Swinden Laboratories

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A BS476:Part 8 Fire Test on an Unprotected 254 x 146 mm x 43 kg/m BS4360:Grade 43A Beam at 50% Design Load

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British Steel Corporation

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A BS476:PART 8 FIRE TEST ON AN UNPROTECTED 254 x 146 mm x 43 kg/m BS4360:GRADE 43A BEAM AT 50% DESIGN LOAD

G. Thomson D.J. Latham R.R. Preston

SYNOPSIS

As part of an experimental programme to generate information on the behaviour of unprotected steel sections in fire, a BS476:Part 8 fire test was carried out on a 254 x 146 mm x 43 kg/m BS4360:Grade 43A beam. The steel member was loaded to 50% of the maximum design stress and achieved a fire resistance of 27 min. The data provided further proof of the improvement in fire resistance that results from a reduction in applied load.

KEY WORDS

3. Fire Resistance
4. Fire Tests
5. +BS 476 Part 8
6. Beams
7. Mechanical Properties
8. High Temperature
9. Lab Reports

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1. INTRODUCTION

Measurements of the heating rates of unprotected steel sections in BS476:Part 8 fire tests suggest that the limiting temperature for stability depends upon the load applied to the member. One section commonly used in fire testing is a 254 x 146 mm x 43 kg/m universal beam which has an H_p/A value of 169 m^{-1} when exposed to three sided attack. A fire resistance of 22 min was obtained on this section when tested in the simply supported condition under maximum design stress[1].

The present report describes the results obtained from a further fire test on an unprotected 254 x 146 mm x 43 kg/m beam to determine the extent to which the fire resistance is increased by a reduction in design stress to 50% of the maximum permitted level.

2. STEEL SUPPLY

The 254 x 146 mm x 43 kg/m universal beam was obtained from a local steel stockholder. After the fire test, samples were taken from an unheated end of the beam to check the chemical composition and room temperature tensile properties.

The product analysis and composition limits for the BS4360:Grade 43A specification are given in Table 1 which shows that the steel was within the compositional limits of the specification.

The tensile test specimen was taken, in accordance with BS4360, from the flange position of the beam and the test results are presented in Table 2. Both the steel yield stress and tensile strength adequately satisfied the requirements for BS4360: Grade 43A.

3. PREPARATION OF BEAM

3.1 Concrete Topping

The beam was covered with a concrete slab (645 mm wide x 130 mm deep) which was dividied up into four discrete segments by 12 mm thick fibre board. The concrete was a non-structural mix and was held in position with lightweight tangs welded to the flange of the beam.

3.2 Temperature Measurements

Thirteen thermocouples, chromel/alumel Type K, 3 mm diameter with Inconel sheath and insulated hot junction were fitted to the beam in the positions shown in Fig. 1. Four thermocouples were attached to the web, five to the lower flange and four to the upper flange of the steel beam.

Six thermocouples were also used to measure the furnace atmosphere temperature. These were located 100 mm away from the test beam and situated along its length level with the lower flange.

The outputs from the thermocouples were monitored using the BSC Compulog 4 computer controlled data acquisition system, the information being stored on floppy disk.

A total load of 6.46 t was required to generate a stress of 82.5 N/mm² in the test beam, i.e. 50% of the maximum permitted in BS449 and the loading calculations are given in the appendix. The beam was loaded at four points along its span ($^1/8$, $^3/8$, $^5/8$, $^7/8$) each with a load of 1.61 t.

Deflection measurements were taken at the centre of the beam by the Warrington Research staff using a theodolite system. Photographs of the beam before and after the test are shown in Fig. 2.

4. RESULTS

The test was stopped after 27 min when the beam reached the L/30 failure criterion, i.e. when the central vertical deflection on the beam reached 150 mm. The deflection-time curve given in Fig. 3 indicates that the deflection increased relatively slowly for the first 22 min and then accelerated rapidly until failure occurred.

The temperature measurements are given in Figs. 4-7 and Table 3. The heating rates for all the lower flange positions on the test beam are shown in Fig. 4. At the end of the test the five temperatures were in the range 741 to 756°C with a mean of 745°C. The heating rates and final temperatures were all remarkably similar. The heating rates recorded on the upper flange, given in Fig. 5, show fairly consistent heating rates and final temperatures were within the range 490 to 581°C, the mean being 535°C. The temperature profiles recorded along the web were similar, as shown in Fig 6; at the end of the test the web temperatures ranged from 719 to 746°C with a mean of 734°C. The average of the lower flange and web temperatures at failure was 740°C.

The furnace atmosphere heating curves are compared with the international time-temperature curve in Fig. 7 which shows that the heating rate was in accordance with the standard curve throughout the test.

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

A letter from the Warrington Research Centre confirming the fire resistance of the beam is shown in Fig. 8.

5. DISCUSSION

A reduction in applied load below the maximum permitted by design increased the fire resistance of the unprotected 254 x 146 mm x 43 kg/m steel beam. In comparison with previous fire test data on the section, given in Table 4, a reduction of 50% in design stress increased the fire resistance from 22 to 27 min. If the limiting temperature is taken to be the average between the lower flange and the web at failure the change in loading conditions raised the temperature from approximately 650 to 740°C.

