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CONTRACT REPORT

The Influence of Thermal and Rotational Restraint on the Fire Resistance of Unprotected BS4360 : Grade 43A Steel Beams

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THE INFLUENCE OF THERMAL AND ROTATIONAL RESTRAINT ON THE FIRE RESISTANCE OF UNPROTECTED BS4360 : GRADE 43A STEEL BEAMS

SYNOPSIS

Earlier work has shown the beneficial effect of rotational end restraint on the fire resistance of unprotected steel beams when subjected to a BS476 : Part 8 fire test. In view of the importance of thermal expansion the present investigation was designed to determine whether the addition of longitudinal restraint would detract from these improvements. Four tests were carried out on BS4360 : Grade 43A beams with a serial size of 254 x 146 mm x 43 kg/m. A 30% end restraint was applied to two beams and 70% to the remaining two beams. Thermal restraint was provided in three tests by placing a rigid steel framework in intimate contact with the ends of the beam. Neither dimensional nor torsional restraint were deleterious to the fire resistance properties of the beam which easily exceeded the 30 min fire resistance target. A complicated pattern of deformation developed in each beam and this is discussed. The failure criterion used for three tests was the L/30 deflection limit while the fourth test was also determined by a critical rate of deflection.

1. INTRODUCTION

Earlier work, carried out under a joint BSC/Department of Environment programme, highlighted the beneficial effect of rotational end restraint on the fire resistance time of unprotected steel beams when subjected to a BS476 : Part 8 fire test[1]. It was recognised that the degree of rotational restraint that was imposed on a steel member in a building construction should be considered in any fire engineering analysis. Longitudinal restraint is also present in steel frameworks and its influence on the thermal expansion behaviour during a fire is important. A steel beam 6 m in length can expand by 51 mm when uniformly heated to 600°C and it is a common observation that external walls are pushed outwards during a fire. Large forces are required to prevent such an occurrence which can result in overstressed connections and large deflections in the beam leading to a decreased fire life. This situation is considered to be extreme since experience of natural fires suggests that most of the thermal expansion is taken up through bending of the columns and local buckling of the beam.

In view of the importance of thermal expansion the present investigation was designed to ascertain whether the addition of longitudinal restraint would detract from the improvements in fire resistance gained by rotational restraint. Four tests were carried out at the Warrington Research Centre on BS4360 : Grade 43A unprotected steel beams with a serial size of 254 x 146 mm x 43 kg/m. Two levels of rotational restraint were selected, 30% and 70%, which spanned the range of end loads with which improvements in fire resistance had been observed in the past. Thermal restraint was provided by an additional stiff frame, manufactured from heavy steel section, that surrounded the furnace and made intimate contact with the ends of the beam. No connections were used. As no freedom of movement could be accommodated in the longitudinal direction it was considered that the beam would deform in an extreme manner during the BS476 : Part 8 fire test. A continuous concrete cover slab was attached to the top flange of two beams in a manner which conferred some degree of composite action with the steel while four discrete segments covered each of the remaining beams. The strain pattern which developed in the ends of the beam during the test was monitored using strain gauges attached to the top and bottom flanges.

2. EXPERIMENTAL PROCEDURE

2.1 Thermal Restraint Frame

In order to restrict the longitudinal movement of the beam caused through thermal expansion an additional frame was designed, as shown in Fig. 1, to contain the test beam. This was fabricated from two 7.1 m lengths of a 254 x 254 mm x 73 kg/m universal column for the long sides of the frame and two 4.1 m lengths of a 914 x 305 mm x 224 kg/m universal beam for the end pieces. All the steel sections were ordered to BS4360 : Grade 50 specification thus enabling the frame to cope with the stress levels generated when testing at the higher levels (70%) of rotational restraint.

The sections were bolted together with M20 8.8 bolts which allowed the frame length to be adjusted thereby enabling different lengths of beams to be tested. The frame could possibly also be adapted to thermally restrain floors during testing.

The frame was designed to sit over the gantry of the furnace resting on stools level with the test beam while contact between the beam ends and the frame (flange of 914 x 305 mm x 224 kg/m beam) was made by inserting various thicknesses of shim which were then tack welded to prevent slipping out during testing. A photograph of the test arrangement is shown in Fig. 2.

2.2 Steel Supply

The four 254 x 146 mm x 43 kg/m BS4360 : Grade 43A universal beams were obtained from a steel stockholder. Following the fire tests a sample was taken from an unheated end of each beam to check the chemical composition and room temperature tensile properties.

The product analyses are given along with the chemical composition limits for the BS4360 : Grade 43A specification in Table 1 which shows that all the steel beams easily satisfied the requirements for the specification.

The results from the tensile test specimens sampled in accordance with BS4360 from the flange position are given in Table 2 along with the permissible strengths for the specification. Inspection shows that the tensile properties of all the beams more than adequately satisfied the BS4360 : Grade 43A requirements.

2.3 Beam Preparation

The concrete cover slab toppings on two of the beams were cast as a continuous length and allowed to key into lifting tangs, made from 12 mm thick plate, which were welded to the flange of the beam. The concrete topping on the remaining two beams which were completely free of the lifting tangs were cast as four discrete segments each separated with a strip of 12 mm thick mineral fibre board. The concrete on all the test beams was made from a weak non-structural mix.

The test beams were approximately 6.2 m in overall length and web stiffeners made from 12 mm thick plate were welded onto each side of the beam above the roller support positions.

Sixteen mineral insulated thermocouples (Pyrotenax 3 mm diameter chromel/alumel Type K with insulated hot junction and inconel sheaths) were fitted to each beam in the positions shown in Fig. 3. Five thermocouples were fitted at the centreline on the web, six to the lower flange and five to the upper flange.

Six mineral insulated thermocouples were also used to monitor the furnace atmosphere temperature. These were located 100 mm away from the lower flange at positions adjacent to the Warrington Research Centre thermocouples, used to control the furnace heating rate.

The outputs from the thermocouples were monitored using the BSC Compulog 4, computer controlled, data aquisition system which was similar to that used in previous tests.

Each beam was stressed using the loads calculated in Appendix 1 for a simply supported member and these were applied at four positions ($^1/8$, $^3/8$, $^5/8$ and $^7/8$) on the effective beam span (4.5 m) to generate a bending stress of 165 N/mm^2. The end moments required to achieve the level of rotational restraint (30 and 70%) were applied using a hydraulic ram and load cell with loads of 3.4 and 8.1 t respectively (see Appendix 2) positioned at a distance of 715 mm from the roller supports. Throughout the tests the ram height was altered to maintain a constant load. The ram movements were also recorded.

Vertical deflection measurements were taken at the centre of the beams by the Warrington Research Centre personnel using their potentiometric system. The local strain pattern which occurred in the lower flange of the beams as a consequence of the fire test was measured at intervals of 500 mm and the lateral distortion was measured at intervals of 200 mm.

In view of the limited space available between the roller supports and the edge of the furnace and the positioning of web stiffeners it was decided to measure longitudinal strains in the cantilever sections that were subjected to rotational restraint. 'Showa' strain gauges (N11-FA-10-120) having a gauge length of 10 mm and a gauge factor of 2.1 ± 1% were mounted on the top of the upper flange and the lower flange of the beam at a distance of 50 mm beyond the roller supports using M-bond 200 adhesive. At one end of the beam the longitudinal strains at the centre and the edges of the top flange near the edges of the lower flange were recorded. Only strains towards the edges of the flanges were measured at the other end of the beam. For temperature compensation purposes, dummy gauges mounted on a length of BS4360 : Grade 43A plate were attached either to the web stiffener above the support or mounted on the top of the lower flange. Changes in resistance were recorded for all the gauges at 2 min intervals throughout the test. In addition the local temperature rise in both the cantilever and dummy gauge block were measured to enable a correction factor for apparent strain to be made.

3. RESULTS

The fire resistance times and mean lower flange and web temperatures at failure of the beams are summarised in Table 3 for the different restraint conditions. Although only four tests were completed it would appear that neither dimensional nor torsional restraint are deleterious to the basic fire resistance properties of a beam. In addition, the use of a continuous concrete cover slab that had keyed into the lifting tang on the top flange of the beam gave a 10% improvement in life compared with the beam topped with a segmented concrete cover.

The temperatures recorded at failure in the web and flange locations of each test beam are given in Table 4. Based on the deflection failure criterion (L/30) the beams supported the design load to a higher temperature when restrained. The temperatures recorded for the beam with a notional 70% rotational restraint were lower than anticipated although the heating rate was within the bottom tolerance limit set for the ISO furnace curve. This particular test was extended beyond the deflections limit to record temperatures associated with a proposed maximum rate of deflection $\delta = L^2/(9000\ d)$ which for the current beam span and effective depth was 10.25 mm/min defining 'd' as the distance between the flanges of the beam. In view of the concern over the loading rams above the beam the test was stopped at 10 mm/min. However the observations suggested that the sole use of the rate of deflection criterion would extend the apparent elevated temperature life of test beams.

The vertical deflection measured at the centre of each beam during the fire test is shown in Fig. 4. The beam subjected to 30% restraint exhibited a constant rate of deflection which was typical of earlier data. However, the imposition of thermal restraint resulted in virtually no vertical deflection after approximately 15 min of the fire test had elapsed. The increase in vertical deflection resumed after approximately 25 to 30 min depending upon the degree of rotational restraint imposed.

As the same section size had been used throughout the test programme the steel heating rates recorded in each beam were similar especially in the early stages of the test. Therefore, only one set of temperature-time curves are presented as being representative of the conditions. The individual temperatures recorded throughout the fire tests at the various thermocouple locations along the beam are available on data sheets Nos. 28-31 (see Appendix 3). Little temperature variation occurred along the lower flange, web, or upper flange of the beam, as shown in Figs. 5-7, obtained from the second test in the series. The temperature variation recorded across the beam at a distance of 100 mm from the furnace wall is shown in Fig. 8. A plastic hinge formed at this position during the test. The time interval required to heat the bottom flange and web of the beam (with an HP/A value of 169 m^{-1}) to a temperature at which the 1% proof stress of the steel equalled the design stress was estimated to be 22 min, using available design data and an emmissivity factor for the furnace of $\epsilon = 0.25$.

The average furnace atmosphere temperatures recorded from each test are compared with the ISO temperature time curve in Fig. 9 which shows that the heating rates from all the tests were in accordance with the standard. However, although within the permitted tolerance, the furnace heating rate on the fourth test was below the others. This discrepancy was reflected in the comparatively low mean steel temperature of 814°C after 46 min, a temperature that was attained after 41 min in the first test.

Local strain measurements at various positions along the lower flange of the beams taken at the completion of the fire tests are given in Table 5. The variation was greatest for beams subjected to thermal restraint where the deformation behaviour was complicated by lateral displacement, as shown in Fig. 10. At the centre of the beam the local strain ranged from 1.6% for the rotationally restrained only condition to 2.4% for the most highly restrained condition. In the latter case the test had continued beyond the L/30 deflection criterion and was stopped at a deflection of L/22; local strains as high as 5.39% were measured in the vicinity of an area of significant buckling corresponding with the outer plastic hinge.

The measurement of longitudinal stresses on the flanges of the beams resulted in a confused pattern of behaviour. This arose principally from the slight misalignment of the beam relative to the restraining frame which led to a preferential loading from one corner as expansion took place. The features observed in the 30% rotational restrained beams were typical of all the tests, as shown in Figs. 11 and 12.

A 30% rotational restraint was applied to the end of the beam by the application of a load of 34 kN at a distance of 71.5 cm from the roller support. The maximum surface stress recorded by gauges positioned 5 cm from the support was calculated as +44 N/mm^2 on the top flange and -40 N/mm^2 on the upper face of the bottom flange. The stress behaviour during the course of the first test depended on the accuracy of control over the hydraulic jacks at both the ends and centre of the beam. At one end of the beam, the stress measurements remained constant but at a level of approximately ± 80 N/mm^2 which suggested that the end load applied was higher than indicated. At the other end of the beam, Fig. 11, the initial build up of tensile or compressive stress in the flange due to the application of load was as expected. However, a malfunction of the loading jack after 26 min of the test had been completed resulted in a sudden increase in stress which recovered partially in the later stages.

The behaviour of one end of a similarly loaded beam subjected to thermal restraint is shown in Fig. 12. Once the furnace was lit rapid expansion of the bottom flange took up any clearances with the frame. At the same time the slight gap at the ends of the top flange allowed it to twist. After approximately 10 min the bottom flange near the roller (Gauge No. 4) started to yield at a compressive stress of -285 N/mm^2. After 20 min the compressive load on Gauge No. 7 started to drop due to general yielding of the bottom flange in the furnace. This allowed the top flange to make contact with the restraining frame with Gauge No. 6 taking up the compressive load. After 30 min of the test had elapsed the further collapse of the beam in the furnace removed the thermal restraint from the top flange.

A maximum difference in temperature of only 8°C was recorded between the surfaces of the beam and the dummy gauge mounting block. In view of this comparatively small change no correction for apparent strain was considered necessary.

During the early stages of the test the ends of the beam tended to move upwards and the ram pressure in the hydraulic jacks was reduced to maintain a constant load. However, once yielding had taken place in the furnace the ram pressure had to be increased. The relative ram movements are shown as a function of time in Fig. 13. For a notional 30% end restraint the initial deflection of the beam was sufficient to raise the restraining frame by approximately 20 mm; the magnitude of rotational restraint influenced the total displacement. In consequence the weight of the frame provided an additional end moment raising the total rotational restraint from 30 to 43% and from 70 to 82%.

After cooling all the test beams were reloaded satisfactorily and removed from the furnace. Longitudinal cracks were observed along the continuous concrete cover slab between the lifting tangs. Photographs of two beams subjected to combined restraint are shown in Fig. 14 indicating the hinge positions and the flange and web buckling resulting from the fire test. Copies of the letters received from the Warrington Research Centre confirming the general results are given in Appendix 4.

