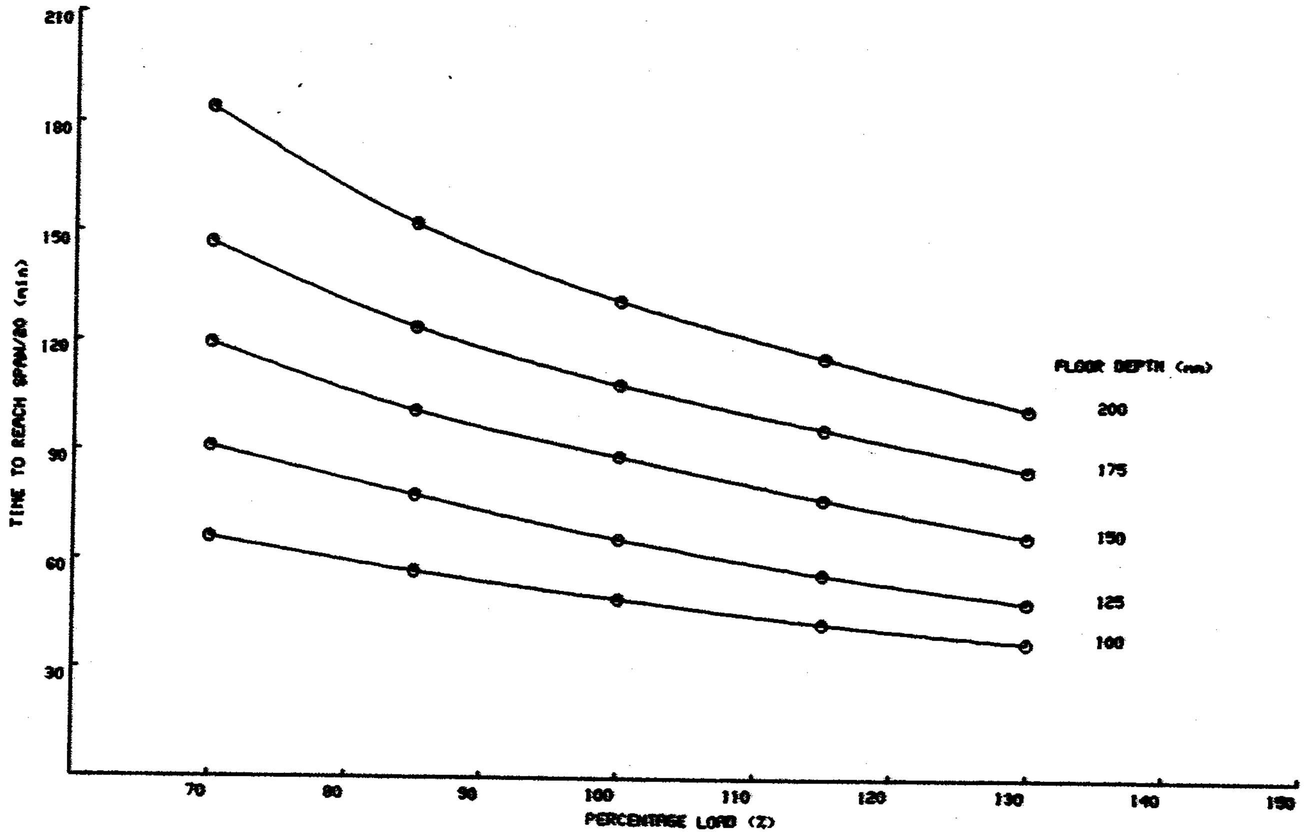


FIG. 36

254 x 146 x 43 kg/m SHELF-ANGLE FLOOR SYSTEMS

EFFECT OF APPLIED LOAD ON FIRE RESISTANCE TIMES



254 x 146 x 43 kg/m SHELF-ANGLE FLOOR SYSTEMS FIG. 37

EFFECT OF APPLIED LOAD ON FIRE RESISTANCE TIMES

APPENDIX 1 LOAD CALCULATION

254 x 146 mm x 43 kg/m UB Grade 43A

125 x 75 x 12 mm Shelf angles

effective span 4.5 m

Maximum safe working unformly distributed load = 148 kN

Total dead weight of cover slabs and spreader beam = 54 kN

$$\therefore \textit{Reaction on each shelf angle} = \frac{54}{2} \times \tfrac{1}{2} = 13.5\ kN$$

Total force required on each shelf angle to produce maximum operating stress (165 N/mm^2) in test beam $= \frac{148}{2} - 13.5 = 60.5$ kN

$$\therefore \textit{Force required by each set of rams} = \frac{60.5 \times 1.6}{1.1} = 88 kN$$

$$\therefore \textit{Force required by each ram} = \frac{88}{4} = 22 kN$$

Total hydraulic forces applied = 22 x 8 = <u>176 kN</u>

APPENDIX 2

WFRC

WARRINGTON FIRE RESEARCH CENTRE

Holmesfield Road, Warrington, Cheshire WA1 2DS.
Tel: (0925) 55116 Telex: 628743 WARRES G Telefax: (0925) 55419

Our Ref: 42786 - SGE/LD
Date: 24th March 1988

British Steel Corporation
Swinden Laboratories
Moorgate
Rotherham
S60 3AR

For the attention of Mr. G. Thompson

Dear Mr. Thompson

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf, which utilised the heating conditions of BS 476: Part 21: 1987 on a steel beam of serial size 254 mm by 146 mm by 43 kg/m, Grade 43A, which supported precast reinforced concrete slabs of overall size 1550 mm by 550 mm by 150 mm deep with one end of the concrete slabs tapered to 100 mm deep over a distance of 300 mm. The concrete slabs were supported on a continuous angle of size 125 mm by 75 mm by 12 mm thick, Grade 50B, on each side of the web of the beam. The load was applied to the concrete slabs at $^1/_8$, $^3/_8$, $^5/_8$, $^7/_8$ span positions, and 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 filled in using dry sand.

The soffit of the steel beam and angles were unprotected. The load was calculated by the sponsor to be 100% of the steel beams maximum design stress (i.e. 165 N/mm^2 x 100%).

The test specimen was assessed against the criteria of failure, given in BS 476: Part 21: 1987, and the results were as follows:

Loadbearing Capacity	:	69 minutes
Residual Loadbearing Capacity	:	Satisfied
Test Discontinued	:	70 minutes

Date of Test : 23rd March 1988

Continued ...../.....

Warrington Fire Research Centre Limited
Registered in England No. 1247124

Page 2

Mr. G. Thompson
British Steel Corporation

Our Ref: 42786 - SGE/LD
Date: 24th March 1988

After a period of 47 minutes, $^{L}/_{30}$ was exceeded on the deflection of the steel beam.

Assuring you of our best attention at all times.

Yours faithfully

S.G. EASTON
Technical Assistant
Structural Fire Protection
WARRINGTON FIRE RESEARCH CENTRE

WP Ref. LD1246