A computer model is being developed to simulate the performance of steel beams in a BS476:Part 8 fire test. This analysis is tackled in two stages. The first involves the prediction of the temperature fields which are generated in the steelwork as the fire progresses. The second stage uses this information to calculate the deflection behaviour in the structure. The heating rates in the BS476:Part 8 fire test of the range of beams and columns currently produced by BSC together with their anticipated periods of fire resistance have been predicted. On the basis of the steel temperatures measured during the tests at 100 and 50% of maximum design load the analysis predicts respective fire resistances of 22.8 and 30.5 min.

The only other BS476:Part 8 fire test carried out on an unprotected 254 x 146 mm x 43 kg/m Grade 43A beam at less than the maximum design stress involved the application of 2 point loading[2] to generate a stress in the beam of 148.5 N/mm^2. The fire resistance was 35.5 min, which taken in the context of data since recorded on unprotected steel beams is uncharacteristic and high. The mathematical model predicts a fire resistance of 25 min based on the steel temperatures recorded at failure. An examination of the deflection measurements recorded in the early test and in a more recent test on a beam when 2 point loading was also used revealed a marked difference in behaviour. This suggested that in the former test the vertical deflection might have been interrupted by lateral twisting thereby artificially prolonging the fire resistance.

6. CONCLUSIONS

A BS476:Part 8 fire test was carried out on a 254 x 146 mm x 43 kg/m BS4360:Grade 43A beam loaded to 50% of the maximum permissible design stress in the simply supported condition. A fire resistance of 27 min was obtained for a limiting deflection of

L/30. This value was approximately 5 min longer than the fire resistance recorded on fully loaded beams.

A prediction of heating rates in the steel member using a mathematical model suggested that a fire resistance of 30.5 min would be achieved.

7. REFERENCES

1. Smith, C.I. and Thomson, G., BSC Teesside Report T/RS/1380/17/81/B.

2. Smith, C.I., Thomson, G. and Bunyan, R., BSC Teesside Report T/RS/1195/6/79/D.

G. Thomson
D.J. Latham
Investigators

R.R. Preston
Manager,
Rails and Sections Department

J. Lessells
Research Manager -
General Steel Products

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TABLE 1 CHEMICAL COMPOSITION OF 254 x 146 mm x 43 kg/m UNIVERSAL STEEL BEAM USED IN THE TEST

Code No.	Sample Form	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	N	Nb	Sn	V
RS556	Solid	0.23	0.030	1.0	0.018	0.035	0.02	0.005	0.04	0.003	0.03	0.006	0.001	0.002	0.004
BS4360:Grade 43A Product spec.		0.30 max.	0.55 max.	1.70 max.	0.06 max.	0.06 max.									

TABLE 2 TENSILE TEST DATA FROM THE FIRE TESTED BS4360:GRADE 43A 254 x 146 mm x 43 kg/m (50% DESIGN LOAD)

Code	Yield Stress N/mm²	Tensile Strength N/mm²	Elongation %
RS556	297	517	34
BS4360:Grade 43A specification requirements	255 (min.)	430/540	