4. DISCUSSION

The structural steel sections used in building construction are subjected to three types of restraint, namely a limit to longitudinal, lateral and torsional movement. The general experience with steel frameworks in fire is that collapse only occurs in exceptional circumstances, implying that restraint provides a degree of stability to the structure. Previous work on BS4360 : Grade 50B beams indicated that, in comparison with a simply supported member, the application of torsional restraint increased the fire resistance time as a consequence of the reduction in stresses in the centre of the beam. On the basis of these preliminary tests a design philosophy was proposed to facilitate the use of rotational restraint in fire engineering calculations to provide 30 min fire resistance for unprotected steel beams.

The current series of tests was carried out using 254 x 146 x 43 kg/m BS4360 : Grade 43A beams. Available test data on this product are limited, as shown in Table 6. A simply supported beam recorded a failure time of 22 min, whereas experience gained in early experiments using a nominal 63% rotational restraint provided by a bolted connection extended the failure time to approximately 40 min. The application of 30% rotational restraint to the simply supported Grade 43A beam in the present work resulted in a failure time of 41 min which was higher than expected. This could be due to two factors, a degree of composite action between the continuous concrete slab and the beam and the increase in rotational resistance that occurred in the later stages of the experiment. The failure temperature of 814°C was similar to that recorded by the beam with the bolted connection. In view of the fact that the failure temperature of the unrestrained beam was 676°C calculations suggest that a more realistic failure temperature for a 30% restrained Grade 43A beam would be 740°C on the web, equivalent to 33 min fire resistance.

The superposition of the steel frame around the Grade 43A beam, still with a rotational resistance of 30% increased the failure time to 48 min. The additional resistance to longitudinal expansion of the beam resulted in a complicated pattern of behaviour. As the test beam supported the weight of the restraining frame the effective rotational restraint increased to 43%. During the fire test failure occurred by the formation of plastic hinges in the beam within the furnace close to the supports with the point of contraflexure in the centre. This feature had also occurred in the earlier rotational restraint tests. The strain gauge readings taken on the cantilever section beyond the roller indicated that the bottom flange yielded locally after approximately 12 min, other positions across the flange being affected to a lesser extent as thermal expansion continued and the end of the beam made overall contact with the restraining frame. On the top flange of the cantilever the stress recorded by Gauge No. 1 increased by approximately +120 N/mm^2 due to the longitudinal restraint but after 20 min a degree of relaxation occurred due to yielding in the furnace. It is of interest to note that at this time the temperature in the vicinity of the plastic hinge (100 mm from the support) was 550°C such that the yield strength was similar to the design stress superimposed on the beam. Replacing the keyed-in concrete slab by a segmented topping removed any composite action with the steel beam and in consequence the failure time and temperature were reduced to 44 min and 834°C respectively.

No significant improvement in fire resistance for the thermally restrained beam was obtained by increasing the rotational resistance to a notional 70%. Although the pattern of yielding exhibited by the strain gauges situated on the cantilever was not altered significantly the higher restraint further restricted longitudinal movement since the lateral distortion of the lower flange was much greater than with the beam having only 30% rotational resistance. In addition the degree of upward deflection of the cantilever was much smaller.

A particular feature of the time deflection curves observed in the tests was the plateau which developed under conditions of combined restraint. This feature occurred after 12 to 15 min into the test and lasted for periods of 10-15 min. It was caused by two mechanisms, lateral buckling and relative changes to the vertical deflection brought about by a combination of changing Young's modulus with increasing temperature and differential thermal expansion.

The effect of rotational and rotational plus longitudinal restraint on the behaviour in a fire of the 254 x 146 mm x 43 kg/m BS4360 : Grade 43A beam is summarised in Fig. 15 in terms of the failure temperature and time.

The points on the graphs represent individual test results which are subject to differences in test condition and therefore only serve to indicate trends. Although not as well defined as earlier experimental data on Grade 50 beams, it is clear that the imposition of rotational restraint of 30% or more raises the fire resistance of this steel section above the 30 min barrier. The addition of longitudinal restraint by the manner used in the tests increases the fire resistance to that anticipated from a fixed ended beam, equivalent in this case to a 'notional' rotational restraint of 67.4%. Such a comparison is determined by a failure criterion based on a limit to vertical deflection. The extent of lateral buckling is not considered. An isolated result suggested that if the criterion had been based on a vertical rate of deflection of 10 mm/min the failure time in the fire test for all the beam conditions would be increased.

The imposition of longitudinal restraint to a beam influences the manner in which thermal expansion is accommodated during a fire. Real fire experience suggests that most thermal expansion is taken up through bending of the columns the remainder by buckling or deflection of the beam. These competing deformation procedures will depend on the location of the fire in the overall structure, movement of internal columns being restricted by the surrounding framework. The extent of thermal expansion can be considerable. For example, heating a 6 m beam to 600°C will cause an expansion of 51 mm, resulting in a central deflection of 340 mm, should there be no column movement and no twisting or buckling of the beam. The experience gained in the current series of tests has been based on a structure in which two stiff pin jointed 914 x 304 x 224 kg/m beams acting as columns provided full longitudinal restraint by direct contact with a 254 x 146 x 43 kg/m test beam. Such a combination is probably untypical of multistorey construction. The bending stresses at the centre of the pin jointed column and the end stresses on the test beam due to thermal expansion of the beam have been estimated making a number of simplifyling assumptions.

If:- test beam expansion - column deflection = test beam compression then:-

$$\left(\frac{\alpha\,\ell_2\,\Delta t}{2}\right) - \left(\frac{1}{48}\,\frac{W_1\,\ell_1^{\,3}}{E_1\,I_1}\right) = \left(\frac{W_2\,\ell_2}{A_2\,E_2}\right)$$

where the suffixes 1 and 2 relate to the column and beam respectively, ℓ = length, I = moment of inertia, α = coefficient of linear expansion, A = cross sectional area, E = Young's modulus, Δt = change in temperature and W = force. At equilibrium $W_1 = W_2$.

$$\therefore W = \frac{\alpha \ell_2 \Delta t}{2\left[\frac{\ell_2}{A_2 E_2} + \frac{\ell_1{}^3}{48 E_1 I_1}\right]}$$

Bending moment in column = $\frac{W \ell_1}{4}$

$$\therefore \text{stress} = \frac{W \ell_1}{4 Z_1}$$

where Z = section modulus, and the end stress on the test beam = $\frac{W}{A_2}$

Consider a 7.28 m long column, typical of a 2 storey height, in contact with a 6 m long beam. Allowing for changes in Young's modulus and the coefficient of linear expansion with temperature, the longitudinal stresses in the beam and the maximum bending stresses in the column have been calculated on the assumption that the beam is heated uniformly in a fire, see Fig. 16. At a test beam temperature of 300°C the maximum bending stress in the 914 x 305 x 224 kg/m beam acting as the column is 135 N/mm^2 and the end stress in the test beam is 110 N/mm^2. By using the Euler buckling formula and a coefficient of x 2 for the end conditions the test beam could buckle at an end stress of 142 N/mm^2 achieved at a temperature of 390°C. If the test beam is assumed to have a uniformly distributed load in addition to the axial compression resulting from thermal expansion, the maximum bending stress at 300°C becomes 205 N/mm^2 and the 1% proof stress value is possibly reached in the beam at a temperature of 450°C.

In a multistorey building construction a 203 x 203 x 46 kg/m column is frequently used in conjunction with a 254 x 146 x 43 kg/m beam[2]. As also shown in Fig. 18, the respective stresses developed in the assembly due to thermal expansion of the beam are much lower than those in the rigid structure.

These calculations are an over simplification of the real situation. The nominal clearance between a 254 x 146 x 43 kg/m beam and a column is 6 mm/end. A rise in temperature of 160°C would be required before complete longitudinal restraint occurs. Beams are linked to columns by connections which in the case of bolted framework can provide variable end restraint. This effect could be simulated in a fire test by the use of spring disc washers placed between an experimental beam and its column. However, what should be determined now are the loading patterns imposed on a column by the deflection of a beam which intensifies the bending stresses at a position just below the connection. A sophisticated approach would involve mathematical modelling; however, the stress pattern around the connection is complicated and at present an appropriate program for calculating the temperature distribution in this locality (from which a stress pattern is derived) is not developed. Once available, the mathematical analysis would then be checked and refined as necessary by completing fire tests on at first two and then three dimensional structures.

The introduction of the L/30 deflection limit for beams and columns in BS476 : 1972 was expected to ensure that the structure remained stable after a fire. Recent developments in structural design have produced structural systems whose limit of load bearing capacity under the fire resistance test is not adequately predicted by a deflection limit of L/30. Discussions within FSB1/6 on failure criteria centre around a maximum rate of deflection, $\delta = L^2/(9000\ d)$ and a deflection limit for structural collapse of L/20(3). In the current work one beam was loaded in the fire test until the rate of deflection was 10 mm/min, just short of the maximum value set by the above equation. The strain in the beam was estimated to be 2.4%, similar to values recorded in earlier Australian work[4]. At this point the beam had a deflection of L/22 and although it was not in an imminent stage of collapse there was some concern for the integrity of the test equipment. From this point of view the criteria considered by FSB1/6 represent an upper bound condition. A second rate of deflection formula suggested by Constrado, $\delta = 1.1\ L^2$ gives a limit of 22 mm/min for the beam span used in the tests which, on present evidence, is considered to be a high value.

5. CONCLUSIONS

Four tests were carried out on BS4360 : Grade 43A unprotected steel beams with a serial size of 254 x 146 x 43 kg/m to examine the effect of thermal and rotational restraint on the fire resistance as measured in the BS476 : Part 8 fire test.

Under the conditions imposed by the tests neither dimensional nor torsional restraint were deleterious to the fire resistance properties of the Grade 43A beam.

Available test data on this beam size are limited. A simply supported beam recorded a failure time of 22 min in an earlier experiment. The application of a 'nominal' 30% rotational restraint increased the failure time to 41 min. This improvement was influenced to a certain extent by a degree of composite action between the concrete cover slab and the beam, and the fact that some increase in rotational resistance occurred during the test. The superposition of a rigid frame around the beam provided an added resistance to longitudinal expansion and the failure time increased to 48 min. No significant improvement in fire resistance resulted by increasing the degree of rotational resistance to a nominal 70%. As the deflection of the test beam lifted the restraining frame the effective rotational restraint was slightly greater than that applied by the hydraulic jacks.

During the fire test failure occurred by the formation of plastic hinges in the beam within the furnace close to the supports with the point of contraflexure in the centre. The strain gauge readings taken on the cantilever section of the beam between the roller support and the restraining frame indicated that the bottom flange yielded locally after 12 min, other positions being affected to a lesser extent as the ends of the beam twisted and made intimate contact with the frame. After 20 min the surface stresses in the cantilever relaxed as the central span of the beam yielded in the furnace.

The effect of restraint on the time-deflection curves was to delay the rate of vertical deflection after 12 to 15 min which lasted for periods of 10-15 min. This was caused by combined lateral buckling and competing mechanisms on the vertical movement of the beam.

One beam was tested to a limit close to the maximum rate of deflection determined by $\delta = L^2/9000\ d$ which FSB/1/6 is considering as a possible failure criterion. At the completion of the test the vertical deflection of the beam was L/22. This isolated result suggests that the committee proposals on stability failure represent an upper bound condition.

6. REFERENCES

1. Smith, C.I., Thomson, G., Chilvers, N. and Hogan, G., Teesside Report T/RS/1380/37/82/D.

2. Gray, B.A. and Walker, M.B., 'Steel Framed Multistorey Buildings, the Economics of Construction in the UK', Constrado, September 1982.

3. Porter, A., Report DG/SB/TF/Q1088 submitted to FSB/1/6, 3rd May 1983.

4. Skinner, D.H., 'Runaway Temperature - A Design Criterion Based on the High Temperature Properties of Steel', BHP Tech. Bulletin, 16, (No. 2), November 1972, pp 22-37.

5. Smith, C.I. and Thomson, G., Teesside Report T/RS/1380/17/81/D.

7. ACKNOWLEDGEMENT

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TABLE 1 CHEMICAL COMPOSITION OF BEAMS USED IN TEST PROGRAMME

Sample No.	Test	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Nb	Tot. Al	N_2
RS394	30% rotational restraint (continuous concrete	0.24	0.03	0.91	0.013	0.031	0.03	0.007	0.03	<0.005	<0.005	0.05	<0.005	<0.005	0.005
RS460	30% rotational and thermal restraint (continuous concrete)	0.23	0.02	0.91	0.012	0.029	0.02	<0.01	0.03	<0.01	<0.01	0.05	<0.005	<0.005	0.005
RS461	30% rotational and thermal restraint (segmented concrete)	0.23	0.02	0.92	0.010	0.029	0.02	<0.01	0.03	<0.01	<0.01	0.05	<0.005	<0.005	0.005
RS462	70% rotational and thermal restraint (segmented concrete)	0.20	0.02	0.88	0.007	0.022	0.02	<0.01	0.03	<0.01	<0.01	0.05	<0.005	<0.005	0.005
BS4360 : Grade 43A product requirements		0.30 max.	0.55 max.	1.70 max.	0.06 max.	0.06 max.									

TABLE 2 TENSILE TEST DATA FROM THE 254 x 146 mm x 43 kg/m BEAMS USED IN THE TEST PROGRAMME

Sample No.	Test	Yield Stress N/mm^2	Tensile Strength N/mm^2	Elongation %
RS394	30% rotational restraint (continuous concrete)	267	485	29.0
RS460	30% rotational and thermal restraint (continuous concrete)	285	481	28.0
RS461	30% rotational and thermal restraint (segmented concrete)	294	484	31.0
RS462	70% rotational and thermal restraint (segmented concrete)	286	480	31.0
BS4360 : Grade 43A requirements		255 min.	430/ 540	20.0 min.

