G. THOMSON

RESEARCH SERVICES

Ref. No.	T/RS/1380/12/81/D
Date	8 MAY 1981
Classification	CONFIDENTIAL

CONTRACT REPORT

BSC/FRS Fire Test Programme

Report 4: Simply Supported Composite Steel/Concrete Beam Designed to CP117, Tested at Non–Composite Load

Contract No RSC 4164/81

BRITISH STEEL CORPORATION

TEESSIDE LABORATORIES

T/RS/1380/12/81/D

BRITISH STEEL CORPORATION
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18th May, 1981

BSC/FRS FIRE TEST PROGRAMME ON 254x146mmx43kg/m, BS 4360 GRADE 43A UNPROTECTED UNIVERSAL STEEL BEAMS

(CONTRACT NO. RSC 4164/81)

Report 4: Simply Supported Composite Steel/Concrete Beam Designed to CP117, Tested at Non-Composite Load

SYNOPSIS

A series of fire tests has been carried out on bare steel beams under partial sponsorship from the Department of Environment (Fire Research Station). In the fourth experiment a BS 476 part 8 fire test has been carried out on a BS4360:Grade 43A unprotected 254x146mmx43kg/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 which was held in position by 32 steel anchor studs welded to the top flange of the beam. The beam was tested using a non-composite load ie. equivalent to a simply supported load for a design stress of 165 N/mm^2. The test has demonstrated the beneficial effect of using steel beams in composite with the concrete slab, which increased the failure time from 21 to 35 minutes. This improvement was a direct result of the lower stress generated in the steel beam because of the supporting action of the concrete slab which maintained a load bearing function throughout the test.

Authors: C I Smith
G Thomson
Department: Rails & Sections

Pages: 5
Tables: 4
Figs.: 14
Data Sheets: 1

Appendix

T/RS/1380/12/81/D

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

REPORT 4 - SIMPLY SUPPORTED COMPOSITE STEEL/CONCRETE BEAM DESIGNED TO CP117, TESTED AT NON-COMPOSITE LOAD

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BSC/FRS FIRE TEST PROGRAMME ON 254x146mmx43kg/m BS 4360 GRADE 43A UNPROTECTED UNIVERSAL STEEL BEAMS

(CONTRACT NO RSC 4164/81)

Report 4: Simply Supported Composite Steel Concrete Beam Designed To CP 117, Tested at "Non-Composite" Load

1. INTRODUCTION

This report describes the preparation and observations made during a BS476:Part 8 fire test on an unprotected BS 4360 Grade 43A (1979) steel beam, serial size 254 x 146 mm x 43 kg/m, carried out on 2nd March, 1981. The beam was designed to act in composite with the concrete cover slab, ie. stud welded connections were used as well as reinforcement in the concrete slab, following the recommendations of CP 117. The test was carried out using a test load calculated as if the beam was acting along in the simply supported condition.

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

The product analysis is given along with the composition limits for the BS 4360 Grade 43A specification in Table 1 which shows that the steel satisfied the requirements for the specification with carbon and manganese levels of 0.26% and 0.88% respectively.

The results from the tensile test specimen sampled in accordance with BS 4360 from both the web and flange positions are given in Table 2. The strength properties of the beam were satisfactory, easily satisfying the BS 4360 Grade 43A requirements.

3. PREPARATION OF THE COMPOSITE BEAMS D AND E

Two identical beams were prepared for testing both of which incorporated studs welded to the top flange of the section.

The concrete slabs were cast from Grade 30 concrete, and contained B503 reinforcing weld mesh.

These composite steel/concrete beams were designed according to the recommendations of CP 117. Appendix 1 shows the basis of the design calculations. In total 32 studs were welded to the top flange of the beam. The studs, 75 mm long, 19 mm dia. and supplied by Nelson Stud Welders, were welded to the beam in two rows 95 mm apart. The studs were spaced at 285 mm centres (see Figs. 1 and 2). Welding was carried out at the Warrington Research Centre by Stud Welding Services of Blyth, an approved Nelson contractor, using on-site stud welding equipment and following procedures recommended by Nelsons.

B503 Reinforcing Mesh was supplied by BSC Reinforcement Steel Services. The reinforcement utilised a bar diameter of 8 mm and a mesh size of 200 x 100 mm. The mesh was cut into sheets of width 600 mm with the 100 mm bar spacing transverse to the rolling direction of the beam.

The concrete cover slab was cast using Grade 30 concrete, 2" slump, supplied by Trumix. The slabs had a nominal width of 650 mm and a thickness of 125 mm, and the two slabs required approx. 1 cu. metre of concrete.

The concrete was tamped to ensure adequate compaction and an anti-crack chicken wire mesh was incorporated nominally 10 mm from the upper surface of the concrete (see Fig. 3).

The B503 mesh was located a nominal 35 mm from the upper surface of flange. The joints in the mesh were overlapped on either side of a shear stud.

In the absence of a cubical mould satisfying BS 1881:Part 3 nominal 100 x 100 mm square 150 mm deep blocks of concrete were cast into wooden moulds for subsequent cube testing. Because of the shortcomings of this technique, the concrete strength values, Table 5, obtained cannot be regarded as absolute but rather provide a guide to the true concrete strength values.

4. TEMPERATURE MEASUREMENT

Thirteen thermocouples (Pyrotenax, 3 mm dia. chromel/alumel type K with insulated hot junctions) were fitted to the beam in the position shown in Fig. 4. Four thermoocuples 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 Fig. 5.

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 also recorded.

Six thermocouples were also used to measure the furnace atmosphere temperature. These were located 100 mm away from the test beam along its length at the positions shown in Figure 6.

The outputs from the theromcouples were monitored using the BSC Compulog 4 computer controlled data logging system which was similar to that used on previous tests.

The loading calculations are presented in the Appendix for both the composite beam and the non-composite beam and for this test beam a total load of 13.2 tonnes was required to obtain a design stress of 165 N/mm^2. The beam was loaded at four points along its span ($\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$) with a load equivalent to that required to produce a stress of 165 N/mm^2 in a simply supported beam. The calculated actual stress was 108 N/mm^2 ie. equivalent to 65% of the maximum permissible stress. Deflection measurements were taken at the centre of the beam by the Warrington Research Centre using a 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 re-measured after the test.

5. RESULTS OF TESTS

Test failure as defined by the L/30 failure criterion occurred after 35 minutes and the letter from Warrington Research Centre confirming this result is presented in Fig. 7. The rate of deflection was steady throughout the test, so heating was continued until the deflection reached 190 mm after 40 minutes. Figure 8 shows the deflection time curve. The results of temperature measurements are given in Figs. 9-14. Fig. 9 shows the heating curves for all the bottom flange positions on the test beam. After 35 mins (officialy the end of the test) the five temperatures were in the range of 728 to 750°C with a mean of 737°C. The heating rates and final temperatures recorded were all similar apart from values recorded on thermocouple Flange 1. The heating curves recorded for the upper flange given in Fig. 10 show no appreciable differences in heating rate and final temperatures which were within the range 523 to 569°C, mean 554°C. The web temperature in Fig. 11 were within the range 709 to 740°C after 35 mins (mean 728°C and indicated very little scatter within the heating curves. The mean of the bottom flange and web temperatures at failure was 733°C.

Heating underload was continued for 40 mins. and at this time the steel temperatures were as follows:

	Range	Average
Lower flange	747 - 776°C	762°C
Upper flange	583 - 616	606
Web	733 - 764	750
Mean Lower Flange and Web		756

The furnace atmosphere heating curves are compared with the international time temperature curve in Fig. 12, which shows that the heating rate was slightly below the standard curve after the first 14 minutes of the test. A summary of steel temperatures and the furnace atmosphere temperatures are shown in Data Sheet 12.

