RESEARCH SERVICES

Ref. No:	RS/RSC/7281/12/86/E
Date:	12th May, 1986
Classification:	CONFIDENTIAL

CONTRACT REPORT
for

BSC SECTIONS & COMMERCIAL STEELS/DEPARTMENT OF THE ENVIRONMENT - BUILDING RESEARCH ESTABLISHMENT/FIRE RESEARCH STATION

SECOND NATURAL FIRE TEST ON A LOADED STEEL FRAME AT CARDINGTON

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RS/RSC/7281/12/86/E

SECOND NATURAL FIRE TEST ON A LOADED STEEL FRAME AT CARDINGTON

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SYNOPSIS

The second of two natural fire tests on a loaded, two dimensional steel framework is described. The structure comprised an unprotected 406 x 178 mm x 54 kg/m beam which spanned the compartment at ceiling height and was attached at each end by bolted connections to 'blocked in' columns. Maximum design loads as permitted by BS 449, were applied to both the beam and the columns in the structure. A fire load density of 25 kg/m² of wood and the 1/8 ventilation of two walls were selected to ensure that the stability of the test frame was exceeded.

The unprotected beam reached a maximum lower flange temperature at mid-span of 775°C after 20 minutes. The 'blocked in' columns reached maximum temperatures of 575°C and 600°C respectively. A time equivalent of 32.5 minutes was estimated to be appropriate for this fire.

During the test the beam initially hogged but then sagged at an increasing rate such that the loads had to be removed at a deflection of $^{L}/_{33}$. Extrapolation indicated that the limiting deflection of $^{L}/_{30}$ would have occurred ½ minute later. The 'blocked in' columns bowed towards the adjacent walls at the conclusion of the test.

These observations emphasised the fact that steel frameworks exhibit a significantly greater fire resistance than their individual steel elements.

This work completed the experimental programme of the joint BSC/DoE contract concerned with the structural stability of steel frames in natural fires.

KEY WORDS

3. Fire Resistance
4. Natural Fires
5. Structural Components
6. Construction Industry
6. Temperatures
7. Deflection
8. Testing

12th May 1986

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SECOND NATURAL FIRE TEST ON A LOADED STEEL FRAME AT CARDINGTON

1. INTRODUCTION

The prediction of the performance of steel frames in naturally occurring fires is an important aspect of fire resistant structural design. Currently, the analysis is being approached in two stages involving, initially, the simulation of the behaviour of loaded but restrained beams followed by a study of beam/column combinations. However, experimental data are required to assist in the verification of the mathematical model.

The Cardington compartment was modified to enable natural fire tests to be carried out on a loaded framework. The structure comprised a 406 x 178 mm x 54 kg/m bare steel beam which spanned the compartment at ceiling height and was attached at each end to a 203 x 203 mm x 52 kg/m 'blocked in' column. Maximum BS 449 design loads were applied both to the columns and the beam. In the first test a fire load density of 20 kg/m² of wood and the 1/8 ventilation of two opposite walls were selected to ensure that the limiting temperature for the load carrying capacity of the beam was attained[1]. Despite the fact that a maximum lower flange temperature of 657°C was measured there was no significant deflection, due principally to the degree of end restraint imposed at the connections.

The present report describes a second natural fire test on the loaded steel framework which formed the twenty-third experiment in the Cardington series sponsored jointly by the BSC and DoE. Both the blockwork in the test columns and the bolts in the connections had been replaced and additional fire protection had been given to the tie members of the loading frame to reduce thermal expansion. A more comprehensive coverage of the deflection characteristics of the assembly was provided. A fire load density of 25 kg/m² of wood and the 1/8 ventilation of two opposite walls in the compartment were used to ensure that the structural stability of the framework was exceeded.

2. EXPERIMENTAL PROCEDURE

The fire compartment, which measures 8.6 m x 5.5 m x 3.9 m high has been built within the No. 2 Hangar at RAF Cardington so that tests are almost independent of weather conditions. The constructional materials were selected on the basis that they would withstand repeated exposure to high temperatures without collapsing or changing their thermal characteristics and so some of them would not normally be found in modern buildings.

A total of twenty-one fire tests had already been carried out in the compartment to measure the heating rates of several unprotected beams and columns as well as a water filled hollow section. The steelwork was evenly distributed throughout the compartment to minimise its effect as a heat sink. Before the loaded framework was installed these sections were removed and this necessitated certain repairs to the structure and the removal of the precast concrete roof slabs. Once the new loaded framework had been installed a number of unused concrete planks were placed on the roof for the first loaded test. The inner exposed surfaces of the compartment comprised heat resistant brickwork.

2.1 Steel Framework

The steel framework selected for testing under load was typical of that used in a multi-storey building of 2 to 3 storeys in height. The design is detailed in Drawing No. C/01/AO/A but the salient features are given in Figs. 1 to 4.

The test sections comprised a 4.55 m length of 406 x 178 mm x 54 kg/m BS 4360 : Grade 43A universal beam and two 3.53 m lengths of a 203 x 203 mm x 52 kg/m universal column. These serial sizes were chosen because they had previously been included in earlier BS 476 : Pt. 8 fire tests on partially protected members.

The general arrangement of the test frame is shown in Fig. 1. The beam was connected to the columns by M20 Grade 8.8 bolts through welded end plates. The assembly was centrally positioned inside the compartment parallel to the short walls. Each column, which extended above the beam, was pin jointed at the base to 1.5 m lengths of 533 x 210 mm x 92 kg/m section which also formed the base of the loading frame. The webs of each column were protected by lightweight blocks built between the flanges using an ordinary mortar mix followed by a 28 day drying out period. Four 1200 x 550 x 150 mm concrete slabs which formed part of the compartment roof were attached to the top flange of the beam by welded 12 mm diameter threaded bars. The slabs were separated by a gap of 25 mm to prevent composite action with the beam and the gap was filled with ceramic fibre blanket.

A second frame shown in Fig. 2 provided a structure from which the appropriate design loads could be applied to the test assembly beneath. This comprised a 533 x 210 mm x 92 kg/m universal beam as a crosshead, each end of which was attached to two vertical 152 x 89 mm channel sections that straddled the blocked in columns and were fixed to the base sections of the loading frame. These sections were braced and bolted to the concrete floor.

Both frames were held in position by a combination of external bracing and a subsidiary steel framework contained within the compartment. General views of the assembly are shown in Fig. 3. With the exception of the test frame the remainder of the structure inside the compartment, Fig. 4, and lengths of the external braces in front of the ventilators were lagged with ceramic blanket. Despite these precautions the two vertical 152 x 89 mm channel sections attached to each end of the crosshead had expanded during the first fire test on the frame. Therefore, each tie member was given additional fire protection by coating the steel with wet plaster (50 mm thick) to a nominal diameter of 220 mm held in position by retaining mesh.

2.2 Loading the Frame

A hydraulic ram and load cell were superimposed between the top bearing plate of each 'blocked in' column and the crosshead member to provide the maximum permissible, compressive, design load of 552 kN (BS 449:1972). The beam was loaded at four positions (Fig. 5) along the span each with a load of 39.6 kN to generate a maximum design stress in bending of 165 N/mm² (BS 449:1972). The loads were maintained throughout the period of the fire test. A general view of the loading arrangement is shown in Fig. 6.

2.3 Instrumentation

The temperature distribution of the combustion gas in the compartment during the fire was monitored by 3 mm diameter chromel/alumel Type K thermocouples with Inconel sheaths and insulated hot junctions. In the vicinity of the test frame, the thermocouples were positioned 300 mm from each flange face of the blocked in columns and at heights of 1200, 2400 and 3330 mm above the floor. Thermocouples were also positioned 100 mm from the test beam and at 6 locations along the length of the lower flange. The combustion gas temperatures were also measured at locations half way between the main frame and each of the short walls of the compartment at heights of 2000 or 3300 mm above the floor. The disposition of the thermocouples is shown in Fig. 7(a).

Similar thermocouples were used to measure the steel temperature gradients in the flanges and webs of the test frame at the positions shown in Fig. 7(b). The tip of each thermocouple was inset into a 3 mm diameter hole drilled into the steel section at the positions shown in Fig. 7(c). Thermocouples were also attached at mid-height to the 152 x 89 mm channel sections of the loading frame.

In order to compare the steel temperatures recorded in the test with earlier measurements a 1.6 m length of 203 x 203 mm x 52 kg/m indicative column was placed in the compartment at the same position as that occupied by FSC1[2].

Thermocouples were attached to the flanges and web of this section at a height of 1500 mm above the floor. The 203 x 203 mm x 52 kg/m external column used in the earlier tests was also included in the comparison, the thermocouples were mounted at heights of 1.9 m and 3.3 m from the floor (corresponding to distances of 2.0 m and 0.5 m respectively from the ceiling of the compartment as referred to in earlier reports).

Deflection measurements were made at the centre of the loaded beam using two separate potentiometric transducers mounted to a fixture on the roof of the compartment. A similar device was located between the crosshead and the top of one blocked in column. Three linear displacement transducers were installed by FRS to follow the lateral bowing of each blocked in column. The transducers were positioned 850 mm, 2180 mm and 3550 mm respectively above the floor of the hangar outside the compartment, as shown in Fig. 8.

