RESEARCH SERVICES

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CONTRACT REPORT

BSC/FRS Fire Test Programme

Report 6: Simply Supported Composite Steel/Concrete Beam Designed to CP117. Tested at Full Design Load

Contract No. RSC 4164/81

BRITISH STEEL CORPORATION
TEESSIDE LABORATORIES

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T/RS/1380/14/81/D

BSC/FRS FIRE TEST PROGRAMME ON 254 x 146mm x 43 Kg/m, BS4360 GRADE 43A UNPROTECTED UNIVERSAL STEEL BEAMS CONTRACT NO. RSC 4164/81)

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SYNOPSIS

A series of six fire tests has been carried out on bare steel beams under partial sponsorship from the Department of the Environment (Fire Research Station). In the sixth experiment a BS476: part 8 fire test was carried out on a BS4360 Grade 43A unprotected 254 x 146mm x 43 Kg/m steel beam in the simply supported condition. The test was designed, according to CP117, to achieve composite action between the concrete cover-slab and the steel beam. Structural grade 30 concrete reinforced with B503 mesh was used as a cover slab and it was held in position by 32 steel anchor studs welded to the top flange of the beam. The beam which was tested at full design stress (180 N/mm^2) failed after 22 minutes. This failure time is directly comparable with that recorded from fully stressed (165/mm^2) non-composite constructions indicating that there is no beneficial effect to be derived from composite construction when tested at its full composite design stress.

Pages : 4
Tables : 3
Figures: 12
Data Sheet : 1
Appendix

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1. INTRODUCTION

This report describes the preparation and observations made during a BS476 : Part 8 fire test on an unprotected BS4360 Grade 43A: 1979 beam, serial size 254 x 146 mm x 43 Kg/m carried out on 6.3.81. The beam was designed to act in composite with the concrete cover slab i.e. stud welded connections with reinforcement in the slab, following the recommendation of CP117. The specimen was identical to that used in the test on 2.3.81 and reported in Report No. 4[1]. However, the present test was carried out using the full design stress taking into account the composite action and load bearing function of the concrete.

The report presents information on:

(a) Preparation of the specimen

(b) Temperature and deflection measurements made during the test.

(c) Metallurgical details of the test specimen

2. STEEL SUPPLY

The beam was obtained from BSC Shelton Works. Following the fire tests samples were taken from an unheated end of the beam to check the chemical composition and room temperature tensile properties.

The product analysis is given along with the composition limits for the BS4360 Grade 43A specification in Table 1 which shows that the steel satisfied the requirements for the specification with carbon and manganese levels of 0.28% and 0.87% respectively.

The results from the tensile test specimen sampled in accordance with BS4360 from both the web and flange positions are given in Table 2. The strength properties of the beam were satisfactory, easily satisfying BS4360 Grade 43A requirements.

3. PREPARATION OF TEST BEAM

The beam was identical to beam E and full details of the preparation method and material are presented in Report No. 4[1].

This beam was fitted with strain gauges and the measurements made at various stages in the test with these instruments are presented in separate reports[2]. Thirteen thermocouples (Pyrotenax, 3 mm dia chromel/alumel type K with insulated hot junctions) were fitted to the beam in the positions shown in Figure 1. Four thermocouples were fitted to the web, five to the lower flange and four to the upper flange.

Four additional thermocouples were embedded at depths of 30 and 100 mm in the concrete cover slab, to monitor temperature changes, at the positions shown in Figure 2.

The heat input to the furnace was also monitored using a 15 mm dia copper pipe which had water flowing through it continuously during the test at a known flow rate. The water entry and exit temperatures were continuously recorded.

Six thermocouples were also used to measure the furnace atmoshere temperature. These were located 100 mm away from the test beam along its length at the positions shown in Figure 3.

The loading calculations and design data are presented in the Appendix and for this test beam a total load of 25.4 tonnes was required to obtain a design stress of 180 N/mm^2. The beam was loaded at four points along its span ($\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$) each with a load of 6.35 tonnes.

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

The strain which occurred in the lower flange of the test beam as a result of deformation during the test was also monitored. Fiducial marks spaced at 500 mm intervals along the lower flange, were remeasured after the test.

4. RESULTS OF TESTS

Test failure occurred after 22 minutes and the letter from Warrington Research Centre confirming this result is presented in Figure 4. Figure 5 shows the deflection time curve which indicated that the deflection increased steadily during the first 18 minutes and then accelerated rapidly.

Heating was continued under load after the deflection exceeded 150 mm i.e. L/30, but the increase in deflection was so rapid that the test was discontinued after 23 mins when the deflection was 224 mm.

The results of temperature measurements are given in Figures 6-11. Figure 6 shows the heating curves for all the bottom flange positions on the test beam. At the end of the test (L/30) the five temperatures were in the range 651°C to 658°C with a mean of 654°C. The heating rates and final temperatures recorded were all remarkably similar. The heating curves recorded for the upper flange given in Figure 7 show a slight difference in heating rate and final temperatures which were within the range 424°C to 546°C, mean 470°C. At the end of the test the web temperatures, as shown in Figure 8, were within the range 623 to 645°C, mean 636°C, and indicated very little scatter within the heating curves. The mean of the bottom flange and web temperatures at failure was 646°C.

The furnace atmosphere heating curves are compared with the international time temperature curve in Figure 9, which shows that the heating rate was in accordance with the standard curve throughout the test. A summary of steel temperatures and the furnace atmosphere temperatures are shown in data sheet 14.

The temperature rises which were monitored in the concrete cover slab at the quarter width and centre positions at depths of 30 and 100 mm are shown in Figure 10. The temperature rose steadily in the central position from 13°C to 44 and 82°C at the 30 and 100 mm depths respectively. The temperature also rose steadily in the quarter width position from 14°C to 91 and 102°C at the 30 and 100 mm depths.

Water flowed through the pipe at a rate of 16.0 ℓ/m and by the end of the test as shown in Figure 11, water which entered the pipe at 8°C was heated to 27°C, i.e. equivalent to a heat input rate of 304 kcals/min.

After cooling the test beam was reloaded satisfactorily and removed from the furnace.

The 500 mm gauge lengths marked along the bottom flange of the beam were measured after the test and results are shown in Table 3. The data suggests that the local strain at the end of the test was the order of 5%.

The concrete slab was cracked at the end of the test in the neighbourhood of the thermocouple holes, and also other hair line cracks were apparent - see Figure 12.

Following the test the concrete slab was removed from the test beam and the studs examined in detail. No studs exhibited any signs of deformation.