TABLE 3 SUMMARY OF FIRE RESISTANCE TIMES AND MEAN LOWER FLANGE/WEB TEMPERATURES OF TEST BEAMS

Test No.	Section Size	Concrete Topping	Initial Rotational Restraint, %	Thermal Restraint	Failure Time, min	Mean Lower Flange/ Web Temperature, °C
1	254 x 146 mm x 43 kg/m	Continuous	30	-	41	814
2	254 x 146 mm x 43 kg/m	Continuous	30	Yes	48	865
3	254 x 146 mm x 43 kg/m	Segmented	30	Yes	44	834
4	254 x 146 mm x 43 kg/m	Segmented	70	Yes	46	814

TABLE 4 TEMPERATURE, °C, PROFILES ACROSS BEAMS AT FAILURE

Test Date:	27.1.83	22.2.83	24.2.83	22.3.83	
Run No:	57	59	60	61	
Design stress:	165 N/mm^2	165 N/mm^2	165 N/mm^2	165 N/mm^2	
Beam size:	254 x 146 mm x 43 kg/m continuous concrete	254 x 146 mm x 43 kg/m continuous concrete	254 x 146 mm x 43 kg/m segmented concrete	254 x 146 mm x 43 kg/m segmented concrete	
HP/A m^{-1}	169	169	169	169	
End restraint:	30%	30% (increased to 43%)*	30% (increased to 43%)*	70% (increased to 82%)*	
Thermal restraint:	No	Yes	Yes	Yes	
Quality:	Grade 43A	Grade 43A	Grade 43A	Grade 43A	
Failure time:	41 min	48 min	44 min	46 min (L/30)	55 min (204 mm)
Lower flange 1	830	868	840	828	878
2	834	874	851	831	849
4	819	866	825	805	858
6	751	881	846	834	882
7	836	877	843	823	871
Mean	814	873	841	824	873
Web 1	804	849	815	798	852
2	827	866	839	815	866
3	822	865	836	805	859
4	808	841	810	786	841
Mean	815	855	825	801	854
Mean lower flange and web	814	865	834	814	865
Upper flange 3	675	724	693	669	732
5	649	726	665	665	732
8	646	732	690	695	743
9	666	711	693	655	713
Mean	659	723	685	671	730
Flange 10	766	771	737	738	793
Web 5	684	753	734	718	763
Upper flange 11	450	607	522	506	616
Mean furnace	896	906	890	869	902
ISO curve	885	906	893	898	924

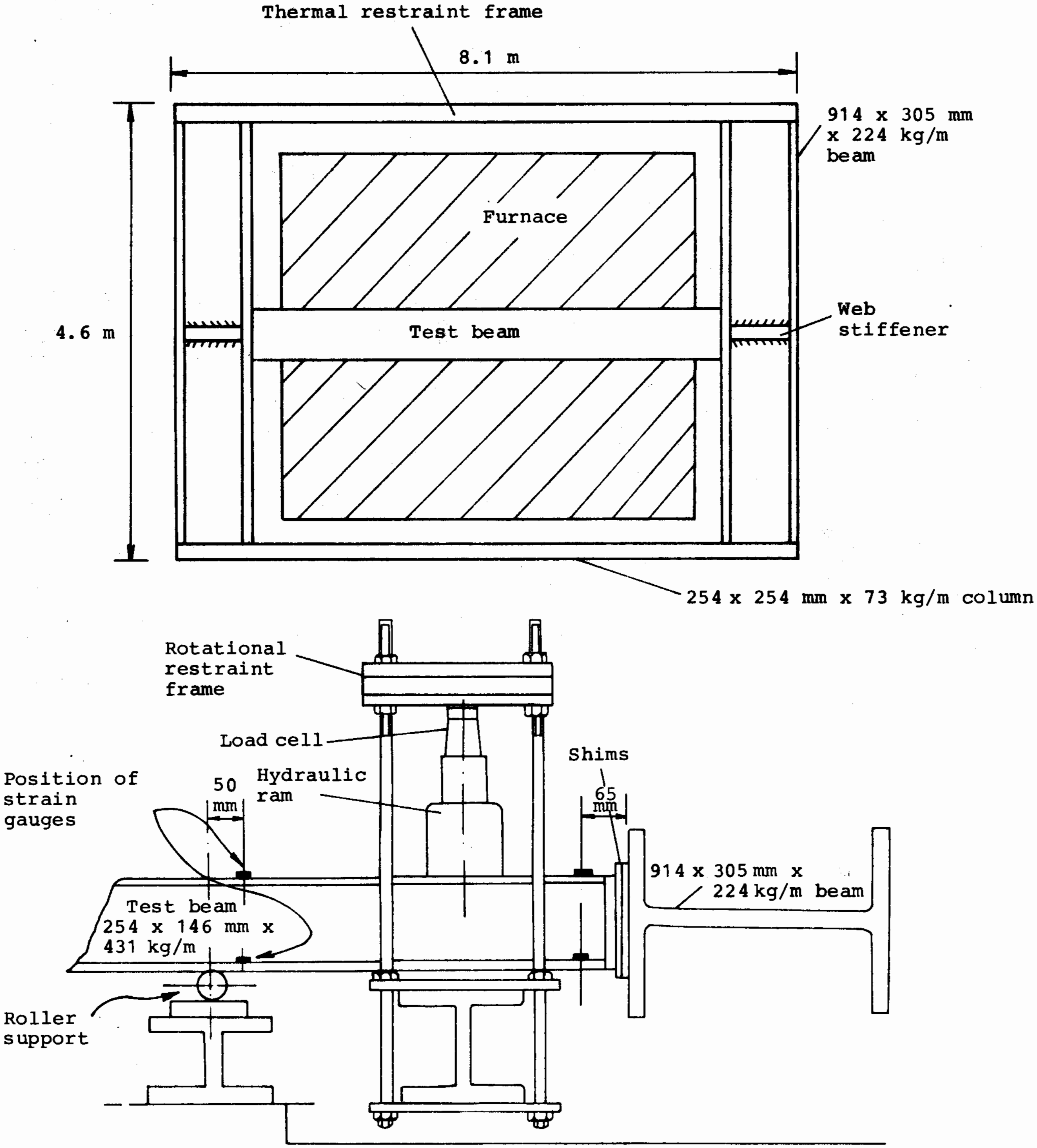
* Due to lifting of the restraining frame during the test

TABLE 5 LOCAL STRAIN MEASUREMENTS OBTAINED AFTER THE TESTS FROM GAUGE LENGTHS MARKED ON THE LOWER FLANGE OF THE TEST BEAMS

Initial Test Conditions	Local Strain, %, at Intervals of 500 mm							
	Position							
	1	2	3	4	5	6	7	8
30% rotational restraint (continuous concrete) Tested 27.1.83	-0.6	-0.2	1.0	1.6	1.6	0.79	0	-0.74
30% rotational plus longitudinal restraint (continuous concrete) Tested 22.2.83	-3.9	-0.19	1.20	1.0	1.20	1.0	-1.0	-4.43
30% rotational plus longitudinal restraint (segmented concrete) Tested 24.2.83	-3.39	-0.80	0.60	1.60	1.79	0.40	-2.60	-2.67
70% rotational and plus longitudinal restraint (segmented concrete) Tested 22.3.83	-5.59	-0.20	1.00	2.40	2.39	0.80	-3.00	-2.78

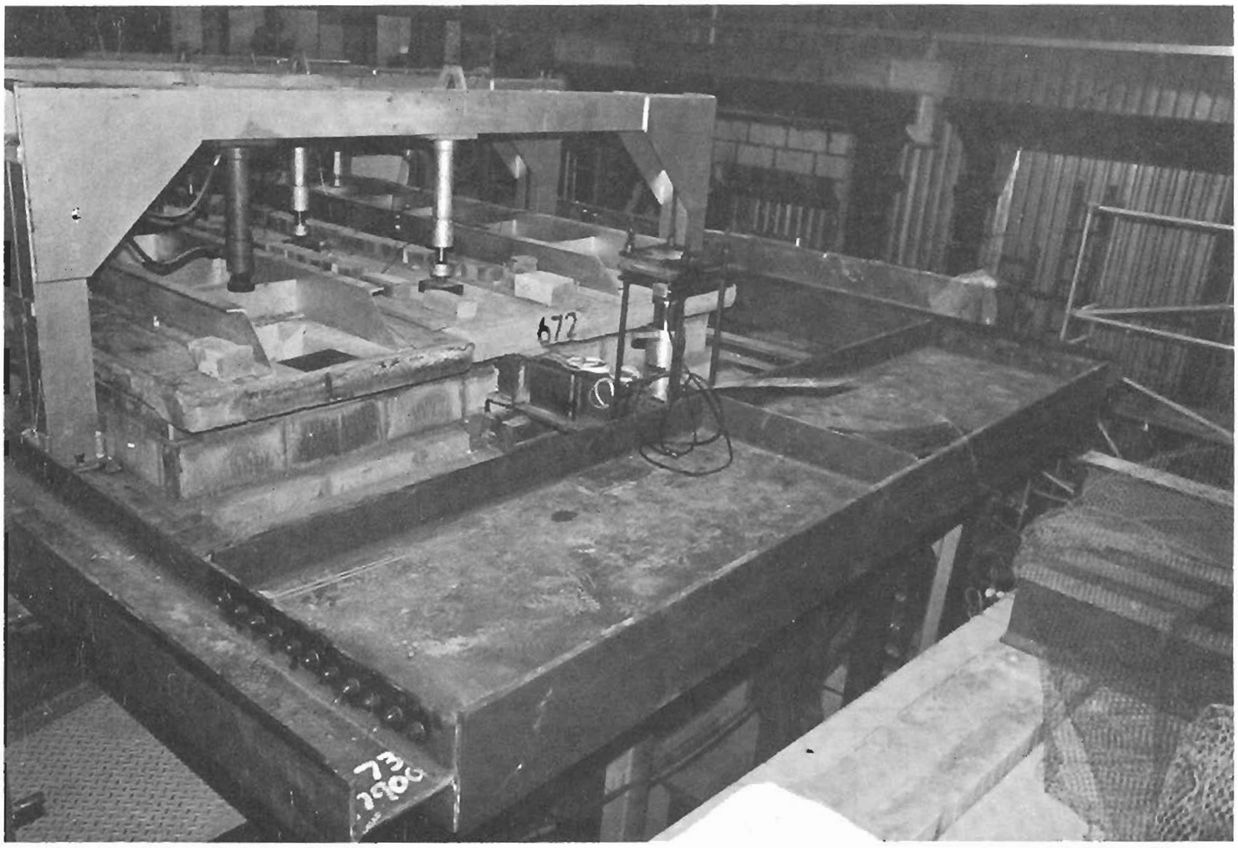
TABLE 6 PREVIOUS BS476 : PART 8 TEST DATA ON BS4360 : GRADE 43A BEAMS OF 254 x 146 mm x 43 kg/m SERIAL SIZE[5]

Beam Details			BS476 : Part 8 Tests	
Yield Stress N/mm^2		End Condition	Failure Time min	Mean Failure Temperature ^oC
Web	Flange			
311	293	Simply supported	22	676
329	295	Bolted connection 63% restraint	41	816
298	275	Hydraulic rams 'nominal' 30% restraint which increased	40	761

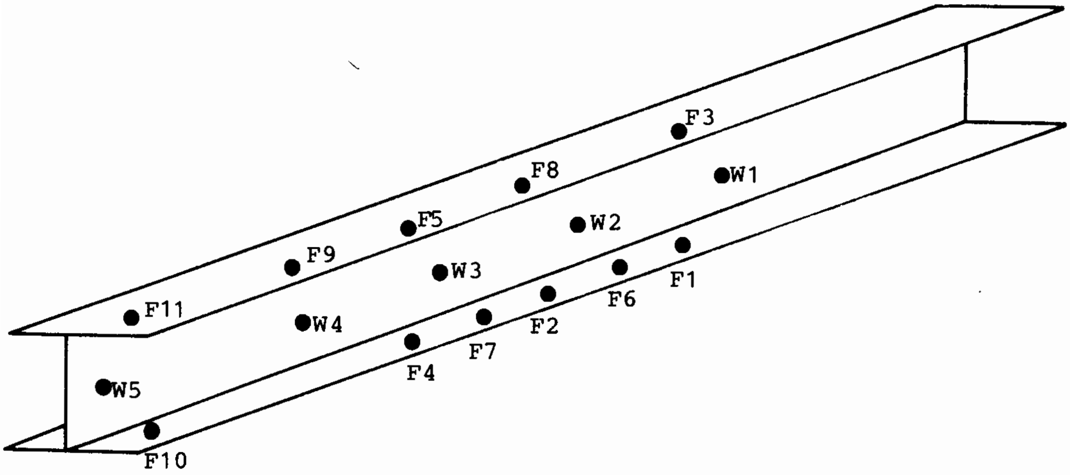


SCHEMATIC ILLUSTRATIONS OF THERMAL RESTRAINT FRAME AND TEST ARRANGEMENT

FIG. 1
(R1/8733)