The temperatures of the top and bottom bolts of the connection were monitored with thermocouples inserted to a depth of 22 mm from the face of the exposed bolt head and to a depth of 12 mm from the end of the threads that were surrounded by mortar and blockwork. In addition, one top bolt was adapted to accept a temperature compensated strain gauge to measure the tensile stresses in the thread during the test. The strain gauge comprised a 6 x 2.6 mm Ni-Cr foil element with a gauge factor of 2.3 mounted on a polyimide carrier suitable for use up to 300°C.

The outputs from the separate measuring instruments were fed back to a Compulog 4 computer controlled data acquisition system. The output from the strain gauged bolt was also directed to a visual display unit.

2.3 Fire Load and Ventilation

Based on observations made during the first loaded frame test it was considered that the maximum lower flange temperature of the beam would have to increase by approximately 100°C to ensure structural collapse. The studies of the temperatures attained by unprotected steelwork in natural fires suggested that for similar ventilation conditions the wooden fire load density should be 25 kg/m², representing the highest fuel load examined at Cardington.

Previous work had also suggested that for a given total ventilation to the compartment the difference in the fire behaviour caused by openings in one wall, or the two opposite walls was small[2]. As it was important to obtain as symmetrical a heating pattern across the loaded frame as possible, openings were made in both long walls of the compartment using the appropriate shutters to maintain the 1/8 ventilation in the area of each wall that was used in Test No. 22.

It was considered advisable to reduce the rate of burning, as experienced in the earlier fires on unloaded members, to allow time for the loads on the beam to be effectively controlled and also to establish a more realistic temperature distribution over the cross section of the blocked in column. This had been achieved in the first test on the loaded frame by wiring together a number of the standard wooden sticks to form bundles 100 x 100 mm and placing these in two consecutive layers in the crib. Such a reduction in the total surface area of the fuel was too great. Therefore, the layout of each of the 12 cribs in the present test comprised 50 x 50 x 1000 mm sticks spaced 50 mm apart with alternate rows at right angles to each other but with the third layer from the bottom replaced by 100 x 100 bundles placed 100 mm apart.

3. EXPERIMENTAL RESULTS - CARDINGTON FIRE TEST NO. 23.

Date: 21st February, 1986.

Fire Load Density: 25 kg/m² in 12 cribs, total wood fire load = 1320 kg based on a 15% moisture content. (The wood comprised a mixture of kiln dried and sawn wood stored at Cardington).

Ventilation: 1/8 of North wall + 1/8 of South wall ≡ 0.06 $m^{\frac{1}{2}}$

3.1 General Observations

The cribs were ignited simultaneously on a still day when the air temperature inside the compartment was -5°C. General combustion of the fuel at the back of the compartment occurred later than elsewhere. Once the fire became established the intensity was greatest at the centre of the compartment. Representative photographs of the fire test are shown in Fig. 9.

The maximum load applied to both columns and the beam was maintained until the beam became unstable. At this time the rate of movement of the test frame became greater than the rate and extent of ram travel on the jacks. The load was removed after 22 minutes but by this time the maximum temperature in the beam had been passed.

The thermocouple outputs from the tie members supporting the crosshead were erratic due to the presence of moisture in the plaster but showed no rise in temperature. The test beam initially hogged but later sagged at an increasing rate. The blocked in columns bowed towards the sides of the compartment in the later stages of the test but the connections remained intact.

As in the first test,the output from the strain gauge bolt was erratic. A maximum tensile load of 145 kN was recorded after 4 minutes which then rapidly reduced to about 20 kN. Later a compressive load of -70 kN was indicated. In view of the nature of the deformation behaviour in the vicinity of the connection these observations were considered to be spurious.

An examination of the loaded frame at the conclusion of the test showed it to be distorted and probably incapable of supporting a significant load. A number of concrete slabs on the roof of the compartment exhibited considerable spalling.

3.2 Atmosphere Temperatures

The atmosphere temperatures in the vicinity of the loaded structure are given in Table 1 and at other positions inside the compartment in Table 2 as a function of time. Reference should be made to Fig. 7(a) for the thermocouple numbering system. Unfortunately, a fault in one data logger prevented the comprehensive monitoring of temperatures after 28 minutes.

A maximum average temperature of 837°C was recorded at the centre of the compartment after 17 minutes.

The change in combustion gas temperature with height is shown in Fig. 10, measured in the vicinity of the columns. After 17 minutes the average temperature at the 3.3 m level was 758°C, at the middle position 800°C but at the 1200 mm level the temperature ranged from 780°C ($\frac{A11 + A13}{2}$) to 713°C (A16); the lower value may be associated with the sluggish combustion of cribs in the vicinity.

The average change in combustion gas temperature across the top of the compartment is shown in Fig. 11. The development of the combustion gas temperature with time along the beam is represented in Fig. 12 for a number of time periods throughout the fire test. As a result of equal ventilation from both walls of the compartment the hottest region of the fire occurred at the centre of the beam. Once the peak temperature had been reached the heating became more uniform.

3.3 Steelwork Temperatures

The temperatures recorded during the test are given in Tables 3 to 9 and typical patterns of behaviour in Figs. 13 to 18. The numbered thermocouple positions used in the presentation of data are depicted at the head of each table.

3.1.1 Loaded Beam

The steel temperatures along the flanges of the beam are presented in Table 3 and the web temperatures in Table 4. The steel heating rate was faster at the centre of the beam as shown by the individual temperature profiles in the lower flange (Fig. 13(a)) and web (Fig. 13(b)). For example F4, close to the centre of the beam reached a maximum temperature of 775°C after 20 minutes whereas F1, close to the connection reached 671°C at the same time. The corresponding temperatures in the web were 777°C and 702°C and the upper flange (F10) reached 577°C at the same time.

The average changes in both atmosphere and steel temperatures at the ends and at the centre of the beam are summarised in Fig. 14. The maximum combustion gas temperature occurred approximately three minutes before the beam reached its highest temperature.

3.3.2 Loaded Columns

The steel temperatures for the blocked in column at the front of the compartment nearest to the hangar door are presented in Table 5 and for the blocked in column attached to the other end of the beam in Table 6. The steel heating rate was faster on the flange facing into the compartment. The temperatures measured in the front column are shown in Fig. 15. Based on both the atmosphere temperatures in the vicinity and the temperatures measured on the other column, Fig. 16, it is assumed that the thermocouple F3 was suspect. The maximum temperature on the exposed flange of the front column was therefore 606°C reached after 20 minutes by which time the maximum temperature in the unexposed flange was 514°C. The corresponding temperatures on the back column after 20 minutes were 575°C and 494°C.

The temperatures recorded by individual thermocouples in the webs of each column are shown in Fig. 17. The highest web temperature on the front column of 358°C was recorded after 35 minutes. The lowest temperature of 296°C occurred in the vicinity of the connection. In comparison with the first trial the steel temperatures were not influenced by the presence of moisture.

The average changes in both the atmosphere and steel temperatures at the centre of the blocked in column are typified by the curves of Fig. 18 recorded at the back of the compartment. The maximum average flange temperature of 545°C occurred 6 minutes after the fire had reached its peak.

3.3.3 Bolts

The temperatures measured in the thread of the bolts used for the connections are presented in Table 7 and Fig. 19 shows typical temperature profiles beneath the bolt head and nut for the front connection. The bolts in the lower part of this connection were the hottest during the fire test. The average maximum temperatures reached by the thread of the bolts beneath the head were 475°C for the lower and 435°C for the upper bolt, recorded after approximately 32 minutes. The drop in temperature along the thread was similar for both bolts.

In an earlier indicative BS 476 : Pt. 8 fire test on a similar connection the bottom bolts also exhibited a faster heating rate than the top bolts. After 25 minutes the bottom bolt threads reached a temperature of 336°C below the head and 238°C behind the brickwork. In the present test the corresponding temperatures were 470°C and 387°C for one connection and 464°C and 374°C for the other.

3.3.4 Indicative Column

The temperature measurements recorded at the 1500 mm position on the indicative column ($^{HP}/A = 180\ m^{-1}$) are presented in Table 8 and Fig. 20. A maximum average steel temperature of 768°C was reached after 21 minutes.

3.3.5 External Column

The external column with an $^{HP}/A = 180\ m^{-1}$ reached a peak temperature of 255°C (1900 mm level) after 23 minutes. The peak temperature recorded on the exposed flange at a height of 3300 mm was 149°C. The results are presented in Table 9.

3.4 Deflection Behaviour

The central vertical displacement of the beam is shown in Fig. 21. As the equipment was mounted independent of the loading frame the results are considered to represent an accurate reflection of the behaviour. After approximately 5 minutes the beam began to hog; this trend continued to give a maximum apparent upward deflection of 45 mm. The beam started to sag after 14 minutes at an increasing rate rising to 30 mm/minute and the load was eventually removed after 22 minutes. At the point of inflexion the maximum lower flange temperature was 678°C. The total sagging deflection from a horizontal position was 138 mm (i.e. 120 + initial permanent deflection of the beam following the first test), equivalent to L/33. As the upper flange of the beam moved below the lateral support provided by the concrete roof planks the lower flange underwent torsional buckling. Subsequent examination revealed the presence of a plastic hinge approximately 600 mm from each end and a 5 mm separation at the top of the end plate of the connection from the column flange. The appearance of the beam on completion of the test is shown in Fig. 22. For safety reasons a check on the residual vertical deflection at the centre of the beam was not possible.