TABLE 3 SIMPLY SUPPORTED BEAM TEST - TEMPERATURE DATA

Section: 254 x 146 mm x 43 kg/m tested at 50% design load

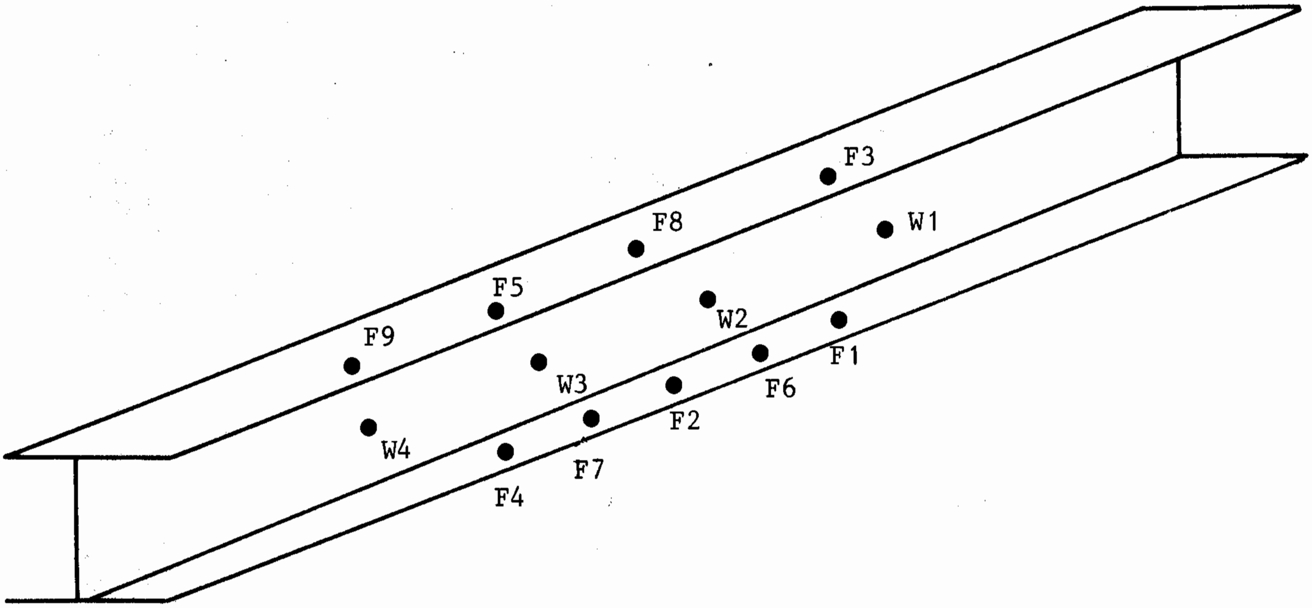
Date: 20.6.84 Failure time: 27 min

Thermocouple Position	Temperatures, °C, After Various Times, min								
	3	6	9	12	15	18	21	24	27
Lower flange 1	116	221	335	467	560	625	671	714	742
2	119	228	342	483	579	645	691	731	756
4	117	223	333	468	567	632	679	722	742
6	124	228	337	472	567	633	680	722	743
7	124	234	343	470	565	631	679	721	741
Mean lower flange	120	227	338	472	568	633	680	722	745
Web 1	145	255	357	475	561	612	653	697	731
2	150	267	380	508	594	642	681	720	741
3	152	277	387	512	598	646	683	725	746
4	142	250	350	464	547	597	638	682	719
Mean web	147	262	368	490	575	624	664	706	734
Mean lower flange and web	132	242	351	480	571	629	673	715	740
Upper flange 3	69	112	156	224	282	341	398	457	525
5	80	129	174	249	311	370	425	482	546
8	81	133	183	270	344	415	477	532	581
9	74	115	155	214	267	320	375	431	490
Mean upper flange	76	122	167	239	301	361	419	475	535
Mean atmosphere	495	549	639	713	739	756	774	814	834
ISO curve, 20°C	502	603	663	705	738	766	789	808	826
Deflection, mm	7	16	27	42	51	60	72	100	150

TABLE 4 TYPICAL STEEL TEMPERATURES RECORDED IN BS476:PART 8 FIRE TESTS ON 254 x 146 mm x 43 kg/m BEAMS LOADED IN THE SIMPLY SUPPORTED CONDITION

Test date	3.9.79	27.1.81	30.1.81*	6.3.81*	20.6.84
Design stress, %	90	100	100	100	50
Fire resistance, min	35½	21	22	22	27
Av. lower flange temperatures, °C	678	655	683	654	745
Av. web temperatures, °C	687	652	667	636	734
Av. lower flange and web temperatures, °C	682	654	676	646	741
Av. upper flange, °C	530	431	456	470	535