5. CONCLUSION

A composite beam tested under full load failed after 22 minutes. This failure time is directly comparable with failure times recorded on fully stressed non-composite constructions.

The result indicates that there is no beneficial effect to be derived from composite constructions when tested at the full composite design stress.

The steel temperatures at failure were also comparable with those observed on non-composite tests with similar failure times.

ACKNOWLEDGEMENT

The assistance of Messrs Newman and Hogan of Constrado and the B.S. Section respectively in the design of the test specimen is gratefully acknowledged.

18th April 1981

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REFERENCES

1. C.I. Smith and G. Thomson Teesside Laboratories Report T/RS/1380/12/81/D

2. P.A. Sterrett Teesside Laboratories Reports T/WE/1380/15/81/D and T/WE/1380/16/81/D

SAMPLE NO.	SAMPLE FORM	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Sn	Nb	Zr	B	N_2	%Sol Al	%Tot Al
RS	SOLID	.28	.044	.87	.020	.039	.013	<.005	.030	<.005	<.005	.027	<.005	<.005	<.005	<.0005	.0053	<.002	<.002
BS4360 GRADE 43A PRODUCT REQUIREMENT		.30 max	.55 max	1.70 max	.06 max	.06 max													

CHEMICAL COMPOSITION OF THE TEST BEAM

TABLE 1

CODE	YIELD STRESS (N/mm^2)		TENSILE STRENGTH (N/mm^2)	%El
RS:81	Web Flange	299 273	483 481	19.0 25.0
BS4360 Grade 43A Specification Requirements	Web Flange	270(min) 255(min)	430/ 540	20 min

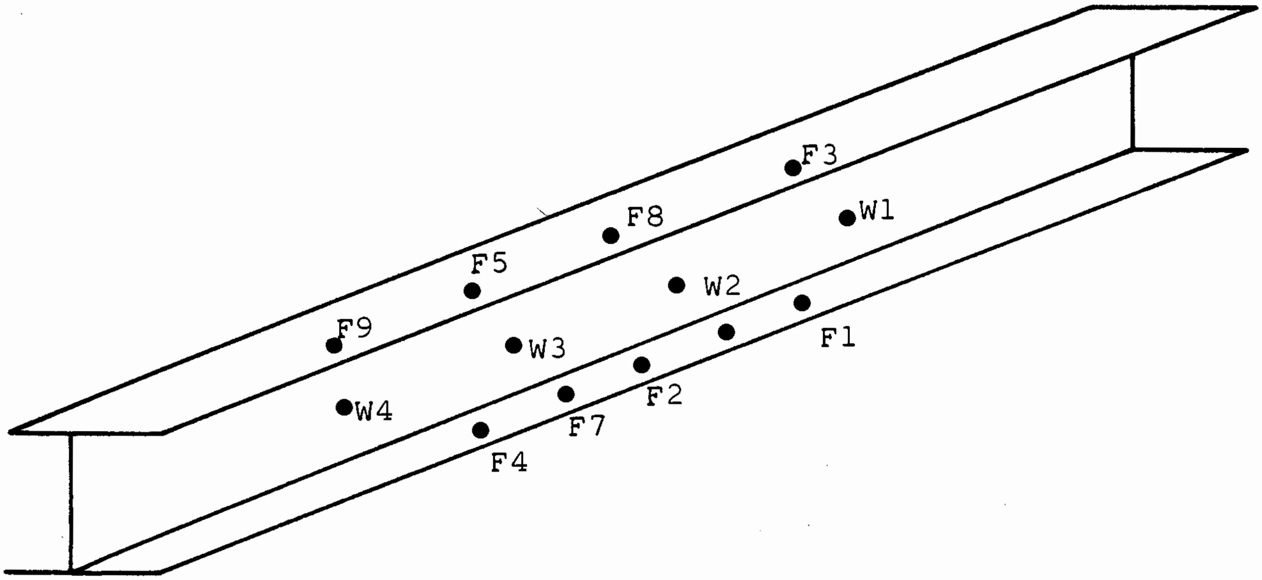
TENSILE TEST DATA FROM AN UNHEATED END OF THE FIRE TESTED BS4360 43A 254 x 146 mm x 43 kg/m UNIVERSAL BEAM

TABLE 2

FROM DOOR END (mm)	AFTER TEST (mm)	CHANGE IN GAUGE LENGTH (mm)	% STRAIN
500	500	4	0.8
1000	1004	10	2.0
1498	1512	25	5.0
1998	2037	22	4.4
2499	2560	9	1.8
3000	3070	6	1.2
3499	3575		

MEASUREMENTS OF GAUGE LENGTH ON BEAM BEFORE AND AFTER THE FIRE TEST AND STRAIN VALUES IN THE LOWER FLANGE AT THE END OF THE TEST