As the vertical tensile members linked to the crosshead showed no significant rise in temperature the measured extension of the front blocked in column, Fig. 23, is considered to be realistic. The column expanded to reach a maximum extension of 20 mm after 15 minutes. Beyond that time lateral movement of the column became more pronounced as the test beam sagged into the compartment. The lateral movement of each column as determined by FRS is presented in Table 10 and Fig. 24. These results showed that during the early stages of the test the inward facing flanges became convex the effect being more noticeable on the front member. This distortion accompanied the hogging of the test beam. After 20 minutes the centre of each column bowed towards the adjacent wall. The measured column displacements at the time when the load was removed are plotted in Fig. 25. The measurements on the column have been extrapolated to the corresponding positions of the top and bottom flanges of the beam. Thus, the total lateral movement of both columns towards the walls of the compartment was 65 mm from the upper flange of the beam and 68 mm from the lower flange. The residual displacement measured by the FRS transducers at a height of 2090 mm is also included in Fig. 25. Subsequent measurements at the same position on the columns when at ambient temperature recorded respective lateral displacement of 25 mm and 20 mm, consistent with the observations made during the test.

4. DISCUSSION

The behaviour of a natural fire can be related to an equivalent heating time in the BS476 : Pt. 8 fire resistance test. For the fire load and ventilation conditions used at Cardington the theoretical relationship established by FRS predicted a time equivalent of 30.75 minutes. The unprotected steel beam reached a maximum average lower flange temperature of 774°C in the fire (adjusted to an ambient temperature of 20°C) from which a time equivalent of 32 minutes was predicted by finite element mathematical analysis. A time equivalent of 33 minutes was also predicted from the maximum average temperatures recorded on the indicative column

The observations all emphasised that the particular framework under test exceeded the ½ h fire rating. In comparison with a fire resistance of 20 minutes established for the unprotected beam in the simply supported condition this was a considerable improvement. The increased fire resistance was due principally to the rotational restraint imposed at the ends of the beam. The maximum bolt thread temperatures ranged from 435°C to 475°C and apart from slight distortion of the end plate the connections were sufficiently fire resistant to avoid the need for any additional protection.

The deflection behaviour of the frame was complicated. The front 'blocked in' column recorded a maximum axial expansion of 20 mm after 15 minutes. Therefore after 14 minutes the measured upward displacement of the centre of the beam relative to its ends was no greater than 25 mm. As the stiffness of the beam was much greater than the universal column sections thermal bowing in a downward direction had been expected to override any tendency towards hogging from differential thermal expansion across the columns. Once the lower flange exceeded 678°C the beam failed to support the load and commenced to sag. The rate of vertical deflection then increased until the displacement could not be followed by the hydraulic jacks which were then endangered by the heat from the fire. The load was therefore removed after 22 minutes when the total deflection of the beam was L/33. Had it been possible to maintain the load, a deflection of L/30 would probably have occurred after a further 30 seconds.

Laboratory studies at FRS have developed theories for calculating the angular rotation and lateral deflection of a steel member in the absence of externally applied loads when the member has a temperature gradient across the section[3]. The same analysis has been used to calculate the influence of temperature gradients alone on the total lateral separation between the 'blocked in' columns and the change in length of the beam at a height corresponding to its lower flange from the data in Table 11. The calculated displacements are compared with those measured on the loaded columns in Fig. 26. During the first four minutes of the test no lateral thermal movement of the columns was detected. Apart from some realignment of the framework that might have occurred there was no obvious experimental reason for this discrepancy, although a similar occurrence occurred in the FRS study on thermal bowing. After 14 minutes into the test the calculated lateral extension of the beam was 41.4 mm which compared favourably with the measured displacement of both columns. As the bottom of the columns were pin jointed the high rotational forces at the connections due to thermal bowing would superimpose only a small axial tensile stress in the beam. Once the beam began to sag the increasing separation between the columns of the test frame would result in plastic deformation of the longitudinal member.

5. CONCLUSIONS

A test frame comprising an unprotected 406 x 178 mm x 54 kg/m beam bolted to two 'blocked in' 203 x 203 mm x 52 kg/m columns was installed in the Cardington compartment. The maximum design load (BS 449:1972) was applied axially to each column and over four points to the beam. The test frame was subjected to a natural fire based on a fire load density of 25 kg/m² and the 1/8 ventilation of two walls.

The FRS relationship predicted a time equivalent of 30.5 minutes for the fire load and ventilation conditions used. The finite element mathematical model predicted a time equivalent of 31 minutes for the beam in the test frame and 33 minutes for an indicative column placed inside the compartment.

The unprotected beam reached a maximum lower flange temperature at the centre of the span of 775°C after 20 minutes. The 'blocked in' columns reached respective maximum temperatures of 575°C and 606°C on the inner facing flanges; the outer facing flanges were about 100°C cooler and the temperatures in the web were not influenced by the presence of moisture. The bottom bolts in the connections were hotter than the upper bolts with an average maximum temperature in the thread beneath the head of 475°C.

The beam 'hogged' during the early stages of the test but started to sag after 14 minutes when the maximum lower flange temperature was 678°C. The maximum deflection achieved was L/33. The inward facing flanges of the blocked in columns became convex during the early stages of the test but bowed towards the adjacent walls at the end.

These observations emphasised the fact that steel frameworks can exhibit a greater fire resistance than their individual steel elements. The particular structure under test satisfied the ½ h fire rating without the need for additional protection.

6. REFERENCES

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ACKNOWLEDGEMENTS

Thanks are due to Mr. J. Fallon, a Structural Advisory Engineer in BSC Sections and Commercial Steels for designing the steel framework and also to Mr. G.M.E. Cooke of FRS for helpful discussions during the investigation.

TABLE 1 ATMOSPHERE TEMPERATURE DATA (ADJACENT TO LOADED STRUCTURE)

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

COMPONENT IDENTITY : ATMOSPHERE
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

TIME	ATMOSPHERE TEMPERATURES (deg C)															
	<---------------- COLUMNS ---------------->								<---------------- BEAM ---------------->							
	1200mm LEVEL				2400mm LEVEL				3300mm LEVEL							
	(s)	(s)	(n)	(n)	(s)	(s)	(n)	(n)	(n)	(n)	(n)	(s)	(s)	(s)	(s)	(n)
(mins)	A9	A11	A13	A16	A8	A10	A12	A15	A1	A2	A3	A4	A5	A6	A7	A14
0	0	0	0	0	-1	0	-1	0	1	-4	1	-2	0	-1	-1	0
1	24	24	28	27	37	39	40	45	54	42	45	44	39	28	37	59
2	151	151	164	151	270	255	282	263	305	281	309	333	305	233	251	305
3	350	336	361	327	438	465	488	468	475	482	509	532	527	456	400	453
4	473	491	525	486	506	563	574	541	543	586	590	614	587	524	470	510
5	541	573	593	556	556	627	626	590	594	642	664	706	665	589	518	557
6	560	602	612	565	576	643	639	600	612	622	647	674	668	602	558	565
7	582	621	626	581	604	657	642	614	605	638	656	680	665	609	573	576
8	598	638	637	591	619	668	659	625	629	647	668	690	675	620	596	598
9	619	656	663	616	646	688	684	653	652	672	692	715	699	639	608	630
10	641	678	681	631	658	710	695	670	658	688	708	734	719	664	631	652
11	671	701	716	659	688	739	733	699	686	716	737	767	752	698	666	677
12	688	726	730	673	701	757	737	712	702	734	760	780	759	711	682	689
13	705	737	708	688	715	770	759	730	725	750	777	805	775	726	701	700
14	*	723	709	677	736	777	767	750	738	768	796	832	798	739	713	709
15	*	741	805	677	752	789	781	762	755	795	811	831	801	747	723	721
16	*	704	811	676	770	792	791	777	774	811	831	840	803	746	739	735
17	*	731	830	713	780	803	800	785	775	805	826	832	811	767	748	746
18	*	743	765	693	776	804	800	781	773	799	813	824	805	763	748	751
19	*	747	747	672	801	798	791	768	763	795	820	842	807	760	768	747
20	*	718	768	677	762	783	769	772	750	784	790	807	780	753	752	754
21	*	680	*	632	731	764	742	725	732	753	754	772	740	729	725	723
22	*	637	*	630	691	713	706	690	700	724	725	735	718	701	690	687
23	*	*	*	602	658	678	668	660	676	695	697	705	703	671	659	656
24	*	*	*	568	633	652	632	630	653	671	674	688	686	649	638	635
25	*	*	*	546	595	614	634	615	637	656	659	668	668	620	606	623
26	*	*	*	532	569	600	623	592	634	656	653	646	656	613	596	622
27	*	*	*	527	550	577	617	603	633	657	657	628	643	594	579	620
28	*	*	*	496	522	551	594	572	616	639	637	607	630	575	558	599
29	*	*	*	*	503	526	*	*	*	*	*	584	616	551	536	*
30	*	*	*	*	487	513	*	*	*	*	*	565	606	534	521	*
31	*	*	*	*	471	494	*	*	*	*	*	540	596	513	499	*
32	*	*	*	*	451	473	*	*	*	*	*	526	582	497	479	*
33	*	*	*	*	434	452	*	*	*	*	*	510	571	482	464	*
34	*	*	*	*	419	433	*	*	*	*	*	492	552	464	446	*
35	*	*	*	*	399	420	*	*	*	*	*	476	534	443	426	*
36	*	*	*	*	389	405	*	*	*	*	*	460	524	439	413	*
37	*	*	*	*	370	390	*	*	*	*	*	449	508	424	399	*
38	*	*	*	*	350	378	*	*	*	*	*	433	493	410	380	*

(*) Thermocouples and/or data logger faulty : Data invalid.
(s) South side of compartment.
(n) North side of compartment.