* Concrete - one segment

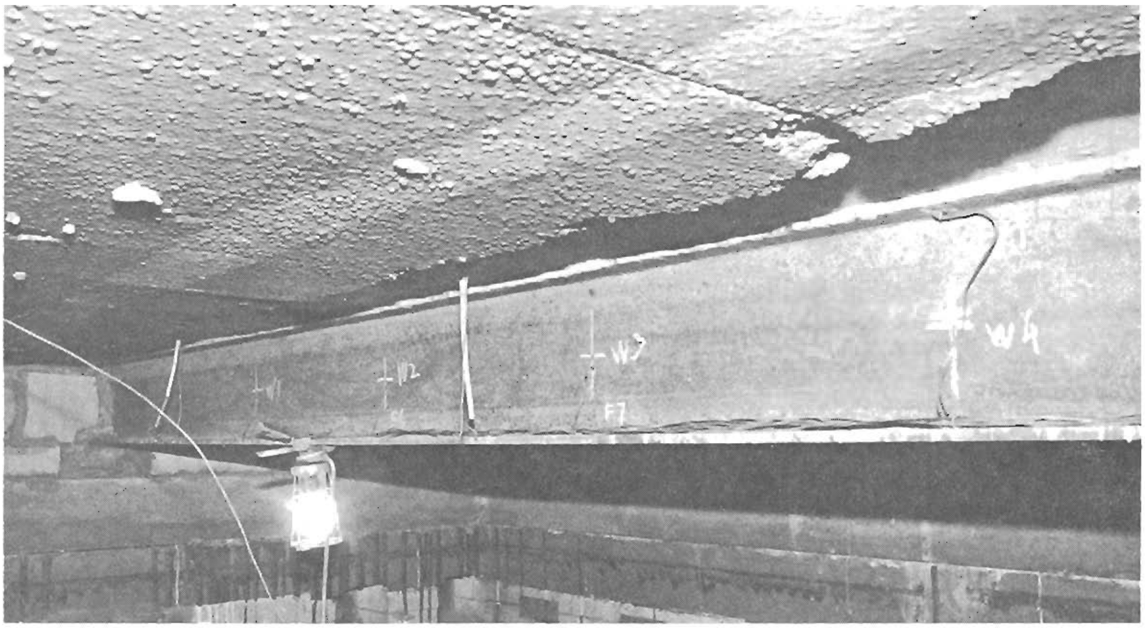


Distance from end of beam to thermocouples -

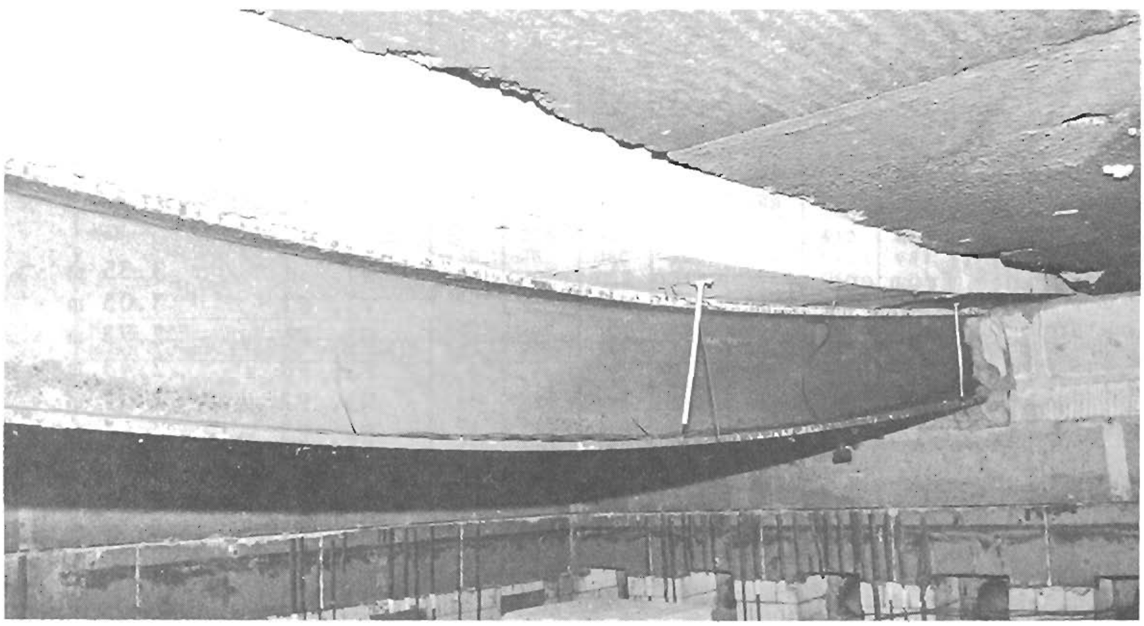
W1	3.35	m
F3, F1	3.05	m
W2, F6	2.73	m
F2, F8	2.43	m
W3, F7	2.11	m
F4, F5	1.81	m
W4, F9	1.5	m
End of beam	4.84	m
W5, F10	0.50	m

POSITION OF THERMOCOUPLES ON TEST BEAM

FIG. 1
(R2/2987)