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 Fig. 13. The temperature rose steadily in the central position from 12°C to 80 and 139°C at the 30 and 100 mm depths respectively. The temperature also rose steadily in the quarter width position from 13°C to 176 and 98°C at the 30 and 100 mm depths respectively.

Water flowed through the copper pipe at a rate of 16.0 l/min and by the end of the test as shown in Fig. 14 water which entered the pipe at 8°C was heated to 25°C, ie. equivalent to a heat input rate of 272 k cals/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 4. The data suggests that the local strain at failure was of the order of 2.8%.

The concrete slab did not exhibit any significant cracking on its lower surface and did not become detached from the upper flange of the beam.

After the test, the concrete slab was removed and the studs on the upper flange of the beam were examined, and no significant deformation was observed.

6. CONCLUSIONS

The test has demonstrated the beneficial effect of using steel beams in composite with the concrete slab, which increased the failure time from 21 minutes to 35 minutes.

This improvement was thought to be a direct result of the lower stress generated in the beam because of the load bearing action of the concrete slab which maintained a load bearing function throughout the entire test.

ACKNOWLEDGEMENT

The assistance of Messers. Newman and Hogan of CONSTRADO and the BS Sections respectively in the design of the test specimen is gratefully acknowledged.

Authors: C I Smith
G Thomson
Department: Rails & Sections
Department Manager: R R Preston

RESEARCH MANAGER

Mr J Lessells
Product Applications Group,
Teesside Laboratories,
PO Box 74,
Ladgate Lane,
Middlesbrough,
Cleveland. TS8 9EG

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 74	SOLID	.26	.041	.88	.019	.034	.006	<.005	.022	<.005	<.005	.020	<.005	<.005	<.005	<.0005	.0082	<.002	<.002
BS4360 GRADE 43A PRODUCT REQUIREMENT		.30 max	.55 max	1.70 max	.06 max	.06 max													

CHEMICAL COMPOSITION OF THE STEEL BEAM

TABLE 1

CODE	YIELD STRESS (N/mm^2)		TENSILE STRENGTH (N/mm^2)	%El
RS: 74	Web	280	475	25.0
	Flange	283	469	26.5
BS4360 Grade 43A Specification Requirements	Web	270 (min.)	430/540	20 min
	Flange	255 (min.)		

TENSILE TEST DATA FROM AN UNHEATED END OF THE FIRE TESTED BS 4360 GRADE 43A 254 x 146 mm x 43 kg/m UNIVERSAL BEAM

TABLE 2

TIME	COMPRESSIVE STRENGTHS (N/mm^2)
14 days	28.7
31 days	35.5
89 days	43.2

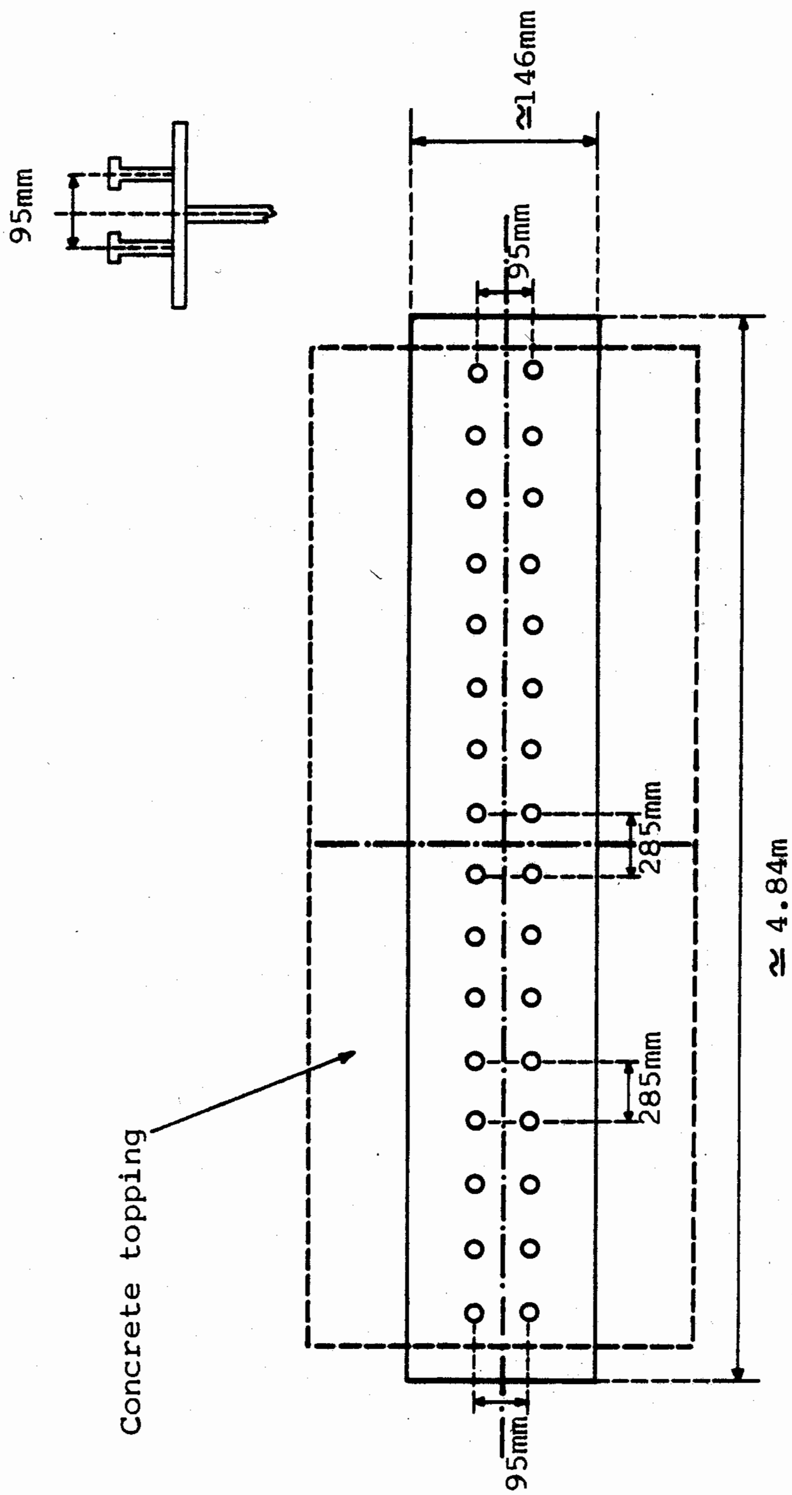
COMPRESSIVE STRENGTH VALUES OF GRADE 30 CONCRETE

TABLE 3

FROM DOOR END (mm)	AFTER TEST (mm)	CHANGE IN GAUGE LENGTH (mm)	% STRAIN
250	250	4	0.8
753	757	8	1.6
1254	1266	12	2.4
1754	1778	14	2.9
2255	2293	14	2.8
2757	2809	10	2.0
3258	3320	6	1.2
3758	3826		

