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The Effect of Load Ratio on the Limiting Temperatures Observed During Two BS476 : Part 21 Fire Resistance Tests Carried Out on 254 x 146 mm x 43 kg/m Universal Beams Protected with 20 mm Thick Vicuclad Insulating Board

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SUMMARY

THE EFFECT OF LOAD RATIO ON THE LIMITING TEMPERATURES OBSERVED DURING TWO BS476 : PART 21 FIRE RESISTANCE TESTS CARRIED OUT ON 254 x 146 mm x 43 kg/m UNIVERSAL BEAMS PROTECTED WITH 20 mm THICK VICUCLAD INSULATING BOARD

D. E. Wainman

Two BS476 : Part 21 standard fire resistance tests have been carried out on universal beam sections of serial size 254 x 146 mm x 43 kg/m which were fully protected with 20 mm thick Vicuclad insulation board. The loads applied to each test assembly were designed to create conditions of extreme over and under loading in the steel beams. Based on the actual dimensions and properties of the steel sections load ratio values of 0.736 and 0.207 were obtained. The performance of both test assemblies was judged against the load bearing capacity criterion outlined in Section 5 of BS476 : Part 21 : 1987. The fire resistance rating of the higher loaded assembly was 92 min whilst that for the other was 156 min. For both situations the temperature of the lower flange at failure has been compared with the limiting temperature data given in BS5950 : Part 8 : 1990 and it has been concluded that the limits set in BS5950 : Part 8 may be slightly optimistic for steel beams protected with Vicuclad boards.

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THE EFFECT OF LOAD RATIO ON THE LIMITING TEMPERATURES OBSERVED DURING TWO BS476 : PART 21 FIRE RESISTANCE TESTS CARRIED OUT ON 254 x 146 mm x 43 kg/m UNIVERSAL BEAMS PROTECTED WITH 20 mm THICK VICUCLAD INSULATING BOARD

1. INTRODUCTION

The load bearing steel members making up the framework of a building are required, by the UK building regulations, to possess specified levels of fire resistance, such as one, two, or more hours. For steel sections this property can either be measured in the standard fire resistance test, (BS476 : Parts 20/21 : 1987), or may be calculated by methods described in BS5950 : Part 8 : 1990. One of the calculation procedures outlined there-in is referred to as the limiting temperature method. This is based on a study of the behaviour of the critical element, which is defined as being that part of the section which will attain the highest temperature in fire conditions. In the standard fire resistance test the critical element of a beam section is usually considered to be that portion of the lower, (tensile), flange of the section which is at the mid-length of the supported span. The limiting temperature is the temperature attained by this element of the beam at 'failure'. It therefore follows that the time taken for the critical element to heat up to its limiting temperature is a measure of the fire resistance rating of the section under test. Furthermore, the extent to which the test member is loaded clearly influences the time taken for it to reach failure, as defined by the standard. Consequently, the limiting temperature recorded for a lightly loaded steel section will be greater than for the same member subjected to a higher level of loading.

BS5950 : Part 8 provides a table of limiting temperatures, as a function of load ratio, for various steel members including beams supporting concrete floor slabs. This table is largely based on data obtained during the fire resistance testing of unprotected steel beams and columns. It is therefore of interest to ensure that the tabled data are equally valid for steel beams which are fire protected.

The present report gives details concerning the measurement of the limiting temperature, at two extreme values of load ratio, for 254 x 146 mm x 43 kg/m universal beams protected with 20 mm thick Vicuclad boards.

2. DETAILS OF THE TEST ASSEMBLIES

2.1 Steel Supply

The steel sections used in the construction of both test assemblies were obtained from a local steel stock-holder. Each test required a 5 m length of 254 x 146 mm x 43 kg/m serial size universal beam in BS4360 : Grade 43A steel. Samples were taken from each of the sections for chemical analysis, and for mechanical testing. The chemical compositions and room temperature tensile results are given in Tables 1 and 2 respectively. These show that both test beams almost certainly came from the same parent section, and that both satisfied the requirements specified in BS4360 : 1986 for Grade 43A steel.

The low silicon content of 0.08% indicates that the feedstock used came from a steelmaking/casting route employing a balanced steel composition, and suggests that manufacture was probably via the BOS/ingot route. The sections were devoid of any marks identifying the original manufacturer. It is worth noting that the nitrogen level of 0.0083% is somewhat higher than would normally be expected for BOS produced steel. The residual copper content is also rather high at 0.12%, though the other residual elements, (Ni, Cr, and Mo) are at or below expected levels.

2.2 Concrete Cover Slabs

A concrete cover slab, nominally 650 mm wide x 135 mm thick, and in four sections each 1125 mm in length, was cast onto the upper flange of each test beam. The slabs were secured in position by thin gauge mild steel ties welded to the beam as indicated in Fig. 1, and described in the schedule of components, Table 3.

2.3 Instrumentation

2.3.1 Temperature Measurement

A total of twenty 3 mm diameter mineral insulated 'K' type thermocouples, (Ni/Cr-Ni/Al), each with insulated hot junctions and inconel sheaths, were used to monitor the temperature of the steel beam during each test. These thermocouples were located at the positions shown in Figs. 2 and 3, and were embedded to the mid-thickness position of the relevant section. All were installed prior to the application of the Vicuclad fire protection material. The positions may be summarised as :-

(a) Four thermocouples embedded in the upper flange of the beam.
Identified as :- F3, F5, F8, F9

(b) Five thermocouples embedded in the lower flange of the beam.
Identified as :- F1, F2, F4, F6, F7

(c) Four thermocouples embedded in the web of the beam at the mid-height position.
Identified as :- W1, W2, W3, W4

(d) Seven thermocouples embedded in the web of the beam at the mid-span position. These were used to monitor the temperature profile through the depth of the assembly.
Identified as :- W5 to W11 inclusive

After the test assembly had been located in the furnace a further six thermocouples, (of the same type), were installed in order to monitor the furnace gas temperature at positions along its length. These thermocouples were located at the positions indicated in Fig. 4, their tips being level with the lower flange of the beam and 100 mm away from the fire protection material.

2.3.2 Beam Central Displacement

Vertical movement of the beam at the mid-span position was monitored throughout each test by Warrington Fire Research Centre Personnel using a displacement transducer connected to their data logging facility.

2.4 Application of the Fire Protection System

Application of the Vicuclad board insulation material was carried out during the week commencing August 7th 1989 by Fylde Fire Protection Ltd., a firm of specialist structural fireproofing contractors based in Blackpool, Lancashire. The protection applied to each of the test assemblies was the same, and comprised the enclosure of the three exposed sides of the beam within a box profile formed from 20 mm thick boards as illustrated in Fig. 1. The protection covered a central 4300 mm long portion of the steel section. A board thickness of 20 mm was specified in order to provide a minimum of one hours fire protection.

No special preparation of the steel-work preceded the fitting of the insulation material, application of which was carried out generally in accordance with the manufacturers recommended practices and procedures. 25 mm wide noggings of Vicuclad board material were bonded to the steel beam using Vicubond adhesive. These noggings extended over the full height of the web and were spaced at 500 mm centres to coincide with every board joint position. Recesses were cut in the noggings, as required, to accommodate the thermocouples. Figure 5 shows one of the beams at this stage of preparation. The 20 mm thick boards, which were 1000 mm in length, were both bonded and nailed to the noggings using Vicubond adhesive and 50 mm long nails. The method employed for closing off the end of the beam is shown in Figure 6.

The board joint positions on each side of the beam did not, by design, coincide with each other along the protected length; the relative positions of the panels being as shown in Fig. 7. The joints between the boards protecting the lower flange were at the same positions as those in the boards protecting the right hand side of the beam, when viewed from the door end of the test furnace, as shown in Fig. 8. Figure 9 shows the offset of the panels on the left hand side of the beam.

2.5 Assembly

Each complete test assembly, consisting of a protected beam and its segmented concrete cover slab was positioned so as to form the roof of the floor furnace at the Warrington Fire Research Centre. The assemblies were simply supported on a steel loading frame, lined with refractory cement, so as to give a total effective span between the roller supports of 4500 mm. This frame was supported on the outer walls of the gas fired furnace so that the length of beam exposed to the heating conditions of the test was 4000 mm. The arrangement is shown schematically in Fig. 10 and described in the schedule of components, Table 3. A general view of one of the assemblies installed in the furnace and just prior to testing is shown in Fig. 11.

2.6 Loading

Loading of both test assemblies was effected through the concrete cover slabs to simulate conditions which would be encountered in service. The load was applied via four hydraulic rams which were positioned at points corresponding to 1/8, 3/8, 5/8 and 7/8 of the supported span, and along the centre-line of the web of the beam, as shown in Figs. 1 and 10.

In the case of the first test, (WFRC 46738 on 24/08/89), the load applied to the beam via the four rams, (the imposed load), was 21.0 tonnes. This, together with the contribution made by the self weight of the beam and the concrete cover slab, (the dead load), was calculated to generate a nominal load ratio value of 0.7 when calculated in accordance with the general provisions of BS5950 : Part 1 : 1985. In the case of the second test, (WFRC 46734 on 06/09/89), the dead load, plus an imposed load of 5.25 tonnes, was calculated to develop a nominal load ratio value of 0.2

Load ratio is defined in BS5950 : Part 1 as being the ratio of the applied moment at the fire limit state to the moment capacity of the member at ambient temperature.

i.e. Load Ratio, (R), $= Mf / Mc$

where: Mf is the product of the maximum tensile stress in the member and its elastic modulus.

and: Mc is the product of the room temperature yield stress of the member and its plastic modulus.

Hence

$$\text{Load Ratio, (R)} = \frac{f(\max) \times Z}{Py \times S} \qquad \ldots (1)$$

When calculating Mc, the design strength, Py, corresponding to the minimum guaranteed yield strength for the particular grade of steel is normally used, ie, for a BS4360 Grade 43A steel, Py = 275 N/mm^2. However, for the purpose of evaluating the effect of load ratio on the limiting temperature, the influence of variations in the strength of the as-received material may be diminished by adopting the measured yield strength values for Py. As indicated in Table 2, the average room temperature yield strength of the material used in the construction of both test assemblies was 306 N/mm^2.

Details of the loading calculations for each test assembly are given in Appendix 1. In both cases the loads were initially calculated on the basis of serial size dimensions and properties for the beam, and the nominal dimensions of the concrete cover slab. The calculations show that, in the case of the first test assembly, the combined loads were sufficient to generate a maximum tensile stress in the lower flange of the section of 240.9 N/mm^2. This is 46% in excess of the maximum permissible stress in bending when calculated according to BS449 design rules. Similarly the maximum tensile stress in the second assembly was calculated to be 68.8 N/mm^2 which is approximately 42% of the maximum permissible value of 165 N/mm^2.

The influence of variations in the dimensions of the as-received material on the values of both Mc and Mf may be eliminated by using section property data calculated on the basis of actual dimensions. Retrospective calculations were therefore carried out based on the measured dimensions of the steel sections and the concrete cover slabs, in order to more accurately determine the load ratio values associated with each test assembly. These calculations, which are set out in Appendix A1.2, indicate that in the case of the first test assembly the maximum tensile stress in the lower flange of the beam was 252.8 N/mm^2, or approximately 53% in excess of the maximum permitted design stress according to BS449. The recalculated value for the load ratio was 0.736. In the case of the second test assembly the corresponding values were 71.22 N/mm^2, (approximately 43% of the permitted maximum), and a load ratio of 0.207.

2.7 Failure Criteria

The performance of both test assemblies was judged against the load-bearing capacity criterion outlined in Section 5 of BS476 : Part 21 : 1987. The maximum allowable deflection and the maximum allowable rate of deflection for both test assemblies, as specified by the standard, were calculated to be 225 mm, (span/20), and 8.62 mm/min, ($span^2/9000 \times D$), respectively, where D = 261 mm, the measured depth of the section. The allowable rate of deflection criterion is not applicable until the deflection exceeds span/30, ie 150 mm.

3. EXPERIMENTAL RESULTS

3.1 Beam Tested at a Nominal Load Ratio of 0.7 (Test No. WFRC 46738 of 24th August 1989)

The load was removed from the beam after 93 min, at which time the mid-span vertical deflection was 156 mm, and the rate of deflection was 16 mm/min. Since both the span/30 deflection criterion and the limiting rate of deflection criterion of 8.62 mm/min had been exceeded the test was considered to be complete. In accordance with the provisions of BS476 : Part 21, the fire resistance rating of the test assembly was 92 min. In order to obtain additional thermal data, heating of the unloaded beam continued for a further period of 27 min. A copy of the letter received from Warrington Fire Research Centre confirming the general results is included in Appendix 2.

3.1.1 Temperature Measurements

A summary of the steel temperatures and furnace gas temperatures recorded at various times during the test is presented in Table 4. The temperature data from thermocouples W5 - W11, located at the mid-span of the beam, which were included to give a detailed temperature profile through the depth of the section, are given in Table 5.

In Fig. 12 the average furnace gas temperature is compared with the international time/temperature curve. This plot shows that the average furnace gas temperature was generally well maintained, although it tended to be slightly in excess of that required by the standard throughout most of the test. From the data in Table 4 the over-temperature has been estimated to be typically about 17C°. It should be noted that the temperatures indicated by the six 'atmosphere' thermocouples are not used for controlling the furnace, Warrington Fire Research Centre installing their own thermocouples for this purpose.

Average heating rates measured at the different locations over the central 2 m portion of the test assembly are presented in Fig. 13. At failure, (92 min), the measured temperatures were as follows:-

Location	Thermocouple Identity	Temperature °C		
		Minimum	Maximum	Mean
Upper Flange	F3, F5, F8, F9	363	409	387
Mid-Height Web	W1, W2, W3, W4, W8	531	541	533
Lower Flange	F1, F2, F4, F6, F7	561	576	569

The temperature profile at the mid-span position through the depth of the assembly is shown in Fig. 14.

3.1.2 Deflection Behaviour

The vertical deflection measurements made at the mid-span of the beam are presented in Table 6 and are shown plotted in Fig. 15. The rate of deflection remained well below the limiting rate of 8.62 mm/min throughout the test, only exceeding this value during the 90th min.

3.1.3 General Observations

3.1.3.1 Prior to the Test

(a) The beam dimensions were recorded as:

Depth	261 mm
Width	143 mm
Flange Thickness	12.28 mm
Web Thickness	6.8 mm
Root Radius	not measured

(b) The concrete cover slab dimensions were recorded as:

Width	642 mm	
Thickness	134 mm	
Length	4000 mm	(4 x 1000 mm.)

(c) The moisture content and density of samples of the Viculad board material, taken on the day of the fire test, were recorded as:

Moisture Content	3.1 % w/w
Density	529 kg/m^3

3.1.3.2 During the Test

The following observations were recorded during the conduct of the test.

Time min/s	Event
-15.00	Load applied to the beam. Initial deflection = 22 mm
00.00	Test commenced
07.00	Slight emission of blue/grey smoke from the roof of the furnace commenced.
10.00	Test specimen visible in the furnace. No visual changes since the commencement of the test.
13.00	Lower corners of the protection beginning to radiate a dull orange colour.
25.00	Sides of the protection beginning to radiate a dull orange colour. Lower corners of the protection glowing bright orange. (shown in Fig. 16).
45.00	Protection on the beam glowing bright orange over the entire surface. Protection appears to be stable and intact.
60.00	No significant visual changes since 45 min.
80.00	A small split is apparent in the protection near the mid-span position. It appears to extend across the full width of the lower flange and is approximately half the specimen height on its left hand side, as viewed from the door end of the furnace. (Shown in Fig. 17).
92.43	Central vertical deflection equals span/30, (150 mm). Rate of deflection is in excess of that allowable.
93.00	Load removed from the beam. The split in the protection remains as at 80 min. No other significant visual changes since 45 min. Test continuing with no imposed load.
120.00	Test terminated.

3.1.3.3 Subsequent to the Test

On removing the beam from the furnace, (25/08/1989), it was apparent that damage to the Vicuclad protection was more extensive than had been noted during the course of the test. Figures 18 and 19 show the left hand/soffit, and right hand sides of the assembly respectively. Board failure had occurred approximately 150 mm from the mid-span position, and this coincided with a soffit board joint, and also a web board joint on the right hand side. (Refer to Fig. 7). The split on the right hand side, which extended the full height of the section, had not been apparent during the test. Also on this side of the assembly was a section nearly 400 mm in length, where the joint between the soffit and web boards had become separated, thereby exposing the underlying steel flange to the furnace atmosphere. At the centre of the affected area, necking down of the lower flange material by between 3 and 4 mm, over a distance of about 80 mm, had taken place as shown in Fig. 20. A number of smaller, less severe, cracks were also in evidence throughout most of the test assembly, typical examples of which are shown in Fig. 21.

3.2 Beam Tested at a Nominal Load Ratio of 0.2 (Test No. WFRC 46734 of 6th September 1989)

The load was removed from the beam after 156 min, at which time the mid-span vertical deflection was 178 mm, and the rate of deflection was 8 mm/min. At this time a section of the Vicuclad board became detached, (see Section 3.2.3), and the test was terminated after 160 min. The span/30 failure criterion was reached after 152 min but the limiting rate of deflection criterion of 8.62 mm/min was never exceeded. Therefore, in accordance with the provisions of BS476 : Part 21, the fire resistance rating of the test assembly was 156 min. A copy of the letter received from Warrington Fire Research Centre confirming the general results is included in Appendix 2.

3.2.1 Temperature Measurements

A summary of the steel temperatures and furnace gas temperatures recorded at various times during the test is presented in Table 7. Table 8 contains the temperature data from thermocouples W5 - W11, located at the mid-span of the beam, which were included to give a detailed temperature profile through the depth of the section.

The average furnace gas temperature is compared with the international time/temperature curve in Fig. 22. This plot shows that the average furnace gas temperature tended to be slightly in excess of that required by the standard throughout most of the test. Although there were slight losses of control at around 15 min, and again after 30 min, these were quickly corrected, and in general control of the furnace temperature was acceptable. From the data in Table 7 the over-temperature has been estimated to be typically about 15C°. As noted in 3.1.1 these temperature data are independent of those used for furnace control purposes.

Average heating rates measured at the different locations over the central 2 m portion of the test assembly are presented in Fig. 23. After 152 min, (span/30), the measured temperatures were as follows:-

Location	Thermocouple Identity	Temperature °C		
		Minimum	Maximum	Mean
Upper Flange	F3, F5, F8, F9	574	623	596
Mid-Height Web	W1, W2, W3, W4, W8	686	744	705
Lower Flange	F1, F2, F4, F6, F7	718	730	724

The temperature profile at the mid-span position through the depth of the assembly is shown in Fig. 24.

3.2.2 Deflection Behaviour

The vertical deflection measurements made at the mid-span of the beam are presented in Table 9 and are shown plotted in Fig. 25. The rate of deflection remained below the limiting rate of 8.62 mm/min throughout the test. However, had it not been necessary to remove the load from the beam after 156 min the limiting rate of deflection would certainly have been exceeded in the next few minutes.

3.2.3 General Observations

3.2.3.1 Prior to the Test

(a) The beam dimensions were recorded as:

Depth	261 mm
Width	143 mm
Flange Thickness	12.28 mm
Web Thickness	6.8 mm
Root Radius	not measured

(b) The concrete cover slab dimensions were recorded as:

Width	647 mm	
Thickness	130 mm	
Length	4000 mm	(4 x 1000 mm.)

(c) The moisture content and density of samples of the Vicuclad board material, taken on the day of the fire test, were recorded as:

Moisture content	3.1 % w/w
Density	529 kg/m^3

3.2.3.2 During the Test

The following observations were recorded during the conduct of the test.