TABLE 2 ATMOSPHERE TEMPERATURE DATA (REMAINDER OF COMPARTMENT)

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

COMPONENT IDENTITY : ATMOSPHERE
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

TIME	ATMOSPHERE TEMPERATURES (deg C)											
	3300mm LEVEL						1900mm LEVEL					
	(s)	(s)	(s)	(n)	(n)	(n)	(s)	(s)	(s)	(n)	(n)	(n)
(mins)	A17	A19	A21	A23	A25	A27	A18	A20	A22	A24	A26	A28
0	1	0	0	-1	-1	0	2	0	0	-1	*	*
1	58	82	57	35	34	42	97	28	46	43	*	*
2	340	354	337	277	225	270	350	250	294	214	*	*
3	554	537	523	449	445	449	572	497	530	493	*	*
4	634	620	599	617	589	560	724	604	669	649	*	*
5	691	679	657	668	681	643	747	663	743	712	*	*
6	709	707	670	679	681	681	707	681	721	703	*	*
7	708	704	695	696	694	700	732	691	737	730	*	*
8	724	723	711	700	701	712	737	708	752	728	*	*
9	755	767	741	736	714	717	774	747	772	780	*	*
10	760	772	757	774	751	742	778	749	766	824	*	*
11	788	800	770	789	775	780	803	783	796	864	*	*
12	801	810	790	818	784	793	843	796	818	909	*	*
13	820	824	804	816	789	806	847	808	827	847	*	*
14	837	844	809	818	793	797	859	818	805	*	*	*
15	848	838	821	802	798	817	838	832	813	*	*	*
16	851	841	825	815	799	803	858	832	802	*	*	*
17	851	857	830	817	813	812	869	849	833	*	*	*
18	849	830	815	858	812	807	873	839	828	*	*	*
19	827	811	796	847	803	794	859	823	814	*	*	*
20	827	788	786	830	*	797	851	805	800	*	*	*
21	769	755	760	*	*	783	797	763	754	*	*	*
22	733	722	722	*	*	759	766	729	724	*	*	*
23	692	686	689	*	*	714	715	700	691	*	*	*
24	663	660	667	*	*	682	677	674	658	*	*	*
25	640	645	644	*	*	652	654	646	628	*	*	*
26	632	640	617	*	*	625	630	614	590	*	*	*
27	624	635	595	*	*	597	625	585	561	*	*	*
28	612	625	574	*	*	573	595	559	534	*	*	*
29	*	*	549	*	*	550	*	538	512	*	*	*
30	*	*	530	*	*	529	*	517	494	*	*	*
31	*	*	511	*	*	494	*	494	473	*	*	*
32	*	*	492	*	*	473	*	475	454	*	*	*
33	*	*	477	*	*	458	*	454	436	*	*	*
34	*	*	460	*	*	440	*	441	421	*	*	*
35	*	*	445	*	*	432	*	427	398	*	*	*
36	*	*	433	*	*	424	*	412	383	*	*	*
37	*	*	421	*	*	407	*	398	370	*	*	*
38	*	*	407	*	*	396	*	387	358	*	*	*

(*) Thermocouples and/or data logger faulty : Data invalid.
(s) South side of compartment.
(n) North side of compartment.

TABLE 3 TEMPERATURES IN BEAM FLANGES

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

SECTION : 406 mm x 178 mm x 54 kg/m
NOMINAL Hp/A : 190 /m
COMPONENT IDENTITY : BEAM (FLANGES)
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

```
  **  A1        A2        A3                **
  **  /         /         /                 **
  ******************10******11**********   (U/F)
  **                                        **
  ** 1   2   3   4   5   6   7   8   9 **   (Web)
  **                                        **
  ***1***2***3***4***5***6***7***8***9***   (L/F)
  **                /       /       /   **
  **               A4      A5      A6
Back Column                          Front Column
 (North)                               (South)
```

TIME	STEEL TEMPERATURES (deg C)										
	LOWER									UPPER	
(mins)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
0	0	0	0	-1	0	-1	-1	0	0	0	0
1	2	2	3	2	2	2	1	3	2	3	2
2	18	22	28	29	24	24	20	28	18	12	13
3	50	60	74	80	76	72	64	67	51	36	38
4	90	119	141	158	153	141	123	124	88	69	70
5	140	187	220	241	238	218	192	184	134	120	112
6	188	243	284	309	310	289	258	240	180	149	152
7	232	301	347	372	378	356	322	298	226	183	190
8	272	356	400	427	434	412	379	350	269	221	227
9	313	407	453	481	489	466	433	401	312	271	264
10	354	457	500	527	547	516	485	453	355	231	299
11	396	506	546	570	589	560	531	498	397	287	336
12	438	551	589	612	632	603	575	544	438	286	372
13	477	588	625	647	669	639	614	583	477	*	407
14	513	622	657	678	*	671	648	618	512	*	438
15	548	657	689	709	*	700	678	649	544	*	470
16	579	685	715	732	*	723	703	677	573	*	497
17	609	711	734	740	*	737	725	700	600	*	522
18	630	725	737	749	*	741	737	715	622	*	543
19	649	733	743	760	*	751	739	728	640	*	561
20	671	745	762	775	*	758	743	734	653	*	577
21	667	730	745	764	*	758	746	733	661	*	587
22	670	730	742	761	*	752	743	730	663	*	591
23	668	725	733	751	*	742	736	723	660	*	589
24	668	724	735	747	*	730	726	714	654	*	585
25	655	706	708	726	*	718	716	704	648	*	581
26	666	713	716	733	*	712	709	699	640	*	582
27	681	732	738	748	*	700	697	690	631	*	575
28	665	722	712	727	*	686	690	681	620	*	567
29	*	*	*	*	*	676	683	664	607	*	557
30	*	*	*	*	*	674	676	652	599	*	552
31	*	*	*	*	*	661	660	636	588	*	546
32	*	*	*	*	*	644	644	623	578	*	538
33	*	*	*	*	*	627	627	608	566	*	531
34	*	*	*	*	*	610	611	594	555	*	522
35	*	*	*	*	*	592	593	578	544	*	510
36	*	*	*	*	*	577	579	565	533	*	502
37	*	*	*	*	*	563	565	553	522	*	493
38	*	*	*	*	*	549	552	540	511	*	485

(*) Thermocouples and/or data logger faulty : Data invalid.

TABLE 4 TEMPERATURES IN BEAM WEB

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

SECTION : 406 mm x 178 mm x 54 kg/m
NOMINAL Hp/A : 190 /m
COMPONENT IDENTITY : BEAM (WEB)
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

TIME	STEEL TEMPERATURES (deg C)								
	WEB								
(mins)	W1	W2	W3	W4	W5	W6	W7	W8	W9
0	0	0	0	0	-1	0	0	0	0
1	2	5	6	4	7	6	2	5	2
2	22	37	45	45	37	50	31	41	20
3	65	92	111	113	97	130	94	104	61
4	120	167	194	203	202	213	171	172	107
5	186	256	292	308	303	306	258	249	162
6	245	328	364	383	374	383	339	320	214
7	297	393	431	452	446	452	410	387	263
8	345	447	482	504	495	502	468	441	308
9	391	497	530	552	543	551	518	490	351
10	434	539	571	592	587	591	563	537	392
11	477	581	610	632	624	627	603	576	432
12	516	618	645	665	659	661	639	613	470
13	552	648	673	694	691	690	669	644	505
14	584	676	698	719	717	712	695	670	536
15	613	703	725	742	741	734	717	693	565
16	640	724	741	749	*	747	736	713	589
17	663	738	745	761	*	756	742	727	612
18	679	739	753	771	*	759	746	736	630
19	691	743	759	776	*	760	753	736	643
20	702	750	763	777	*	759	755	736	652
21	702	746	754	770	*	747	751	734	655
22	698	738	742	759	*	731	742	726	652
23	687	726	728	743	*	716	728	713	643
24	674	713	720	732	*	702	714	700	632
25	660	696	699	715	*	690	701	686	619
26	664	702	704	718	*	691	691	680	607
27	670	718	717	728	*	676	686	670	595
28	654	704	706	711	*	668	678	654	582
29	*	*	*	*	*	657	660	633	567
30	*	*	*	*	*	642	644	618	559
31	*	*	*	*	*	627	625	601	546
32	*	*	*	*	*	609	609	587	536
33	*	*	*	*	*	594	593	571	524
34	*	*	*	*	*	578	577	556	513
35	*	*	*	*	*	559	561	542	503
36	*	*	*	*	*	546	548	529	492
37	*	*	*	*	*	533	535	516	482
38	*	*	*	*	*	520	522	504	473

(*) Thermocouples and/or data logger faulty : Data invalid.