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 4



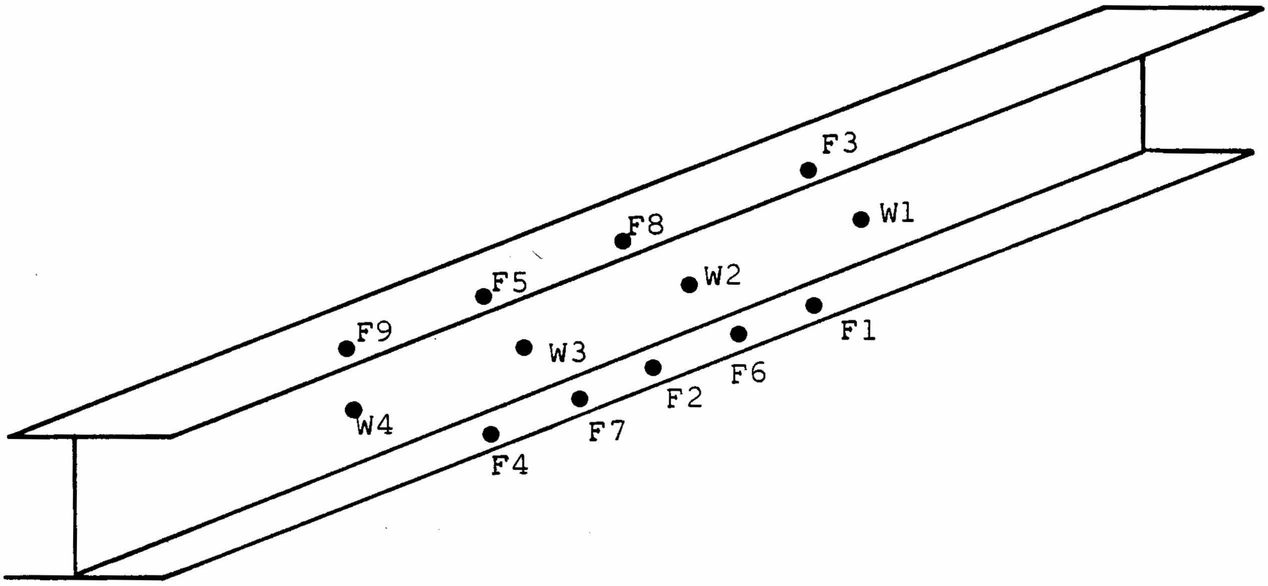
STUD WELD ARRANGEMENT FOR THE 254 x 146mm x 43 Kg/m TEST BEAM
USING 19mm DIA 75mm LONG STUDS

FIGURE 1

SHEAR STUDS WELDED ONTO THE TOP FLANGE OF THE TEST BEAM FIGURE 2.

ANTI-CRACK CHICKEN WIRE MESH POSITIONED APPROXIMATELY 10mm FROM THE UPPER SURFACE OF THE CONCRETE.

FIGURE 3.

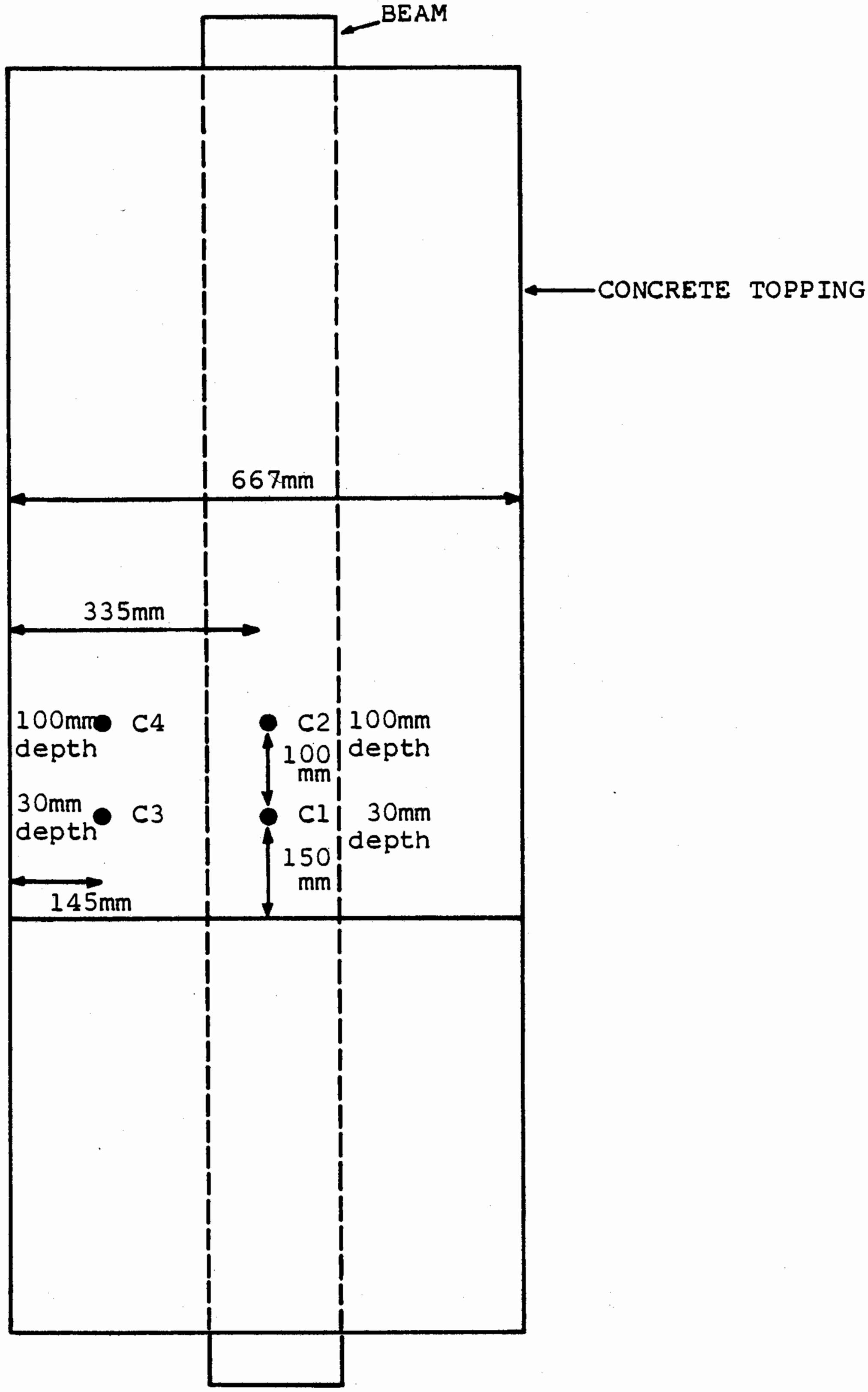


DISTANCE FROM END OF BEAM TO THERMOCOUPLES

W1	3.35 m
F3, F1	3.04 m
W2, F6	2.73 m
F2, F8	2.43 m
W3, F7	2.11 m
F4, F5	1.81 m
W4, F9	1.8 m
End of beam	4.84 m