PHOTOGRAPH OF THERMAL RESTRAINING FRAME AND TEST ARRANGEMENT   FIG. 2

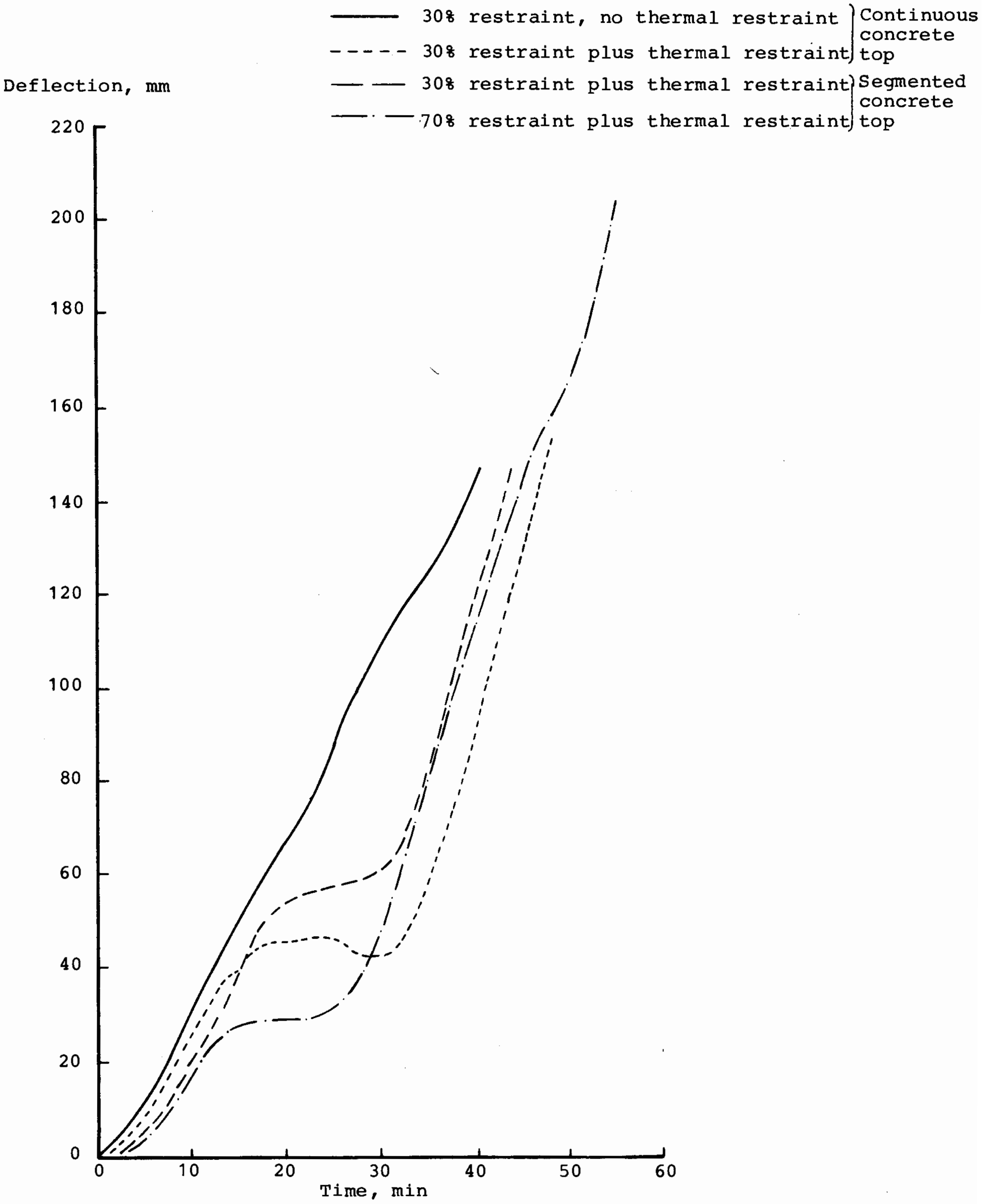


Distance from end of beam to thermocouples:

W1	4.08 m
F3, F1	3.78 m
W2, F6	3.46 m
F2, F8	3.16 m
W3, F7	2.84 m
F4, F5	2.54 m
W4, F9	2.23 m
End of beam	6.30 m
W5, F10, F11	1.25 m

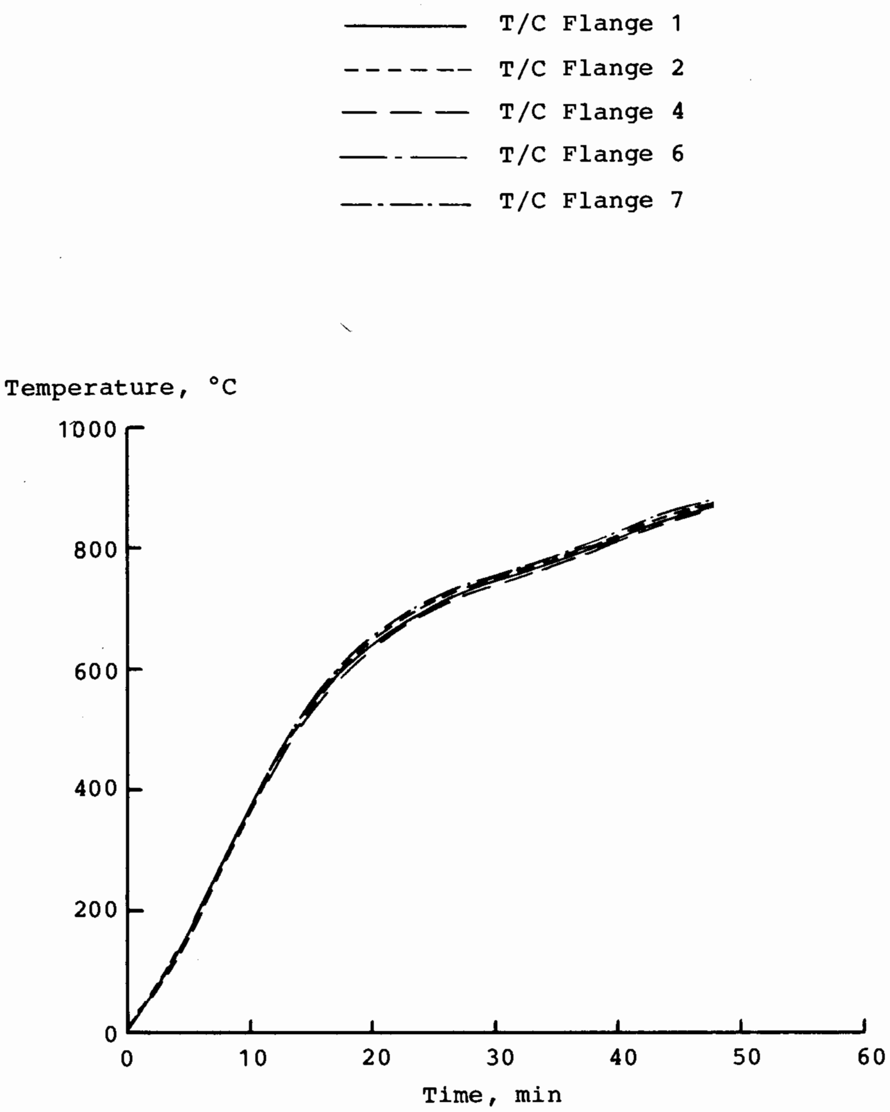
POSITION OF THERMOCOUPLES ON TEST BEAM

FIG. 3
(R1/8734)



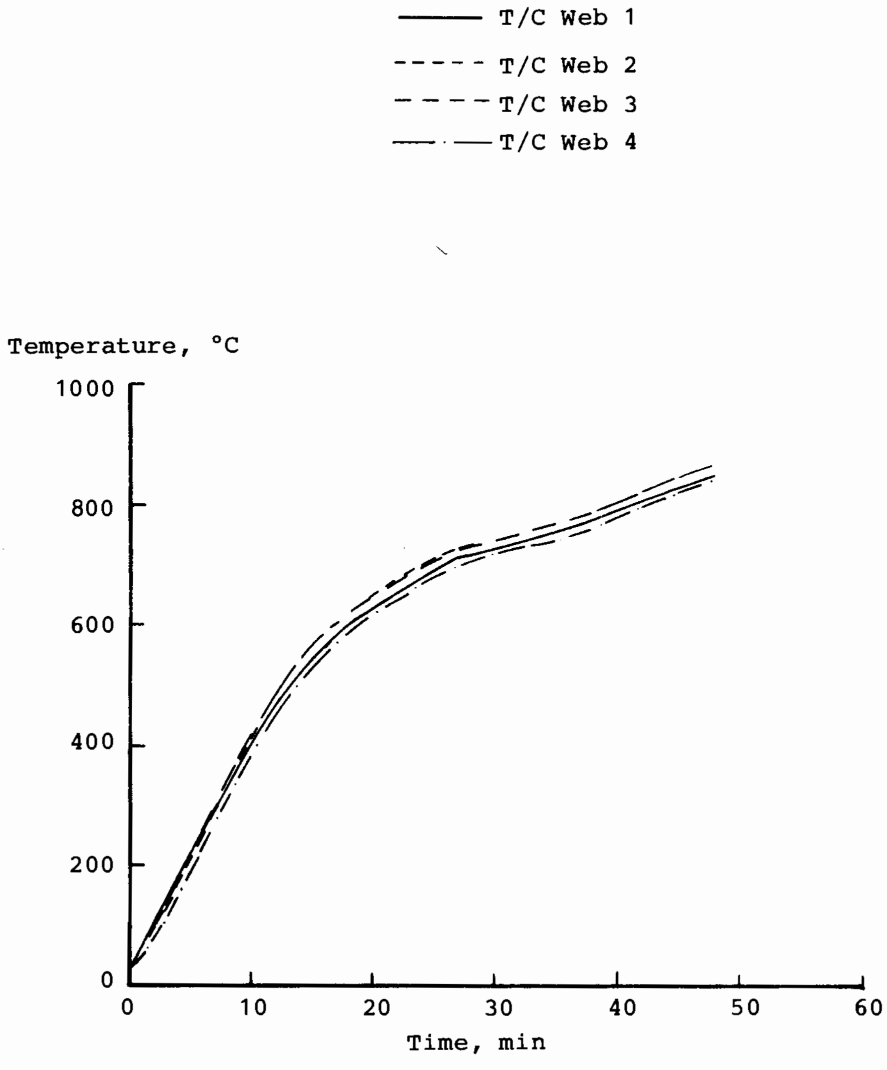
VERTICAL DEFLECTION MEASURED AT THE CENTRE OF THE BEAM DURING EACH TEST

FIG. 4
(R1/8735)



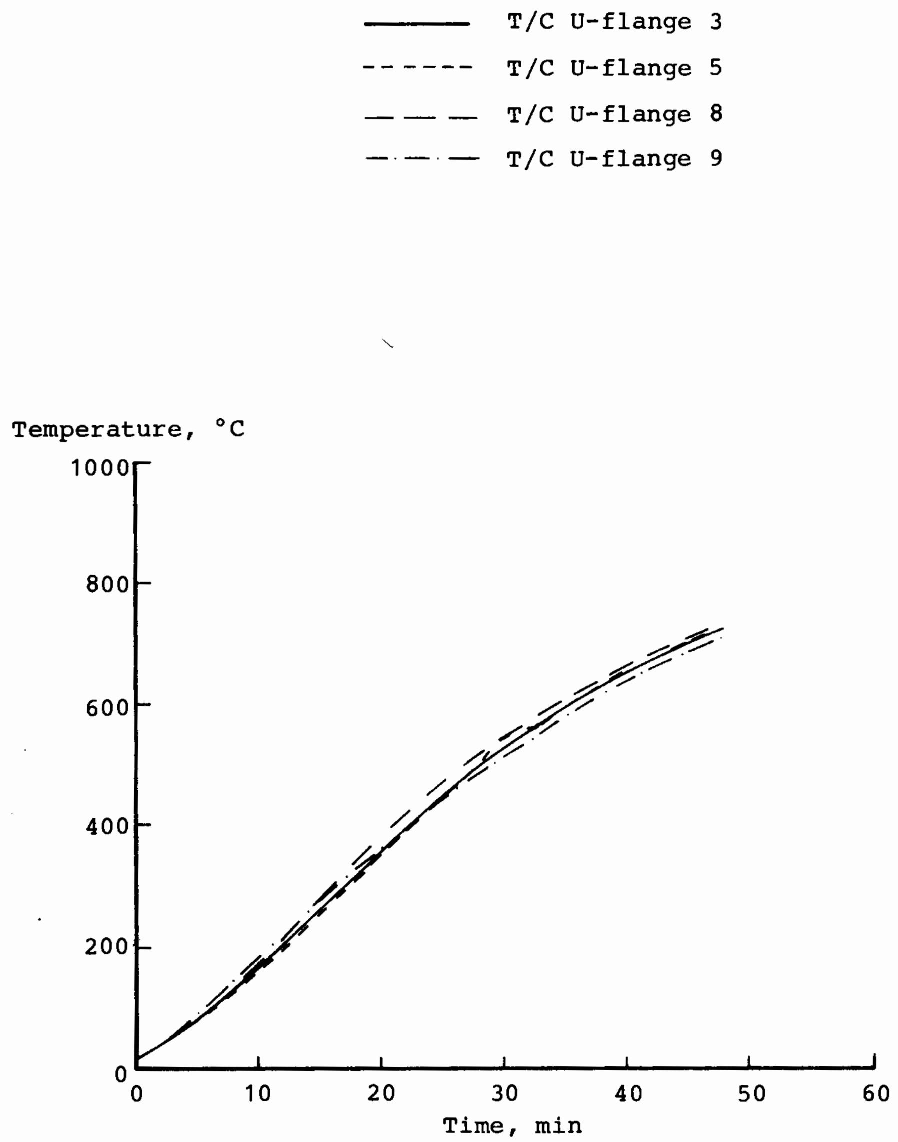
LOWER FLANGE TEMPERATURES RECORDED ON THE BEAM TESTED WITH 30% ROTATIONAL PLUS THERMAL RESTRAINT

FIG. 5
(R1/8736)