Time min/s	Event
-15.00	Load applied to the beam. Initial deflection = 6 mm
00.00	Test commenced
10.00	Test specimen just visible in the furnace. No visible changes since the commencement of the test.
13.00	Lower corners of the protection beginning to radiate a dull orange colour.
20.00	Lower corners of the protection glowing bright orange.
45.00	Protection on the beam glowing bright orange over the entire surface. Protection appears to be stable and intact.
60.00	No significant visual changes since 45 min.
80.00	All protection glowing very bright orange. Protection appears to be stable and intact.
100.00	No significant visual changes since 80 min.
150.00	Two small splits are apparent in the protection near the mid-span position. They appear to extend about 50-60 mm upwards from the lower corners on both sides of the assembly.
152.00	Central vertical deflection equals span/30, (150 mm). Rate of deflection is 6 mm/min. which is not in excess of that allowable.
155.00	A section of the soffit protection has delaminated from the assembly and is hanging down, leaving the lower flange steelwork exposed to the furnace atmosphere. The delaminated section is approximately 500 mm long from the mid-span position towards the door end of the furnace.
156.00	Further sections of the soffit protection have become detached and these, together with that noted above, have fallen into the furnace. The lower flange is now exposed for approximately 1000 mm in both directions from the mid-span position. (see Fig. 26).
156.15	Load removed from the beam.
160.00	Test terminated.

3.2.3.3 Subsequent to the Test

The extent to which the Vicuclad panels protecting the lower flange steelwork became detached may be seen in Figs. 27 and 28. These show the left and right hand sides, respectively, of the test assembly just prior to its removal from the furnace on 07/09/1989. Observations confirmed that two complete panels were absent and that a central 2 m long portion of the lower flange had been exposed to the furnace atmosphere. A number of vertical cracks in the web panels were also noted, the most significant being situated adjacent to the mid-span position. Figures 29 and 30 show such cracks in the left and right hand side panels respectively.

4. DISCUSSION AND CONCLUSIONS

4.1 In Terms of BS5950 : Part 8 : 1990

Figure 31 shows a plot of limiting temperature, as a function of load ratio, for members in bending supporting concrete floor slabs. The data points are taken from Table 5 of BS5950 : Part 8 : 1990 which is reproduced here as Table 10. The upper data points are for unprotected members, or members where it can be demonstrated that the beam and its fire protective cladding can remain intact at mechanical strains of up to 1.5% in the standard fire resistance test. The lower set of data relates to more brittle coatings, where strains of only 0.5% are considered to be appropriate. The two experimental points, measured in the present work, have been superimposed on this graph and they indicate that the limits set in BS5950 : Part 8 may be slightly optimistic for steel beams protected with Vicuclad board.

A summary of the test data relating to seven simply supported, unprotected, steel beams of serial size 254 x 146 mm x 43 kg/m, which have been the subject of standard fire resistance tests at the Warrington Fire Research Centre is given in Table 11. These data are sourced from Reference 1. Also included are data for a single test on a beam of the same serial size which was carried out on behalf of British Steel by the Technical Centre for Fire Prevention, TNO-IBBC, in their facility at Delft, Holland. Retrospective calculation of the load ratio for this test has been carried out using the dimensional and loading data presented in the report prepared by TNO-IBBC(3). A load ratio value of 0.493 has been obtained using the calculation method set out in Appendix A1.3.

Figure 32 shows a plot of both the upper and lower flange temperature, at failure, as a function of load ratio for the eight beams listed in Table 11, and those evaluated in the present exercise. It is clear that, for the Vicuclad board protected beams, the temperature gradients between the upper and lower flanges were smaller than for the unprotected beams. This would lead to a reduction in the overall strength of the beam at a given lower flange temperature and hence it would tend to exhibit a lower limiting temperature than the equivalent unprotected beam.

It should be noted that the converse will generally be true for steel beams protected with spray applied fire protection products since applicators tend to over-spray the upper flange which then remains cooler during the course of a standard fire resistance test.

The present work indicates that when using board fire protection it is unwise to design to the limits of BS5950 : Part 8 : 1990.

4.2 In Terms of Computer Simulated Behaviour

As part of the fire engineering work carried out at Swinden Laboratories a suite of computer programmes has been developed which may be used for predicting the behaviour of steel beams in the standard fire resistance test. The full computer simulation technique is based on the use of two commercially available finite element analysis programmes, namely Fires - T2 and Fasbus 11, together with a number of in-house pre and post processor routines which facilitate data preparation and extraction. A detailed description of the simulation technique has been included in several recent reports, for example reference 2.

The model has been used to predict the behaviour of six beams in the standard fire resistance test, the results of which have been published previously[2]. Regression analysis of these data has produced a relationship by which the temperature of the lower flange, at failure, may be predicted from a knowledge of the load ratio acting on the beam.

The actual equation is:

$$\text{Predicted Temperature } (^\circ C) = 825.232 - (354.044 \times \text{Load Ratio})$$

Therefore, at load ratios of 0.207 and 0.736 the predicted lower flange temperatures are 751.9 and 564.7°C respectively. These compare reasonably well with the observed values of 724 and 569°C.

5. CHANGES TO STANDARDS

It should be noted that in the period between the execution and reporting of these two fire resistance tests changes have been made concerning the following British Standards.

BS449 - 'The Use of Structural Steelwork in Building' has now been superseded by the limit state design approach given in BS5950 - 'Structural Use of Steel in Building'.

BS4360 : 1986 - 'Weldable Structural Steels' has now been replaced by En10 025 : 1990 and Grade 43A steel in the former document now becomes Grade Fe430A in the latter.

In order to avoid inconsistencies in the reporting of data the terminology which was current at the time the work was carried out, has been used in this report.

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3. L. Twilt et al, 'Behaviour of a Simply Supported Concrete Topped Beam and a Shelf Angled Beam Under Standard Fire Conditions' TNO-IBBC Report No. B-89-724, December 1989.

TABLE 1
CHEMICAL COMPOSITIONS OF THE STEEL SECTIONS USED IN THE FIRE RESISTANCE TESTS

BS Code	Section and Test Details	Chemical Composition (Product Analysis - Wt. %)														
		C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	N	Nb	Sn	Ti	V
9J 079 P	254 x 146 mm x 43 kg/m Universal Beam Test Date: 24/08/1989 Test I/D: WFRC 46738	0.16	0.08	0.80	0.023	0.020	0.04	0.008	0.06	<0.005	0.12	0.0083	<0.005	NA	NA	NA
9J 080 P	254 x 146 mm x 43 kg/m Universal Beam Test Date: 06/09/1989 Test I/D: WFRC 46734	0.16	0.08	0.80	0.024	0.021	0.04	0.008	0.06	<0.005	0.12	0.0083	<0.005	NA	NA	NA
	BS4360 : 1986 Grade 43A Product Analysis	0.30 max.	0.55 max.	1.70 max.	0.06 max.	0.06 max.										

NA = Element Not Analysed

TABLE 2
TENSILE TEST RESULTS FROM THE STEEL SECTIONS USED IN THE FIRE RESISTANCE TESTS

BS Code	Section and Test Details	Yield Stress (LYS) N/mm²	Tensile Strength N/mm²	Elongation %
9J 079 P	254 x 146 mm x 43 kg/m Universal Beam Test Date: 24/08/1989 Test I/D: WFRC 46738	305	473	32
9J 080 P	254 x 146 mm x 43 kg/m Universal Beam Test Date: 06/09/1989 Test I/D: WFRC 46734	307	472	31
	BS4360 : 1986 Grade 43A Specification	275 (min.)	430/580	22 (min.)

TABLE 3
SCHEDULE OF COMPONENTS
(REFER TO FIGS. 1 AND 10)

Reference Number	Description		
1	Steel Beam - Serial Size:	245 x 146 mm x 43 kg/m	
	Nominal Dimensions:	Depth	259.6 mm
		Breadth	147.3 mm
		Flange Thickness	12.7 mm
		Web Thickness	7.3 mm
		Root Radius	7.6 mm
2	Concrete Cover Slabs		
	Nominal Dimensions:	Width	650 mm
		Thickness	135 mm
		Length	4500 mm
3	Thin Gauge Mild Steel Ties		
4	Vicuclad Boards - 20 mm thick		
5	Steel Nails - 50 mm long		
6	Specimen Support Frame		
7	Steel Roller		
8	Blockwork Perimeter Wall		
9	Lagging to Ends of Beam		
10	Noggings Between Flanges - 25 mm wide (Held in position with Vicubond adhesive)		
11	Brickwork Furnace Lining		

TABLE 4
TEMPERATURE DATA RECORDED DURING TEST NO. WFRC 46738 ON AUGUST 24TH 1989
(LOAD RATIO = APPROXIMATELY 0.7)

Thermocouple Location		Temperature °C after Various Times (min)															
		0	2	4	6	8	10	12	15	18	21	24	27	30	35	40	45
Upper Flange	F3	24	24	24	30	39	47	54	64	80	92	97	103	111	124	140	159
	F5	24	24	24	28	37	45	53	63	76	90	99	99	105	121	139	159
	F8	25	24	25	31	40	49	57	70	85	96	104	113	126	151	177	200
	F9	25	25	26	34	42	47	53	66	86	101	101	120	128	153	177	202
Mean		25	24	25	31	40	47	54	66	82	95	100	109	118	137	158	180
Web	W1	25	25	25	31	44	55	64	77	94	109	128	148	169	206	245	283
	W2	25	25	25	32	44	55	64	78	93	110	132	154	174	208	243	277
	W3	25	25	26	35	48	57	64	78	93	115	132	152	172	204	236	269
	W4	25	25	25	30	40	51	60	74	91	103	127	150	170	206	242	279
Mean		25	25	25	32	44	55	63	77	93	109	130	151	171	206	242	277
Lower Flange	F1	24	24	25	31	43	55	67	85	99	102	110	130	157	202	246	288
	F2	24	24	25	32	44	55	66	83	95	102	118	141	167	212	257	299
	F4	24	24	25	30	42	53	64	82	93	100	107	127	152	197	241	284
	F6	25	25	25	31	43	55	67	84	96	100	112	137	164	210	254	297
	F7	25	25	25	33	44	54	64	79	93	101	109	134	159	203	246	288
Mean		24	24	25	31	43	54	66	83	95	101	111	134	160	205	249	291
Furnace Gas	A1	33	467	573	644	671	705	734	767	785	808	823	837	853	876	895	908
	A2	42	445	545	617	656	691	729	765	794	819	839	852	871	893	917	932
	A3	28	439	542	614	653	689	724	761	792	817	835	851	869	892	912	931
	A4	45	448	536	610	645	678	708	749	772	805	821	838	853	878	898	917
	A5	42	442	551	624	663	697	724	764	787	823	835	854	867	895	915	930
	A6	52	431	513	602	630	663	688	729	757	782	800	823	838	862	880	898
Mean		40	445	543	619	653	687	718	756	781	809	826	843	859	883	903	919
Standard Curve (20°C)		20	445	544	603	645	678	705	739	766	789	809	826	842	865	885	902

(Cont...)

TABLE 4
(CONTINUED)

Thermocouple Location		Temperature °C after Various Times (min)															
		50	55	60	65	70	75	80	85	90	92	95	100	105	110	115	120
Upper Flange	F3	178	199	220	242	265	288	309	333	354	363	376	396	415	435	455	476
	F5	179	201	222	244	266	290	313	336	360	370	383	404	425	446	466	487
	F8	222	245	268	290	312	333	353	375	398	409	427	456	484	510	535	560
	F9	226	250	274	297	320	343	365	383	398	406	417	438	459	479	499	519
Mean		201	224	246	268	291	314	335	357	378	387	401	424	446	468	489	511
Web	W1	318	351	381	409	436	460	482	503	523	531	542	560	578	595	611	627
	W2	311	343	373	401	427	453	476	499	522	531	544	563	582	600	617	635
	W3	302	334	365	395	420	446	471	496	521	532	547	573	596	617	637	655
	W4	314	347	379	408	436	461	484	505	523	531	542	560	578	595	611	627
Mean		311	344	375	403	430	455	478	501	522	531	544	564	584	602	619	636
Lower Flange	F1	328	365	399	431	460	487	511	534	556	564	576	593	611	626	642	657
	F2	339	376	410	442	470	496	520	543	565	576	594	621	645	666	686	704
	F4	324	362	396	427	456	483	507	531	552	561	573	590	608	624	641	657
	F6	337	374	408	439	468	494	518	541	562	571	583	602	620	636	653	669
	F7	327	365	402	436	466	493	517	540	563	573	588	612	635	655	674	692
Mean		331	368	403	435	464	491	515	538	560	569	583	604	624	641	659	676
Furnace Gas	A1	927	948	959	959	979	987	997	1005	1016	1015	1023	1042	1037	1045	1052	1059
	A2	945	962	977	985	991	1006	1013	1024	1033	1035	1038	1050	1055	1064	1070	1076
	A3	947	965	977	984	991	1005	1015	1025	1035	1036	1040	1051	1056	1064	1072	1077
	A4	930	944	959	968	977	991	996	1012	1015	1021	1022	1033	1041	1048	1058	1063
	A5	944	961	972	979	990	1003	1014	1024	1032	1034	1039	1046	1053	1061	1069	1076
	A6	918	930	942	956	967	972	989	1000	1009	1007	1015	1022	1033	1038	1050	1060
Mean		935	952	964	972	983	994	1004	1015	1023	1025	1030	1041	1046	1053	1062	1069
Standard Curve (20°C)		918	932	945	957	968	979	988	997	1006	1009	1014	1022	1029	1036	1043	1049

TABLE 5
MID-SPAN VERTICAL TEMPERATURE PROFILE DATA RECORDED DURING TEST NO. WFRC 46738 ON AUGUST 24TH 1989 (LOAD RATIO = APPROXIMATELY 0.7)

Thermocouple Location		Temperature °C after Various Times (min)															
		0	2	4	6	8	10	12	15	18	21	24	27	30	35	40	45
Web																	
10 mm from UF	W5	25	25	25	32	44	52	60	73	89	100	113	124	137	163	190	215
30 mm from UF	W6	25	25	26	35	47	55	62	75	90	103	125	139	154	182	211	239
50 mm from UF	W7	25	25	25	36	50	58	65	78	94	112	132	149	166	196	227	258
Mid-Height	W8	25	25	25	32	46	57	66	79	94	114	136	157	178	214	250	286
50 mm from LF	W9	25	25	25	30	42	54	65	80	96	111	129	151	175	216	257	297
30 mm from LF	W10	25	25	25	29	40	52	64	79	94	106	121	144	169	212	255	296
10 mm from LF	W11	25	25	25	29	39	52	63	80	94	103	115	139	165	210	254	296

Thermocouple Location		Temperature °C after Various Times (min)															
		50	55	60	65	70	75	80	85	90	92	95	100	105	110	115	120
Web																	
10 mm from UF	W5	240	264	288	311	333	355	375	397	420	432	451	481	508	533	559	583
30 mm from UF	W6	266	291	317	341	364	386	407	429	451	465	485	515	542	567	591	615
50 mm from UF	W7	287	314	341	366	390	413	434	455	477	492	514	543	569	593	616	639
Mid-Height	W8	320	352	381	409	435	459	480	500	526	541	565	593	617	638	659	679
50 mm from LF	W9	335	371	403	433	461	486	508	530	557	571	591	619	643	664	683	701
30 mm from LF	W10	335	371	405	436	463	489	512	534	559	572	590	617	642	662	682	700
10 mm from LF	W11	336	373	407	439	467	493	517	539	564	576	594	622	647	668	687	705

TABLE 6

MID-SPAN VERTICAL DEFLECTION OF THE BEAM RECORDED DURING TEST NO. WFRC 46738 ON AUGUST 24TH 1989 (LOAD RATIO = APPROXIMATELY 0.7)

Time Min	Deflection mm	Deflection Rate mm/min	Time Min	Deflection mm	Deflection Rate mm/min	Time Min	Deflection mm	Deflection Rate mm/min
0	0	-	32	10	1	64	45	1
1	0	0	33	10	0	65	46	1
2	1	1	34	11	1	66	47	1
3	1	0	35	12	1	67	48	1
4	1	0	36	13	1	68	49	1
5	1	0	37	13	0	69	50	1
6	1	0	38	14	1	70	52	2
7	1	0	39	15	1	71	53	1
8	2	1	40	17	2	72	54	1
9	2	0	41	18	1	73	55	1
10	2	0	42	20	2	74	57	2
11	2	0	43	23	3	75	59	2
12	3	1	44	25	2	76	60	1
13	3	0	45	28	3	77	62	2
14	3	0	46	30	2	78	64	2
15	3	0	47	31	1	79	66	2
16	4	1	48	32	1	80	69	3
17	4	0	49	34	2	81	71	2
18	4	0	50	34	0	82	74	3
19	3	-1	51	35	1	83	77	3
20	3	0	52	36	1	84	81	4
21	3	0	53	37	1	85	85	4
22	3	0	54	37	0	86	89	4
23	3	0	55	38	1	87	95	6
24	3	0	56	39	1	88	101	6
25	4	1	57	40	1	89	108	7
26	5	1	58	40	0	90	117	9 (*)
27	6	1	59	41	1	91	127	10
28	6	0	60	42	1	92	140	13
29	7	1	61	43	1	93	156	16
30	8	1	62	43	0			
31	9	1	63	44	1			

(*) Limiting Rate of Deflection Exceeded
Deflection of 150 mm at 92 min and 43 s

TABLE 7
TEMPERATURE DATA RECORDED DURING TEST NO. WFRC 46734 ON SEPTEMBER 6TH 1989
(LOAD RATIO = APPROXIMATELY 0.2)

Thermocouple Location		Temperature °C after Various Times (min.)															
		0	2	4	6	8	10	12	15	18	21	24	27	30	35	40	45
Upper Flange	F3	25	24	25	29	34	41	49	58	70	84	94	94	103	124	144	167
	F5	24	24	25	26	30	38	47	57	69	85	96	96	102	116	133	151
	F8	24	24	25	27	33	42	53	64	75	89	99	102	119	157	179	205
	F9	26	25	26	27	32	39	49	60	73	91	100	100	112	128	151	171
Mean		25	24	25	27	32	40	50	60	72	87	97	98	109	131	152	174
Web	W1	26	26	27	30	38	48	59	70	84	98	119	141	161	200	240	279
	W2	25	25	26	28	35	45	57	69	82	94	109	129	149	180	211	244
	W3	25	25	25	28	34	44	56	69	81	95	107	123	142	173	204	238
	W4	26	26	26	27	33	43	56	68	83	96	106	128	148	180	212	246
Mean		26	26	26	28	35	45	57	69	83	96	110	130	150	183	217	252
Lower Flange	F1	26	26	27	30	38	49	61	77	90	99	102	109	132	176	217	258
	F2	25	25	26	28	36	47	61	76	88	98	111	126	150	213	237	279
	F4	25	25	25	27	34	46	59	77	91	100	102	106	124	167	212	254
	F6	26	25	26	29	36	46	59	75	90	99	109	123	144	185	224	264
	F7	25	25	25	29	36	47	59	75	89	98	106	116	135	173	214	255
Mean		25	25	26	29	36	47	60	76	90	99	106	116	137	183	221	262
Furnace Gas	A1	47	366	550	543	645	679	702	706	769	805	808	810	767	855	862	895
	A2	74	371	540	537	651	684	718	714	795	816	839	847	787	867	904	923
	A3	56	354	547	534	650	686	717	710	790	815	830	836	783	871	887	920
	A4	86	401	569	565	669	694	718	720	797	819	828	864	795	866	917	931
	A5	79	385	583	578	671	699	727	726	789	838	823	864	796	881	911	942
	A6	89	395	538	549	637	656	685	684	759	776	795	822	769	823	891	897
Mean		72	379	555	551	654	683	711	710	783	812	821	841	783	861	895	918
Standard Curve (20°C)		20	445	544	603	645	678	705	739	766	789	809	826	842	865	885	902

(Cont...)