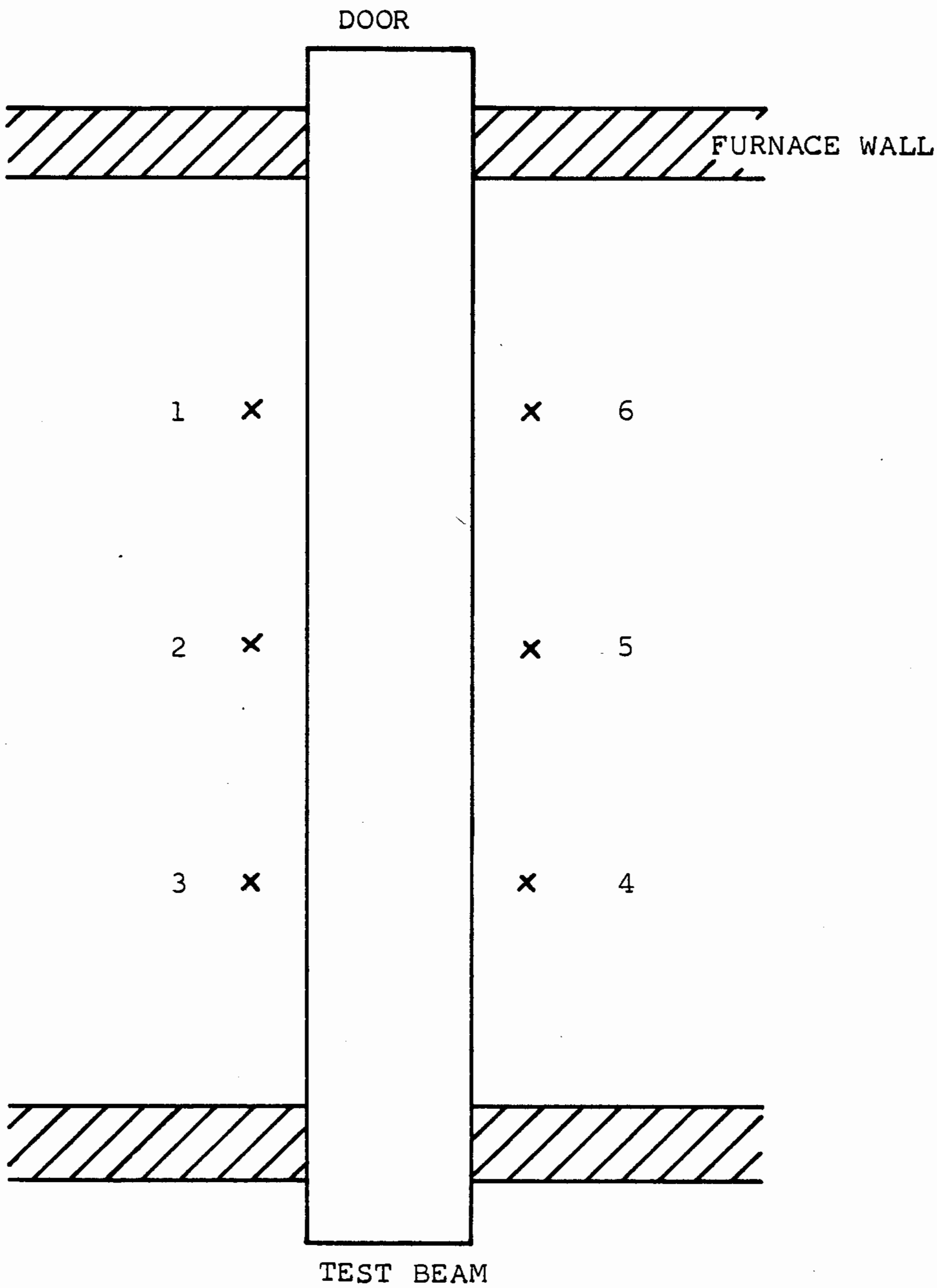
POSITIONS OF THERMOCOUPLES IN TEST BEAM

FIGURE 4



ARRANGEMENT OF THERMOCOUPLES EMBEDDED IN CONCRETE TOPPING

FIGURE 5



POSITION OF FURNACE ATMOSPHERE THERMOCOUPLES

FIGURE 6

T/RS/1380/12/81/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. 27825
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 but this additional strength was not taken into consideration when calculating the maximum load to be applied to the beam. A total load of 13.245 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 : 35 minutes
Re-load test: Satisfied
Test Date : 2nd 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.

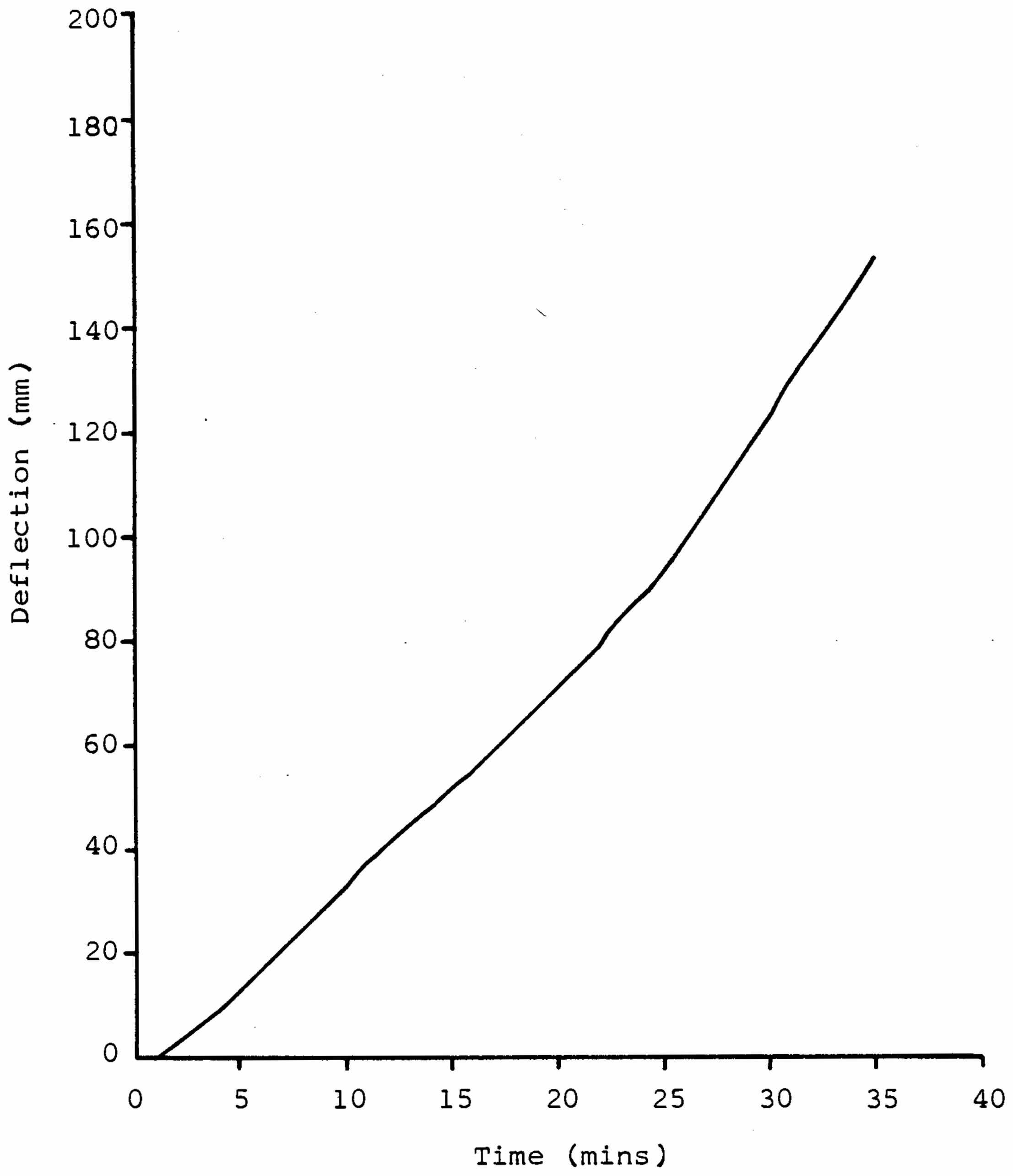
A FULL REPORT IS UNABLE TO BE PROVIDED UNLESS A DETAILED SPECIFICATION OF THE TEST SPECIMEN HAS BEEN PROVIDED.