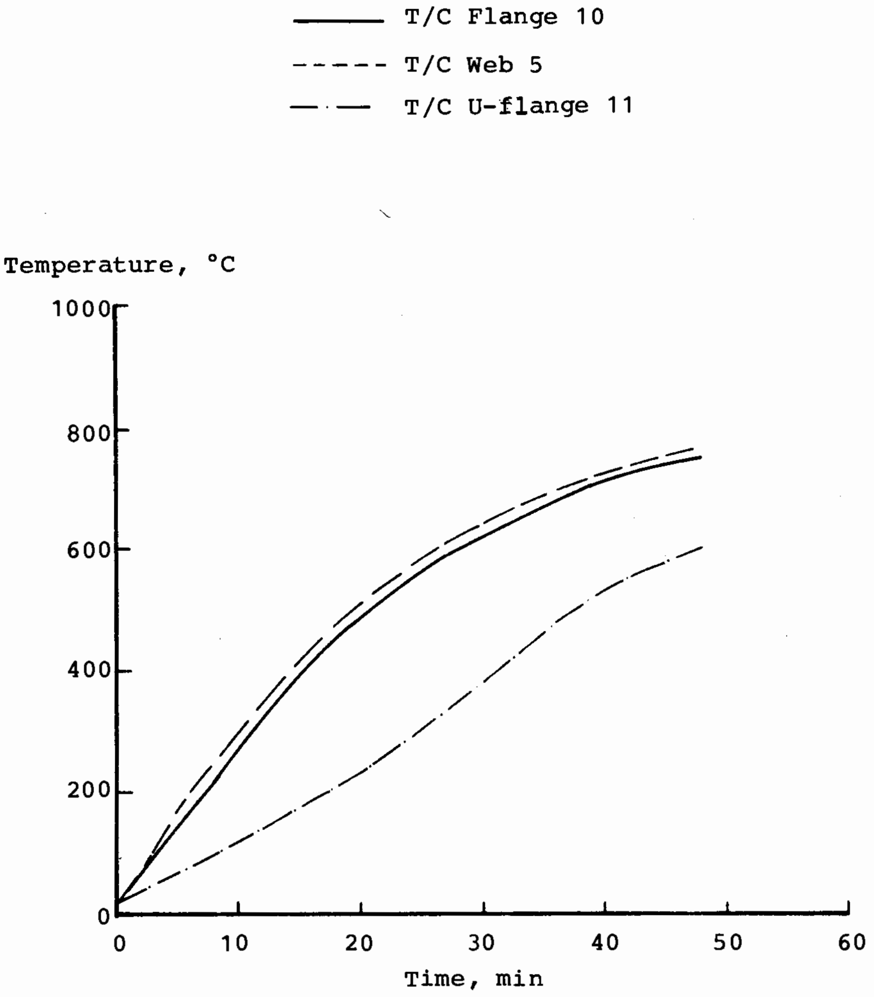
CENTRAL WEB TEMPERATURES RECORDED ON THE BEAM TESTED WITH 30% ROTATIONAL PLUS THERMAL RESTRAINT

FIG. 6 (R1/8737)



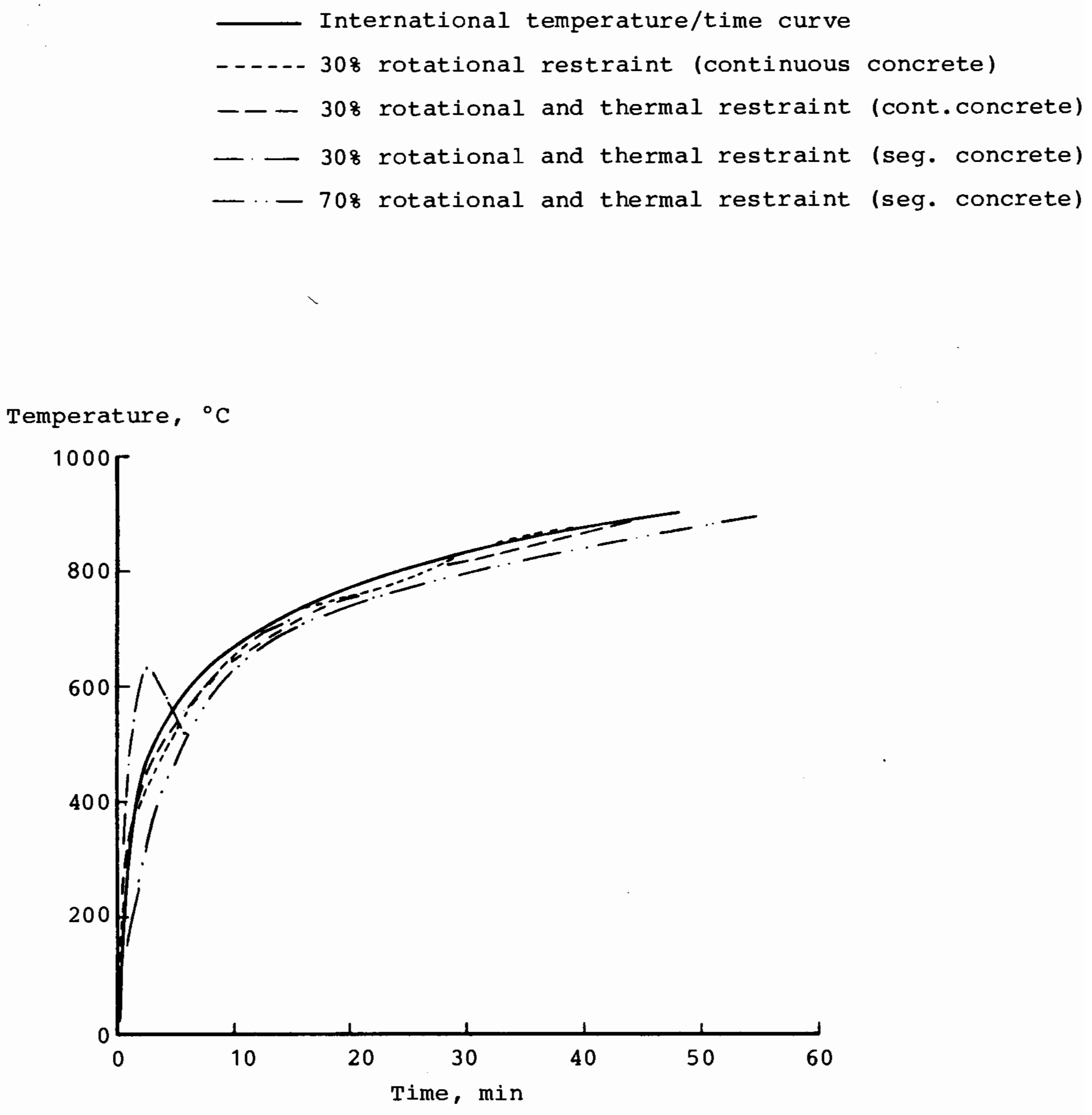
UPPER-FLANGE TEMPERATURES RECORDED ON THE BEAM TESTED WITH 30% ROTATIONAL PLUS THERMAL RESTRAINT

FIG. 7
(R1/8738)



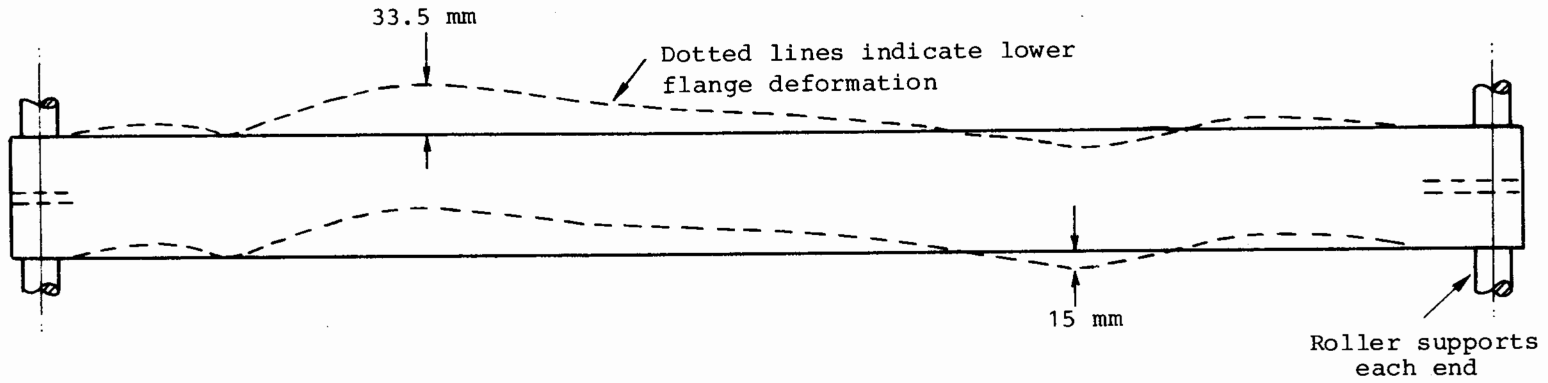
STEEL TEMPERATURES RECORDED 100 mm FROM FURNACE WALL

FIG. 8
(R1/8739)

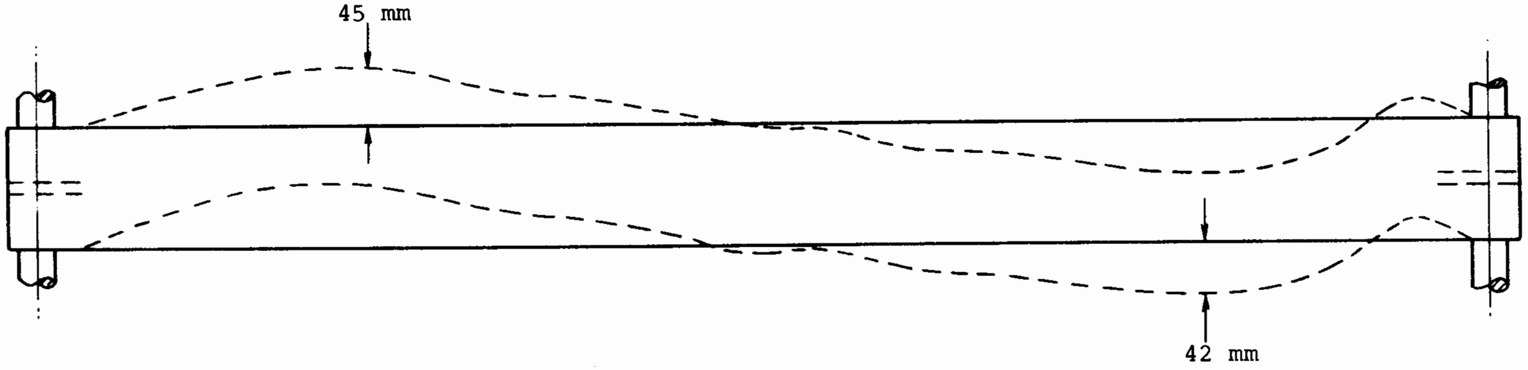


AVERAGE FURNACE HEATING RATE RECORDED DURING EACH TEST COMPARED WITH THE INTERNATIONAL TEMPERATURE/TIME CURVE

FIG. 9
(R1/8740)



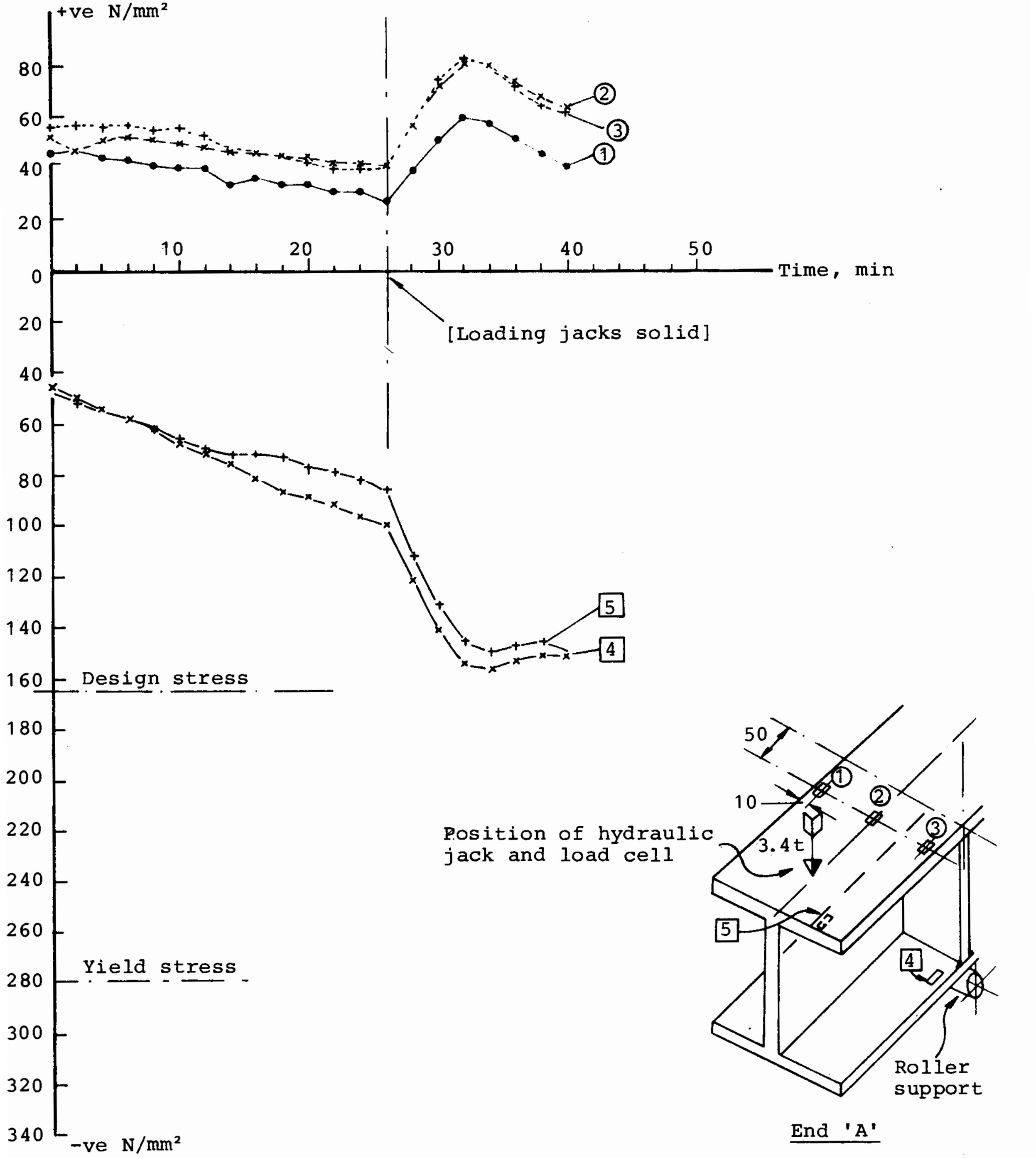
(a) 254 x 146 x 43 kg/m Grade 43A beam with 30% rotational restraint and longitudinal restraint and segmented concrete cover