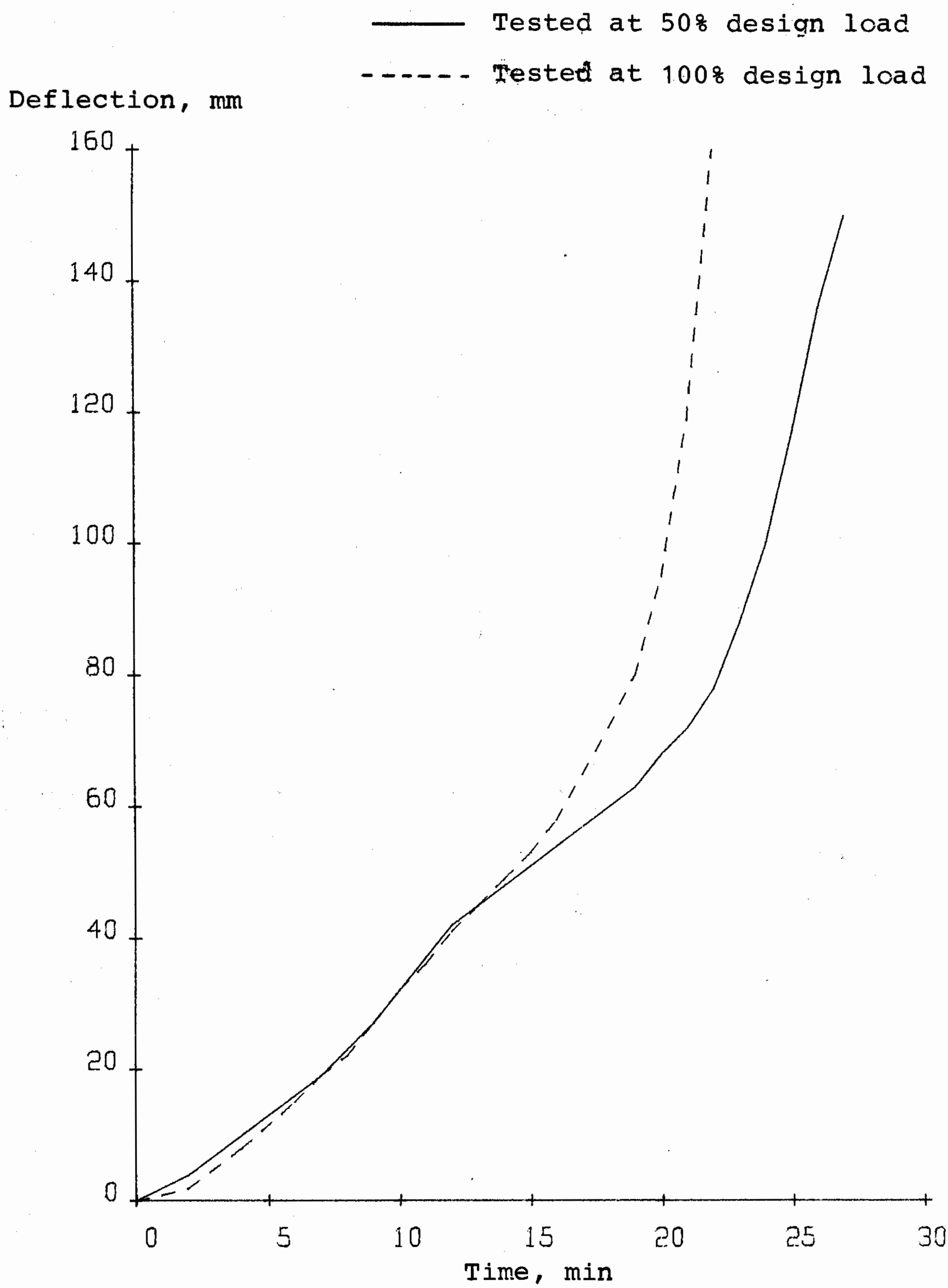


Before (a)



After (b)

PHOTOGRAPHS OF BEAM BEFORE AND AFTER TESTING FIG. 2



VERTICAL CENTRAL DEFLECTIONS MEASURED DURING FIRE TESTS ON 50 AND 100% LOADED 254 x 146 mm x 43 kg/m UNIVERSAL STEEL BEAMS