TABLE 3

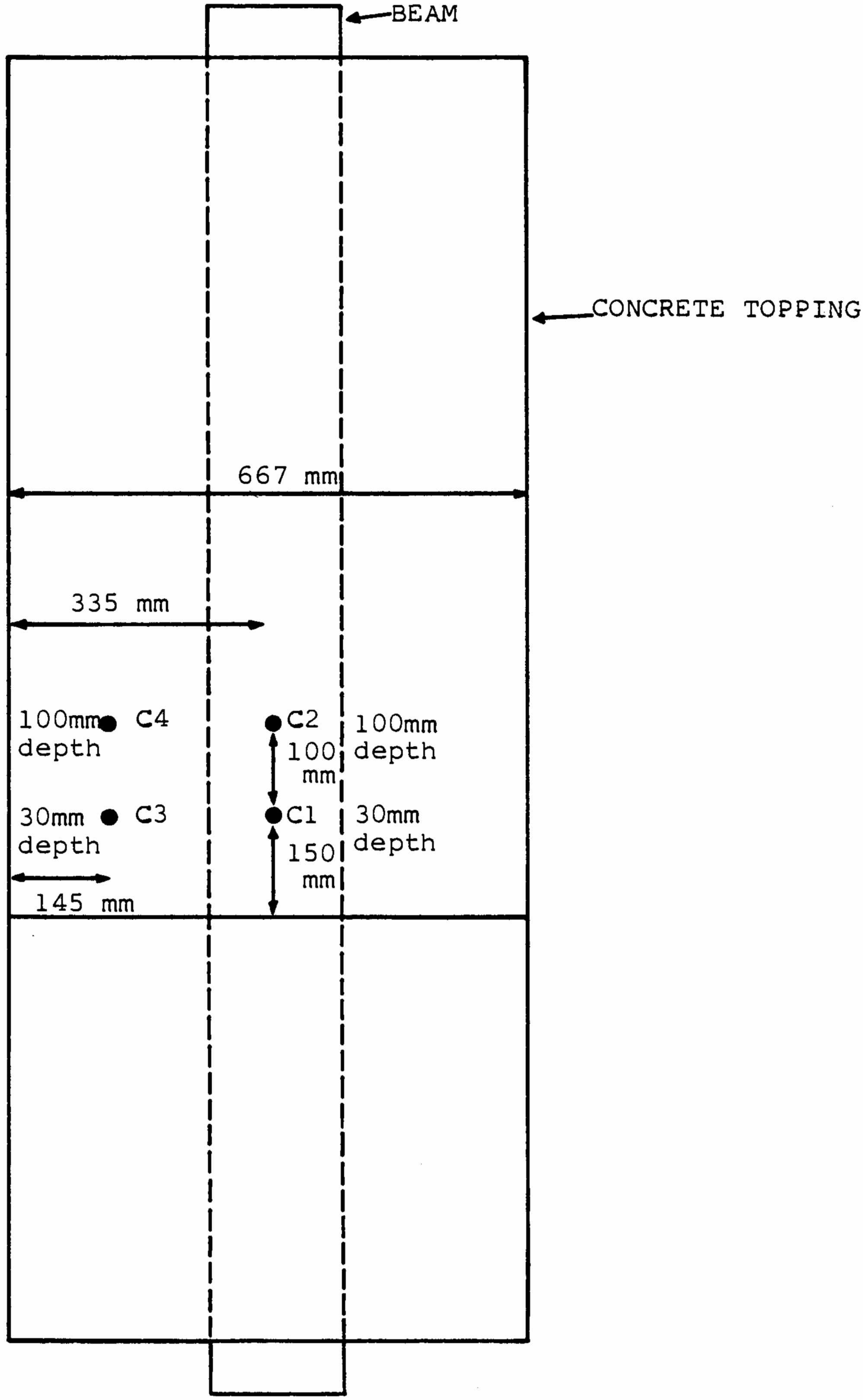


DISTANCE FROM END OF BEAM TO THERMOCOUPLES

W1	3.35 m
F3, F1	3.05 m
W2, F6	2.73 m
F2, F8	2.43 m
W3, F7	2.11 m
F4, F5	1.81 m
W4, F9	1.5 m
End of beam	4.84 m

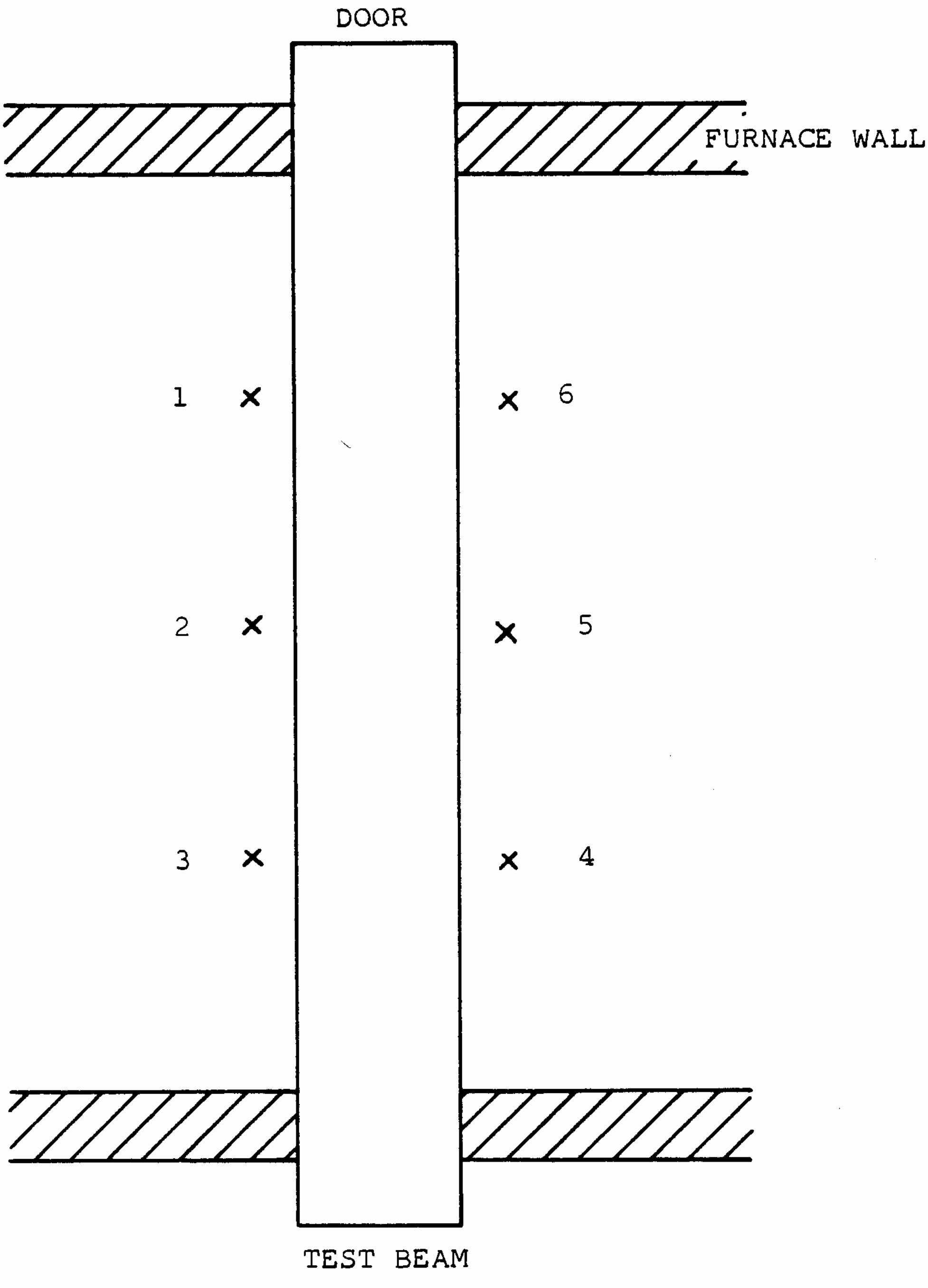
POSITION OF THERMOCOUPLES IN TEST BEAM

FIGURE 1



ARRANGEMENT OF THERMOCOUPLES EMBEDDED IN CONCRETE COVER SLAB

FIGURE 2



POSITION OF FURNACE ATMOSPHERE THERMOCOUPLES

FIGURE 3

T/RS/1380/14/81/D

WARRINGTON RESEARCH CENTRE

Fire Research, Testing and Consultancy

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

W.R.C.S.I. No. 27827
AHB/RC

10th March 1981

Dr. I. Smith,
British Steel Corporation,
Teeside Laboratories,
Ladgate Lane,
P.O. Box 74,
Middlesbrough,
Cleveland, TS8 9EG.