(b) Details as above except 70% rotational restraint

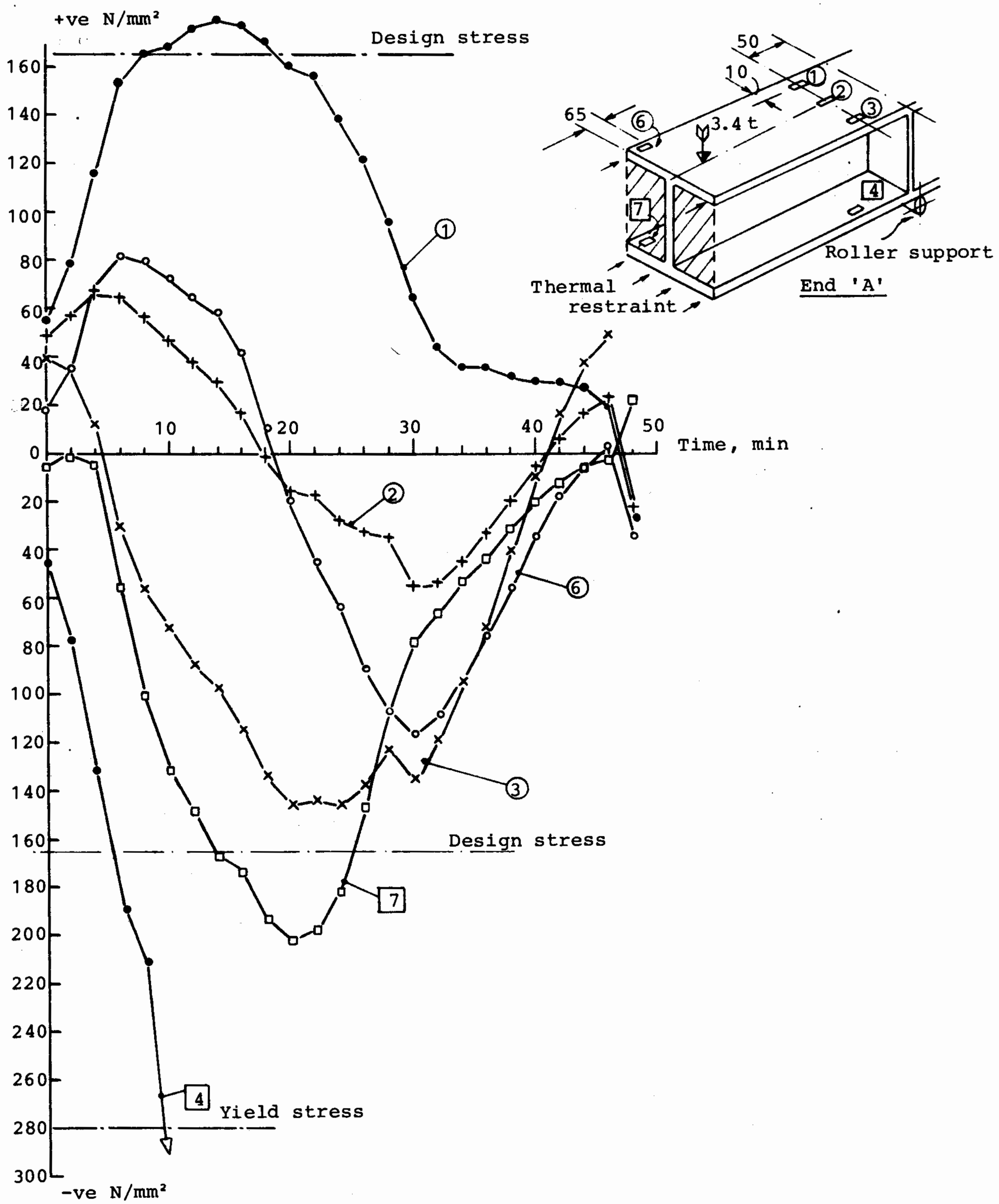
LOWER FLANGE DEFORMATION PATTERNS AFTER TESTING WITH 30 AND 70% ROTATIONAL RESTRAINT

FIG. 10
(R1/8741)



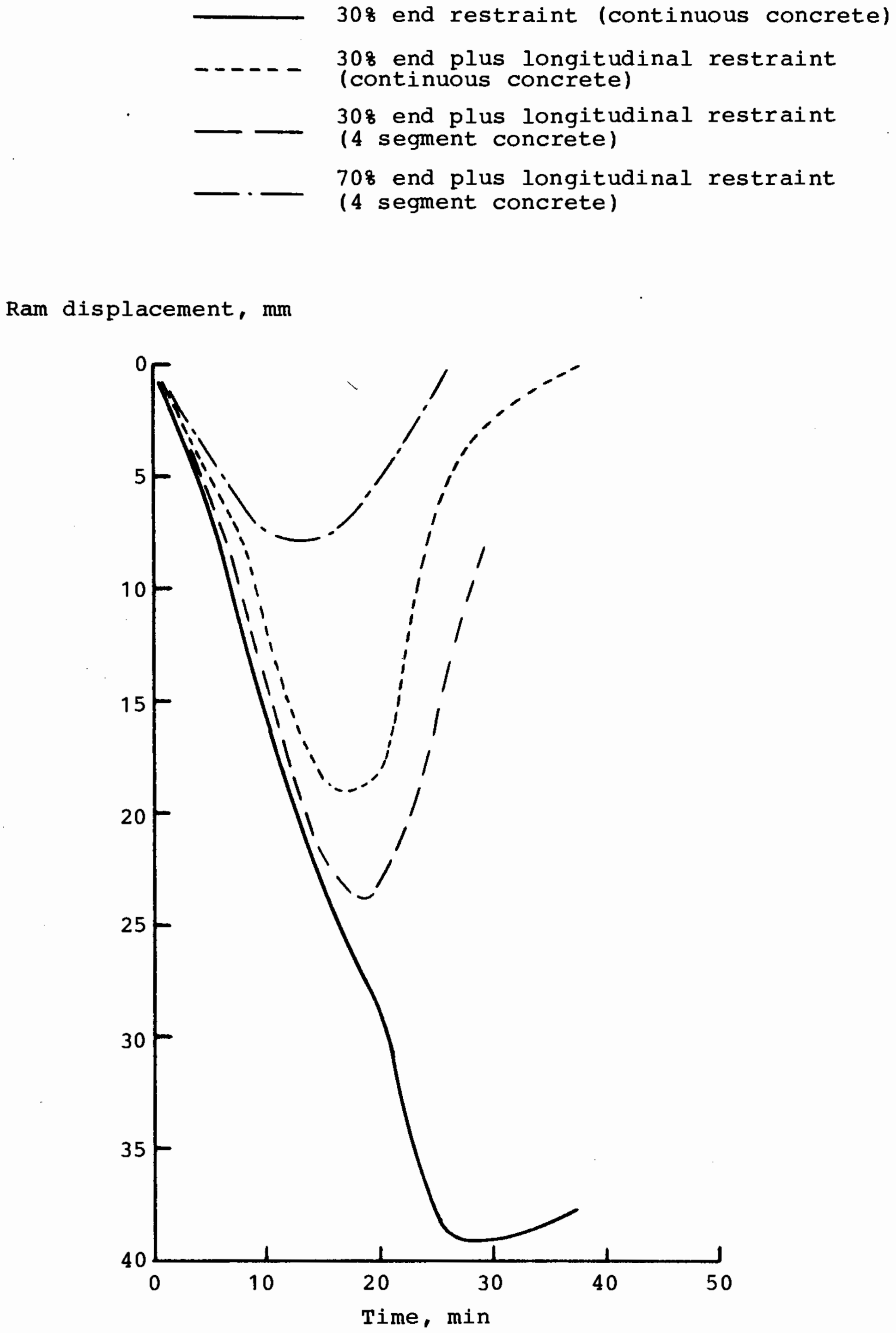
STRESS READINGS ON BEAM WITH 30% ROTATIONAL RESTRAINT
NO LONGITUDINAL RESTRAINT AND WITH CONTINUOUS COVER BLOCK

FIG. 11
(R1/8742)



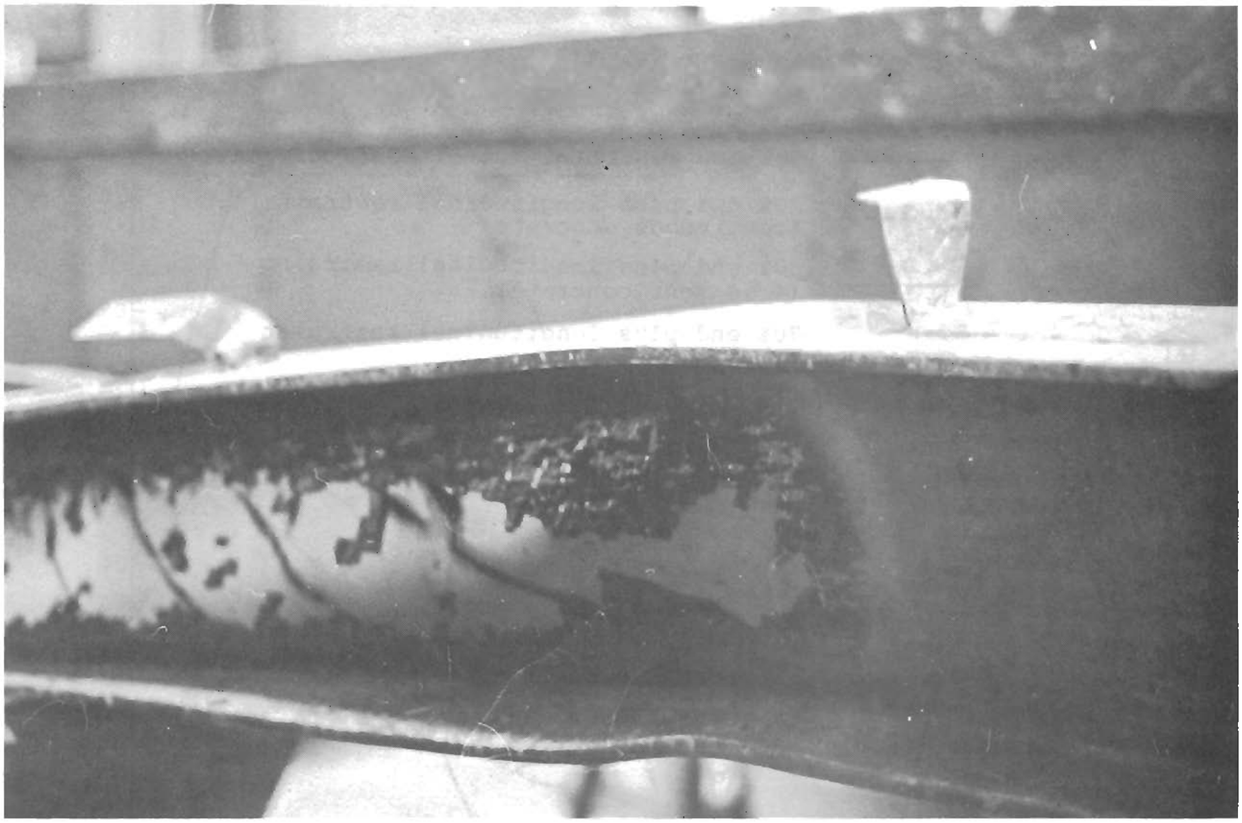
STRESS READINGS ON BEAM WITH 30% ROTATIONAL AND LONGITUDINAL RESTRAINT AND WITH CONTINUOUS COVER BLOCK

FIG. 12
(R1/8743)