Yours faithfully,

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

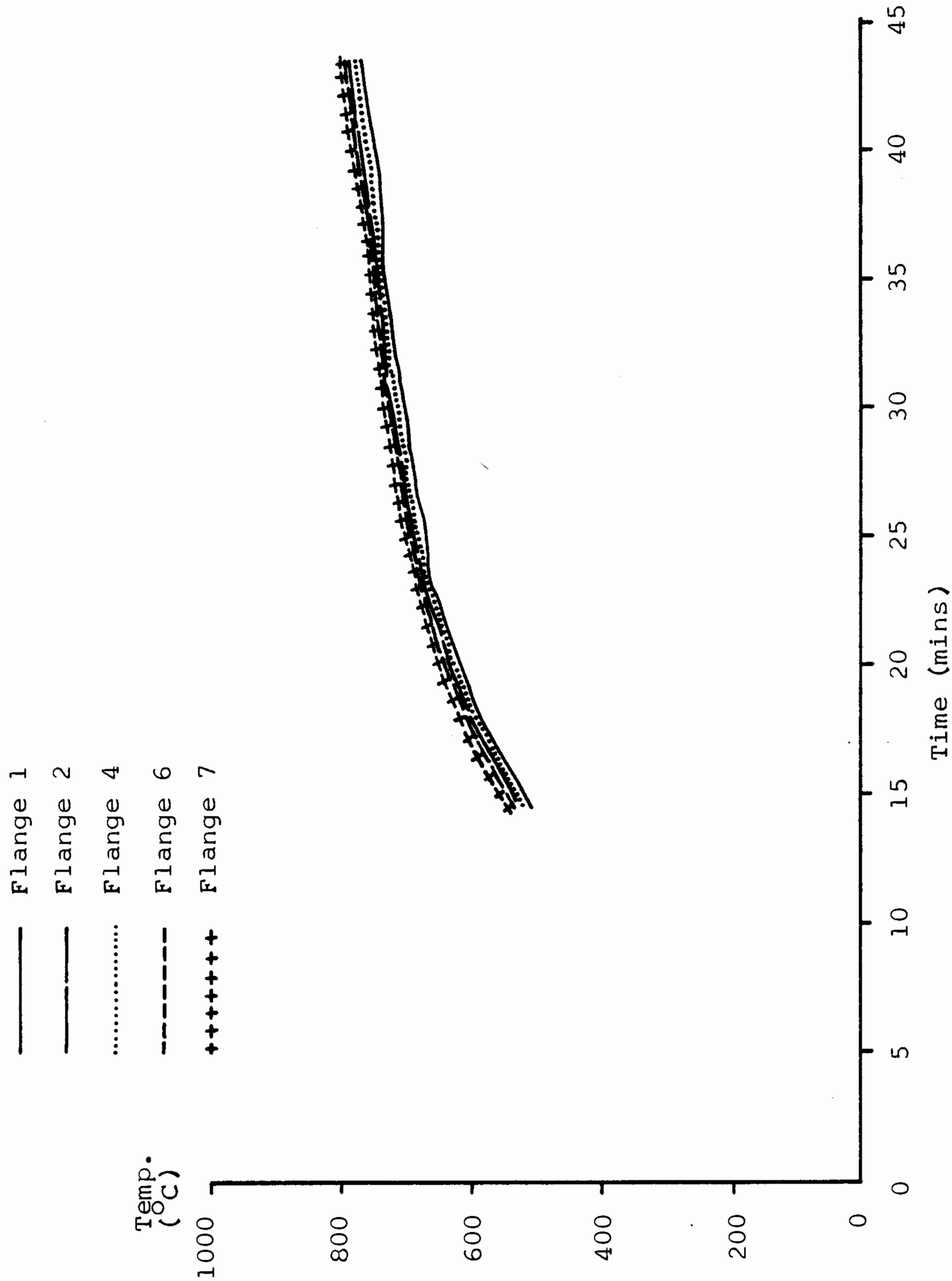
FIG. 7

BEAM DEFLECTION



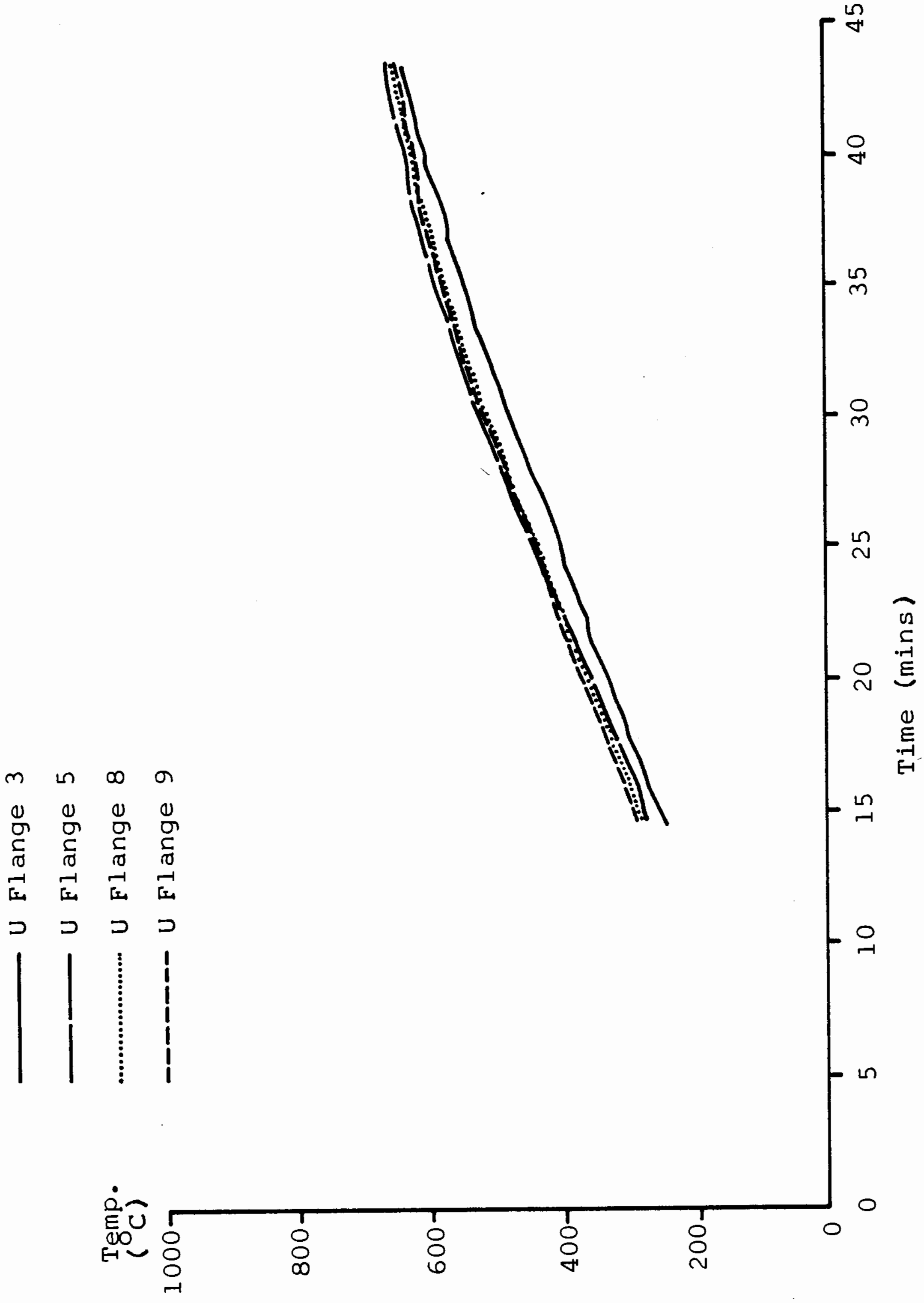
PLOT OF DEFLECTION AT THE CENTRE OF THE BEAM AS A FUNCTION OF TIME