TABLE 5 / FLANGE AND WEB TEMPERATURES IN BLOCKED-IN COLUMN AGAINST SOUTH WALL

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

SECTION : 203 mm x 203 mm x 52 kg/m
NOMINAL Hp/A : ------
COMPONENT IDENTITY : COLUMN (SOUTH)
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

```
              *          *
              *    W5    *  F9          --- 3675 mm
              *          *        A7    --- 3300 mm
         F4   *    W4    *  F8          --- 3000 mm
              *          *
    A10  F3   *    W3    *  F7    A8    --- 2400 mm
              *          *
         F2   *    W2    *  F6          --- 1800 mm
              *          *
    A11  F1   *    W1    *  F5    A9    --- 1200 mm
              *          *
        Exposed        Unexposed
        Flange          Flange
```

TIME	STEEL AND ATMOSPHERE TEMPERATURES (deg C)																		
	EXPOSED FLANGE						UNEXPOSED FLANGE								WEB				
(mins)	F1	F2	F3	F4	A11	A10	F5	F6	F7	F8	F9	A9	A8	A7	W1	W2	W3	W4	W5
0	0	-1	-1	-1	0	0	-1	-1	-1	-1	-1	0	-1	-1	-1	-2	-1	-1	0
1	3	4	13	11	24	39	0	0	0	0	2	24	37	37	0	1	0	-1	0
2	25	25	101	61	151	255	3	7	9	7	15	151	270	251	-1	-2	-1	-1	0
3	63	65	196	84	336	465	13	22	25	21	35	350	438	400	0	-2	0	0	0
4	97	103	232	98	491	563	33	42	45	39	52	473	506	470	5	6	3	3	1
5	125	162	253	178	573	627	56	65	68	60	70	541	556	518	12	10	9	7	3
6	205	210	392	236	602	643	77	88	98	78	90	560	576	558	27	14	17	14	7
7	240	244	429	264	621	657	105	121	139	114	105	582	604	573	49	26	28	24	12
8	273	274	447	289	638	668	131	148	167	141	117	598	619	596	74	32	41	34	19
9	307	308	471	318	656	688	156	175	193	167	159	619	646	608	84	48	56	45	28
10	346	341	499	347	678	710	184	202	222	193	181	641	658	631	98	72	72	58	37
11	388	378	528	380	701	739	214	233	253	222	203	671	688	666	116	81	88	73	47
12	425	416	557	414	726	757	243	263	284	252	227	688	701	682	204	101	107	89	58
13	459	451	582	445	737	770	274	295	315	281	250	705	715	701	*	119	127	108	71
14	486	480	599	473	723	777	303	328	347	314	269	*	736	713	*	136	144	127	84
15	518	510	619	500	741	789	339	362	380	344	290	*	752	723	*	158	164	145	95
16	546	537	637	525	704	792	375	396	412	373	313	*	770	739	*	176	184	161	105
17	579	565	659	551	731	803	412	432	445	403	334	*	780	748	*	193	203	178	114
18	600	582	667	569	743	804	436	460	470	428	348	*	776	748	*	211	220	195	128
19	*	596	672	584	747	798	449	487	495	453	369	*	801	768	*	228	235	212	144
20	*	606	675	595	718	783	466	507	514	473	388	*	762	752	*	244	251	230	159
21	*	603	667	599	680	764	495	518	524	487	399	*	731	725	*	258	265	246	171
22	*	596	648	594	637	713	501	522	527	494	405	*	691	690	*	269	278	260	182
23	*	590	631	589	*	678	*	524	527	498	406	*	658	659	*	282	290	272	193
24	*	583	617	584	*	652	520	523	526	500	406	*	633	638	*	294	300	284	204
25	*	574	601	577	*	614	541	520	522	499	404	*	595	606	*	303	308	294	214
26	*	568	595	572	*	600	522	518	520	498	415	*	569	596	*	318	317	304	224
27	*	558	583	565	*	577	522	512	515	495	415	*	550	579	*	326	323	313	233
28	*	550	570	557	*	551	515	506	509	491	415	*	522	558	*	332	329	320	241
29	*	537	555	545	*	526	514	496	500	483	407	*	503	536	*	335	331	323	245
30	*	531	545	541	*	513	504	493	496	483	410	*	487	521	*	344	338	332	255
31	*	521	533	533	*	494	504	486	488	478	405	*	471	499	*	347	341	336	261
32	*	514	523	527	*	473	491	481	483	474	403	*	451	479	*	353	346	342	269
33	*	505	512	517	*	452	486	473	475	467	397	*	434	464	*	355	348	344	274
34	*	498	501	509	*	433	477	466	467	461	391	*	419	446	*	356	349	346	278
35	*	486	490	501	*	420	457	457	459	454	386	*	399	426	*	357	351	348	282
36	*	478	481	493	*	405	447	449	452	447	380	*	389	413	*	358	351	349	285
37	*	470	471	485	*	390	439	442	444	441	374	*	370	399	*	358	352	350	288
38	*	461	461	477	*	378	429	434	436	434	368	*	350	380	*	358	352	350	290
39	*	453	452	469	*	366	421	427	428	427	361	*	330	358	*	357	351	350	291
40	*	448	444	461	*	352	419	422	421	420	356	*	316	346	*	358	351	350	293
41	*	437	434	453	*	339	406	413	413	413	350	*	305	333	*	355	350	349	294
42	*	429	425	445	*	329	399	407	404	405	344	*	291	316	*	353	349	349	295
43	*	428	421	440	*	324	399	404	401	400	340	*	283	306	*	356	349	349	296

(*) Thermocouples faulty.

TABLE 6 FLANGE AND WEB TEMPERATURES IN BLOCKED-IN COLUMN AGAINST NORTH WALL

TRIAL NUMBER :	23
TRIAL DATE :	21st FEBRUARY 1986
SITE :	FRS CARDINGTON
SECTION :	203 mm x 203 mm x 52 kg/m
NOMINAL Hp/A :	------
COMPONENT IDENTITY :	COLUMN (NORTH)
FIRE LOAD :	25 kg/m2 WOOD
TOTAL VENTILATION :	1/8 OF EACH OF 2 WALLS

		*		*			
	F18	*	W10	*			--- 3675 mm
A14		*		*			--- 3300 mm
	F17	*	W9	*	F13		--- 3000 mm
		*		*			
A15	F16	*	W8	*	F12	A12	--- 2400 mm
		*		*			
	F15	*	W7	*	F11		--- 1800 mm
		*		*			
A16	F14	*	W6	*	F10	A13	--- 1200 mm
		*		*			
	Unexposed Flange				Exposed Flange		

TIME	STEEL AND ATMOSPHERE TEMPERATURES (deg C)																		
	EXPOSED FLANGE						UNEXPOSED FLANGE								WEB				
(mins)	F10	F11	F12	F13	A13	A12	F14	F15	F16	F17	F18	A16	A15	A14	W6	W7	W8	W9	W10
0	0	-1	0	1	0	-1	0	-1	0	-1	0	0	0	0	*	0	0	0	1
1	1	1	0	2	28	40	1	-1	1	1	8	27	45	59	*	-1	-1	-1	0
2	10	10	12	14	164	282	8	3	8	8	38	151	263	305	*	-1	-1	-2	-1
3	29	30	34	38	361	488	26	17	25	21	49	327	468	453	*	-1	0	-2	0
4	55	59	64	66	525	574	41	38	46	42	66	486	541	510	*	2	2	2	1
5	86	92	104	107	593	626	64	64	69	66	88	556	590	557	*	7	7	6	2
6	137	137	148	145	612	639	90	89	99	89	103	565	600	565	*	16	16	12	5
7	172	170	180	176	626	642	146	119	133	117	147	581	614	576	*	26	28	20	11
8	228	199	210	205	637	659	154	145	157	140	174	591	625	598	*	38	41	30	18
9	240	226	240	235	663	684	188	170	183	162	193	616	653	630	*	52	53	42	24
10	273	259	272	266	681	695	210	197	209	189	222	631	670	652	*	65	66	53	33
11	311	306	313	303	716	733	252	231	241	221	249	659	699	677	*	80	78	67	41
12	348	330	344	335	730	737	269	258	268	248	270	673	712	689	*	97	97	84	52
13	*	362	378	368	708	759	295	287	298	276	286	688	730	700	*	115	112	96	60
14	*	395	412	403	709	767	307	319	328	301	306	677	750	709	*	133	129	115	71
15	*	447	452	440	805	781	385	357	362	333	327	677	762	721	*	150	144	130	82
16	*	481	485	472	811	791	410	390	393	365	348	676	777	735	*	166	159	145	94
17	*	511	514	500	830	800	448	423	423	396	366	713	785	746	*	184	173	161	102
18	*	509	529	520	765	800	444	445	445	414	384	693	781	751	*	199	189	176	101
19	*	531	549	540	747	791	462	468	466	436	398	672	768	747	*	214	209	191	110
20	*	575	575	561	768	769	504	494	487	462	413	677	772	754	*	230	228	208	120
21	*	560	576	567	*	742	489	499	495	467	417	632	725	723	*	243	244	221	145
22	*	568	581	573	*	706	492	507	503	475	421	630	690	687	*	257	258	237	161
23	*	570	581	574	*	668	*	512	505	479	419	602	660	656	*	270	271	250	173
24	*	576	582	574	*	632	*	516	506	495	418	568	630	635	*	279	281	262	183
25	*	565	575	570	*	634	*	511	504	483	418	546	615	623	*	288	291	273	195
26	*	578	606	586	*	623	*	527	519	500	437	532	592	622	*	315	316	301	223
27	*	595	637	601	*	617	*	545	537	530	453	527	603	620	*	343	343	329	252
28	*	586	625	594	*	594	*	537	530	520	451	496	572	599	*	347	347	335	260

(*) Thermocouples faulty : Data invalid.
No data recorded after 28 minutes.