RAM MOVEMENT MEASURED AT THE END OF EACH BEAM DURING THE CURRENT SERIES OF TESTS

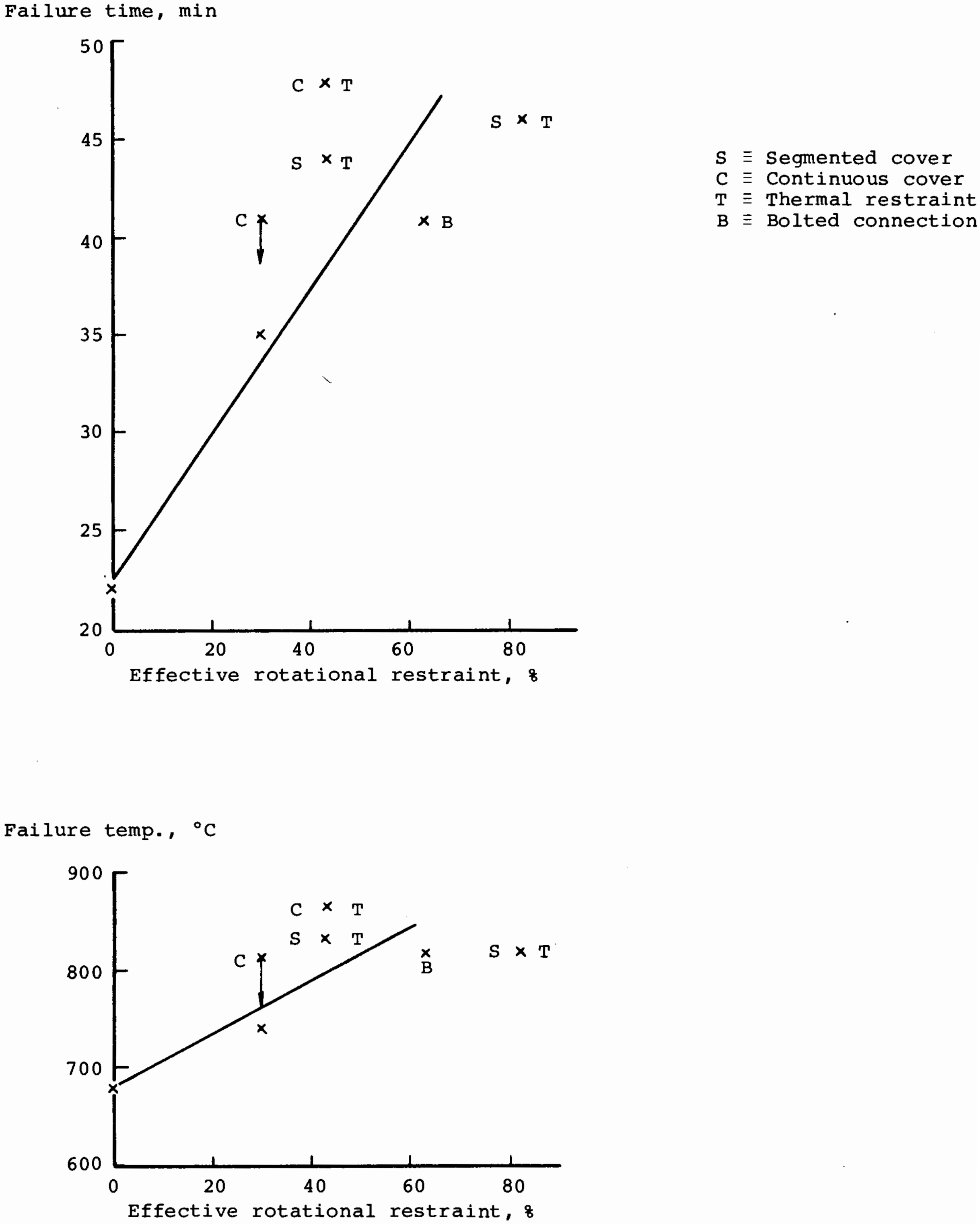
FIG. 13
(R1/8744)



30% Rotational Restraint (a)

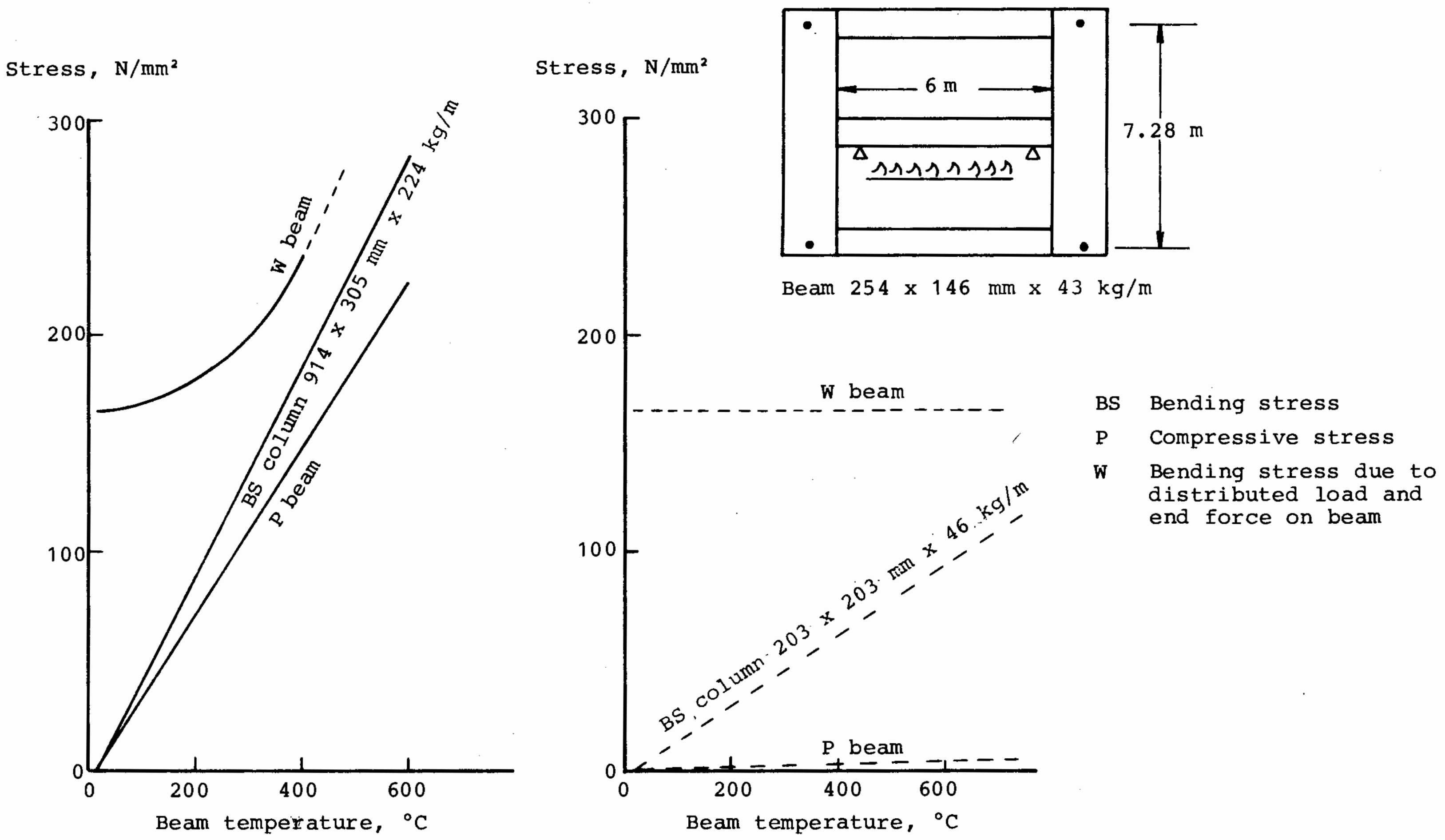
70% Rotational Restraint (b)

PHOTOGRAPHS OF BEAMS FOLLOWING COMBINED RESTRAINT TESTS FIG. 14



FAILURE OF BS4360 GRADE 43A BEAMS UNDER BS476 PART 8 FIRE TESTS

FIG. 15
(R1/8745)



STRESSES IN COLUMNS AND BEAMS DUE TO THERMAL EXPANSION
(SIMPLY SUPPORTED BEAM, PIN JOINTED COLUMN)

FIG. 16
(R1/8746)

APPENDIX 1 LOAD CALCULATIONS

Actual properties of the Universal Beam:-

Depth of section (D) : 260 mm
Breadth of section (B) : 146 mm
Thickness of flange (T) : 12.36 mm
Thickness of web (t) : 7.34 mm
Mass per metre (m) : 412.179 N/m
Moment of inertia (I) : 6.3345E+07 mm^4
Distance of neutral axis
to the base of the beam (y) : 130 mm

Effective span of the beam (L) : 4500 mm

Maximum allowable bending stress to BS449 : Part 2 : 1969, Table 2

$$f = 230 \ N/mm^2$$

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
$w = 8 * 165 * 6.3345E+07/130 * 4500 * 4500$
$w = 31762.7$ N/m

Concrete topping slab:-

Depth = 130 mm
Width = 630 mm
Mass per metre = 1799.7 N/m

Total self weight of beam and topping = 2211.88 N/m

Required imposed load to produce required bending stress

= 31762.7 - 2211.88 N/m
= 29550.8 N/m

Therefore total imposed load = 13555.4 kg

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

Point loads required = 3388.85 kg

APPENDIX 2 CALCULATION OF RESTRAINING MOMENT

Central bending moment $= \frac{wL^{-2}}{8}$

where W is the uniformly distributed load and
L is the beam span

In this case (from Appendix 1) w = 31.76 kN/m

.˙. central bending moment = 80.39 kNm

30% Rotational Restraint

The end moment required is 30% of the central bending moment which was achieved by applying a load of 33.7 kN (3.4 t) at a distance of 0.715 m from the support.

For 70% Rotational Restraint

The end moment required is 70% of the central bending moment which was achieved by applying a load of 78.7 kN (8.1 t) at a distance of 0.715 m from the roller support.

APPENDIX 3 BS4360 : GRADE 43A STEEL, WITH A SECTION SIZE OF 254 x 146 mm x 43 kg/m AND A HP/A VALUE OF 169 m^{-1}

A3.1 BSC Test No. 57, Test Ref. No. 28, WRC No. 31764, Test Date 27.1.83 (Fully Loaded With 30% Rotational Restraint - Continuous Concrete)

	Flange
Yield stress, N/mm^2	267
Tensile strength, N/mm^2	485
Elongation (200 mm GL), %	29.0

Sample No.	Composition, %														
	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Sn	Nb	Zr	Tot. Al	N_2
RS394	0.24	0.03	0.91	0.013	0.031	0.03	0.007	0.03	<0.005	<0.005	0.05	-	<0.005	-	<0.005	0.005

Failure time: 41 min

Thermocouple Location		Temperature, °C, After Various Times, min													
		3	6	9	12	15	18	21	24	27	30	33	36	39	41
Lower flange	1	92	204	329	443	540	606	650	684	710	734	755	785	810	830
	2	124	238	351	455	544	609	651	683	712	739	759	789	816	834
	4	90	186	299	413	514	585	635	671	701	733	745	774	801	819
	6	100	211	335	449	545	608	652	683	707	726	744	769	775	751
	7	105	217	337	453	549	615	659	691	718	739	764	792	817	836
Mean		102	211	330	443	538	605	649	682	710	734	753	781	804	814
Web	1	128	237	355	454	537	591	629	660	686	720	738	757	784	804
	2	141	264	383	482	564	615	652	682	705	738	750	780	809	827
	3	124	246	367	470	551	606	642	672	699	733	745	771	801	822
	4	104	209	326	431	525	583	628	662	689	724	739	760	789	808
Mean		124	239	358	459	544	599	638	669	695	729	743	767	796	815
Mean lower flange and web		112	223	342	450	541	602	644	676	703	732	749	775	800	814
Upper flange	3	70	120	170	222	279	335	382	430	477	526	573	614	652	675
	5	47	83	131	181	237	291	342	393	444	496	543	587	625	649
	8	58	108	161	215	275	333	377	385	433	488	538	583	622	646
	9	52	94	145	201	263	319	375	424	469	519	567	608	643	666
Mean		57	101	152	205	263	319	369	408	456	507	555	598	635	659
Web	5	87	150	209	268	333	396	442	487	524	566	604	638	667	684
Flange	10	161	243	291	341	416	490	541	590	628	671	707	736	753	766
Upper flange	11	39	64	86	114	148	184	215	250	281	318	357	393	427	450
Atmosphere	1	429	546	613	655	697	716	734	747	774	804	820	832	850	860
	2	439	585	653	705	737	761	771	795	810	850	861	878	896	904
	3	455	597	660	707	745	767	783	799	830	860	873	893	906	915
	4	433	554	629	694	727	743	765	779	806	844	862	883	896	903
	5	438	575	656	718	749	762	784	806	820	855	876	895	903	907
	6	413	530	604	673	715	753	757	776	795	825	850	861	878	885
Mean atmosphere		434	564	636	692	728	750	766	783	805	840	857	874	888	896
ISO curve RT 17°C		499	600	660	702	735	763	786	805	823	839	853	866	878	885
Deflection, mm		5	15	27	38	50	60	70	81	96	108	118	127	138	148

A3.2 BSC Test No. 59, Test Ref. No. 29, WRC No. 31765, Test Date 22.2.83
(Fully Loaded With 30% Rotational and Thermal Restraint - Continuous Concrete)
Flange

Yield stress, N/mm^2 285
Tensile strength, N/mm^2 481
Elongation (200 mm GL), % 28.0

Sample No.	Composition, %														
	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Sn	Nb	Zr	Tot. Al	N_2
RS460	0.23	0.02	0.91	0.012	0.029	0.02	<0.01	0.03	<0.01	<0.01	0.05	-	<0.005	-	<0.005	0.005