FIGURE 8



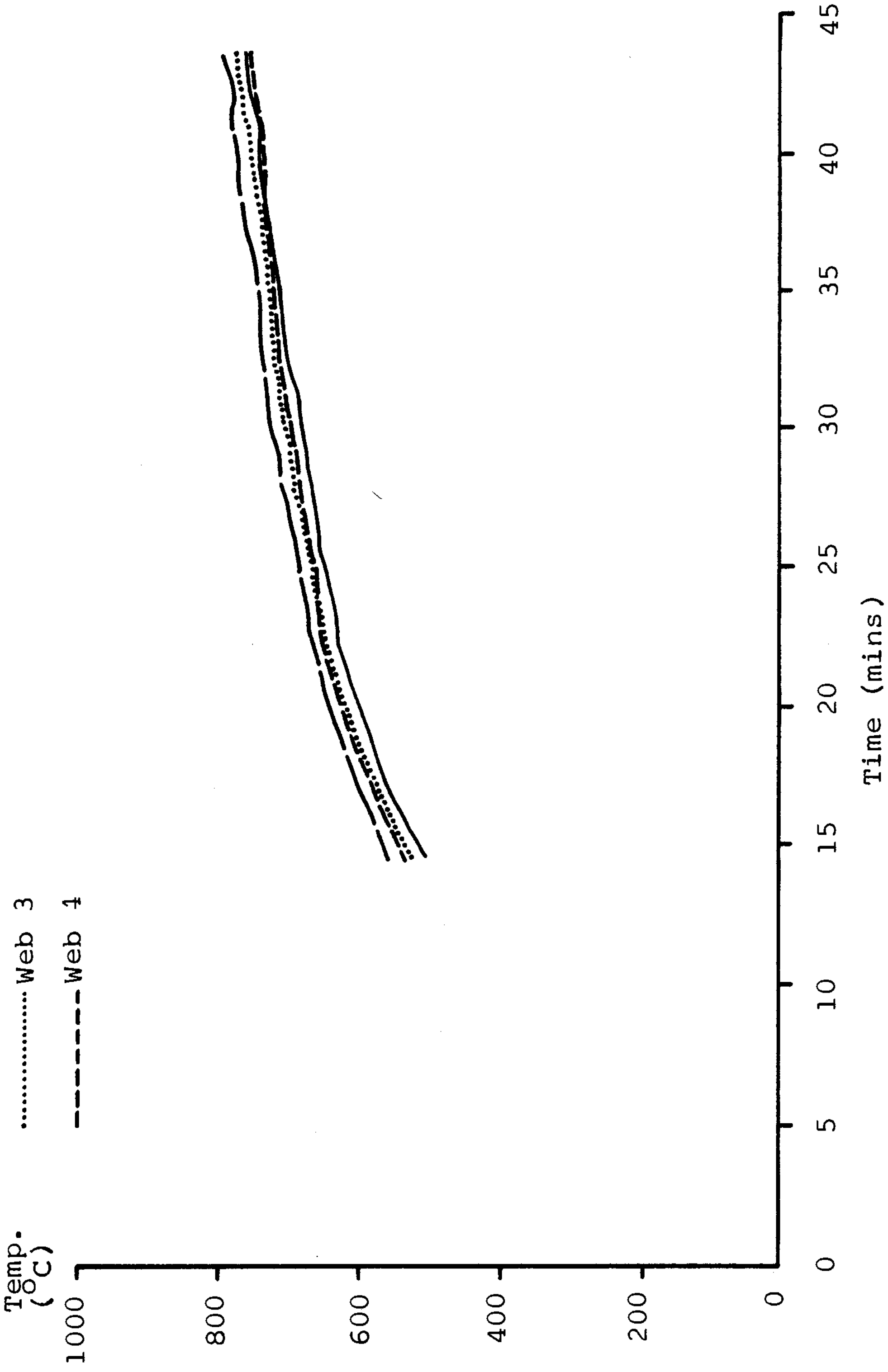
LOWER FLANGE TEMPERATURES RECORDED ON TEST BEAM

FIGURE 9



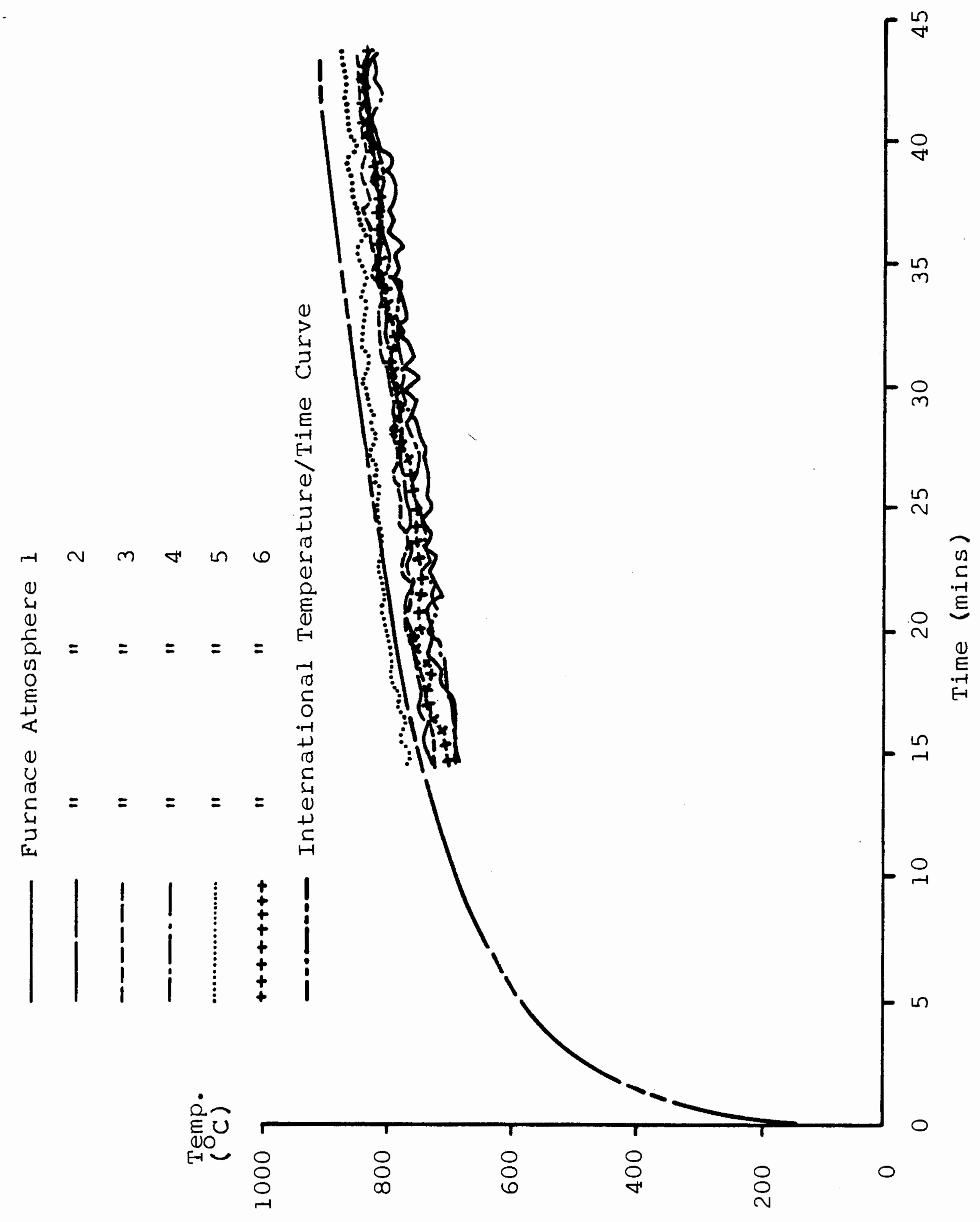
UPPER FLANGE TEMPERATURES RECORDED ON TEST BEAM