Dear Sir,

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf in accordance with B.S. 476: Part 8: 1972 on a loaded and unprotected steel beam containing a concrete topping which was held to the steel beam with weld fixed studs 19 mm diameter at 280 mm centres. In addition, the concrete topping was reinforced with steel reinforcing mesh reference B503. The steel beam was grade 43A, of serial size 254 mm x 146 mm x 43 kg/m. The reinforced concrete topping was of size 642 mm wide x 130 mm deep. The studs in conjunction with the concrete topping were intended to provide a contribution to the strength of the steel beam and this additional strength was taken into consideration when calculating the maximum load to be applied to the beam. A total load of 25.426 tonnes was therefore applied to the beam at 1/8, 3/8, 5/8 and 7/8 span points of the beam. The test results were as follows:

Stability	:	22 minutes
Re-load test:		Satisfied
Test Date	:	6th March 1981

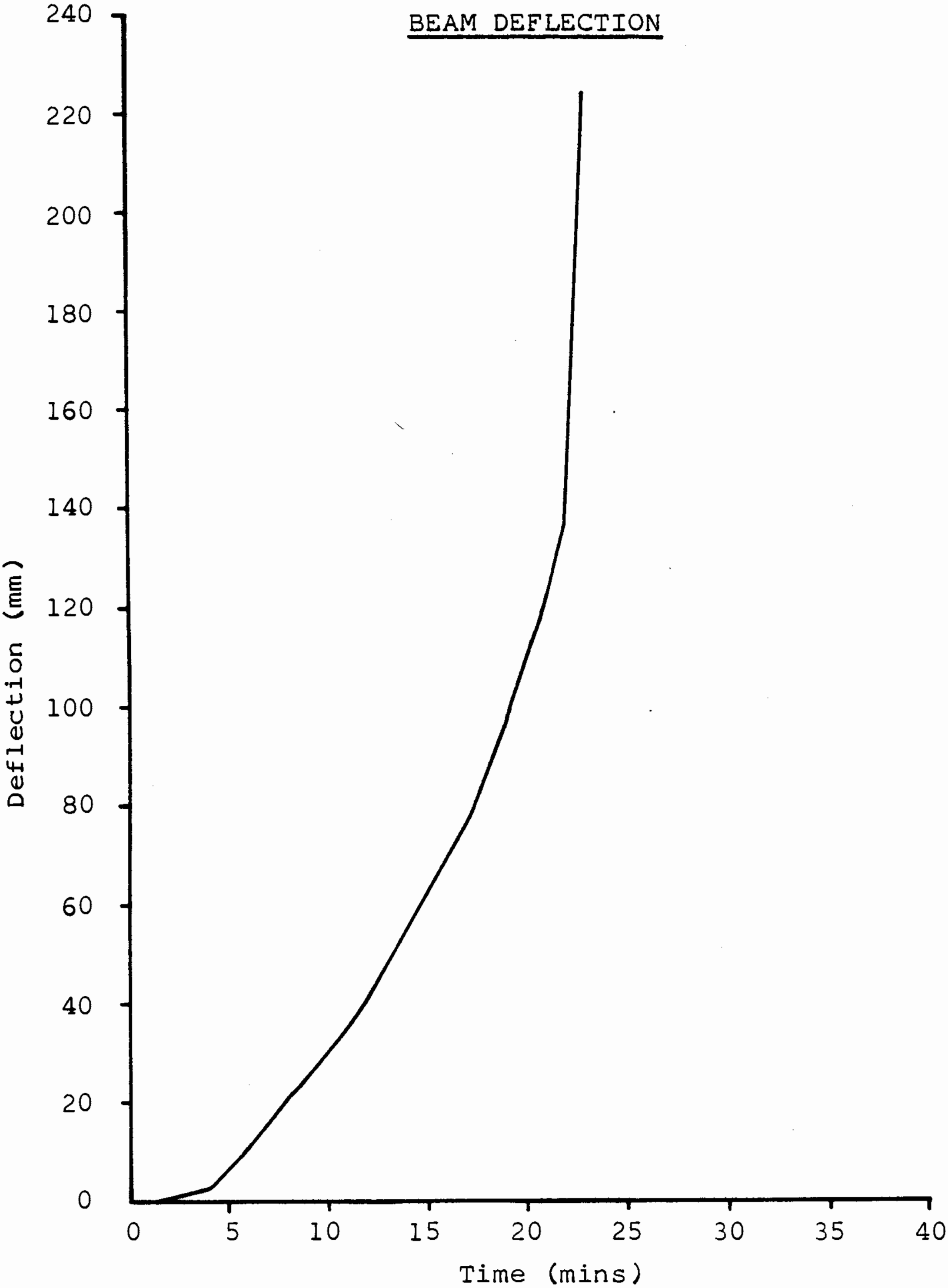
A survey of the specimen was performed prior to the test being conducted, but, if you have not already done so, you are asked to provide an accurate written specification of the specimen tested together with detailed drawings to supplement the survey information.

A FULL REPORT IS UNABLE TO BE PROVIDED UNLESS A DETAILED SPECIFICATION OF THE TEST SPECIMEN HAS BEEN PROVIDED.