TABLE 7
(CONTINUED)

Thermocouple Location		Temperature °C after Various Times (min.)															
		50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
Upper Flange	F3	190	213	236	259	282	305	328	351	373	393	414	434	453	471	490	509
	F5	170	189	209	230	253	275	298	320	343	365	385	406	425	443	462	480
	F8	233	258	284	309	333	356	378	400	422	442	461	480	498	515	532	548
	F9	194	216	239	261	283	306	327	347	368	388	407	426	443	461	480	496
Mean		197	219	242	265	288	311	333	355	377	397	417	437	455	473	491	508
Web	W1	318	356	392	425	454	480	505	527	549	570	587	604	620	637	653	668
	W2	278	310	341	370	397	423	448	471	493	514	532	550	567	584	600	616
	W3	273	308	341	372	400	427	452	476	500	521	540	558	575	591	607	622
	W4	280	313	344	374	401	426	450	473	494	515	533	550	567	583	599	614
Mean		287	322	355	385	413	439	464	487	509	530	548	566	582	599	615	630
Lower Flange	F1	299	338	374	408	439	468	495	519	541	562	579	596	612	627	642	655
	F2	320	358	392	424	454	481	506	529	551	570	588	604	619	633	647	660
	F4	296	334	370	404	434	463	489	513	536	557	574	591	606	620	635	648
	F6	304	342	377	409	439	467	493	516	538	558	576	593	607	622	637	651
	F7	296	335	371	405	436	465	492	517	540	561	580	597	612	627	642	655
Mean		303	341	377	410	440	469	495	519	541	562	579	596	611	626	641	654
Furnace Gas	A1	902	929	956	962	955	978	981	996	1016	1012	1018	1012	1026	1031	1037	1039
	A2	935	954	967	975	987	1008	1012	1025	1032	1036	1034	1036	1051	1052	1058	1069
	A3	936	949	972	984	989	983	1013	1020	1035	1038	1046	1033	1052	1060	1062	1066
	A4	943	959	965	970	1005	1014	1032	1036	1048	1045	1056	1051	1063	1073	1071	1085
	A5	945	963	976	984	1007	1017	1029	1039	1050	1047	1054	1052	1063	1069	1068	1078
	A6	915	933	928	931	973	994	1007	1013	1019	1013	1021	1024	1034	1037	1039	1057
Mean		929	948	961	968	986	999	1012	1022	1033	1032	1038	1035	1048	1054	1056	1066
Standard Curve (20°C)		918	932	945	957	968	979	988	997	1006	1014	1022	1029	1036	1043	1049	1055

(Cont...)

TABLE 7
(CONTINUED)

Thermocouple Location		Temperature °C after Various Times (min.)						
		130	135	140	145	150	152	156
Upper Flange	F3	526	544	562	582	601	609	623
	F5	497	516	533	551	567	574	586
	F8	564	580	594	606	617	623	633
	F9	513	530	546	561	572	577	587
Mean		525	543	559	575	589	596	607
Web	W1	683	698	713	729	739	744	757
	W2	632	648	662	676	688	694	704
	W3	636	651	665	678	690	696	705
	W4	628	643	656	669	681	686	694
Mean		645	660	674	688	700	705	715
Lower Flange	F1	669	683	696	710	723	728	735
	F2	673	687	700	713	725	730	737
	F4	661	675	687	700	712	718	727
	F6	664	679	692	705	716	721	730
	F7	668	682	695	708	720	725	732
Mean		667	681	694	707	719	724	732
Furnace Gas	A1	1064	1051	1059	1067	1078	1075	1068
	A2	1069	1086	1086	1098	1102	1092	1090
	A3	1074	1082	1114	1103	1169	1127	1129
	A4	1080	1100	1103	1111	1114	1099	1102
	A5	1088	1092	1096	1106	1120	1111	1118
	A6	1049	1070	1072	1077	1076	1072	1075
Mean		1071	1080	1088	1094	1110	1096	1097
Standard Curve (20°C)		1061	1067	1072	1077	1082	1084	1088

TABLE 8
MID-SPAN VERTICAL TEMPERATURE PROFILE DATA RECORDED DURING TEST NO. WFRC 46734 ON SEPTEMBER 6TH 1989 (LOAD RATIO = APPROXIMATELY 0.2)

Thermocouple Location		Temperature °C after Various Times (min)															
		0	2	4	6	8	10	12	15	18	21	24	27	30	35	40	45
Web																	
10 mm from UF	W5	25	25	26	31	40	51	60	68	80	94	107	121	134	162	190	218
30 mm from UF	W6	25	25	26	30	39	50	60	69	80	93	108	130	144	172	204	233
50 mm from UF	W7	25	25	26	30	38	49	60	70	82	94	109	131	148	176	209	240
Mid-Height	W8	25	25	26	29	37	48	60	71	84	100	121	143	163	195	232	267
50 mm from LF	W9	26	26	26	29	36	46	58	71	84	103	123	144	162	202	240	279
30 mm from LF	W10	26	25	26	28	34	44	57	71	85	98	114	131	153	194	234	273
10 mm from LF	W11	25	24	25	27	33	43	56	72	86	96	107	121	144	188	228	269

Thermocouple Location		Temperature °C after Various Times (min)															
		50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
Web																	
10 mm from UF	W5	245	272	299	325	350	374	397	420	441	462	481	500	517	534	550	566
30 mm from UF	W6	263	291	319	346	372	396	420	443	465	486	504	523	539	556	572	587
50 mm from UF	W7	272	302	332	360	387	412	437	460	482	503	521	540	556	572	588	603
Mid-Height	W8	303	336	368	398	426	451	476	498	520	540	557	574	590	605	620	633
50 mm from LF	W9	317	352	385	416	444	471	495	517	538	558	575	592	607	621	636	649
30 mm from LF	W10	313	350	384	416	445	472	497	520	541	561	579	595	610	625	639	652
10 mm from LF	W11	309	347	383	416	446	474	500	523	545	565	583	600	615	629	644	657

(Cont...)

TABLE 8
(CONTINUED)

Thermocouple Location		Temperature °C after Various Times (min)						
		130	135	140	145	150	152	156
Web								
10 mm from UF	W5	581	597	612	626	637	643	653
30 mm from UF	W6	602	618	632	646	658	663	674
50 mm from UF	W7	618	633	647	661	673	678	688
Mid-Height	W8	647	662	676	688	700	705	714
50 mm from LF	W9	662	676	689	702	714	719	727
30 mm from LF	W10	666	680	693	706	717	723	731
10 mm from LF	W11	670	684	697	710	722	727	734

TABLE 9

MID-SPAN VERTICAL DEFLECTION OF THE BEAM RECORDED DURING TEST NO. WFRC 46734 ON SEPTEMBER 6TH 1989 (LOAD RATIO = APPROXIMATELY 0.2)

Time Min	Deflection mm	Time Min	Deflection mm	Deflection Rate mm/min	Time Min	Deflection mm	Deflection Rate mm/min
0	0	121	40	1	146	116	5
5	1	122	41	1	147	121	5
10	2	123	42	1	148	127	6
15	3	124	43	1	149	132	5
20	3	125	44	1	150	138	6
25	2	126	45	1	151	144	6
30	3	127	47	2	152	150	6
35	6	128	49	2	153	157	7
40	9	129	50	1	154	163	6
45	11	130	52	2	155	170	7
50	14	131	54	2	156	178	8
55	17	132	57	3			
60	19	133	60	3			
65	21	134	63	3			
70	22	135	65	2			
75	23	136	69	4			
80	24	137	72	3			
85	25	138	77	5			
90	26	139	82	5			
95	27	140	86	4			
100	28	141	91	5			
105	30	142	96	5			
110	32	143	101	5			
115	35	144	106	5			
120	39	145	111	5			

TABLE 10
BS5950:PART 8:1990 TABLE 5

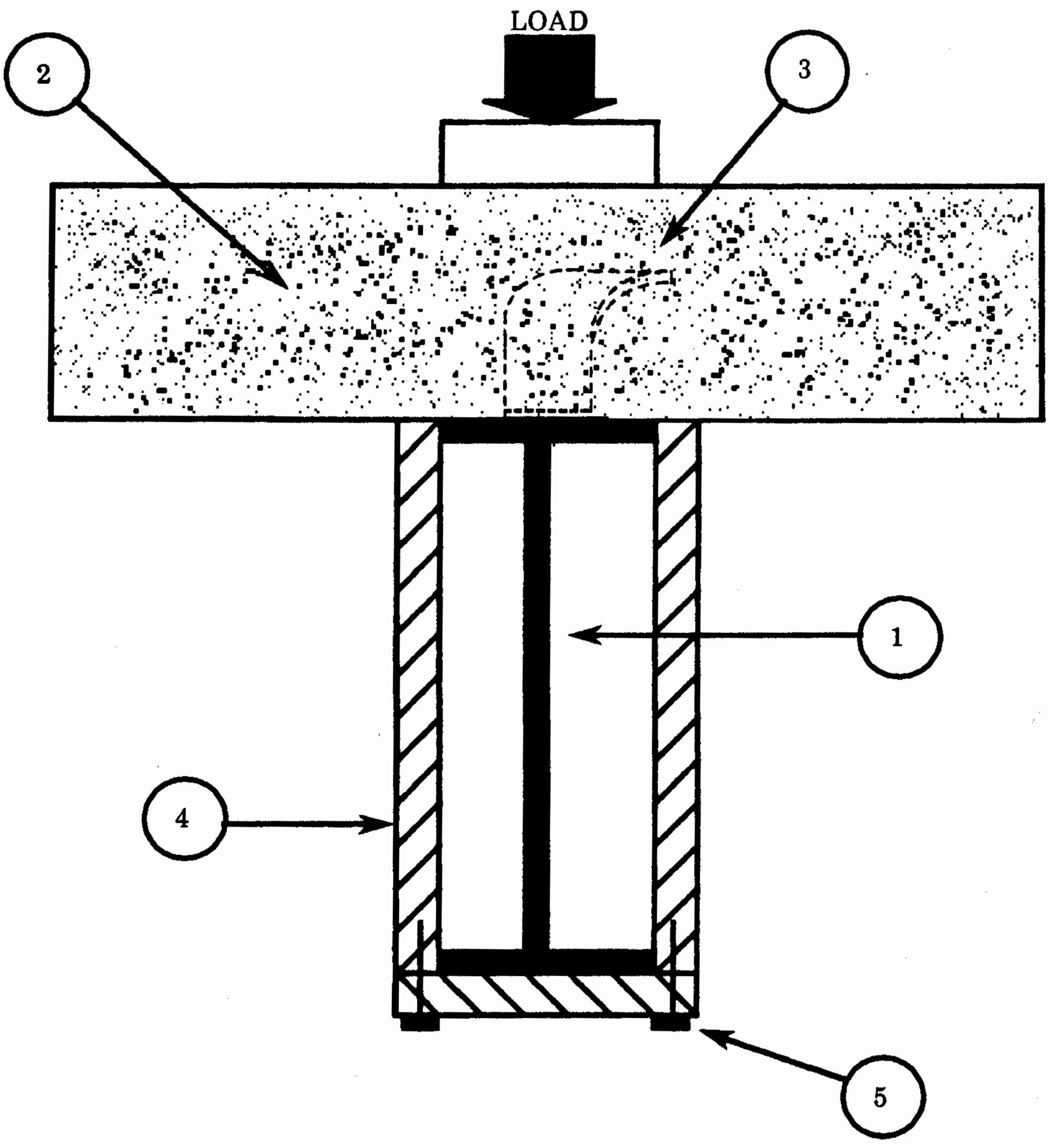
Table 5. Limiting temperatures for design of protected and unprotected hot finished members

Description of Member	Limiting Temperature, °C at a Load Ratio of:					
	0.7	0.6	0.5	0.4	0.3	0.2
Members in compression, for a slenderness λ (see note)						
≤70	510	540	580	615	655	710
>70 but ≤180	460	510	545	590	635	635
Members in bending supporting concrete slabs or composite slabs:						
unprotected members, or protected members complying with item (a) or (b) of 2.3	590	620	650	680	725	780
other protected members	540	585	625	655	700	745
Members in bending not supporting concrete slabs:						
unprotected members, or protected members complying with item (a) or (b) of 2.3	520	555	585	620	660	715
other protected members	460	510	545	590	635	690
Members in tension:						
all cases	460	510	545	590	635	690

Note. λ is the slenderness, i.e. the effective length divided by the radius of gyration

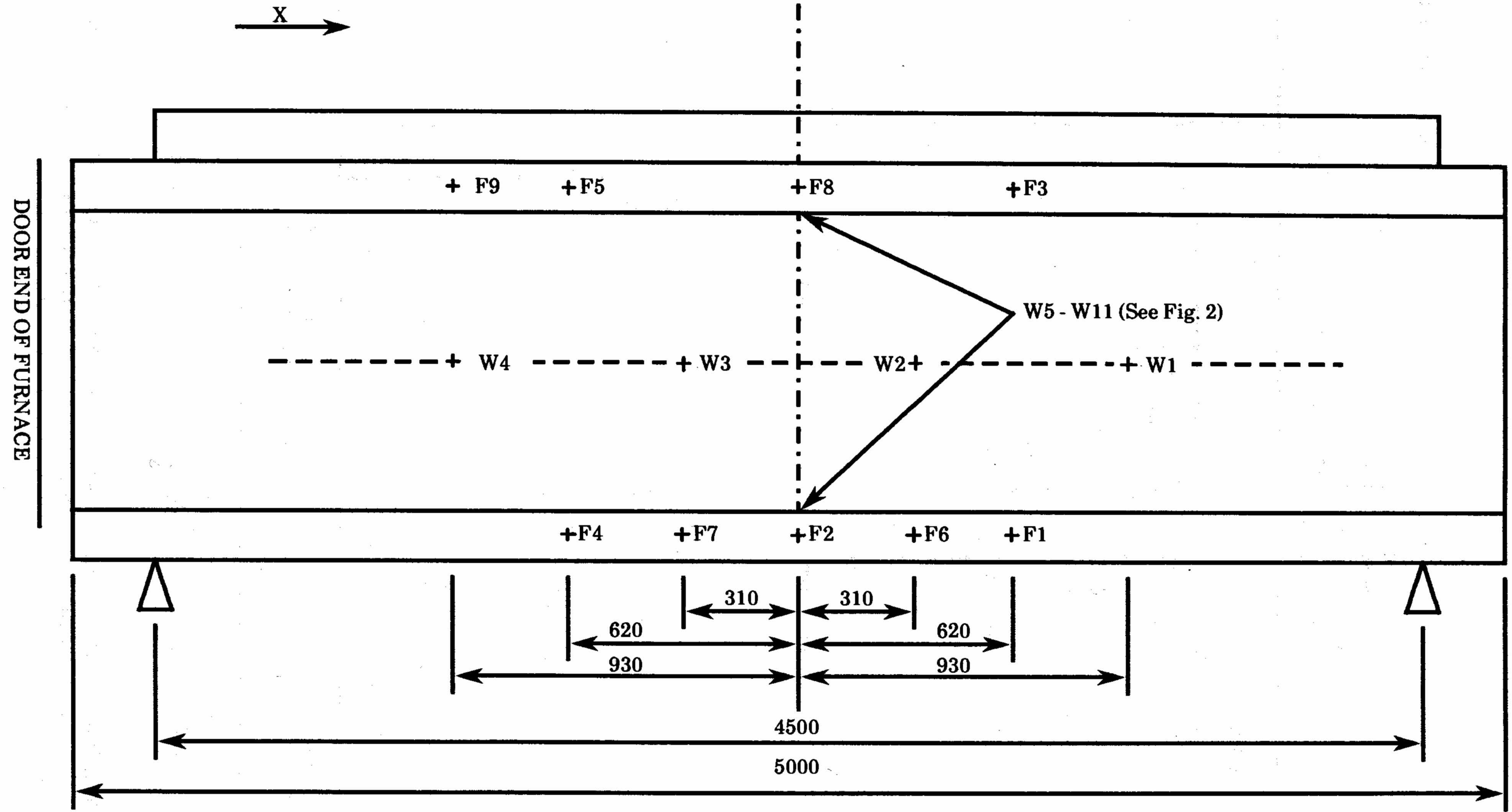
TABLE 11
SUMMARY OF TEST DATA FOR SIMPLY SUPPORTED, UNPROTECTED, STEEL BEAMS OF SERIAL SIZE 254 x 146 mm x 43 kg/m

Test Data Sheet No. (Ref. 1)	Load Ratio	Lower Flange Temperature at Span/30 °C	Upper Flange Temperature at Span/30 °C
1	0.456	682	535
2	0.498	660	423
3	0.587	634	423
4	0.360	701	519
10	0.489	655	431
11	0.501	683	456
13	0.397	716	516
14	0.247	745	536
TNO-IBBC 05/10/89	0.493	629	383