FIGURE 10



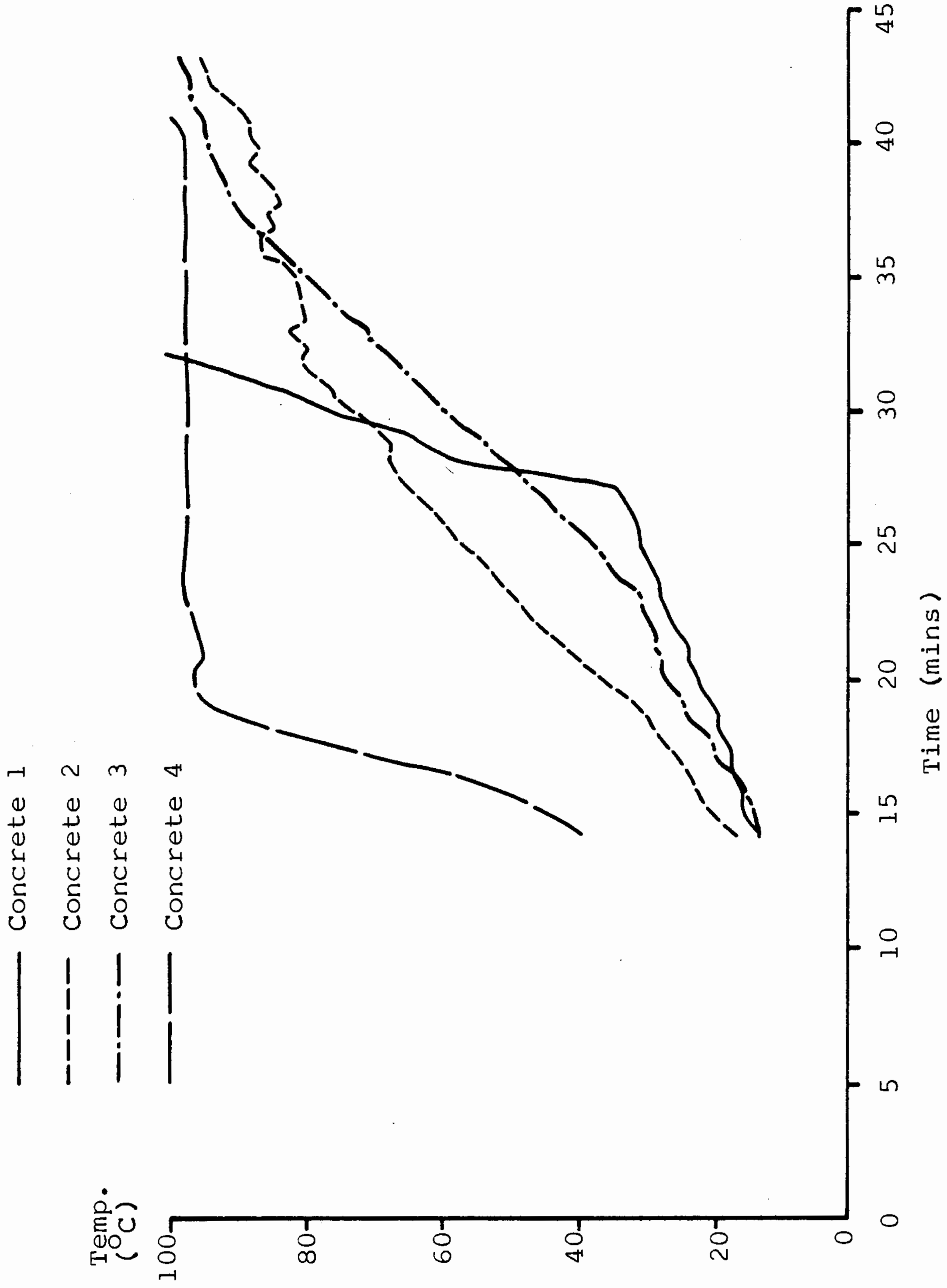
WEB TEMPERATURES RECORDED ON TEST BEAM

FIGURE 11



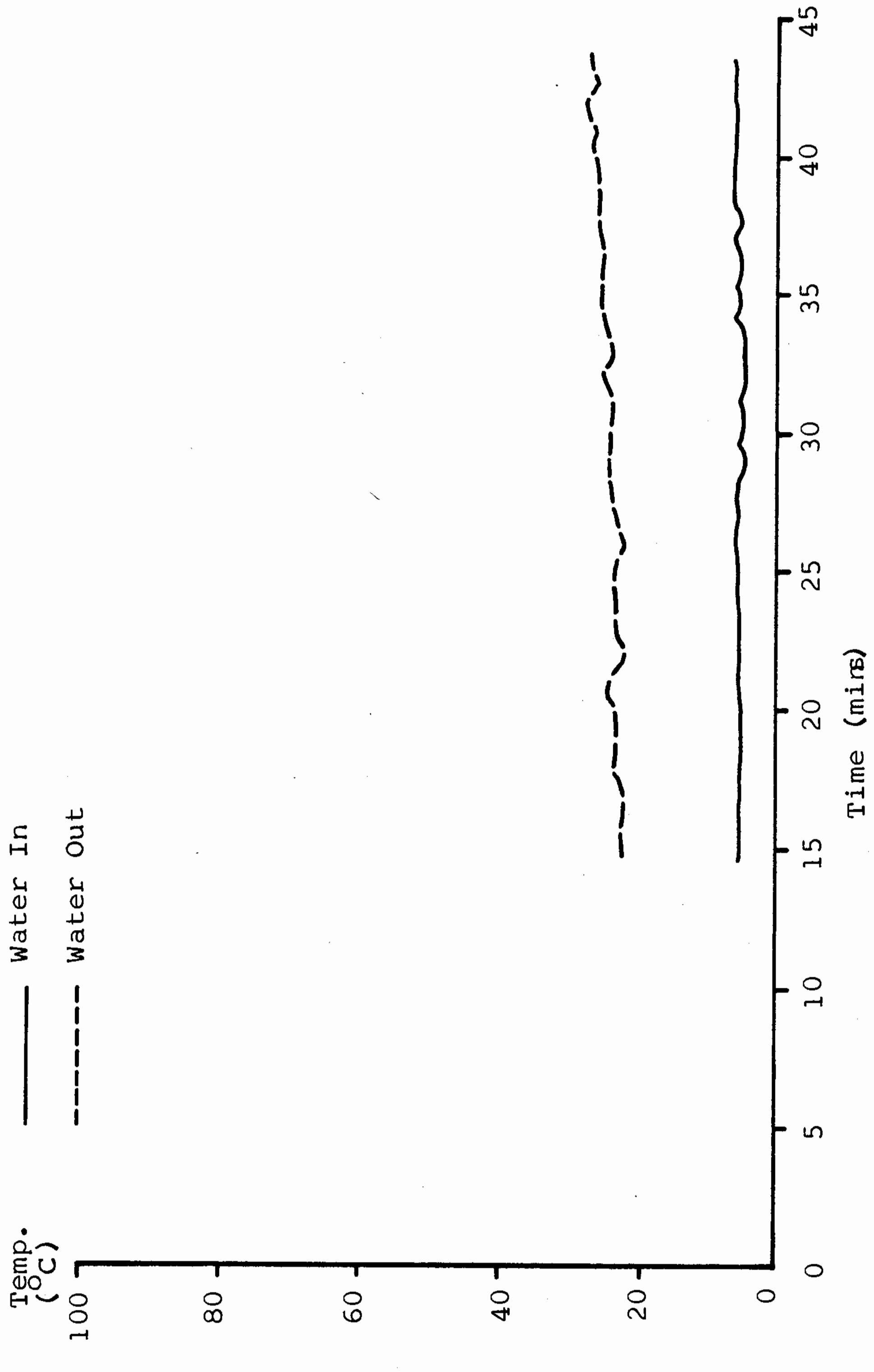
FURNACE ATMOSPHERE TEMPERATURES RECORDED ON THE TEST BEAM