Yours faithfully,

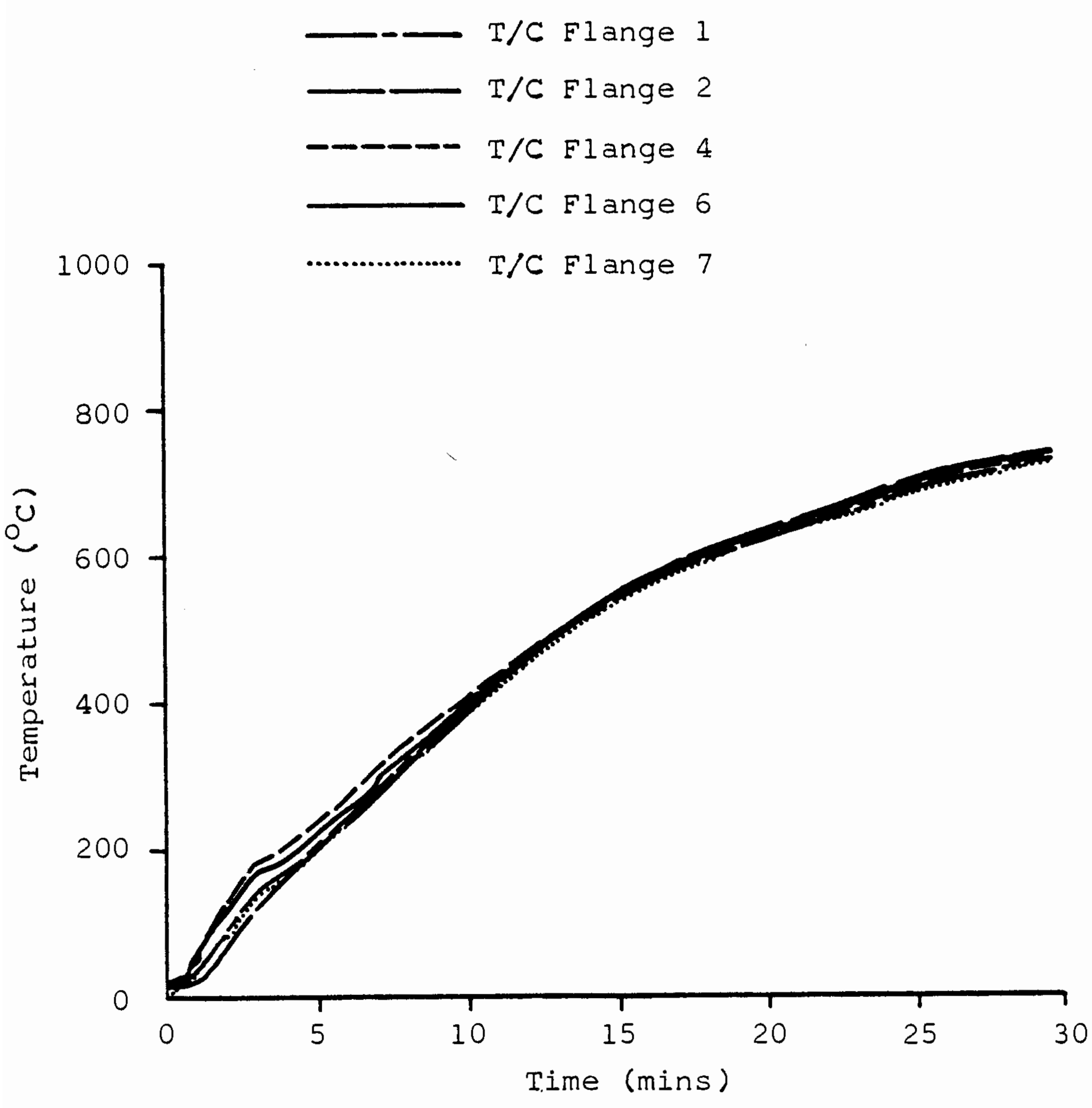
(A.H. BONE)
Technical Manager - Structural Fire Protection
Warrington Research Centre

FIGURE 4



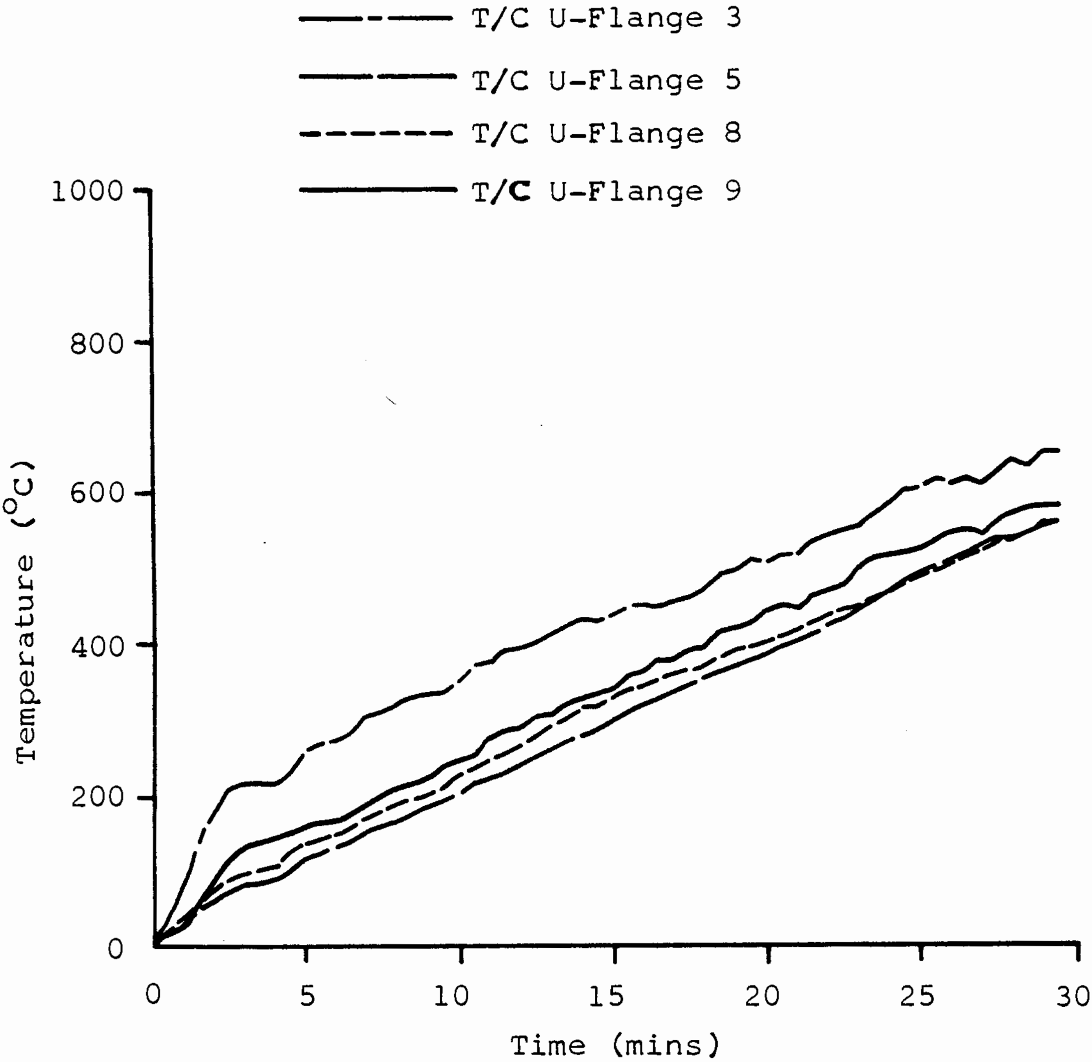
BEAM DEFLECTION MEASUREMENTS MADE DURING THE TEST