Failure time: 48 min

Thermocouple Location		Temperature, ^{o}C, After Various Times, min															
		3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Lower flange	1	92	207	333	452	544	608	658	693	725	746	767	788	809	832	853	868
	2	83	194	320	444	546	615	667	703	732	750	767	788	812	837	858	874
	4	101	209	330	440	534	601	652	689	721	739	759	780	804	827	850	866
	6	95	205	335	456	552	619	669	705	733	754	775	796	820	844	865	881
	7	87	200	326	447	544	612	662	700	731	752	773	794	811	838	860	877
Mean		92	203	329	448	544	611	662	698	728	748	768	789	811	836	857	873
Web	1	149	252	370	466	544	600	643	678	713	728	743	760	781	806	829	849
	2	128	244	375	484	568	623	666	700	729	745	762	778	796	821	847	866
	3	136	257	382	484	567	620	662	696	725	741	758	774	792	822	847	865
	4	109	227	348	452	532	588	632	667	700	718	732	744	769	797	822	841
Mean		130	245	369	471	553	608	651	685	717	733	749	764	784	811	836	855
Mean lower flange and web		109	222	346	458	548	609	657	692	723	741	759	778	799	825	848	865
Upper flange	3	48	94	146	201	258	316	375	431	485	525	565	605	646	674	701	724
	5	49	90	143	194	253	309	368	423	478	546	567	604	642	674	703	726
	8	50	96	151	211	276	341	402	453	504	543	584	617	652	682	710	732
	9	53	106	165	217	274	327	376	425	472	511	551	590	630	659	685	711
Mean		50	96	151	206	265	323	380	433	485	531	567	604	642	672	700	723
Web	5	88	163	242	320	392	452	503	550	592	620	649	677	707	726	737	753
Flange	10	98	200	273	347	417	477	527	571	611	641	672	696	720	737	753	771
Upper flange	11	47	75	108	141	174	210	247	288	334	382	430	478	522	553	580	607
Atmosphere	1	457	525	590	620	660	689	710	739	756	777	800	812	825	838	853	866
	2	473	564	648	685	729	765	782	806	833	846	860	873	887	902	914	926
	3	498	591	667	697	744	775	785	815	832	847	862	875	890	899	920	927
	4	472	579	663	699	743	773	791	815	834	846	857	875	894	909	922	930
	5	490	587	656	673	709	743	762	789	811	824	838	851	868	883	896	911
	6	473	555	629	651	693	724	739	767	781	794	807	820	836	849	873	877
Mean atmosphere		477	567	642	670	713	744	761	788	808	822	837	851	866	880	896	906
ISO curve RT $14^{o}C$		496	597	657	699	732	760	783	802	820	836	850	863	875	886	896	906
Deflection, mm		4	11	22	32	39	45	45	46	43	42	48	64	82	107	128	152

A3.3 BSC Test No. 60, Test Ref. No. 30, WRC No. 31766, Test Date 24.2.83 (Fully Loaded With 30% Rotational And Thermal Restraint - Segmented Concrete)

Flange

Yield stress, N/mm^2	294
Tensile strength, N/mm^2	484
Elongation (200 mm GL), %	31.0

Sample No.	Composition, %														
	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Sn	Nb	Zr	Tot. Al	N$_2$
RS461	0.23	0.02	0.92	0.01	0.029	0.02	<0.01	0.03	<0.01	<0.01	0.05	-	<0.005	-	<0.005	0.005

Failure time: 44 min

Thermocouple Location	Temperature, °C, After Various Times, min														
	2	6	9	12	15	18	21	24	27	30	33	36	39	42	44
Lower flange 1	149	265	372	470	551	608	653	693	724	738	757	779	801	822	840
2	138	249	364	467	553	613	661	701	730	741	763	785	809	833	851
4	148	257	360	454	534	592	639	680	711	732	743	762	787	807	825
6	173	266	382	480	558	616	661	700	731	743	763	784	807	828	846
7	160	261	363	460	542	602	651	692	724	738	757	777	801	823	843
Mean	154	260	368	466	548	606	653	693	724	738	757	777	801	823	841
Web 1	202	298	394	478	543	592	633	673	705	726	735	750	774	797	815
2	189	292	401	496	566	617	659	697	724	736	751	771	796	821	839
3	209	297	403	492	561	612	652	690	717	737	746	766	792	815	836
4	195	288	382	467	534	584	626	666	696	718	735	745	769	791	810
Mean	199	287	390	480	550	602	645	684	713	731	745	762	786	809	825
Mean lower flange and web	174	275	380	474	549	604	648	680	718	734	750	769	793	815	834
Upper flange 3	78	121	170	220	276	335	386	435	486	532	571	606	637	669	693
5	71	111	157	200	250	302	357	404	443	481	521	562	607	641	665
8	70	110	161	215	280	342	403	461	500	532	569	603	636	667	690
9	105	135	189	241	294	345	397	447	479	511	549	590	632	667	693
Mean	81	119	169	219	275	331	386	437	477	514	552	590	628	661	685
Web 5	132	189	256	323	386	439	489	540	582	617	647	674	700	719	734
Flange 10	89	166	234	306	377	437	493	545	589	626	658	686	710	727	737
Upper flange 11	53	75	105	136	167	198	236	279	316	353	389	424	460	493	522
Atmosphere 1	577	494	605	652	672	704	723	760	780	790	807	820	836	848	859
2	617	523	650	701	722	761	767	807	825	834	846	858	876	892	901
3	612	520	672	727	742	790	803	837	850	865	847	886	909	919	927
4	607	503	645	700	719	761	777	813	825	831	849	856	886	884	905
5	636	513	640	685	709	748	764	804	817	827	839	851	873	878	890
6	591	491	611	656	679	714	732	769	784	798	812	819	839	842	860
Mean atmosphere	606	507	637	686	707	746	761	798	813	824	833	848	870	877	890
ISO curve RT 12°C	436	595	655	697	730	758	781	800	818	834	848	861	873	884	893
Deflection, mm	0	7	17	27	39	51	55	57	58	61	71	89	112	133	148

A3.4 BSC Test No. 61, Test Ref. No. 31, WRC No. 31695, Test Date 22.3.83 (Fully Loaded)

	Flange
Yield stress, N/mm^2	286
Tensile strength, N/mm^2	480
Elongation (200 mm GL), %	31.0

Sample No.	Composition, %														
	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	Sn	Nb	Zr	Tot. Al	N_2
RS462	0.20	0.02	0.88	0.007	0.022	0.02	<0.01	0.03	<0.01	<0.01	0.05	-	<0.005	-	<0.005	0.004

Failure time: 46 min

Thermocouple Location	Temperature, °C, After Various Times, min																		
	5	8	10	12	15	18	21	24	27	30	33	36	39	42	45	46	49	52	5
Lower flange 1	118	224	324	432	525	591	646	685	713	734	744	763	783	803	822	828	847	863	878
2	136	245	343	451	525	590	646	685	713	732	745	764	784	805	825	831	849	865	878
4	163	272	364	472	511	575	628	666	695	719	737	745	762	781	799	805	824	842	858
6	117	227	327	435	532	597	651	689	717	736	749	768	790	809	828	834	852	868	882
7	138	238	334	442	513	580	637	676	705	729	740	760	779	797	817	823	840	856	871
Mean	134	241	338	446	521	587	642	680	709	730	743	760	780	799	818	824	842	859	873
Web 1	157	263	350	446	521	579	624	659	688	711	729	737	752	771	792	798	816	834	852
2	146	264	358	454	540	598	643	677	703	723	735	746	765	788	809	815	834	851	866
3	152	261	354	450	523	582	632	668	696	717	732	739	757	778	800	805	824	843	859
4	145	246	336	432	497	557	607	645	675	700	719	734	742	760	780	786	804	822	841
Mean	150	258	349	445	520	579	626	662	690	713	729	739	754	774	795	801	819	837	854
Mean lower flange and web	141	249	343	446	521	583	635	672	700	722	737	751	770	788	808	814	832	849	865
Upper flange 3	57	94	134	178	225	285	347	401	450	495	535	572	604	635	662	669	692	713	732
5	67	111	150	194	224	280	334	389	439	487	530	568	600	630	657	665	689	710	732
8	69	125	169	213	289	353	423	478	523	557	587	614	639	664	688	695	715	733	743
9	68	117	158	202	248	308	367	420	467	509	544	574	602	626	648	655	674	694	713
Mean	65	112	153	197	246	306	368	422	470	512	549	582	611	639	664	671	692	712	730
Web 5	104	172	226	282	356	416	475	526	566	601	630	655	677	696	713	718	731	743	763
Flange 10	89	158	218	282	368	434	500	556	600	635	664	638	710	727	736	738	755	773	793
Upper flange 11	44	69	86	104	124	176	217	256	293	326	363	396	429	462	495	506	538	577	616
Atmosphere 1	453	566	597	620	660	688	715	740	757	769	781	801	816	831	847	848	858	876	883
2	448	599	630	685	729	728	756	768	784	799	806	824	832	849	862	859	873	887	894
3	484	634	677	697	744	769	797	813	830	844	862	810	881	896	908	914	926	936	947
4	495	633	662	699	743	753	782	798	808	830	834	751	861	871	883	883	895	909	917
5	475	606	638	673	709	734	760	767	784	803	815	699	843	850	867	872	880	894	905
6	453	567	600	651	693	697	729	746	752	775	781	757	816	819	836	839	845	855	864
Mean atmosphere	468	601	634	670	713	728	756	772	786	803	813	773	841	852	867	869	879	893	902
ISO curve RT 14°C	568	637	670	697	730	758	781	800	818	834	848	861	873	884	894	898	907	916	924
Deflection, mm	4	11	18	23	28	29	29	30	36	48	67	88	107	126	144	150	161	177	204

APPENDIX 4 BS476 : PART 8, FIRE TEST RESULTS CONFIRMED BY WARRINGTON RESEARCH CENTRE

WRC 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. 31764
11th February 1983

Mr. Gavin Thompson,
British Steel Corporation,
Sheffield Laboratories,
Swindon House,
Moorgate,
Rotherham.

Dear Sir,

FIRE RESISTANCE 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 steel beam which was of serial size 254 mm by 146 mm by 43 kg/m and of Grade 43A steel in accordance with B.S. 4360: 1979. Throughout the duration of the test, the ends of the beam were partially restrained against rotation over their supports. A total load of 129 kN was applied to the beam via four point loads at 1/8, 3/8, 5/8 and 7/8th span positions being the load required for the support and fixity condition to produce a design stress of 165 N/mm^2 at centre span and a stress reduction of 30% x 165 N/mm^2 over the supports, i.e. 30% end fixity. The test results were as follows:

Stability : 41 minutes (Test discontinued)
Re-load test: Satisfied

Date of Test: 7th February 1983

After 41 minutes of testing, the deflection of the beam reached 148 mm at which time the test was discontinued.

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

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CHACOM G WARRES

Mr. Gavin Thompson,
British Steel Corporation,
Sheffield Laboratories,
Swindon House,
Moorgate,
Rotherham.

W.R.C.S.I. No. 31765
28th February 1983

Dear Sir,

FIRE RESISTANCE 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 steel beam which was of serial size 254 mm by 146 mm by 43 kg/m and of Grade 43A steel in accordance with B.S. 4360: 1979. The concrete topping to the beam was cast insitu and monolithic. Throughout the duration of the test, the ends of the beam were partially restrained against rotation over their supports. In addition, the free ends of the beam were restrained against longitudinal expansion movement by a specially designed end restraint frame. A total load of 129 kN was applied to the beam via four point loads at 1/8, 3/8, 5/8 and 7/8 span positions, being the load required for the support and fixity condition to produce a design stress of 165 N/mm^2 at centre span and a stress reduction of 30% x 165 N/mm^2 over the supports, i.e. 30% end fixity. The test results were as follows:

Stability : 48 minutes (Test discontinued)
Re-load test: Satisfied

Date of test: 22nd February 1983

After 48 minutes of testing, the deflection of the beam reached the permissible limit of 150 mm and the test was discontinued.

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,

AHBone

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

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CHACOM G WARRES

Mr. Gavin Thompson,
British Steel Corporation,
Sheffield Laboratories,
Swindon House,
Moorgate,
Rotherham.

W.R.C.S.I. No. 31766
28th February 1983

Dear Sir,

FIRE RESISTANCE 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 steel beam which was of serial size 254 mm by 146 mm by 43 kg/m and of Grade 43A steel in accordance with B.S. 4360: 1979. The concrete topping to the beam was cast insitu in four discrete sections at 1/3 span positions approximately. Throughout the duration of the test, the ends of the beam were partially restrained against rotation over their supports. In addition, the free ends of the beam were restrained against longitudinal expansion movement by a specially designed end restraint frame. A total load of 129 kN was applied to the beam via four point loads at 1/8, 3/8, 5/8 and 7/8th span positions being the load required for the support and fixity condition to produce a design stress of 165 N/mm^2 at centre span and a stress reduction of 30% x 165 N/mm^2 over the supports, i.e. 30% end fixity. The test results were as follows:

Stability : 44 minutes
Re-load test: Satisfied

Date of test: 25th February 1983

After 44 minutes of testing, the deflection of the beam reached 148 mm. The load was removed from the beam after a period of testing of 44 minutes 30 seconds at which time the beam had exceeded its permissible limit of deflection by a distance of 1 mm.

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)

WARRINGTON
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CHACOM G WARRES

Mr. G. Thompson,

British Steel Corporation
Sheffield Laboratories,
Swindon House,
Moorgate,
Rotherham.

W.R.C.S.I. No. 31695
24th March 1983

Dear Sir,

FIRE RESISTANCE 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 steel beam which was of serial size 254 mm by 146 mm by 43 kg/m and of Grade 43A steel in accordance with B.S. 4360: 1979. The concrete topping to the beam was cast insitu in four discrete sections at 1/3 span positions approximately. Throughout the duration of the test, the ends of the beam were partially restrained against rotation over their supports. In addition, the free ends of the beam were restrained against longitudinal expansion movement by a specially designed end restraint frame. A total load of 129 kN was applied to the beam via four point loads at 1/8, 3/8, 5/8 and 7/8th span positions being the load required for the support end fixity condition to produce a design stress of 165 N/mm^2 at centre span and a stress reduction of 70% x 165 N/mm^2 over the supports. i.e. 70% end fixity. The test results were as follows:

Stability : 46 minutes
Re-load test: Satisfied

Date of test: 22nd March 1983

After 46 minutes of testing, the deflection of the beam reached 150 mm. At the request of yourself, the load was maintained and removed from the beam after a period of testing of 54 minutes 20 seconds at which time the total deflection of the beam was 195 mm and increasing at a rate of 10 mm per minute.

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