TRANSVERSE SECTION THROUGH THE PROTECTED BEAM ASSEMBLY FIG. 1
SEE TABLE 3 FOR SCHEDULE OF COMPONENTS

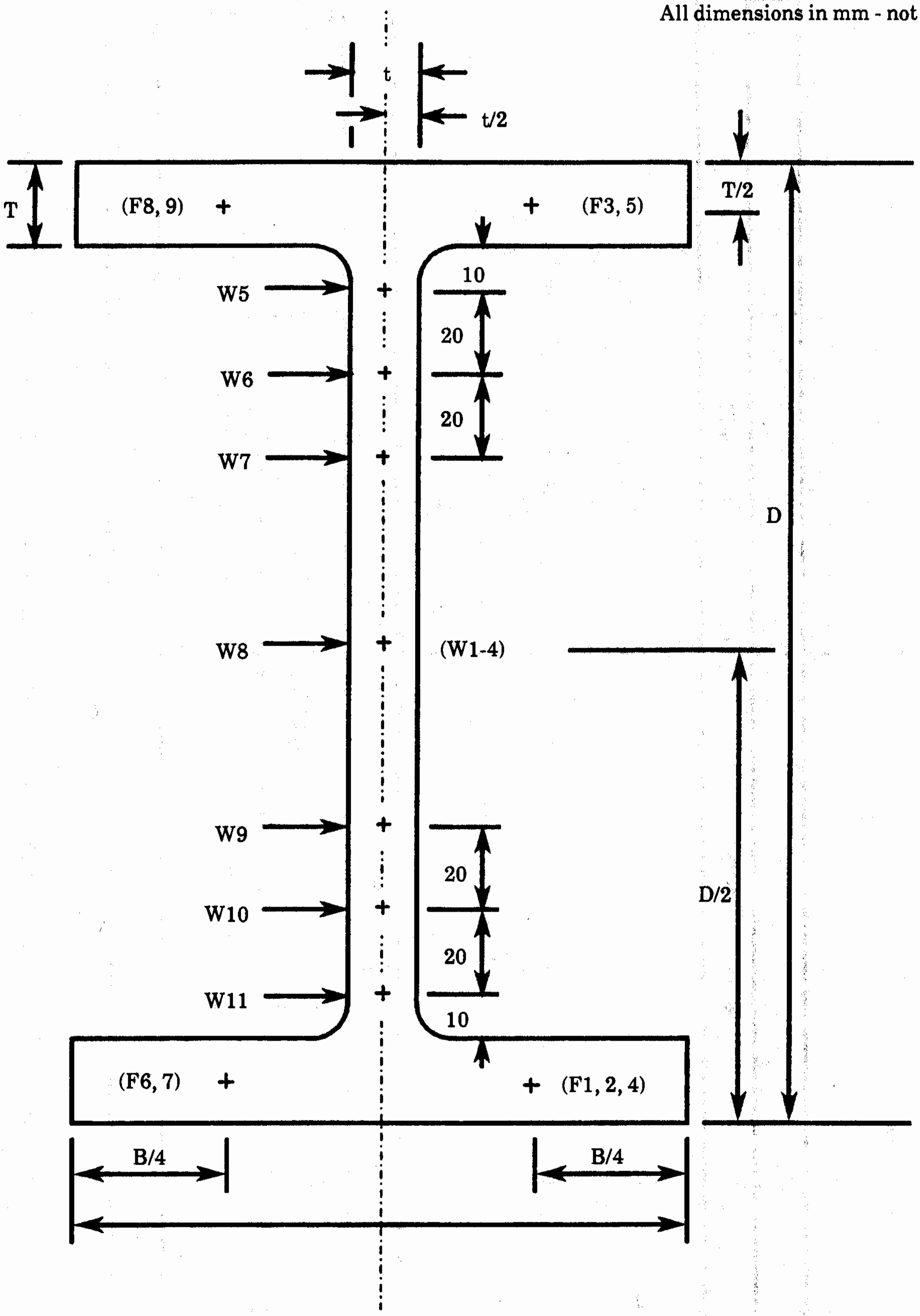
All dimensions in mm - not to scale



THERMOCOUPLE LOCATIONS FOR PROTECTED FLOOR BEAM TESTS - LONGITUDINAL SECTION FIG. 2

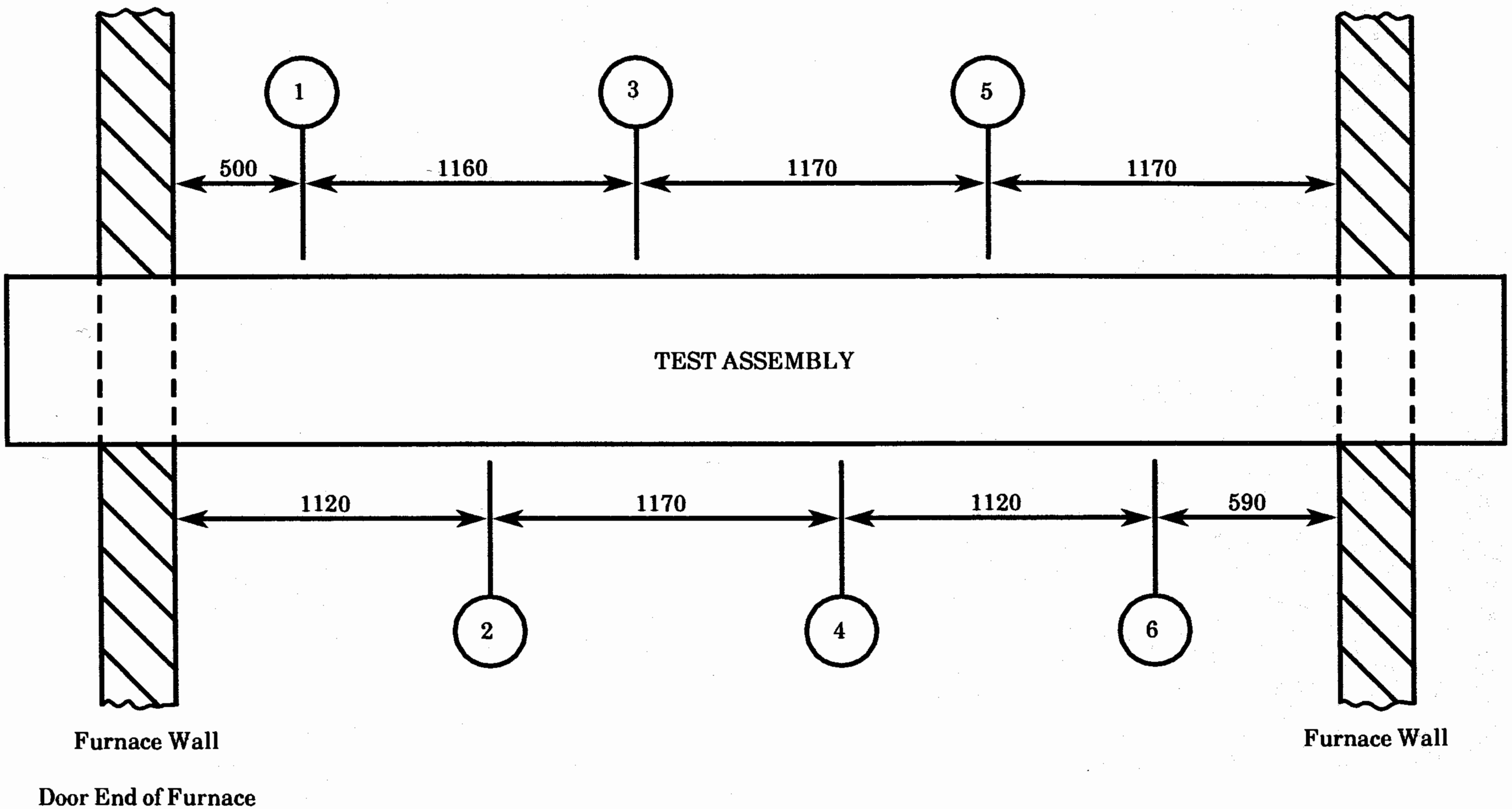
R3/8385

All dimensions in mm - not to scale

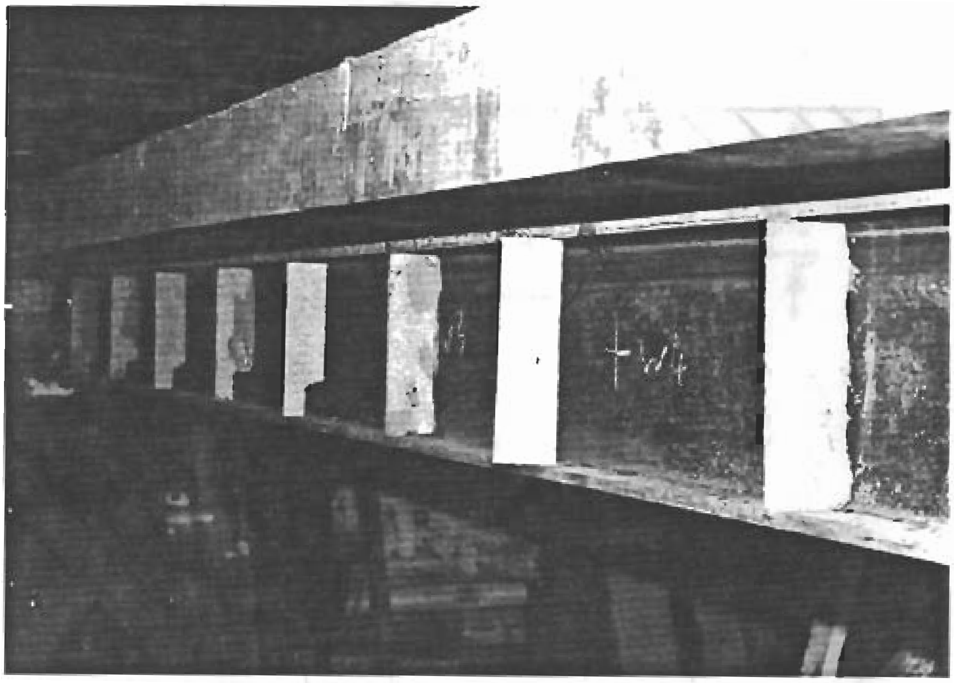


THERMOCOUPLE LOCATIONS FOR PROTECTED FLOOR BEAM TESTS TRANSVERSE SECTION IN DIRECTION OF ARROW 'x' IN FIG. 2 **FIG. 3**

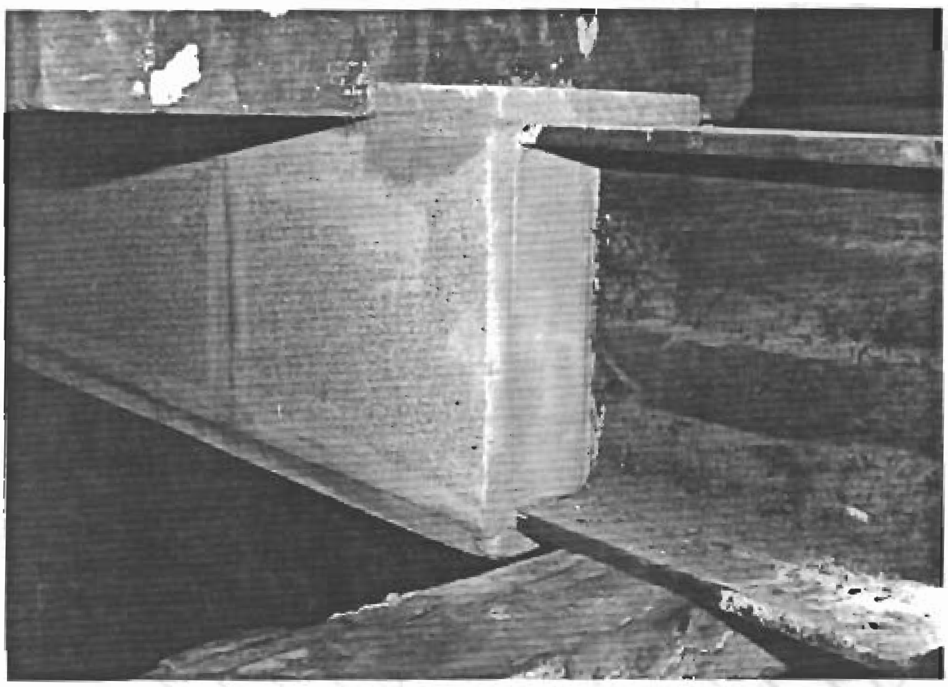
All dimensions in mm - not to scale



POSITION OF THE FURNACE ATMOSPHERE THERMOCOUPLES FIG. 4

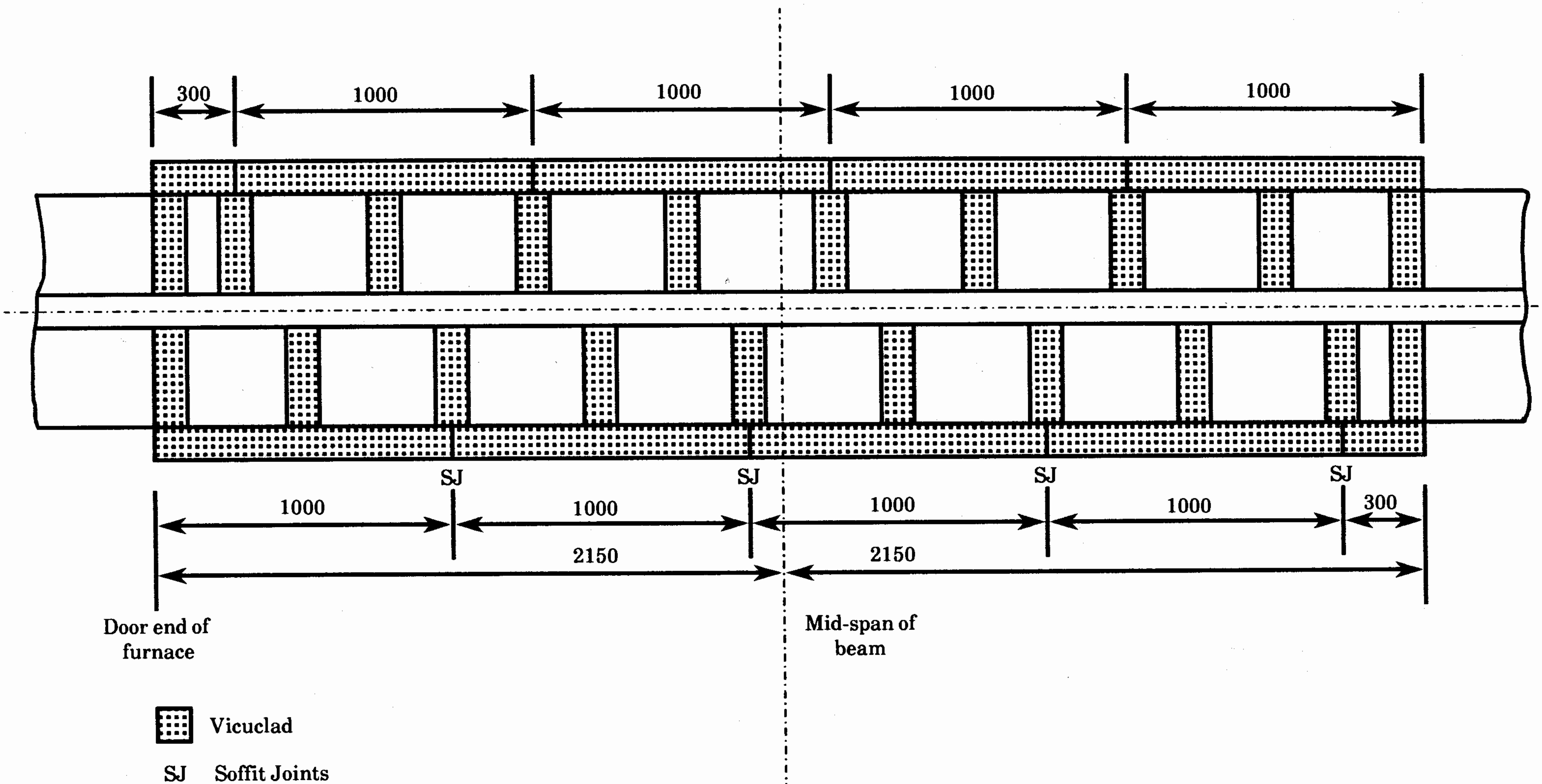


BEAM IN COURSE OF PREPARATION SHOWING NOGGINGS BETWEEN THE FLANGES **FIG. 5**



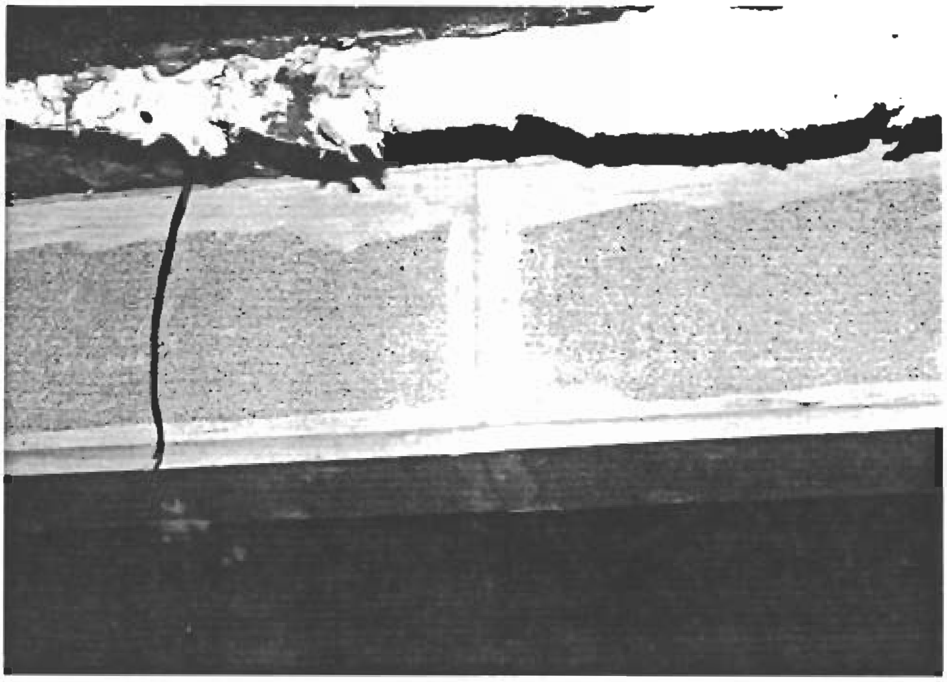
END DETAIL OF VICUCLAD PROTECTED BEAM **FIG. 6**

All dimensions in mm - not to scale



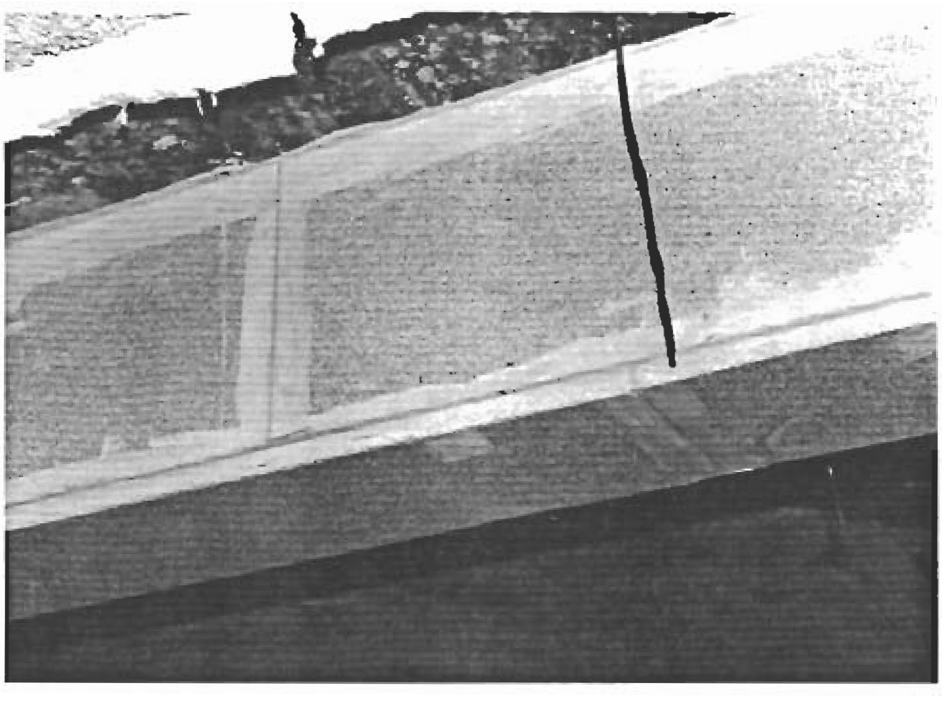
PLAN VIEW SHOWING RELATIVE POSITIONS OF THE VICUCLAD PANELS AND NOGGINGS FIG. 7

R3/8388



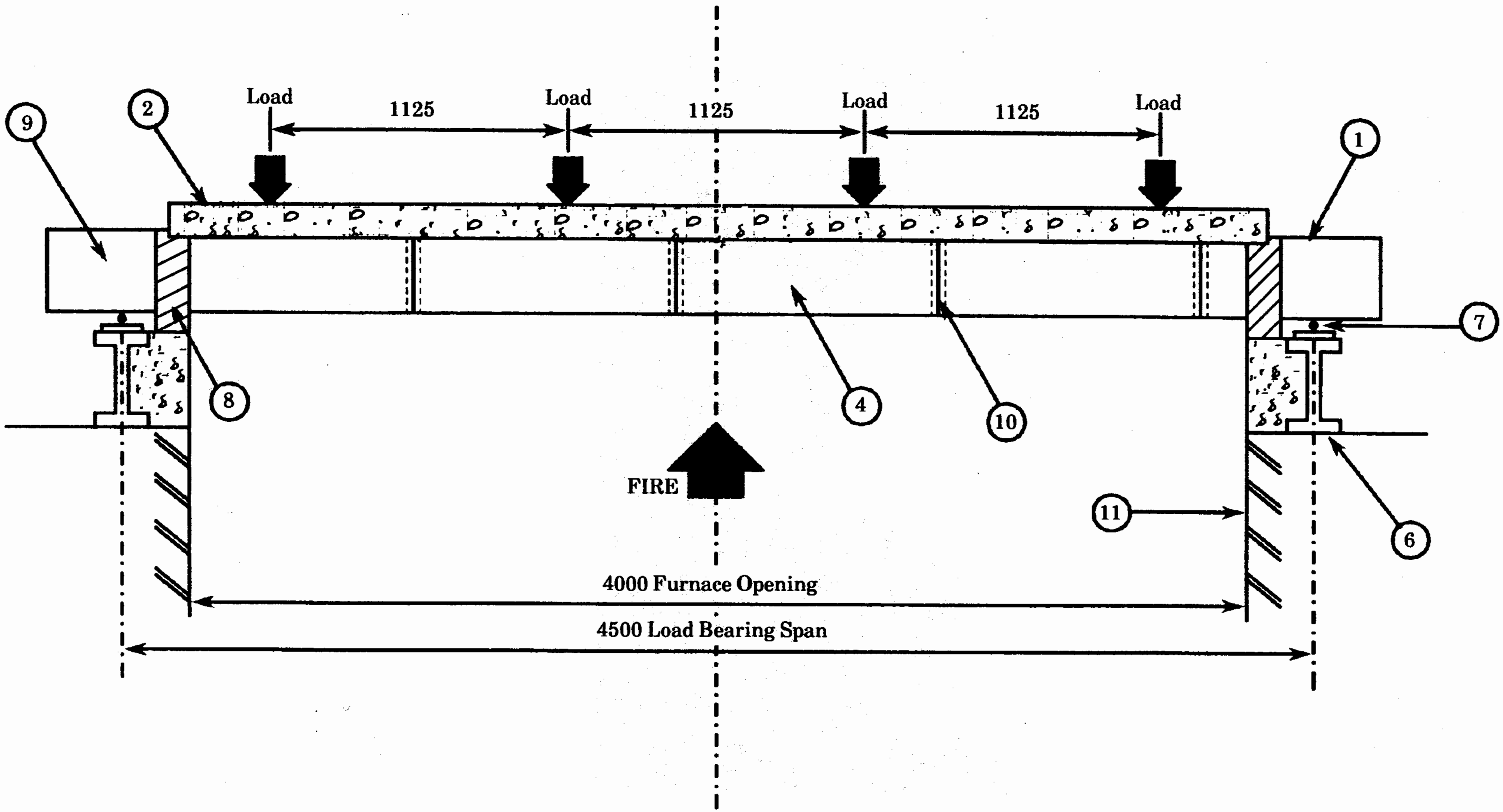
VICUCLAD PANELS ON THE RIGHT HAND SIDE OF THE TEST ASSEMBLY