FIGURE 5



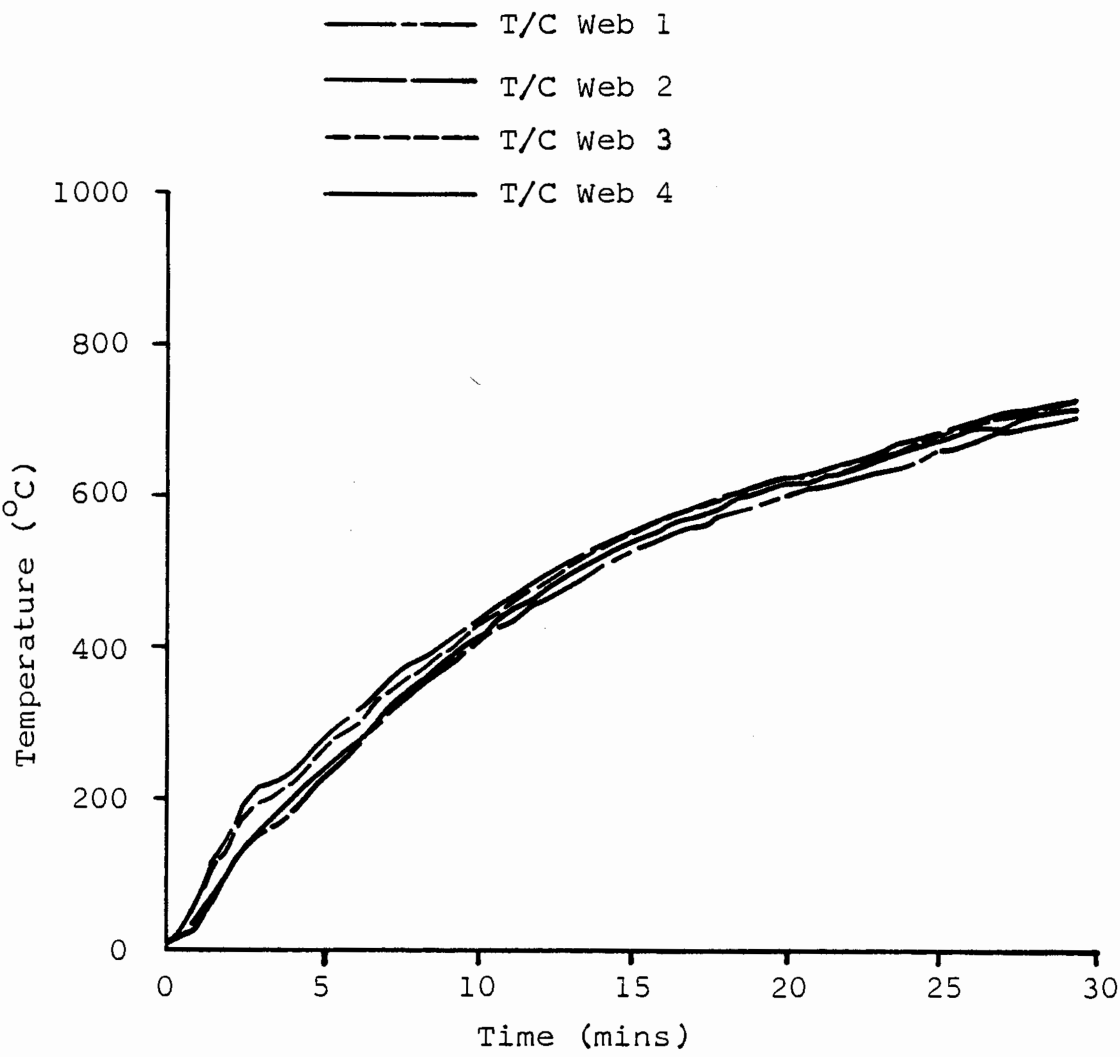
LOWER FLANGE TEMPERATURES RECORDED ON TEST BEAM

FIGURE 6



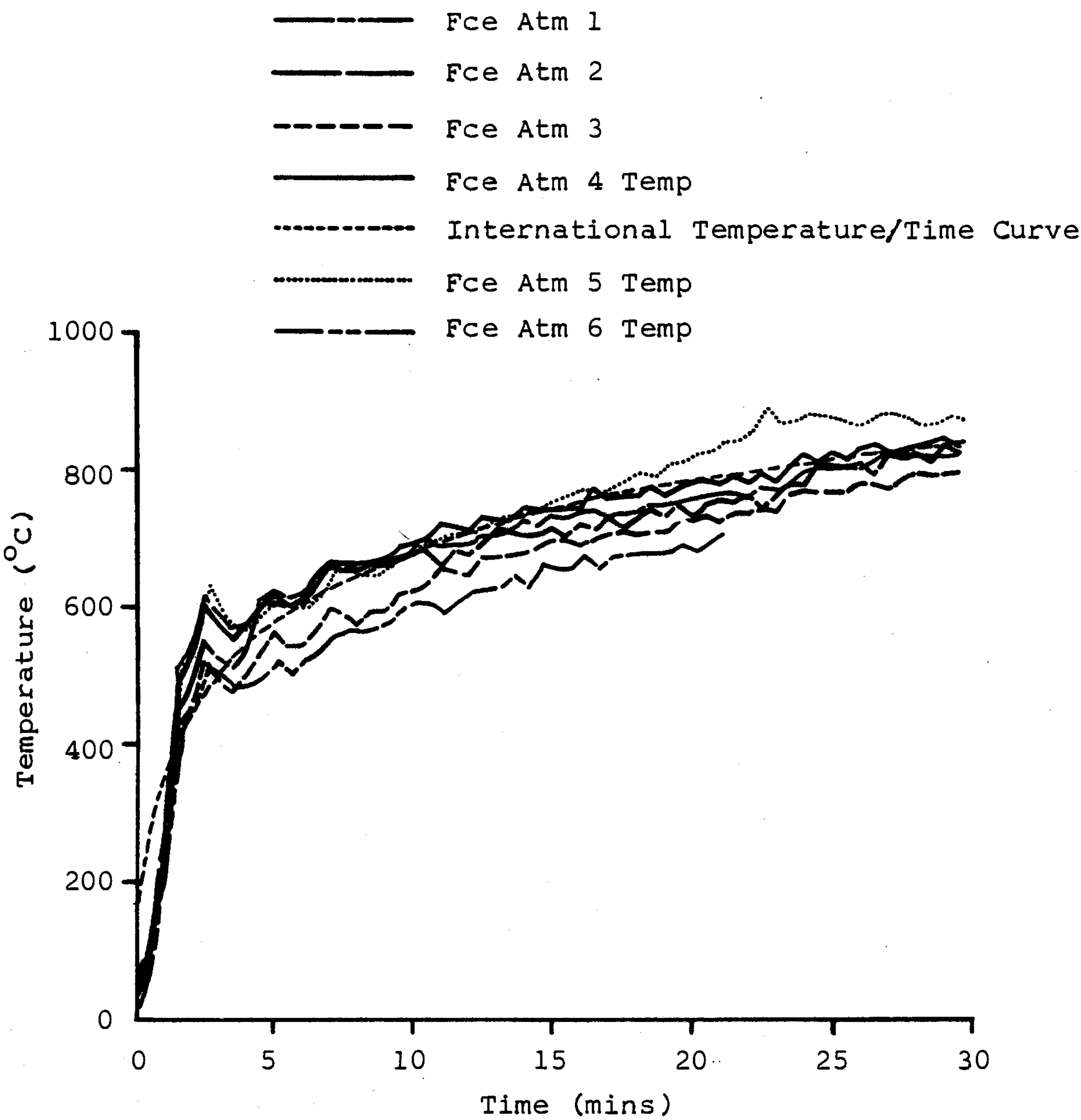
UPPER FLANGE TEMPERATURES RECORDED ON TEST BEAM