TABLE 7 TEMPERATURES MEASURED IN BOLTS OF EACH CONNECTION

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

COMPONENT IDENTITY : BOLTS
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

```
       **                        **
    TH B1                        B1  TH
    TT B2                        B2  TT
       ************************
    BH B3                        B3  BH
    BT B4                        B4  BT
       **                        **
  Back Column              Front Column
    (North)                   (South)
```

TIME	STEEL TEMPERATURES (deg C)							
	NORTH				SOUTH			
(mins)	B1	B2	B3	B4	B1	B2	B3	B4
0	*	1	0	0	0	0	0	0
1	*	-1	-1	-1	0	0	0	0
2	*	-1	8	0	8	1	10	0
3	*	3	25	4	22	6	28	4
4	*	10	45	11	38	16	47	12
5	*	19	66	23	55	27	67	22
6	*	32	85	38	74	40	89	34
7	*	46	106	55	93	54	109	48
8	*	61	124	72	111	69	128	64
9	*	76	145	89	125	86	149	80
10	*	90	167	106	148	99	172	97
11	*	104	192	123	170	114	194	116
12	*	124	215	144	191	127	218	134
13	*	142	239	161	213	142	243	153
14	*	161	266	182	236	159	267	173
15	*	179	294	202	259	177	293	194
16	*	197	322	224	283	196	319	214
17	*	215	349	246	307	215	345	235
18	*	233	373	267	329	234	369	256
19	*	252	397	287	350	252	391	271
20	*	270	421	308	368	270	410	291
21	*	288	438	327	384	278	427	314
22	*	304	452	345	397	298	441	333
23	*	317	460	362	407	313	451	349
24	*	327	465	375	415	325	458	363
25	*	339	470	387	422	336	464	374
26	*	366	492	416	427	345	469	383
27	*	392	515	443	430	353	472	391
28	*	398	513	449	432	359	473	398
29	*	*	*	*	431	361	472	402
30	*	*	*	*	435	369	475	409
31	*	*	*	*	434	372	474	413
32	*	*	*	*	435	377	475	418
33	*	*	*	*	433	378	473	420
34	*	*	*	*	431	379	471	421
35	*	*	*	*	428	380	469	421
36	*	*	*	*	425	380	466	422
37	*	*	*	*	422	380	463	421
38	*	*	*	*	418	379	459	420

(*) Thermocouples and/or data logger faulty : Data invalid.

TABLE 8 TEMPERATURES IN INDICATIVE COLUMN

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

SECTION : 203 mm x 203 mm x 52 kg/m
NOMINAL Hp/A : 180 /m
COMPONENT IDENTITY : COLUMN (INDICATIVE)
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

```
* 1 * * * * * * * *
          *
          *
          *
          3
          *
          *
          *
* * * * * * * * 2 *
```

TIME (mins)	STEEL TEMPERATURES (deg C) 1500mm LEVEL 1	2	3
0	0	0	0
1	1	3	8
2	20	31	25
3	58	80	82
4	111	146	140
5	174	216	205
6	236	280	269
7	297	344	329
8	355	404	386
9	411	462	439
10	463	513	490
11	515	562	539
12	562	607	584
13	603	645	623
14	639	678	657
15	673	707	687
16	692	728	708
17	717	749	730
18	743	760	750
19	753	770	755
20	760	776	759
21	766	778	761
22	764	773	755
23	758	766	746
24	744	753	733
25	724	734	716
26	710	717	704
27	700	700	695
28	692	684	678
29	672	675	657
30	657	665	642
31	639	646	624
32	623	629	609
33	606	611	592
34	589	594	575
35	575	579	562
36	561	564	548
37	547	550	534
38	533	536	521
39	520	522	508
40	507	509	494
41	496	497	485
42	484	486	473
43	477	478	464

TABLE 9 TEMPERATURES IN EXTERNAL COLUMN

TRIAL NUMBER : 23
TRIAL DATE : 21st FEBRUARY 1986
SITE : FRS CARDINGTON

SECTION : 203 mm x 203 mm x 52 kg/m
NOMINAL Hp/A : 180 /m
COMPONENT IDENTITY : EXTCOL
FIRE LOAD : 25 kg/m2 WOOD
TOTAL VENTILATION : 1/8 OF EACH OF 2 WALLS

```
U  *           *
N  1           *  E
E  *           *  X
X  *           *  P
P  2 * * 3 * * 4  O
O  *           *  S
S  *           *  E
E  *           5  D
D  *           *
```

TIME	STEEL AND ATMOSPHERE TEMPERATURES (deg C)					
	3300mm LEVEL			1900mm LEVEL		
(mins)	1	3	5	3	5	ATM
0	-1	-1	-1	-1	-1	-1.0
1	-1	-1	-1	-1	-1	0.0
2	2	6	5	-1	1	9.0
3	8	17	13	0	5	30.0
4	15	32	22	0	12	54.0
5	23	49	32	3	21	76.0
6	31	65	40	5	32	88.0
7	37	81	48	8	43	100.0
8	43	96	56	12	54	107.0
9	48	111	63	16	67	113.0
10	55	126	72	21	79	118.0
11	61	140	81	27	93	122.0
12	67	155	90	33	107	135.0
13	74	168	99	38	120	143.0
14	79	182	106	45	135	149.0
15	84	194	113	52	149	159.0
16	88	205	120	58	162	165.0
17	92	219	127	66	175	168.0
18	97	230	133	73	188	179.0
19	103	237	141	81	200	188.0
20	109	242	146	89	210	187.0
21	111	243	148	96	218	173.0
22	113	241	149	102	222	152.0
23	113	238	149	106	225	137.0
24	114	235	149	110	225	127.0
25	114	232	149	112	224	122.0
26	114	227	147	114	221	113.0
27	113	222	145	116	218	97.0
28	111	216	143	117	214	84.0
29	107	209	138	115	208	77.0
30	108	206	138	117	206	75.0
31	106	200	135	116	202	71.0
32	106	196	135	118	200	67.0
33	103	190	132	116	195	66.0
34	101	185	129	115	190	64.0
35	100	180	126	114	186	58.0
36	98	175	123	113	182	58.0
37	97	170	121	111	177	53.0
38	95	165	118	110	173	50.0
39	93	161	115	108	169	47.0
40	90	156	112	106	165	43.0
41	90	152	110	105	162	41.0
42	88	148	108	103	158	40.0
43	86	145	106	102	155	40.0

TABLE 10 FRS LATERAL DISPLACEMENT TRANSDUCER READINGS FOR BLOCKED-IN COLUMNS

Time, mm	South Facing Column Displacement, mm				North Facing Column Displacement, mm			
	H = 760	H = 2090	H = 3460	LF*	H = 760	H = 2090	H = 3460	LF*
0	0	0	0	0	0	0	0	0
4	0.15	0.20	0	0	0.10	0.10	-0.7	0
6	1.0	2.2	3.3	3.2	1.5	2.3	1.1	1.0
8	2.4	4.9	7.5	7.5	3.4	5.8	4.7	5.1
10	3.9	8.4	11.9	12.4	5.3	9.0	8.1	8.0
12	5.3	11.5	16.0	16.4	7.0	12.3	12.8	12.8
14	6.6	15.7	19.5	19.7	8.5	15.4	15.5	15.5
16	8.8	21.2	23.6	23.5	10.5	20.2	19.2	19.0
18	10.4	30.2	30.6	31.0	12.3	25.5	22.9	22.5
20	11.9	41.6	37.7	37.4	13.1	30.9	28.0	27.5
22	11.9	47.8	41.0	40.5	13.1	34.3	28.0	27.5

H = height from floor LF* = estimate adjacent to lower flange of beam

TABLE 11 UNRESTRAINED DISPLACEMENTS OF BLOCKED-IN COLUMNS AND BEAM IN NATURAL FIRE TEST ON LOADED STEEL FRAME

Time min	Average Steel Flange Temperatures, °C												Lateral Displacement, mm			
	Front Column				Back Column				Beam				Front Column	Back Column	Beam	
	T1	T2	T1-T2	T1+T2	T1	T2	T1-T2	T1+T2	T1	T2	T1-T2	T1+T2	ΔH	ΔH	ΔL	Δh
4	99	38	61	137	61	42	19	103	137	70	67	207	18.5	5.8	8.7	6.0
6	217	81	136	298	142	92	50	234	276	151	125	427	41.3	15.2	17.5	11.2
8	279	140	139	419	211	149	62	360	394	224	170	618	42.3	18.8	25.0	15.3
10	345	193	152	538	268	201	67	469	498	299	199	797	46.2	20.4	31.7	17.9
12	418	253	165	671	339	261	78	600	586	372	214	958	50.2	23.7	37.3	19.3
14	480	315	165	795	403	314	89	717	650	438	212	1088	50.2	27.1	41.4	19.1
16	536	381	155	917	479	390	89	869	708	497	209	1203	47.1	27.1	45.1	18.8
18	584	441	143	1025	519	437	82	956	734	543	191	1277	43.5	24.9	46.8	17.2
20	600	482	118	1082	570	487	83	1057	753	577	176	1330	35.9	25.2	48.0	15.8
22	595	505	90	1100	574	494	80	1068	743	591	152	1334	27.4	24.3	47.3	13.7