FIG. 8



VICUCLAD PANELS ON THE LEFT HAND SIDE OF THE TEST ASSEMBLY

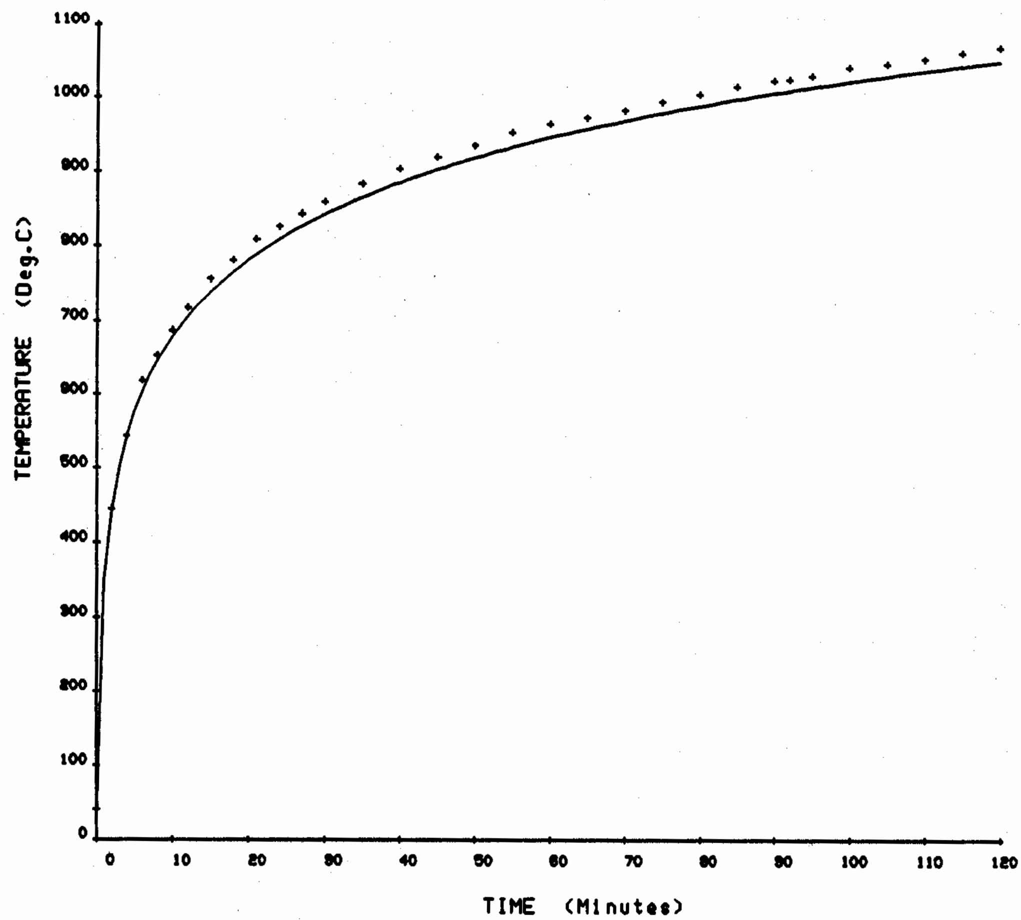
FIG. 9



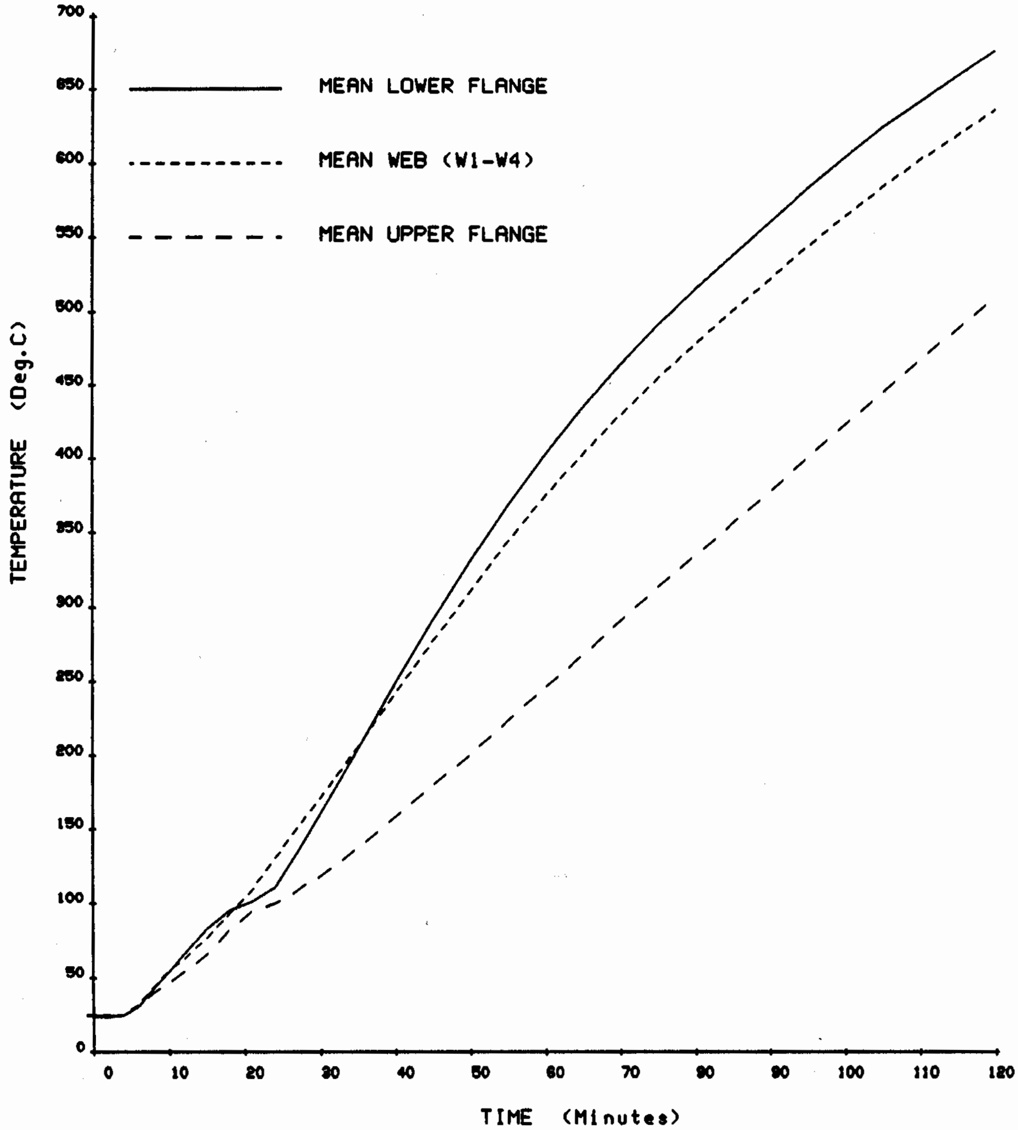
GENERAL ARRANGEMENT SHOWING PROTECTED BEAM MOUNTED IN THE TEST FURNACE FIG. 10

PROTECTED BEAM ASSEMBLY IMMEDIATELY PRIOR TO TESTING

FIG. 11

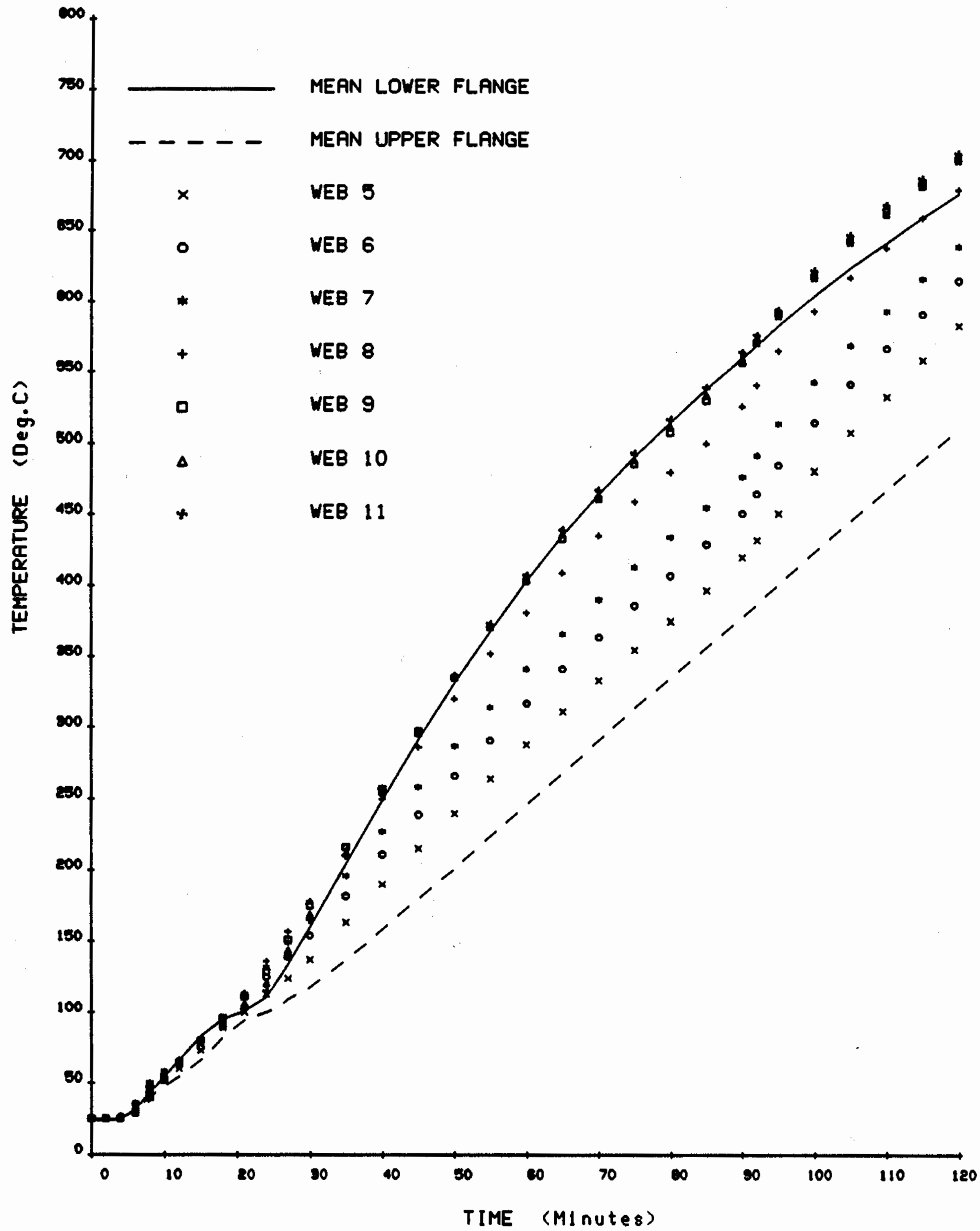


COMPARISON OF AVERAGE FURNACE ATMOSPHERE TEMPERATURE AND THE STANDARD TEMPERATURE/TIME CURVE TEST NO. WFRC 46738 ON 24/08/1989 **FIG. 12**

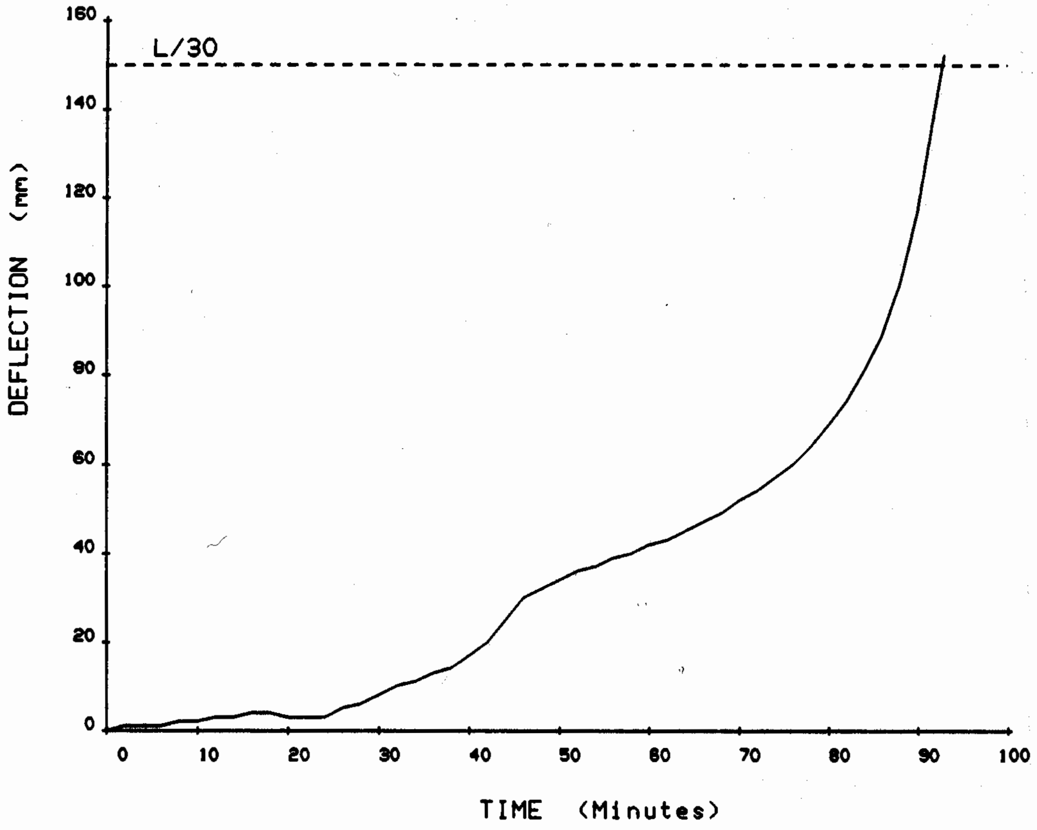


STEELWORK HEATING RATES RECORDED OVER THE CENTRAL 2 m PORTION OF THE BEAM TEST NO. WFRC 46738 ON 24/08/1989

FIG. 13

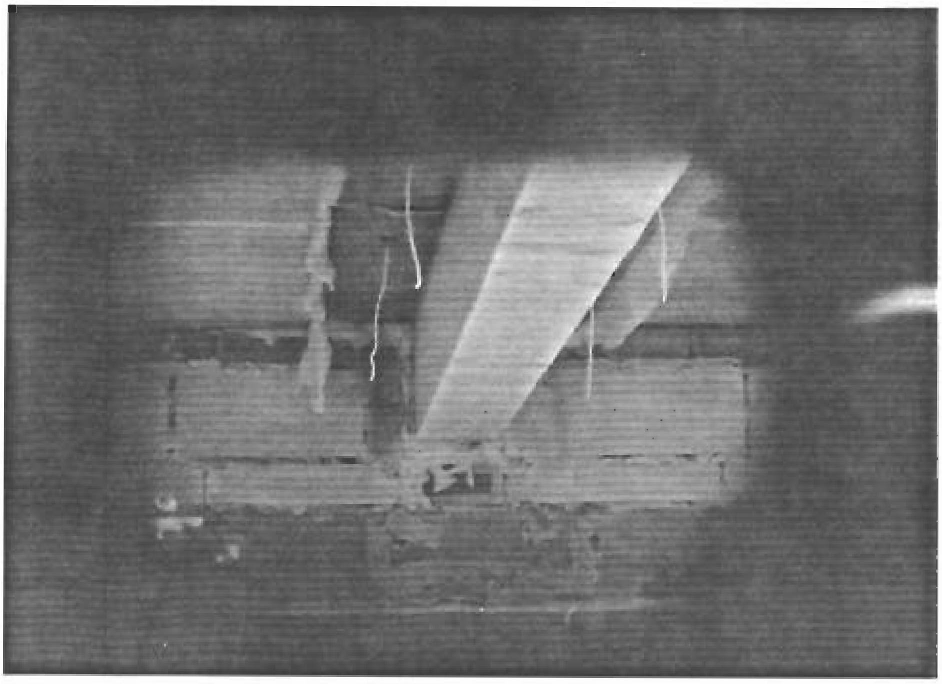


MID-SPAN VERTICAL TEMPERATURE PROFILE RECORDED DURING TEST NO. WFRC 46738 ON 24/08/1989 **FIG. 14**



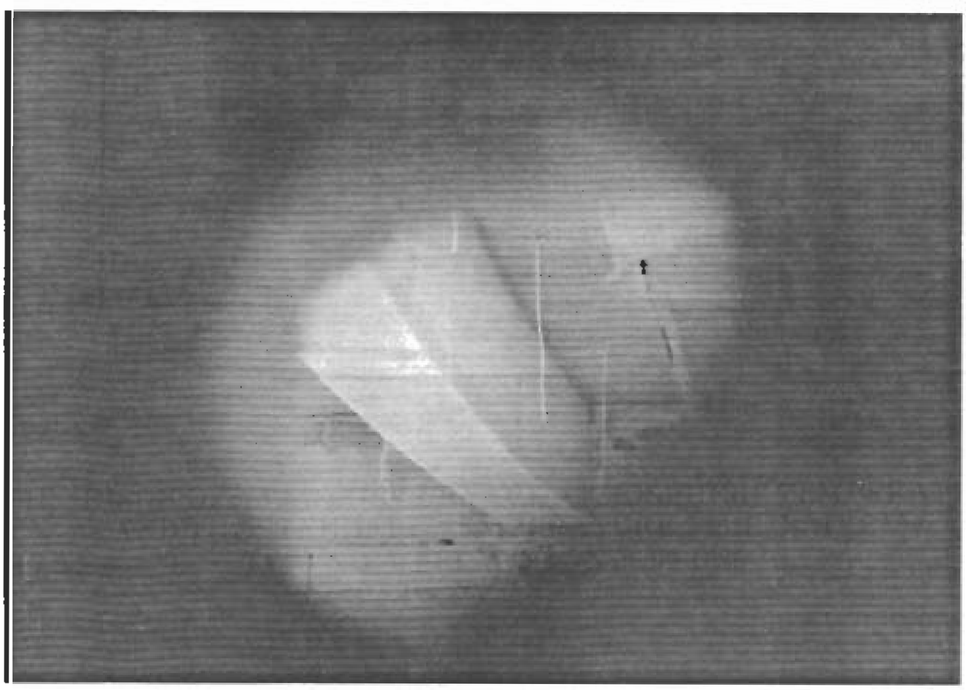
MID-SPAN VERTICAL DEFLECTION OF THE BEAM RECORDED DURING TEST NO. WFRC 46738 ON 24/08/1989