FIGURE 7



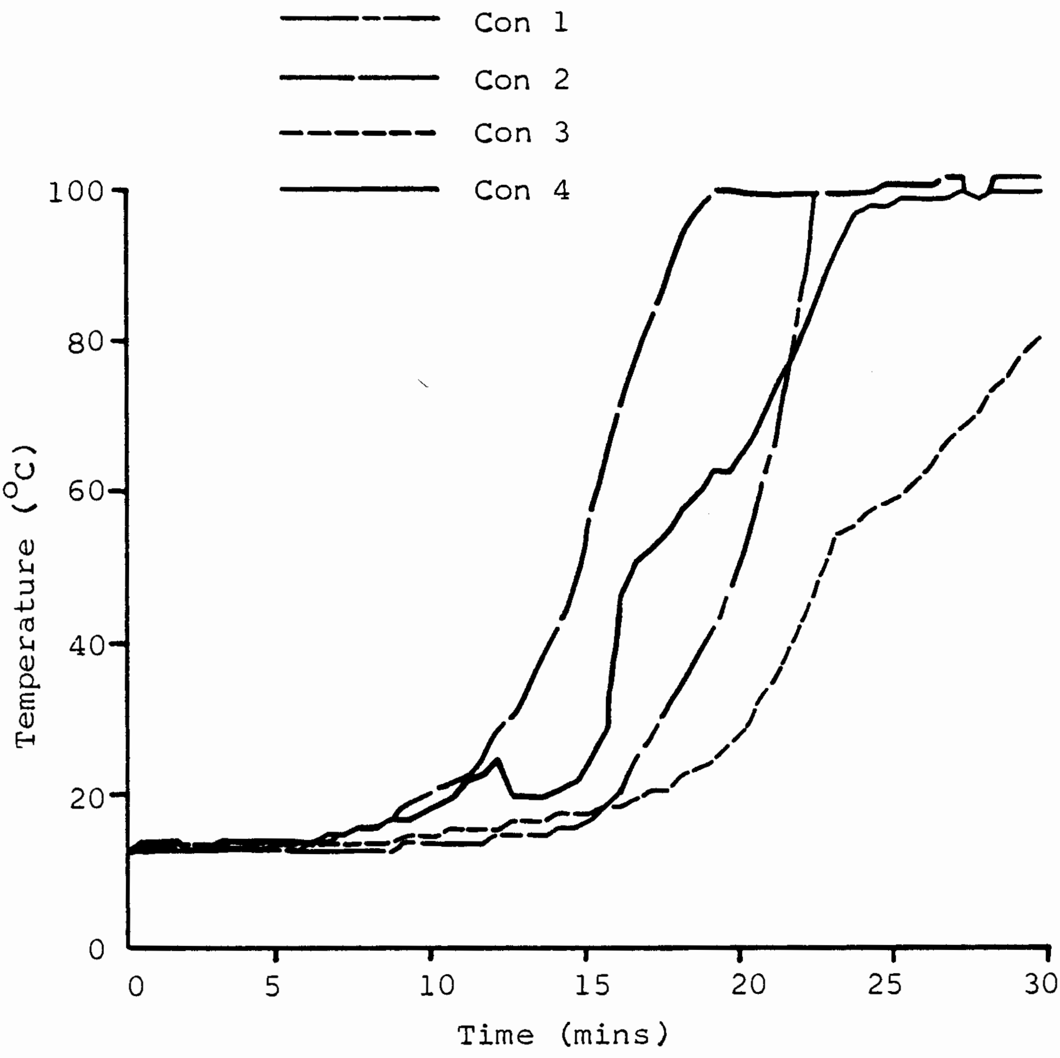
WEB TEMPERATURES RECORDED ON THE TEST BEAM