FIG. 3

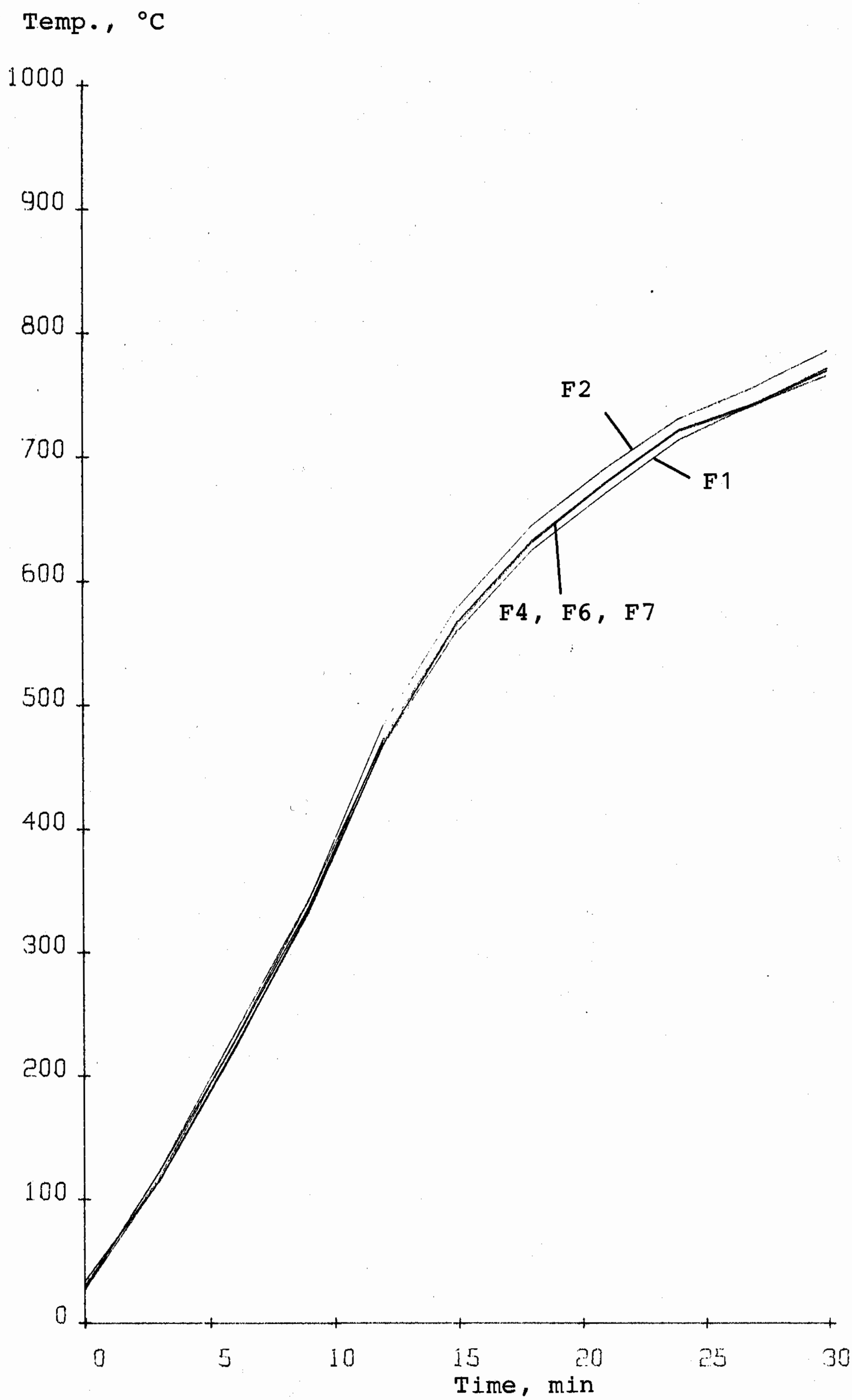
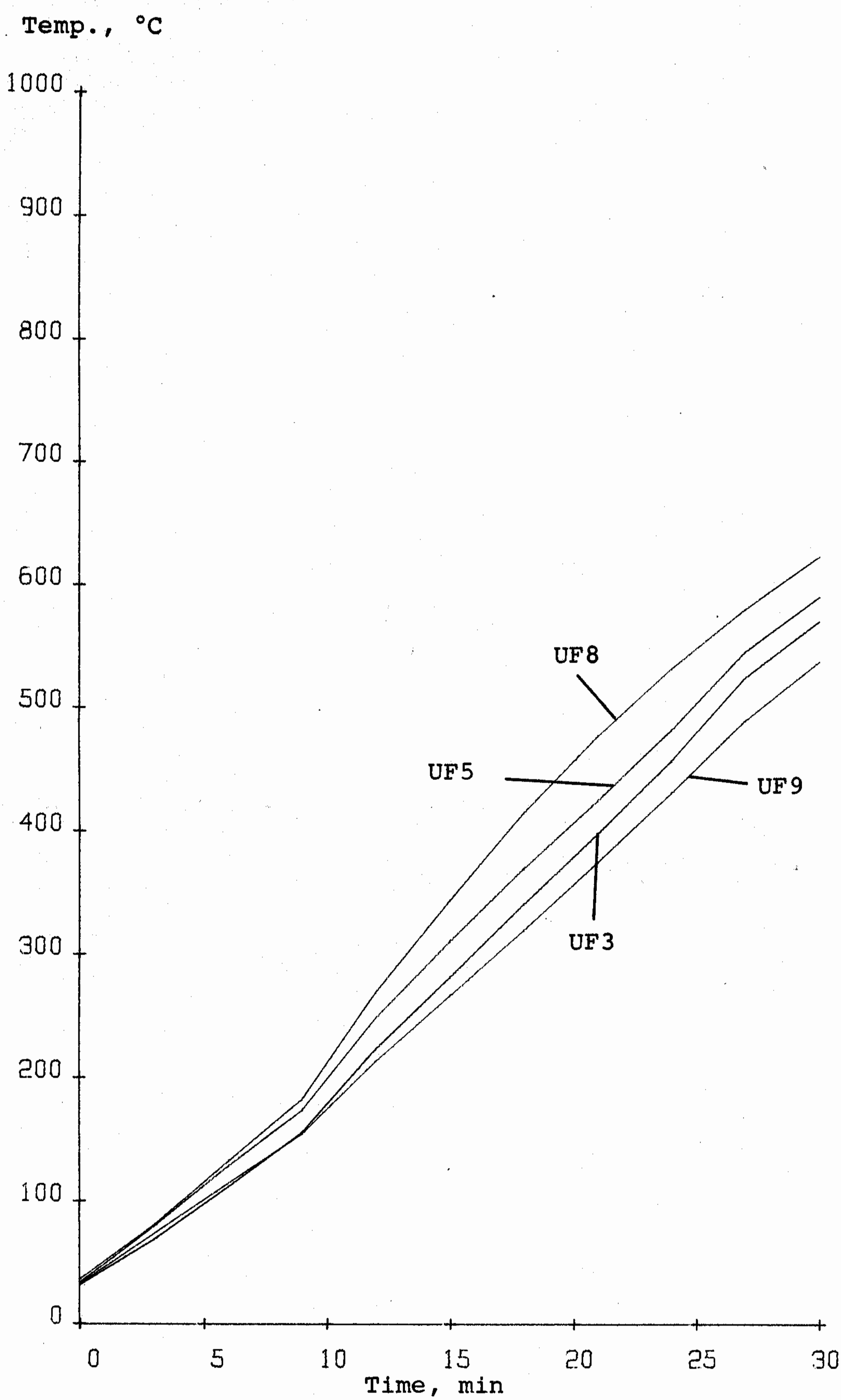