FIG. 15



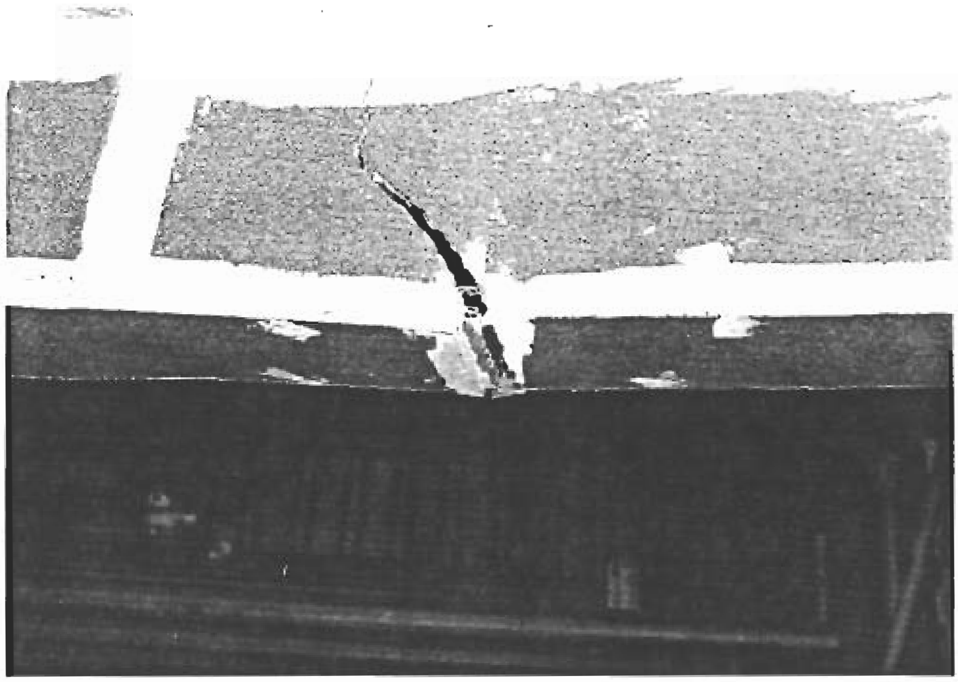
Test No. WFRC 46738

ASSEMBLY 25 min AFTER COMMENCEMENT OF THE TEST **FIG. 16**



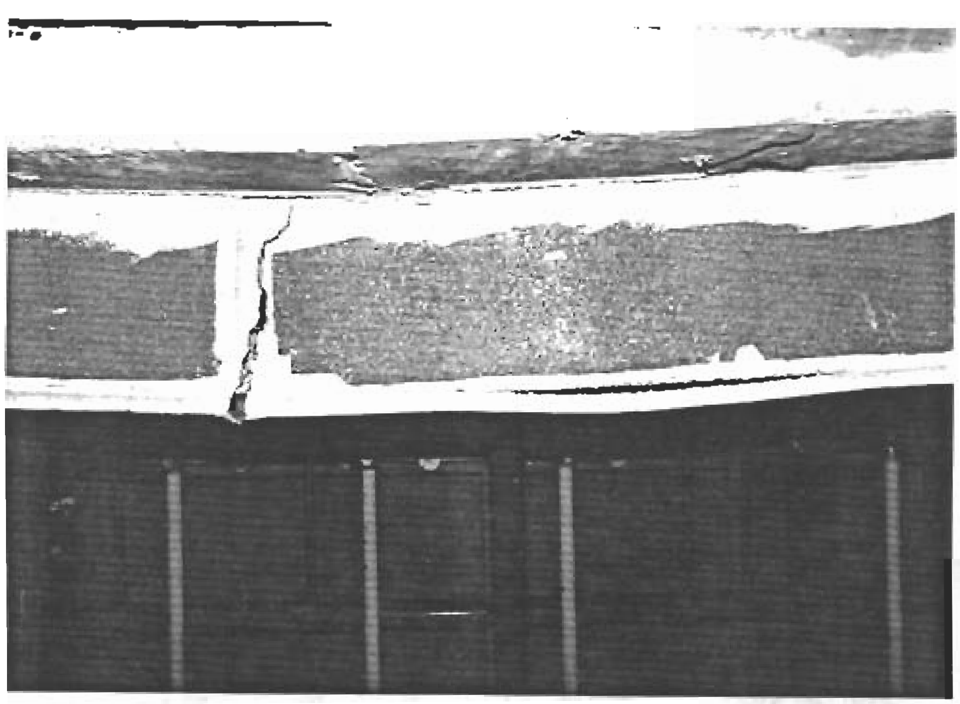
Test No. WFRC 46738

ASSEMBLY 80 min AFTER COMMENCEMENT OF THE TEST **FIG. 17**



Test No. WFRC 46738

LEFT HAND SIDE/SOFFIT OF ASSEMBLY SUBSEQUENT TO THE TEST **FIG. 18**

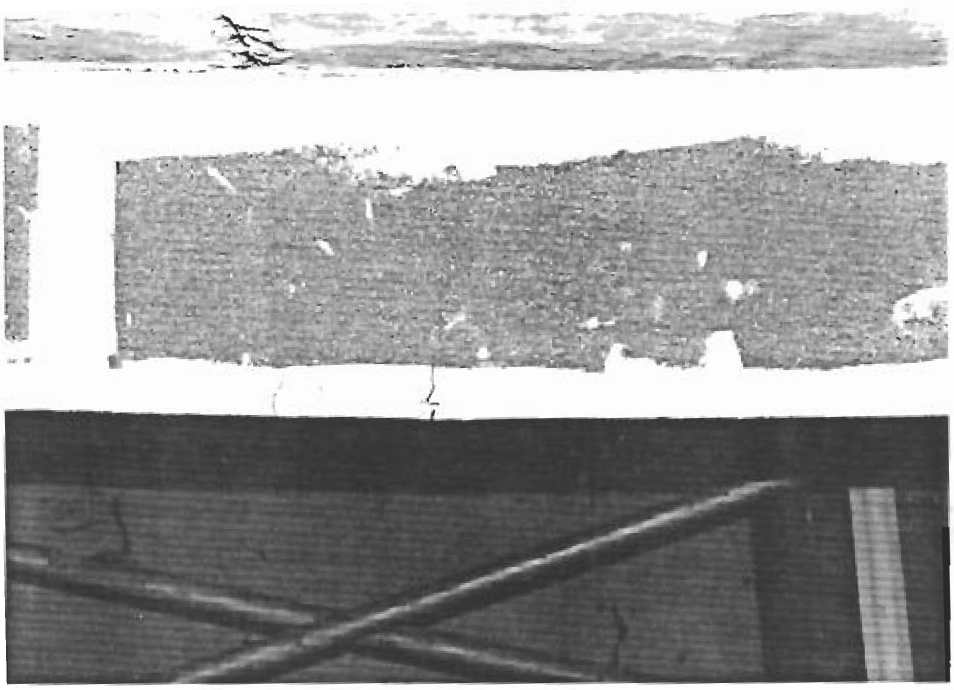


Test No. WFRC 46738

RIGHT HAND SIDE OF ASSEMBLY SUBSEQUENT TO THE TEST **FIG. 19**

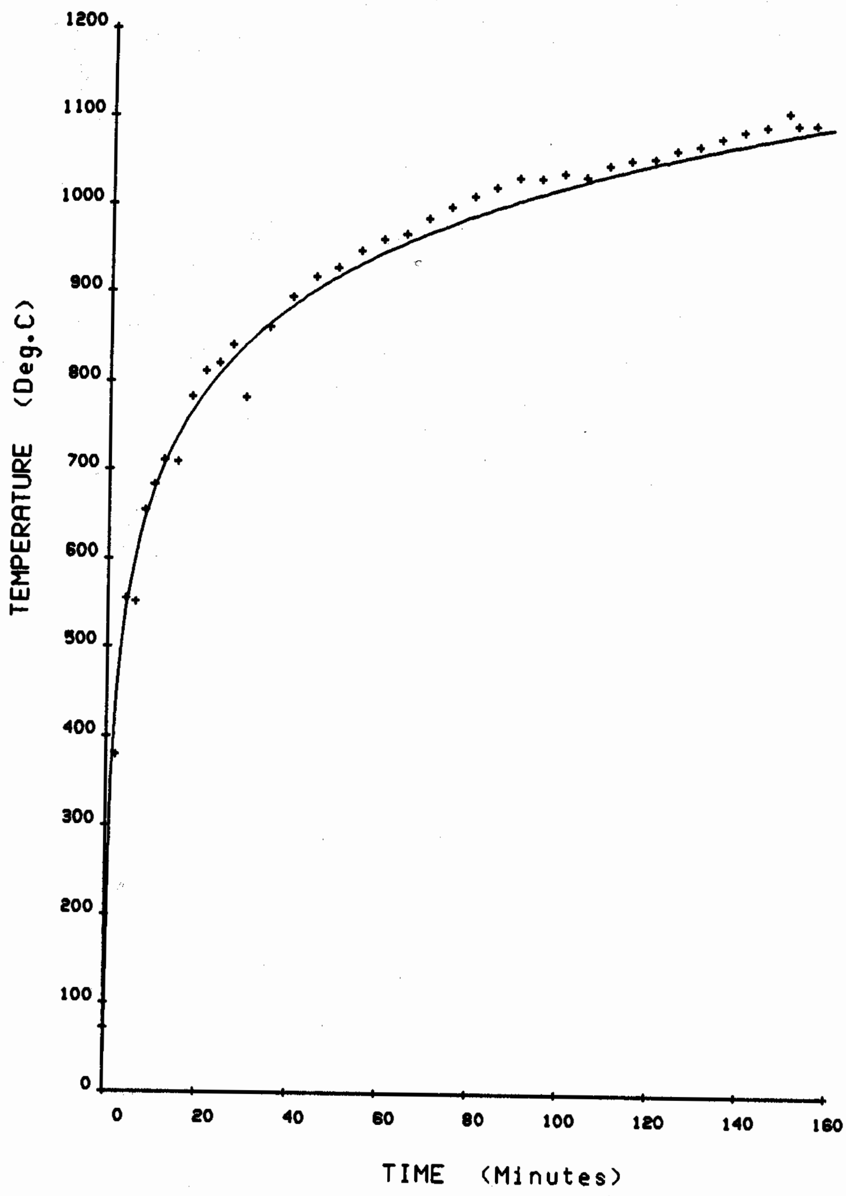
Test No. WFRC 46738

NECKING DOWN OF THE LOWER FLANGE **FIG. 20**

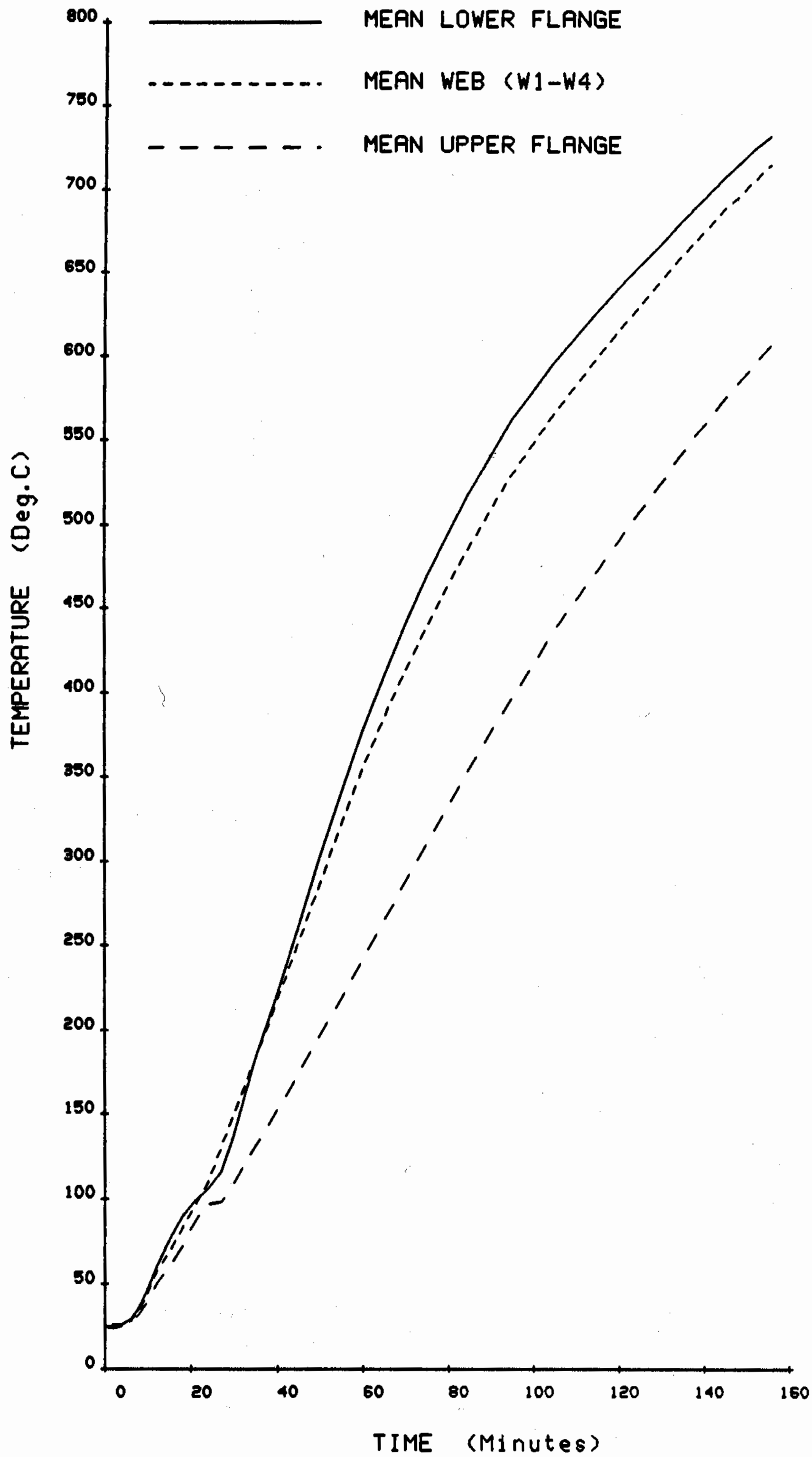


Test No. WFRC 46738

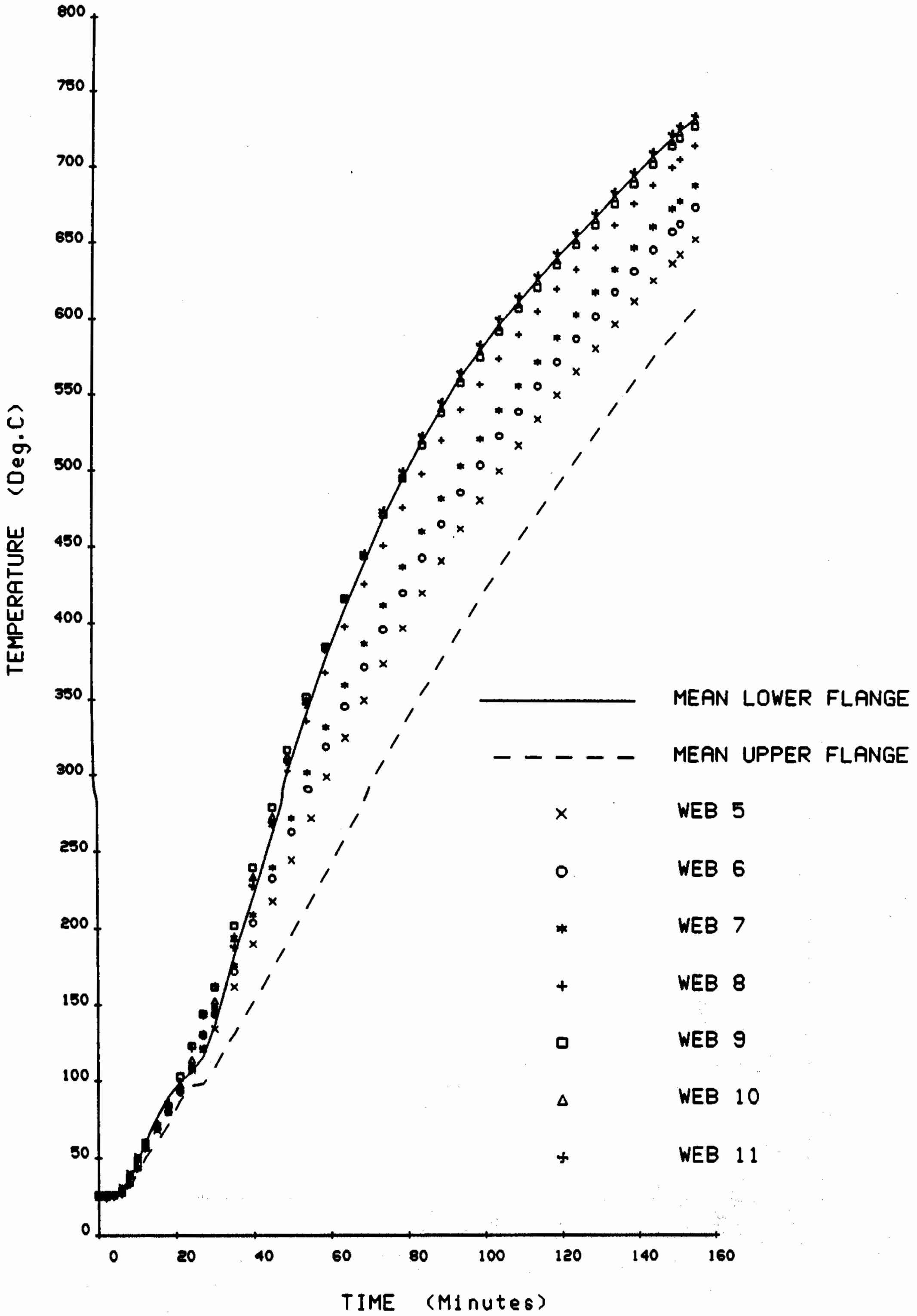
TYPICAL CRACKING IN THE VICUCLAD BOARD MATERIAL **FIG. 21**



COMPARISON OF AVERAGE FURNACE ATMOSPHERE TEMPERATURE AND THE STANDARD TEMPERATURE/TIME CURVE TEST NO. WFRC 46734 ON 06/09/1989 **FIG. 22**