FIGURE 8



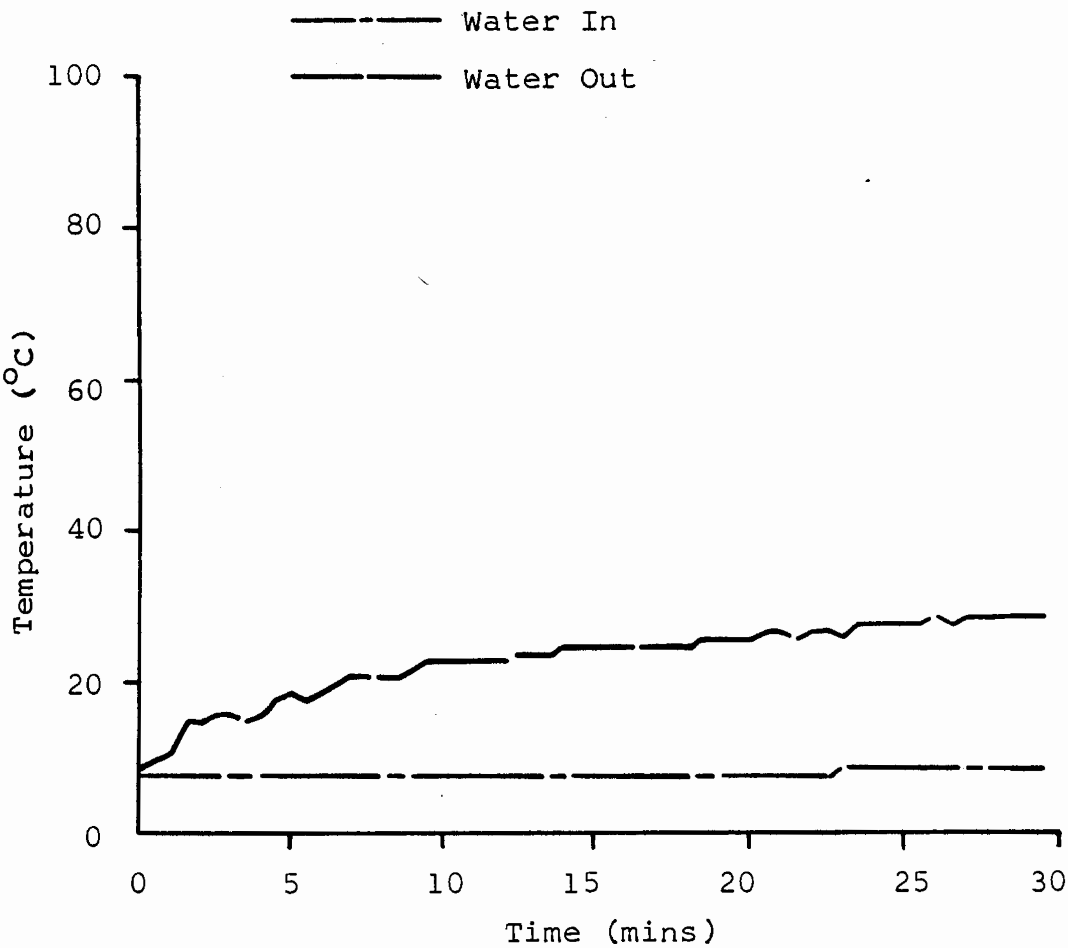
FURNACE ATMOSPHERE TEMPERATURES RECORDED DURING THE TEST

FIGURE 9



TEMPERATURES RECORDED AT THE CENTRE AND QUARTER WIDTH POSITIONS OF THE CONCRETE COVER SLAB

FIGURE 10



WATER TEMPERATURE RISE RECORDED USING . CALORIMETER

FIGURE 11

CONCRETE SLAB AFTER TEST SHOWING CRACKING IN THE CENTRE AND AT THE ENDS

FIGURE 12.

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Test Reference No.

Carried Out

WRC No. 27827

6/3/81

BSC Test Reference No. 31

Section Size BeamD 254 x 146 mm x 43 kg/m	P/A Value 169 m^{-1}		Web	Flange
		Yield Stress (N/mm^2)	299	273
Grade BS 4360 Grade 43A Stud Welded Composite Construction	Design Stress 180 N/mm^2	Tensile Strength (N/mm^2)	483	481

Composition	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%V	%Ti	%Cu	%Sn	%Nb	%Zr	%Sol Al	%Tot Al	$\%N_2$
RS81	.28	.044	.87	.020	.039	.013	<.005	.030	<.005	<.005	.027	<.005	<.005	<.005	<.002	<.002	.0053

FAILURE TIME 22 mins

		TEMPERATURES AFTER VARIOUS TIMES (MINUTES)								
		3	6	9	12	15	18	21	22	23
Lower Flange	1	145	238	353	461	543	597	640	653	662
	2	122	232	347	458	545	606	646	658	672
	4	183	269	376	468	543	600	639	651	664
	6	168	254	363	465	548	607	648	657	669
	7	146	247	356	459	540	598	639	651	664
Mean Lower Flange		153	248	359	462	544	502	642	654	666
Web	1	157	262	375	459	527	576	613	523	632
	2	217	311	404	492	554	600	633	645	657
	3	198	295	395	483	553	600	635	645	653
	4	161	272	380	469	536	585	620	632	646
Mean Web		183	285	389	476	543	590	625	636	647
Av Lower Flange + Web		166	264	372	468	543	597	635	646	658
Upper Flange	3	221	278	336	398	441	474	520	546	556
	5	88	137	190	243	300	356	406	424	447
	8	103	155	207	269	330	373	420	438	451
	9	137	170	225	290	343	396	446	470	500
Mean Upper		137	185	240	300	354	400	448	470	488
Atmosphere	1	528	613	663	682	719	733	758	764	764
	2	591	623	665	693	735	738	766	760	769
	3	496	547	599	650	701	709	726	739	742
	4	576	614	673	711	739	763	779	781	784
	5	588	598	658	708	755	792	838	854	864
	6	499	523	580	623	655	679	708	-	-
Mean Atmosphere		546	586	640	678	717	736	762	780	785
ISO Curve RT=15		497	598	658	700	733	761	784	791	797
Deflection (mm)		2	11	25	41	62	86	121	137	224

APPENDIX

LOAD CALCULATIONS FOR COMPOSITE BEAM

Beam tested 6.3.81   Test 27827

Load calculated using CP117 Part 1, 1965 using load factor method with a factor of 1.75.

The moment capacity was calculated using a standard computer program based upon the formulae given in the CONTRADO publication "Design tables for composite steel and concrete beams"

Data for calculations

Slab width	635mm
Slab depth	135mm
Cube strength	30 N/mm^2
Steel depth	257mm
Steel width	146mm
Flange thickness	12.6mm
Web thickness	7.57 mm
Steel area	55.1 Cm^2
Steel yield	255 N/mm^2

From program :-

Moment capacity	257.2 kN	(factored)
Load in concrete	1143 kN	

Design of shear studs

load on concrete = 1143 kN

Try 19 mm ϕ headed studs 75mm high

Design load per stud = 76.2 kN (CP117)

Number of studs required in each ½ span

$= \frac{1143}{76.2} = 15$ - use 8 pairs per ½ span

Spacing $= \frac{4535}{16} = 283$ mm

Transverse reinforcement

CP117 specifies a method of sizing this
Calculations give

i) Low yield bar At = 4.71 cm^2/m run
or ii) High yield bar At = 2.61 cm^2/m run

Low yield 10mm ϕ at 150mm
High yield 8mm ϕ at 150mm

Top reinforcement

Use A142 mesh or equivalent

Loading

$$\frac{W\ell}{8} = 257.2 \times \frac{1}{1.75}$$

W = 259.6 kN
Slab + Beam = 10.2 kN
$\therefore$ Jack load = (259.6-10.2) x $\frac{1}{4}$

= 62.3 kN per jack

G.M. NEWMAN