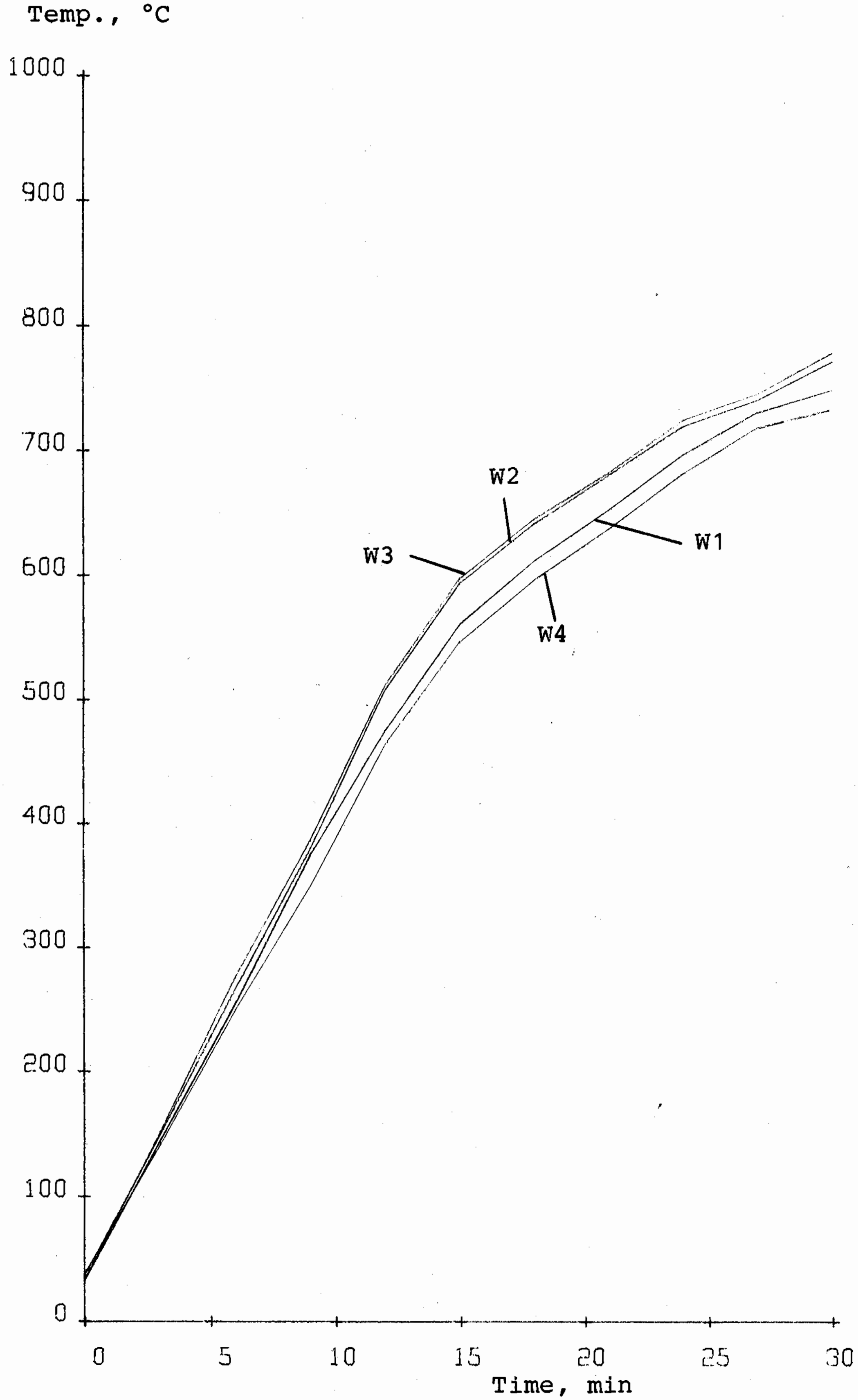
FIG. 4

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



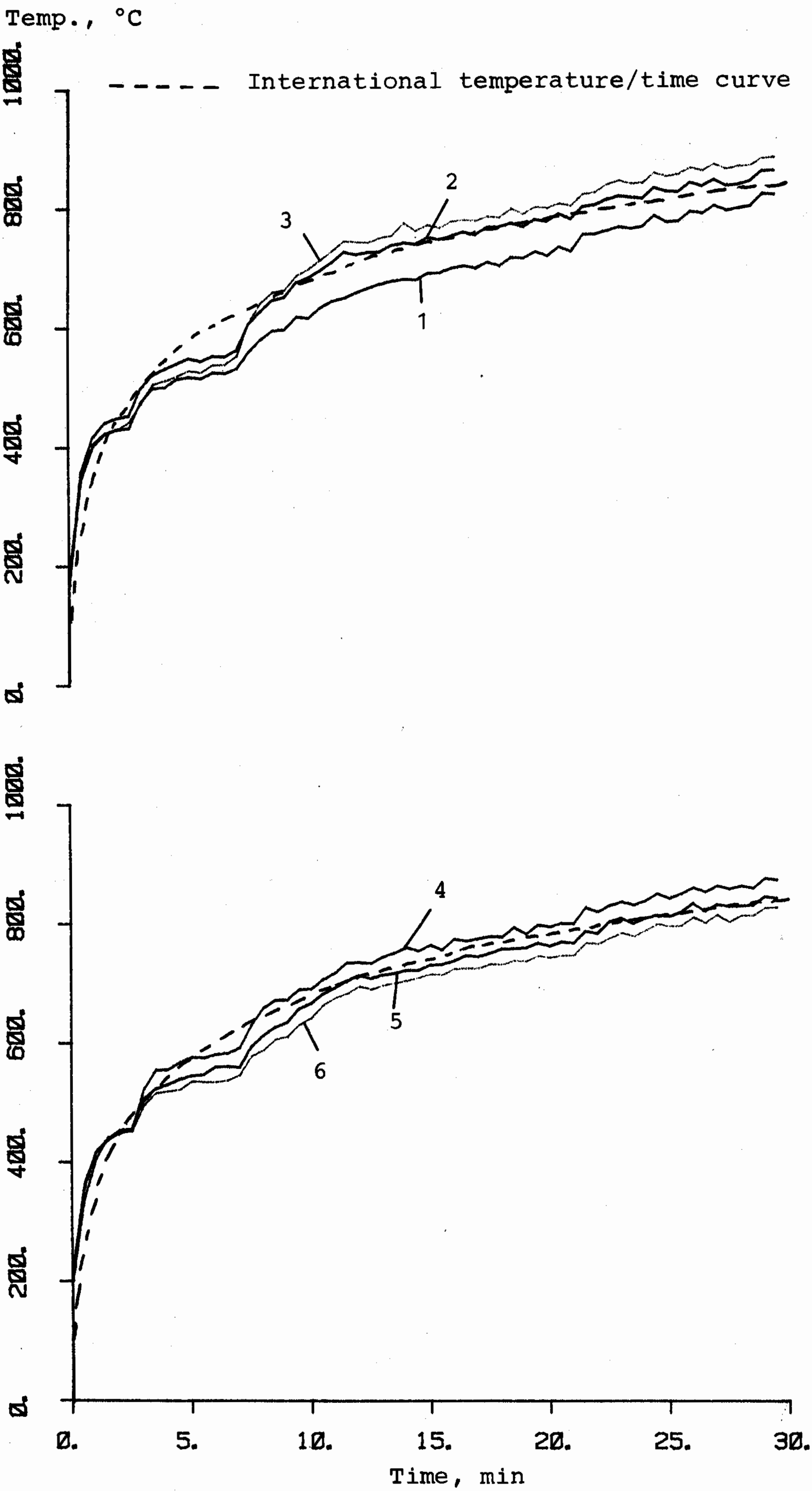
<u>TEMPERATURES RECORDED ON THE UPPER FLANGE OF THE BEAM DURING THE TEST</u>