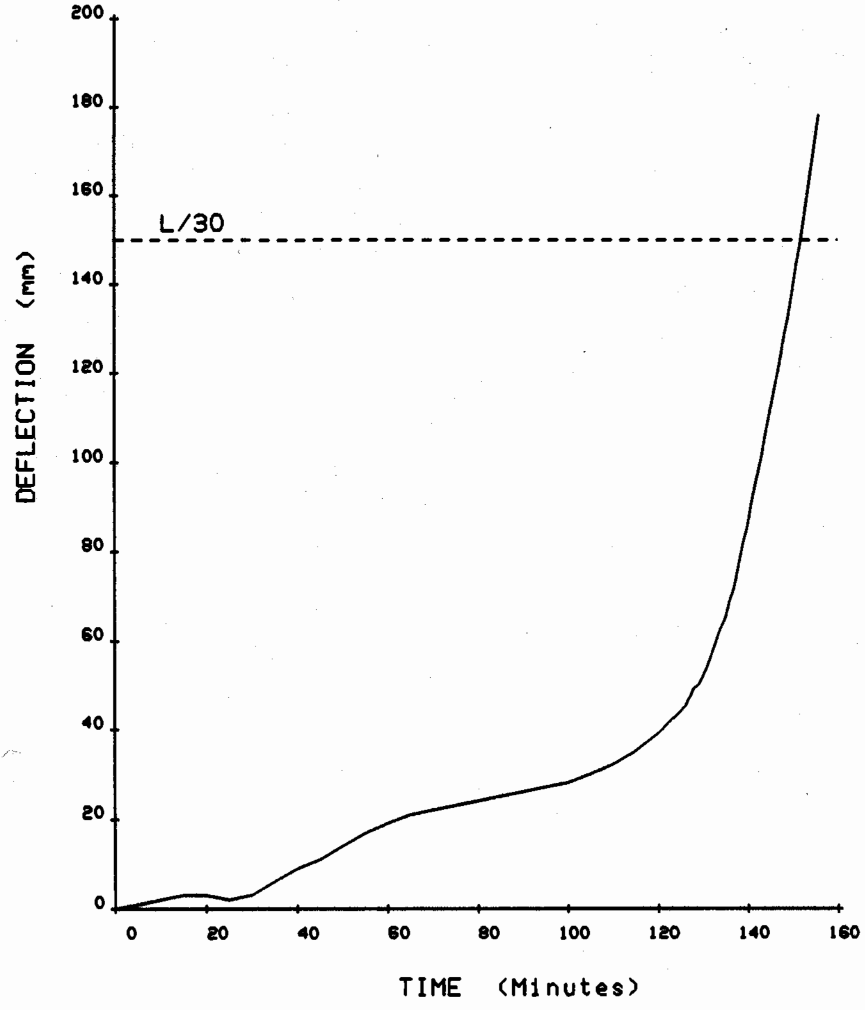


STEELWORK HEATING RATES RECORDED OVER THE CENTRAL 2 m PORTION OF THE BEAM TEST NO. WFRC 46734 ON 06/09/1989 **FIG. 23**

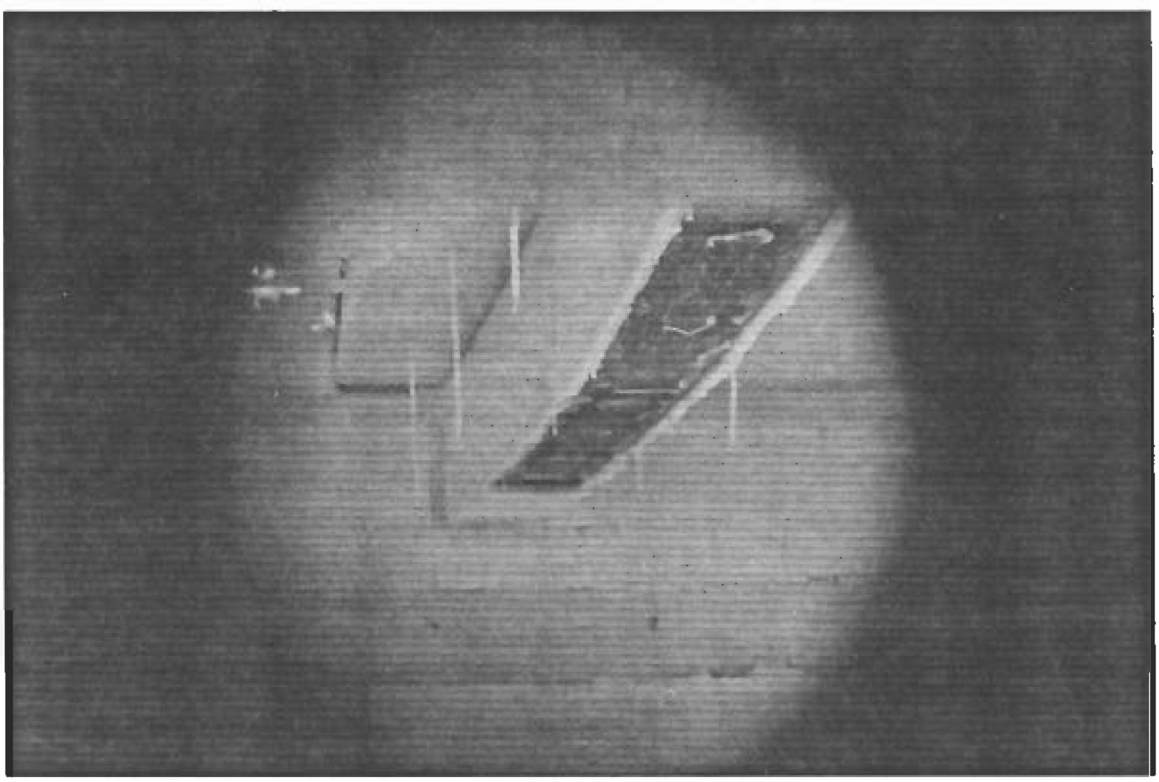


MID-SPAN VERTICAL TEMPERATURE PROFILE RECORDED DURING TEST NO. WFRC 46734 ON 06/09/1989

FIG. 24

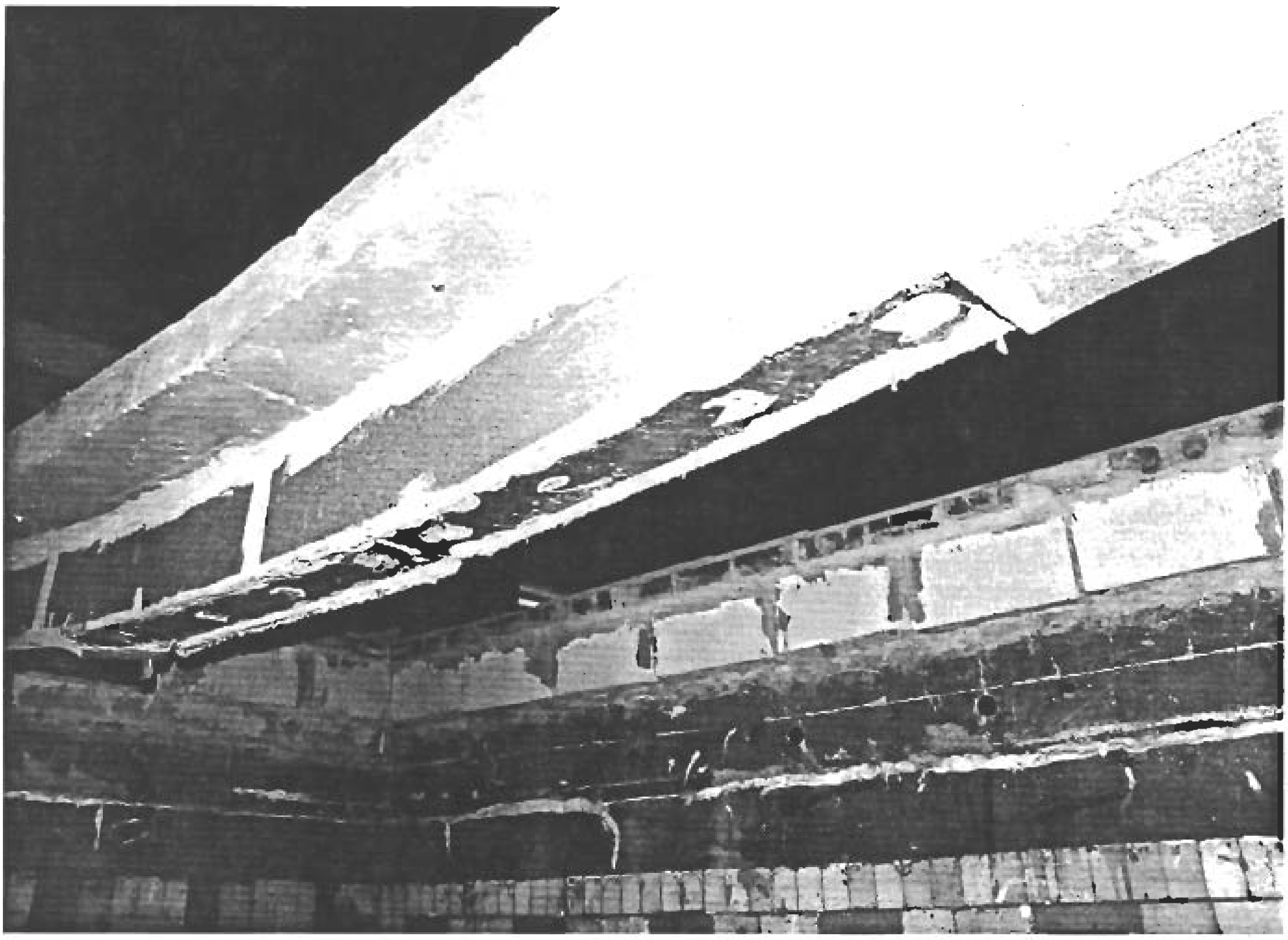


MID-SPAN VERTICAL DEFLECTION OF THE BEAM RECORDED DURING TEST NO. WFRC 46734 ON 06/09/1989 **FIG. 25**

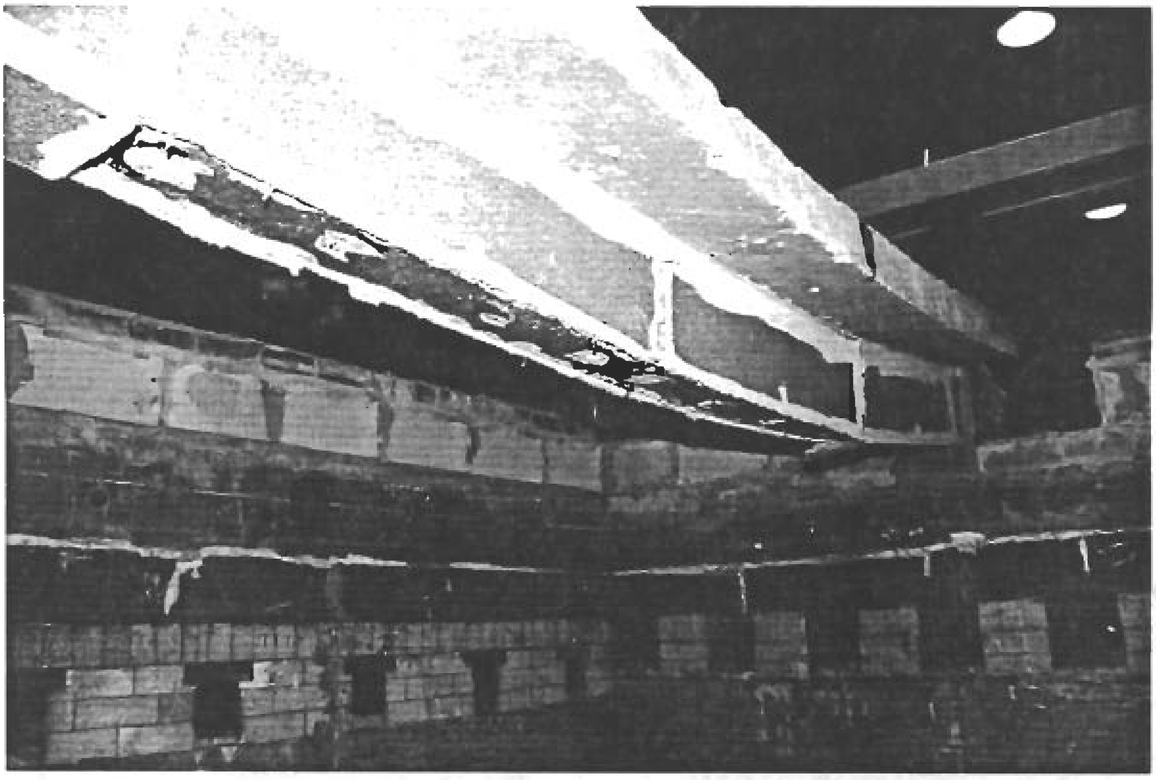


Test No. WFRC 46734

ASSEMBLY 156 min AFTER COMMENCEMENT OF THE TEST **FIG. 26**

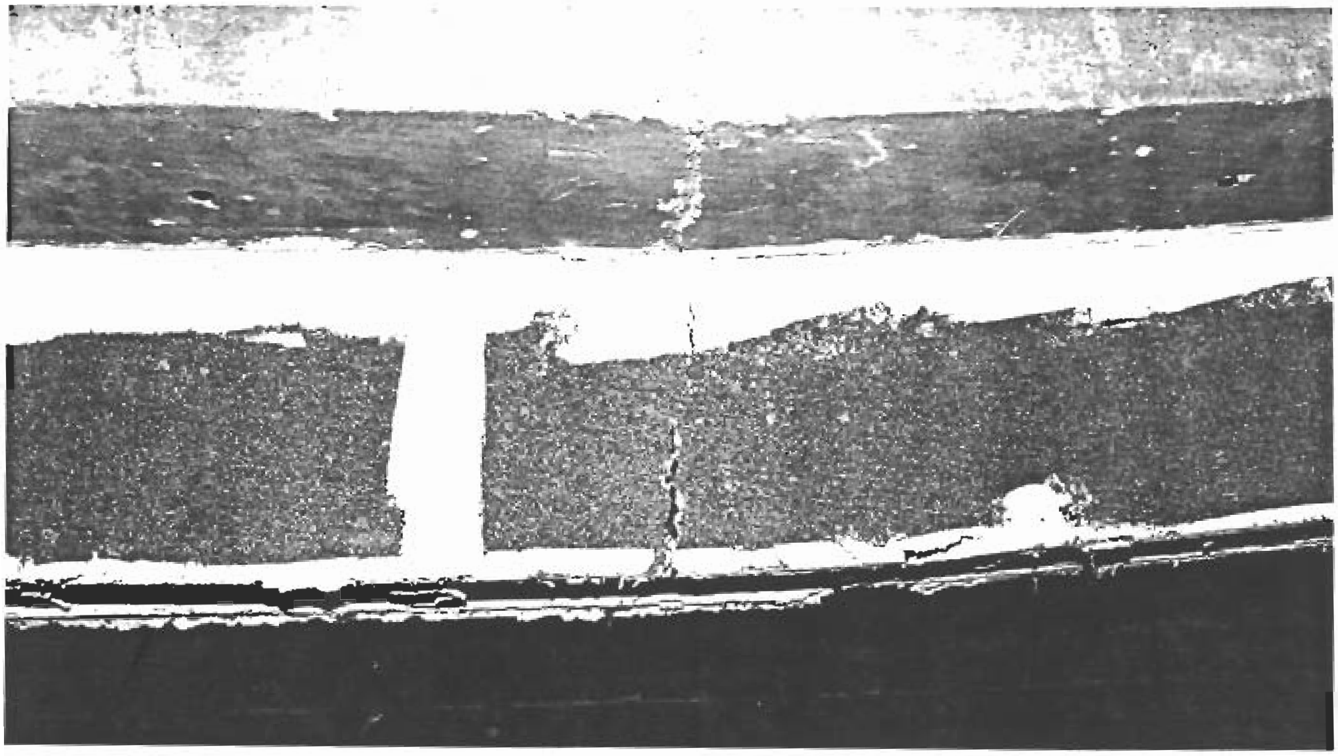


EXPOSED LOWER FLANGE OF ASSEMBLY SUBSEQUENT TO THE TEST (VIEWED FROM LEFT HAND SIDE) FIG. 27



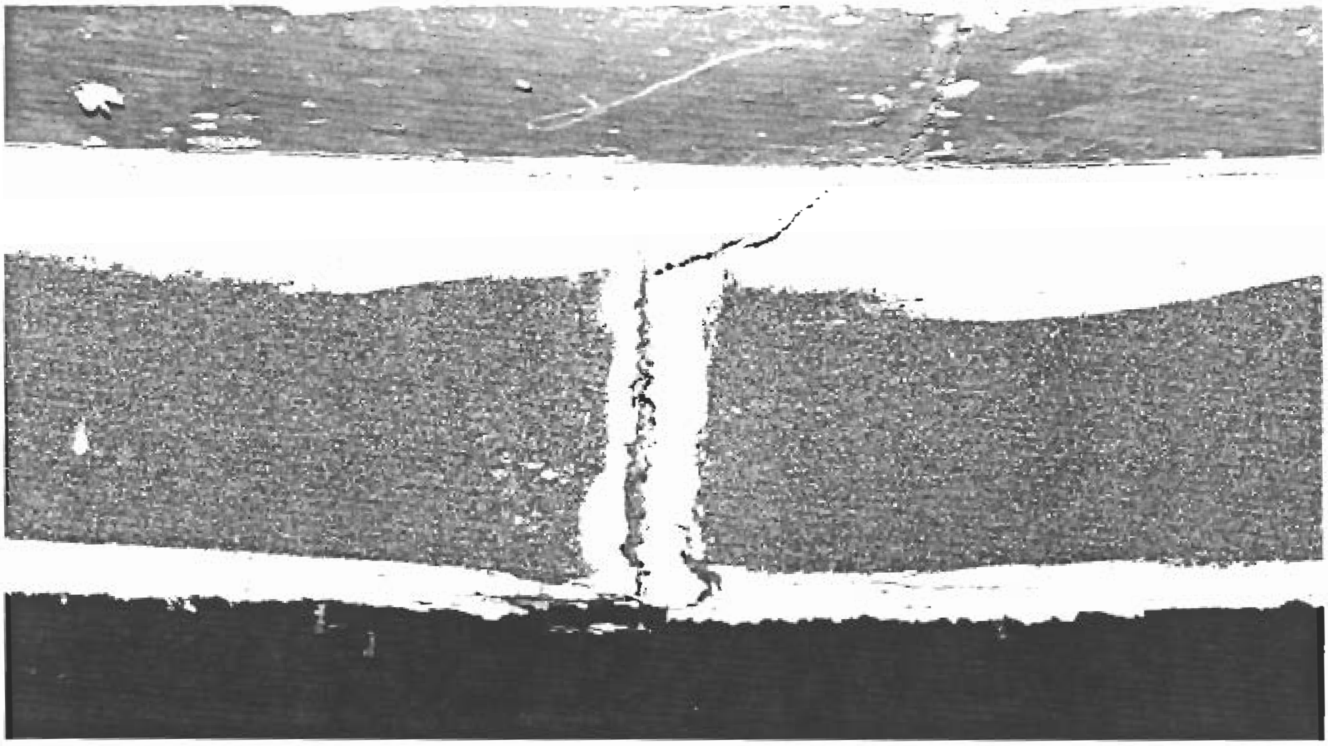
Test No. WFRC 46734

EXPOSED LOWER FLANGE OF ASSEMBLY SUBSEQUENT TO THE TEST (VIEWED FROM RIGHT HAND SIDE) **FIG. 28**



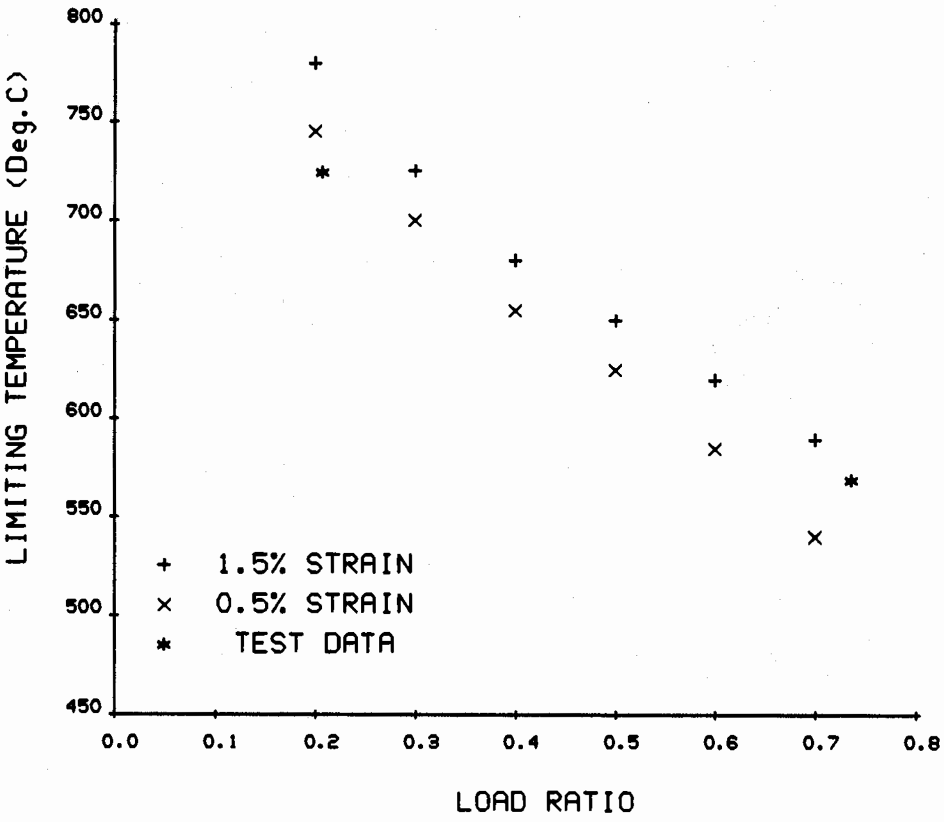
Test No. WFRC 46734

CRACKING IN THE LEFT HAND VICUCLAD PANELS SUBSEQUENT TO THE TEST **FIG. 29**



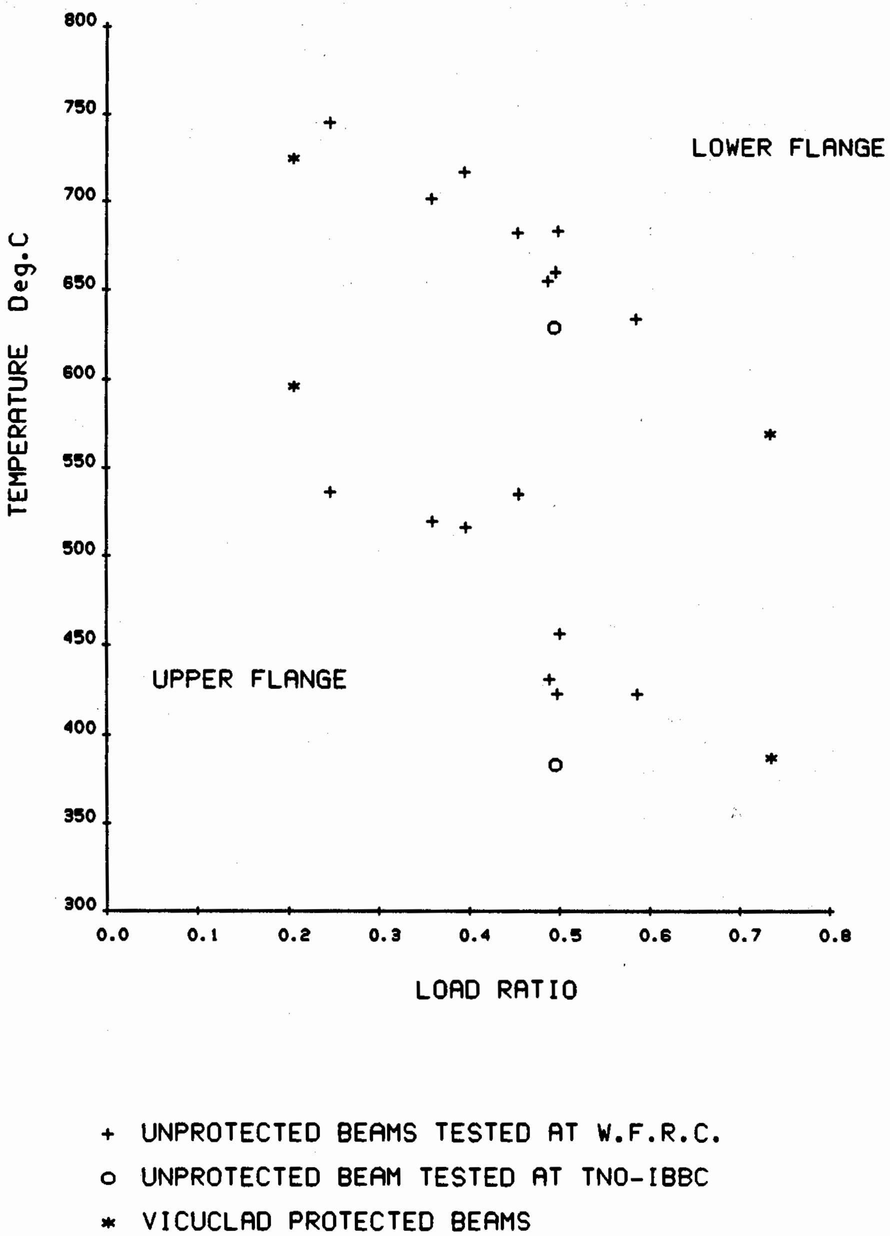
Test No. WFRC 46734

CRACKING IN THE RIGHT HAND VICUCLAD PANELS SUBSEQUENT TO THE TEST **FIG. 30**



LIMITING TEMPERATURE AS A FUNCTION OF LOAD RATIO FOR BEAMS SUPPORTING CONCRETE FLOOR SLABS - (BS5950 : PART 8 - TABLE 5)

FIG. 31



UPPER AND LOWER FLANGE TEMPERATURES, AT FAILURE, FOR 254 x 146 mm x 43 kg/m SERIAL SIZE BEAMS TESTED AT VARIOUS LOAD RATIOS **FIG. 32**

APPENDIX 1

LOAD CALCULATIONS

A1.1 CALCULATIONS BASED ON SERIAL SIZE DIMENSIONS

A1.1.1 Dimensions and Properties

Section Size: 254 x 146 mm x 43 kg/m Universal Beam.
Steel Grade: BS 4360 : Grade 43A : 1986

Depth of Section:	D	259.6 mm
Breadth of Section:	B	147.3 mm
Thickness of Flange:	T	12.7 mm
Thickness of Web:	t	7.3 mm
Root Radius:	r	7.6 mm
Area of Cross Section:	A	55.1 cm^2
Distance of Neutral Axis to Base of Section:	y	129.8 mm
Elastic Modulus (x-x):	Z	505.3 cm^3
Plastic Modulus (x-x):	S	568.2 cm^3
Moment of Inertia (x-x):	I	6558 cm^4
Design Strength (Minimum permitted value):	Py	275 N/mm^2
Design Strength (Average measured value):		306 N/mm^2

A1.1.2 Calculation of the Imposed Load

A1.1.2.1 Test No. WFRC 46738 on 24/08/1989

The nominal load ratio required for this test was 0.7

From Equation (1), and using the average measured yield strength value of 306 N/mm^2 as the design strength, we have:

$$0.7 = \frac{f(max) \times 505.3}{306 \times 568.2}$$

Therefore

$$f(max) = \frac{0.7 \times 306 \times 568.2}{505.3}$$

$$= \underline{240.86 \ N/mm^2}$$

For a simply supported beam the stress in the outer fibre is given by:

$$\text{Stress, (f),} = \frac{w L^2 y}{8 I} \qquad \ldots (2)$$

where:
- w is the applied load per unit length of the beam, (N/mm)
- L is the supported span of the beam, (mm)
- y is the distance of the outer fibre from the centroid, (mm)

and: I is the moment of inertia, (2nd. moment of area), about the horizontal axis passing through the centroid, (mm^4)

Rearranging Equation (2) we have:

$$w = \frac{8 \times I \times f}{L^2 \times y}$$

Therefore

$$w = \frac{8 \times 6558 \times 10E{+}04 \times 240.86 \times 10E{+}03}{4500 \times 4500 \times 129.8} \text{ N/m}$$

$$w = \underline{48075.782 \text{ N/m}}$$

Mass of Steel Section

From A1.1.1, the area of cross section = 55.1 cm^2.

Assuming a value of 7.85 g/cc for the density of steel then:

Mass of section $= \dfrac{55.1 \times 7.85 \times 100}{1000}$ kg/m

= 43.2535 x 9.80665 N/m

= <u>424.172 N/m</u>

Mass of Concrete Cover Slab

Nominal width = 650 mm

Nominal depth = 135 mm

Area of cross section = 0.650 x 0.135 m^2

= $\underline{0.08775 \text{ m}^2}$

Assuming a value of 2240 kg/m^3 for the density of concrete then:

Mass of concrete = 0.08775 x 2240 kg/m

= 196.56 x 9.80665 N/m

= <u>1927.595 N/m</u>

Hence the total dead load = 424.172 + 1927.595 N/m

= <u>2351.767 N/m</u>

And therefore the imposed load $= 48075.782 - 2351.767$ N/m

$= \underline{45724.015 \text{ N/m}}$

For an effective beam span of 4500 mm

Imposed load $= 45724.015 \times 4.5$ N

$$= \frac{205758.07}{9.80665 \times 1000} \text{ tonnes}$$

$= \underline{20.981 \text{ tonnes}}$

Say 21 tonnes for practical purposes, or 4 point loads of 5.25 tonnes each.

A1.1.2.2 Test No. WFRC 46734 on 06/09/1989

The nominal load ratio required for this test was 0.2.

From Equation (1), and using the average measured yield strength value of 306 N/mm^2 as the design strength, we have:

$$0.2 = \frac{f(max) \times 505.3}{306 \times 568.2}$$

Therefore
$$f(max) = \frac{0.2 \times 306 \times 568.2}{505.3}$$

$= \underline{68.82 \text{ N/mm}^2}$

After rearranging Equation (2) we have:

$$w = \frac{8 \times I \times f}{L^2 \times y}$$

Therefore
$$w = \frac{8 \times 6558 \times 10 E+04 \times 68.82 \times 10 E+03}{4500 \times 4500 \times 129.8} \text{ N/m}$$

$w = \underline{13736.508 \text{ N/m}}$

Since the dimensions of the steel section and the concrete cover slab are unchanged, the total dead load remains as previously calculated, i.e. 2351.767 N/m.

And therefore the imposed load $= 13736.508 - 2351.767$ N/m

$= \underline{11384.741 \text{ N/m}}$

For an effective beam span of 4500 mm

Imposed load $= 11384.741 \times 4.5$ N

$$= \frac{51231.335}{9.80665 \times 1000} \text{ tonnes}$$

= <u>5.224 tonnes</u>

Say 5.25 tonnes for practical purposes, or 4 point loads of 1.3125 tonnes each.

A1.2 RETROSPECTIVE CALCULATIONS BASED ON ACTUAL DIMENSIONS

A1.2.1 Dimensions and Properties of the Beams

Depth of Section:	D	261 mm
Breadth of Section:	B	143 mm
Thickness of Flange:	T	12.28 mm
Thickness of Web:	t	6.8 mm
Root Radius:	r	Not measured (assumed to be 7.6 mm)
Area of Cross Section:	A	0.516945 E+04 mm^2
Distance of Neutral Axis to Base of Section:	y	130.5 mm
Elastic Modulus (x-x):	Z	0.479106 E+06 mm^3
Plastic Modulus (x-x):	S	0.537576 E+06 mm^3
Moment of Inertia (x-x):	I	0.625233 E+08 mm^4

A1.2.2 Self Weight of the Steel Section

From A1.2.1, above, the area of cross section = 0.516945 E+04 mm^2

Assuming a value of 7.85 g/cc for the density of steel then:

$$\text{Mass of section} = \frac{0.516945\,E+04 \times 7.85}{1000} \text{ kg/m}$$

= <u>40.580 kg/m</u>

For an effective beam span of 4500 mm

Mass of section = <u>182.61 kg</u>

A1.2.3 Self Weight of the Concrete Cover Slabs

As noted elsewhere the concrete cover slabs were actually cast in four segments each 1000 mm in length, and not 1125 mm as intended. Since no data are available concerning the actual densities of the concrete a value of 2240 kg/m^3 has been assumed in the following calculations.

A1.2.3.1 Test No. WFRC 46738

Width of concrete slab = 642 mm

Depth of concrete slab = 134 mm

Length of concrete slab = 4000 mm

The total weight of the cover slab is given by:

$$C(1) = 0.642 \times 0.134 \times 4.0 \times 2240 \text{ kg}$$

$$= \underline{770.81 \text{ kg}}$$

A1.2.3.2 Test No. WFRC 46734

Width of concrete slab = 647 mm

Depth of concrete slab = 130 mm

Length of concrete slab = 4000 mm

The total weight of the cover slab is given by:

$$C(2) = 0.647 \times 0.130 \times 4.0 \times 2240 \text{ kg}$$

$$= \underline{753.63 \text{ kg}}$$

A1.2.4 Recalculate Load Ratio Values

A1.2.4.1 Test No. WFRC 46738

Load applied via the hydraulic rams = 21 tonnes

= 21000 kg

Self weight of the steel section = 182.61 kg

Self weight of concrete cover slabs = 770.81 kg

Therefore the total load applied = 21953.42 kg

= <u>215289 N</u>

From Equation (2) we have:

$$\text{Stress, (f),} = \frac{w L^2 y}{8 I}$$

Therefore

$$F(\max) = \frac{215289 \times 4500 \times 4500 \times 130.5}{4.5 \times 1000 \times 8 \times 0.625233 E+08} \text{ N/mm}^2$$

$$= \underline{252.76 \text{ N/mm}^2}$$

and from Equation (1)

$$\text{Load Ratio, (R),} = \frac{f(\max) \times Z}{Py \times S}$$

Therefore $$R = \frac{252.76 \times 0.479106\,E+06}{306 \times 0.537576\,E+06}$$

$$= \underline{0.736}$$

A1.2.4.2 Test No. WFRC 46734

Load applied via the hydraulic rams = 5.25 tonnes

= 5250 kg

Self weight of the steel section = 182.61 kg

Self weight of concrete cover slabs = 753.63 kg

Therefore the total load applied = 6186.24 kg

= <u>60666 N</u>

From Equation (2) we have:

$$\text{Stress, (f),} = \frac{w\,L^2 y}{8\ \ I}$$

Therefore $$f(max) = \frac{60666 \times 4500 \times 4500 \times 130.5}{4.5 \times 1000 \times 8 \times 0.625233\,E+08}\ N/mm^2$$

$$= \underline{71.22\ N/mm^2}$$

and from Equation (1)

$$\text{Load Ratio, (R),} = \frac{f(max) \times Z}{Py \times S}$$

Therefore $$R = \frac{71.22 \times 0.479106\,E+06}{306 \times 0.537576\,E+06}$$

$$= \underline{0.207}$$

A1.3 CALCULATION OF THE LOAD RATIO FOR THE BEAM TESTED AT TNO-IBBC

A1.3.1 Dimensions and Properties of the Beam

Section Size: 254 x 146 mm x 43 kg/m Universal Beam.
Steel Grade: BS 4360 : Grade 43A : 1986

Depth of Section:	D	261 mm
Breadth of Section:	B	147 mm
Thickness of Flange:	T	12.8 mm
Thickness of Web:	t	8.13 mm
Root Radius:	r	Not Measured (assumed to be 7.6 mm)

Area of Cross Section:	A	0.572658 E+04 mm^2
Distance of Neutral Axis to Base of Section:	y	130.5 mm
Elastic Modulus (x-x):	Z	0.517337 E+06 mm^3
Plastic Modulus (x-x):	S	0.585392 E+06 mm^3
Moment of Inertia (x-x):	I	0.675125 E+08 mm^4
Design Strength (Minimum permitted value):	Py	275 N/mm^2
Design Strength (Average measured value):		294 N/mm^2

A1.3.2 Self Weight of the Steel Section

From A1.3.1, above, the area of cross section = 0.572658 E+04 mm^2

Assuming a value of 7.85 g/cc for the density of steel then:

Mass of section $= \dfrac{0.572658\ \text{E}+04 \times 7.85}{1000}$ kg/m

= <u>44.954 kg/m</u>

For an effective beam span of 4500 mm

Mass of Section = <u>202.293 kg</u>

A1.3.3 Self Weight of the Concrete Cover Slabs

The concrete cover slabs were cast in four segments each 1250 mm in length

Width of concrete slab = 800 mm

Depth of concrete slab = 130 mm

Area of cross section = 0.800 x 0.130 m^2

= <u>0.1040 m^2</u>

Taking the average measured value of 2409 kg/m^3 for the density of concrete then:

Mass of concrete = 0.1040 x 2409 kg/m

= <u>250.536 kg/m</u>

For an effective beam span of 4500 mm

Mass of concrete = <u>1127.412 kg</u>

A1.3.4 Recalculate Load Ratio

Load applied via the hydraulic rams = 13906.8 kg

Contribution from the load spreaders = 132 kg

Self weight of the steel section = 202.293 kg

Self weight of the concrete cover slab = 1127.412 kg

Therefore the total load applied = 15368.505 kg

= <u>150713.55 N</u>

From Equation (2) we have:

$$\text{Stress, (f),} = \frac{w\,L^2\,y}{8\ \ I}$$

Therefore

$$f(max) = \frac{150713.55 \times 4500 \times 4500 \times 130.5}{4.5 \times 1000 \times 8 \times 0.675125\ E+08}\ N/mm^2$$

= <u>163.87 N/mm²</u>

And from Equation (1)

$$\text{Load Ratio, (R),} = \frac{f(max) \times Z}{Py \times S}$$

Therefore

$$R = \frac{163.87 \times 0.517337\ E+06}{294 \times 0.585392\ E+06}$$

= <u>0.493</u>

APPENDIX 2

LETTERS FROM WARRINGTON FIRE RESEARCH CENTRE CONFIRMING THE GENERAL RESULTS

WFRC

WARRINGTON FIRE RESEARCH CENTRE

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

Our Ref: 46738 - CWM/KC
29th August 1989

BRITISH STEEL TECHNICAL
Rails & Sections Division
Swinden Laboratories
Moorgate
Rotherham
S60 3AR

For the Attention of Mr. G. Thomson

Dear Sir

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried our on your behalf in accordance with BS 476: Part 21: 1987, Section 5, on a loadbearing steel beam of nominal size 254 mm by 146 mm by 43 kg/m, Grade 43A, spanning a distance of 4500 mm.

The beam was protected by an insulative cladding system known as 'Vicuclad' to provide one hours insulation. The 'Vicuclad' boards used were 20 mm thick.

The beam was loaded in accordance with BS 5950. The test results were as follows:

Loadbearing capacity	: 92 minutes
Residual loadbearing capacity	: Satisfied
Test discontinued	: 120 minutes

The load was removed from the beam after a period of 93 minutes at which time the beam had deflected 152 mm and was increasing at a rate of 16 mm per minute.

DATE OF TEST : 24th August 1989

Our full report covering this test will follow in due course.

Yours faithfully

C. W. MILES
Technical Officer
Structural Fire Protection
WARRINGTON FIRE RESEARCH CENTRE

A2/2

WARRINGTON FIRE RESEARCH CENTRE

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

Our Ref: 46734 - CWM/KC
11th September 1989

BRITISH STEEL TECHNICAL
Rails & Sections Division
Swinden Laboratories
Moorgate
Rotherham
S60 3AR

For the Attention of Mr. G. Thomson

Dear Sir

FIRE RESISTANCE TEST RESULTS

We confirm the results of a fire resistance test carried out on your behalf in accordance with BS 476: Part 21: 1987, Section 5, on a loadbearing steel beam of nominal size 254 mm by 146 mm by 43 kg/m, Grade 43A, spanning a distance of 4500 mm.

The beam was protected by an insulative cladding system known as 'Vicuclad' to provide one hours insulation. The 'Vicuclad' boards used were 20 mm thick.

The beam was loaded in accordance with BS 5950, with a load ratio of 0.2. The test results were as follows:

Loadbearing capacity	: 156 minutes
Test discontinued	: 160 minutes

The load was removed from the beam after a period of 156 minutes at which time the beam had deflected 178 mm and was increasing at a rate of 8 mm per minute.

DATE OF TEST : 6th September 1989

Our full report covering this test will follow in due course.

Yours faithfully

C. W. MILES
Technical Officer
Structural Fire Protection
WARRINGTON FIRE RESEARCH CENTRE

KC(1324)

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