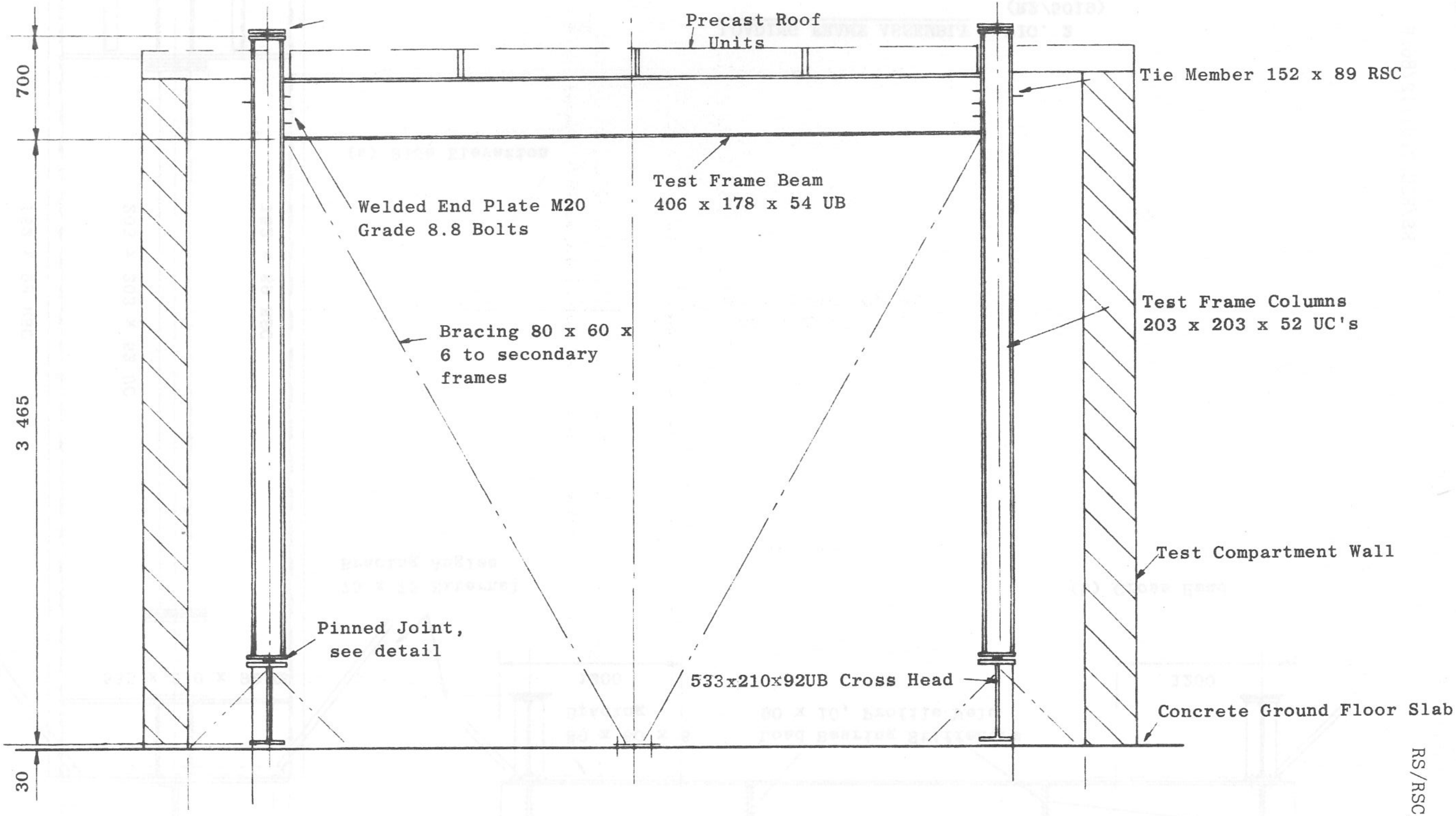
Note: T1 = Temperature rise of hotter flange
T2 = Temperature rise of cooler flange
H = Column height to lower flange of beam = 2992 mm
L = Beam span = 4553 mm
α = Average coefficient of expansion = 0.000014 mm/mm/°C
d_1 = Depth of column = 206.2 mm
d_2 = Depth of beam = 402.6 mm

FRS Equations:

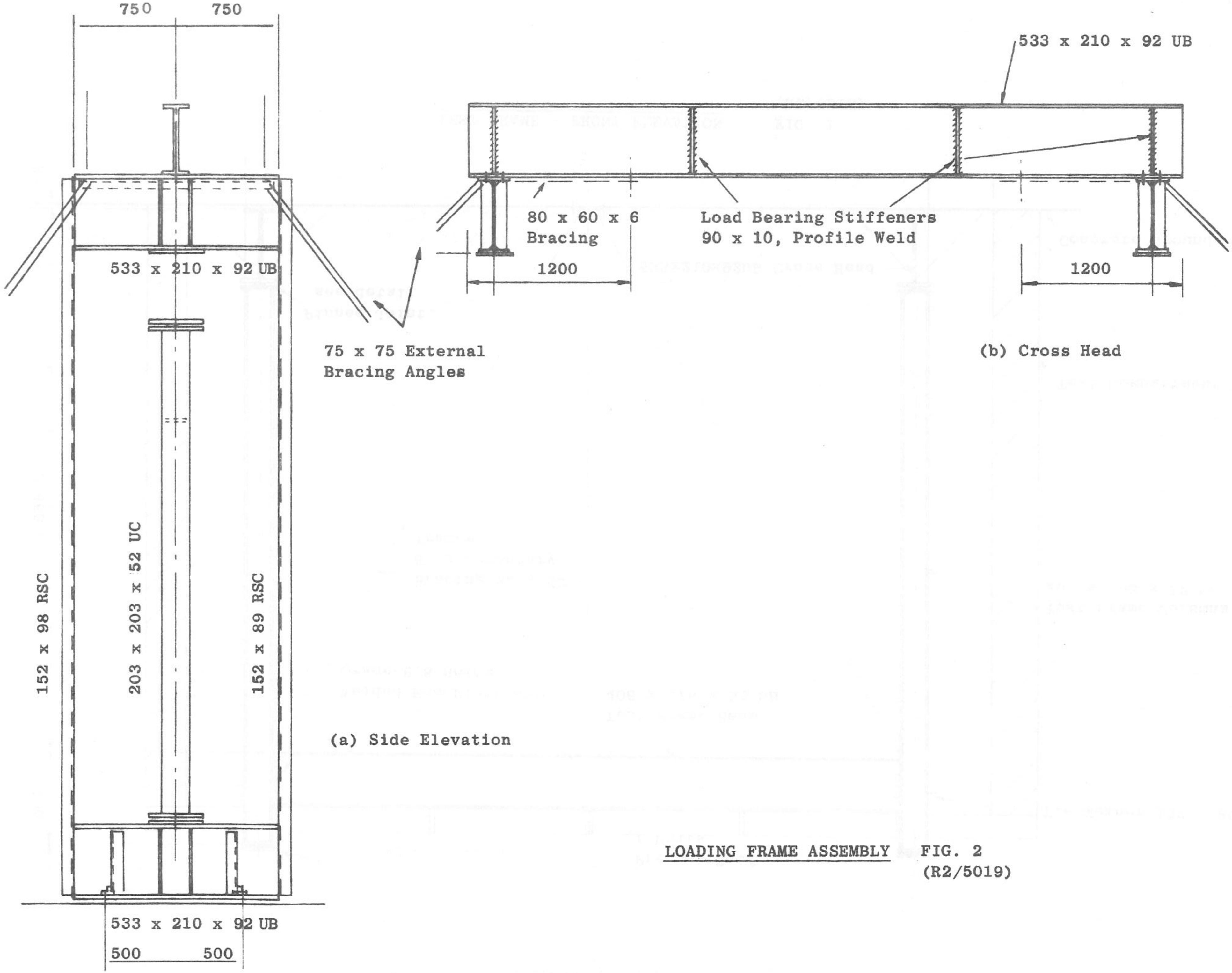
Lateral displacement of column $\Delta H = \frac{\alpha(T1-T2)H^2}{2d_1}$

Lateral displacement of beam $\Delta L = \frac{\alpha(T1+T2)L}{2} + \left[\frac{\alpha(T1-T2)L}{2}\right]$