FIG. 5



WEB TEMPERATURES RECORDED DURING THE TEST

FIG. 6



FURNACE HEATING RATE MEASURED DURING TEST FIG. 7

WARRINGTON RESEARCH CENTRE
Fire Research, Testing and Consultancy

Warrington Research
Consultants (Services) Limited
Holmesfield Road
Warrington WA1 2DS
Tel: Warrington (0925) 55116
Telex: 628743
WARRES G

W.R.C.S.I. No. 34141 - LH/SB

21st June 1984

British Steel Corporation
Sheffield Laboratories
Swinton House
Moorgate
Rotherham

For the attention of Mr. G. Thompson

Dear Sirs,

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 an unprotected loadbearing steel beam of nominal size 254 mm by 146 mm x 43 kg/m by 4500 mm span.

The beam was not protected by any insulation material. The beam was loaded to 50% of its maximum design stress (i.e. 165 N/mm^2 x 50%). The test results were as follows:

Stability	:	27 minutes
Re-load test	:	Satisfied
Date of test	:	21st June 1984.

When the load was removed from the beam, after a period of 26 minutes 45 seconds of testing, the beam was deflecting for a distance of 150 mm and increasing at a rate of 19 mm per minute.

Assuring you of our best attention at all times.

Yours faithfully,

L Healey

(L. HEALEY)

Warrington Research Centre

E.S. LONDON, A.M.C.T., C. Chem., F.R.S.C.
B. SAYERS. B.Sc., A.M.C.T., C. Eng., M.I.E.E.
F.D. WILLIAMS, F.C.A., F.C.C.A.

LETTER CONFIRMING TEST RESULT FIG. 8

APPENDIX LOAD CALCULATIONS

Actual properties of the Universal Beam

Depth of section	(D)	:	262 mm
Breadth of section	(B)	:	148 mm
Thickness of flange	(T)	:	12.39 mm
Thickness of web	(t)	:	7.65 mm
Mass per metre	(m)	:	423.465 N/m
Moment of inertia	(I)	:	6.56821E+07 mm^4
Distance of neutral axis to the base of beam	(y)	:	131 mm

Effective span of the beam (L) : 4500 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 = 82.5 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 * 82.5 * 6.56821E+07 / 131 * 4500 * 4500

w = 16341.6 N/m

Concrete topping slab

Depth = 130 mm

Width = 645 mm

Mass per metre = 1842.55 N/m

Total self weight of beam & topping = 2266.02 N/m

Required imposed load to produce required bending stress = 16341.6 - 2266.02 N/m

= 14075.6 N/m

Therefore total imposed load = 6456.69 Kg

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

Point loads required = 1614.17 Kg

INITIAL CIRCULATION

Swinden Laboratories

General Steel Products Group
Standard Circulation
Mr. T.R. Kay
Dr. B.R. Kirby
Mr. D.E. Wainman

Teesside Laboratories

Dr. R. Baker

GENERAL STEELS GROUP

BSC Sections and Commercial Steels

Steel House (Redcar)

Mr. N.J. Cavaghan
Mr. R.A.C. Latter
Mr. J.T. Robinson
Mr. D.C. Shenton

Scunthorpe

Dr. M.J. Pettifor

EXTERNAL CIRCULATION

Mr. G.M. Newman - Constrado
Mr. G.M.E. Cooke - Fire Research Station (DOE/BRE)