FIGURE 12



TEMPERATURES RECORDED AT THE CENTRE AND QUARTER WIDTH POSITION ON THE CONCRETE COVER SLAB

FIGURE 13



WATER TEMPERATURE RISE RECORDED USING COPPER CALORIMETER

FIGURE 14

Test Reference No.
WRC No. 27825
BSC Test Reference No. 29

Carried Out
2.3.81

Section Size
Stud Welded Composite
254 x 146mm x 43 kg/m (BEAM E)

P/A Value
169 m^{-1}

Grade
BS 4360 Grade 43A

Design Stress
Loaded appropriate
to a non-composite beam

	Web	Flange
Yield Stress (N/mm^2)	280	283
Tensile Strength (N/mm^2)	475	469

Composition	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%V	%Ti	%Cu	%Sn	%Nb	%Zr	%Sol Al	%Tot Al	$\%N_2$
RS 74	.262	.041	.88	.019	.034	.006	<.005	.022	<.005	<.005	.020	<.005	<.005	<.005	<.002	<.002	.0082

FAILURE TIME 35 mins for L/30

	TEMPERATURE °C AFTER VARIOUS TIMES (MINS)														
	3	6	9	12	15	18	21	24	27	30	33	35	36	39	40
Lower Flange 1				447	520	583	629	659	679	701	719	728	731	739	747
2				444	529	594	641	673	696	716	728	734	738	755	763
4				449	530	593	640	669	694	712	727	732	735	751	757
6				457	539	604	650	680	703	721	734	741	745	762	767
7				478	558	617	661	690	711	730	739	750	755	773	776
Mean Lower Flange				455	535	598	644	674	697	716	729	737	741	756	762
Web 1				448	514	569	609	634	656	678	696	709	714	730	733
2				497	563	612	651	674	696	717	733	740	743	762	764
3				466	536	592	632	661	683	704	722	732	734	746	752
4				480	548	597	638	660	683	702	720	730	734	744	749
Mean Web				473	507	593	633	657	680	700	718	728	731	746	750
Av Lower Flange.Web				463	518	596	639	667	689	709	724	733	737	751	756
Upper Flange 3				203	249	296	338	376	413	460	500	523	537	568	583
Upper Flange 5				221	273	318	368	413	462	504	544	569	578	608	615
Upper Flange 8				223	277	322	365	415	455	496	533	556	567	593	609
Upper Flange 9				236	288	338	384	425	467	508	544	566	578	607	616
Mean Upper				221	272	319	364	407	449	492	530	554	565	594	606
Atmosphere 1				657	688	719	736	729	738	775	766	778	773	799	815
2				695	741	761	774	776	788	799	808	820	819	833	837
3				701	730	753	761	770	789	801	820	833	836	847	840
4				652	697	709	725	748	758	783	788	809	810	825	825
5				734	767	796	811	813	825	838	844	846	852	868	860
6				693	715	743	760	771	779	812	810	830	826	831	850
Mean Atmosphere				689	723	749	762	768	780	801	806	819	819	834	838
ISO Curve RT=11	493	594	654	696	729	757	780	799	817	833	847	856	860	872	876
Deflection (mm)	7	18	30	42	53	64	76	90	106	124	142	154	163	185	190

NOTE: No data collected during first 12 minutes of the test due to data logger malfunction

APPENDIX

LOAD CALCULATIONS FOR COMPOSITE BEAM

Beam tested 2/3/81. Test 27825

Data for calculations

Slab width	642 mm
Slab depth	130 mm
Cube strength	30 N/mm^3
Steel depth	257 mm
Steel width	146 mm
Flange thickness	12.45 mm
Web thickness	7.08 mm
Steel area	53.5 cm^2
Steel yield	255 N/mm^2
Modular ratio	15
Steel I	6177.7 cm^4

From program:-

Moment capacity	247.2 kNm
Load in concrete	1112.8 kN
Z steel	756 cm^3

Steel stress at working load

$$= \frac{247.2}{1.75} \times \frac{10^3}{756} = 187 \text{ N/mm}^2$$

Applied moment $= \frac{165}{10^2} \times \frac{6177.7}{128.5} = 79.3$ kNm

Steel stress at applied moment

$$= \frac{79.3}{247.2} \times 1.75 \times 187 = 105 \text{ N/mm}^2$$

$\therefore$ % of full load $= \frac{105}{187} = 56\%$

Alternative % of full stress based upon beam only

$$= \frac{105}{165} \times 100 = 63.6\%$$

G.M. Newman

APPENDIX (CONT'D)

LOAD CALCULATIONS

FOR NON-COMPOSITE BEAM

Actual properties of the Universal Beam

Depth of section	(D)	:	257 mm
Breadth of section	(B)	:	146 mm
Thickness of flange	(T)	:	12.45 mm
Thickness of web	(t)	:	7.08 mm
Mass per metre	(m)	:	407.745 N/m
Moment of inertia	(I)	:	6.17774E+07 mm^4
Distance of neutral axis to the base of beam	(y)	:	128.5 mm

Effective span of the beam (L) : 4530 mm

Maximum allowable bending stress to B.S.449: Part 2: 1969, Table 2
f = 165 N/mm^2

Percentage of allowable bending stress required during the test
f1 = 165 N/mm^2

Required bending moment = f1I/y = wL^2/8 N/mm

Therefore w = 8f1I/yL^2
where w = load per metre run in N/m

w = 8 * 165 * 6.17774E+07 / 128.5 * 4530 * 4530
w = 30924.6 N/m

Concrete topping slab

Depth	=	130 mm
Width	=	642 mm
Mass per metre	=	1833.98 N/m

Total self weight of beam & topping = 2241.73 N/m

Required imposed load to produce required bending stress = 30924.6 - 2241.73 N/m
= 28682.9 N/m

Therefore total imposed load = 13245 Kg

Using four point loads at 1/8, 3/8, 5/8 and 7/8 span equivalent to wL/4.

Point loads required = 3311.25 Kg