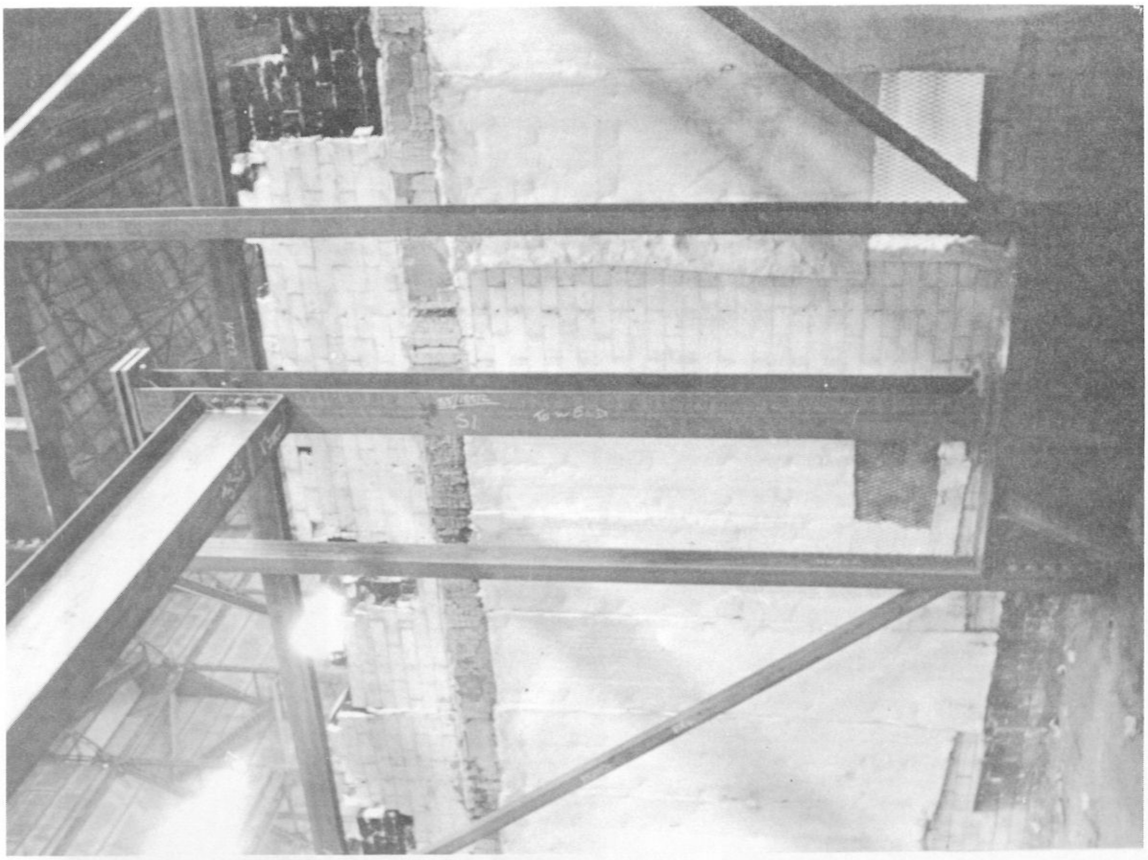
Thermal bowing of beam $\Delta h = \frac{\alpha(T1-T2)L^2}{8d_2}$



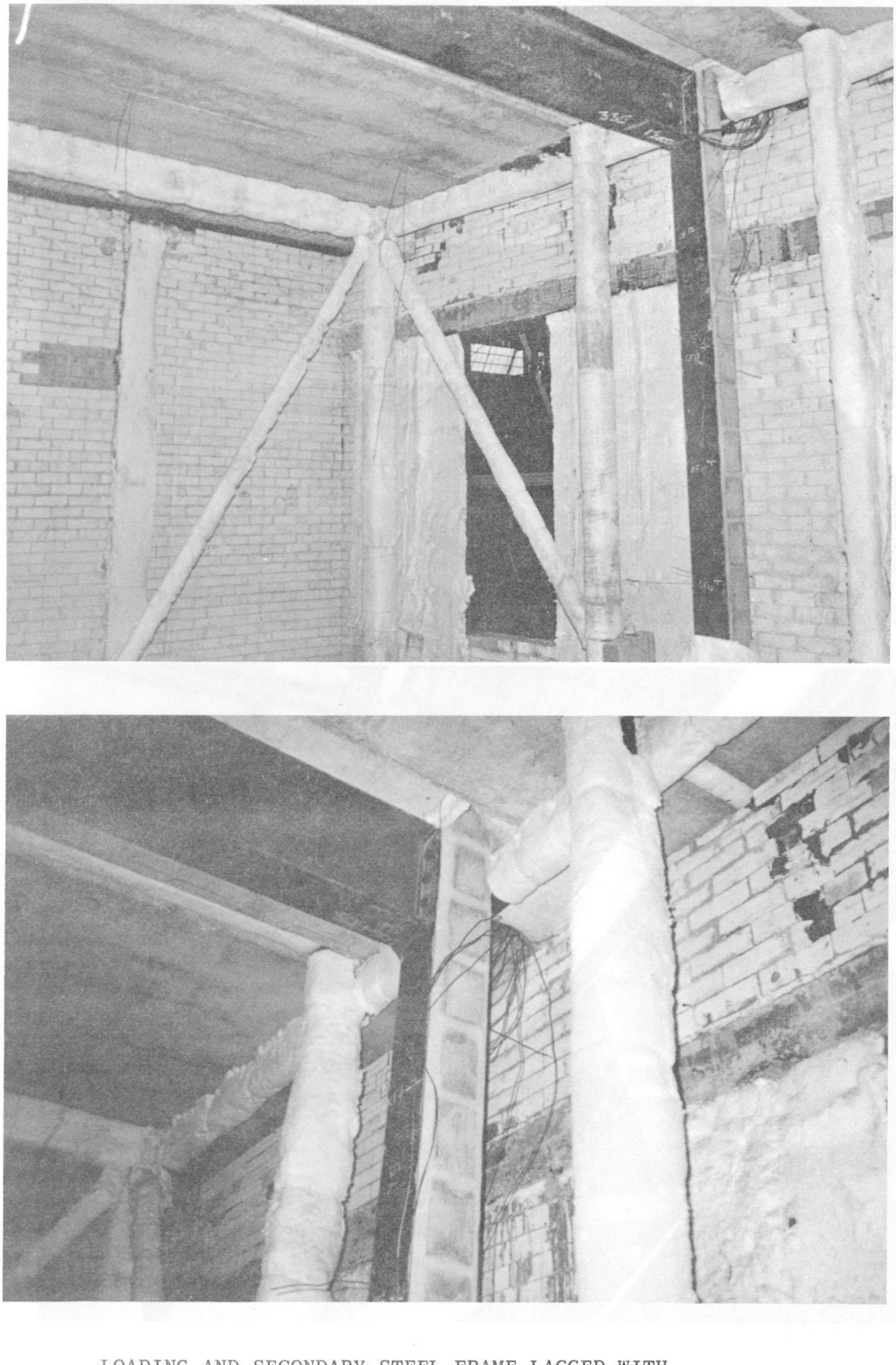
TEST FRAME - FRONT ELEVATION   FIG. 1
(R2/5018)



LOADING FRAME ASSEMBLY FIG. 2
(R2/5019)

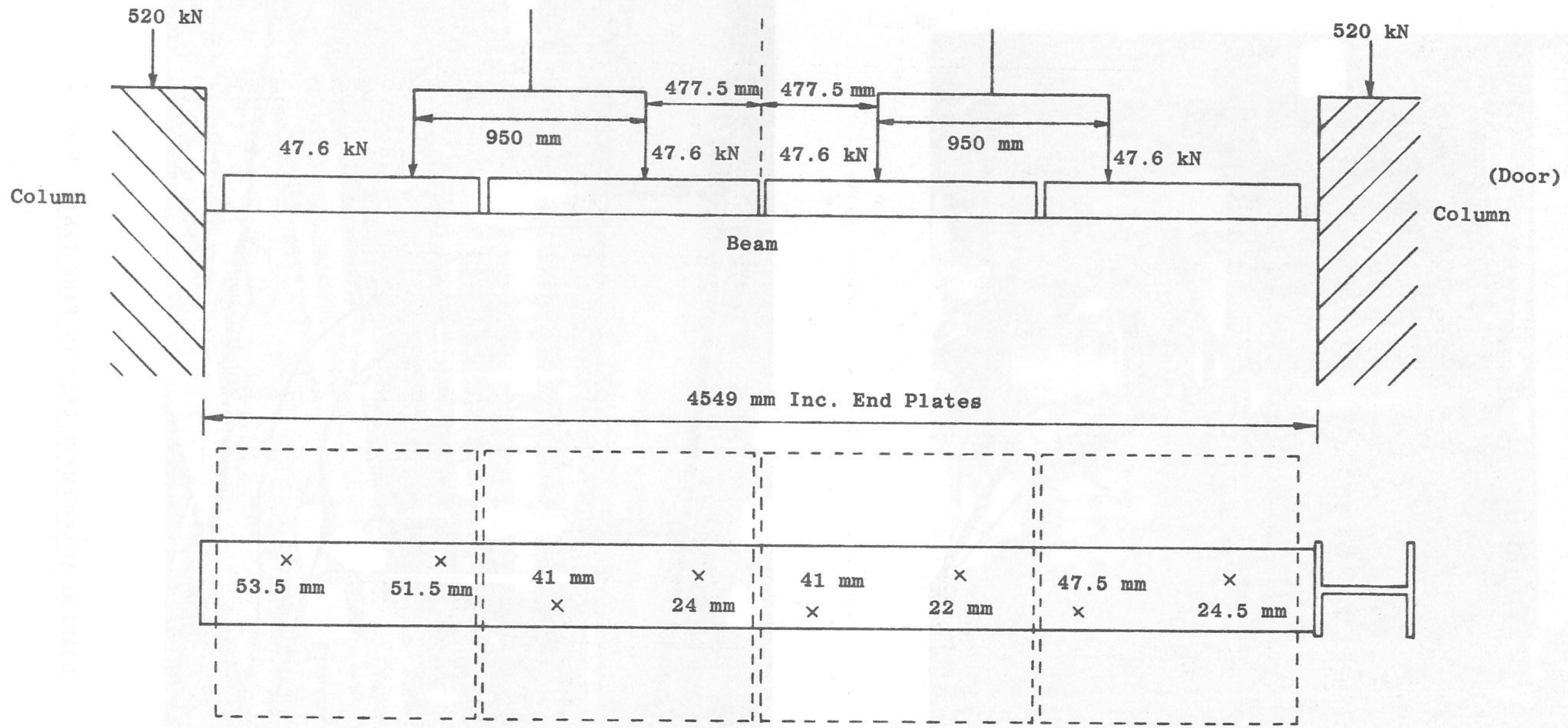


ERECTION OF TEST FRAME AND LOADING ASSEMBLY FIG. 3

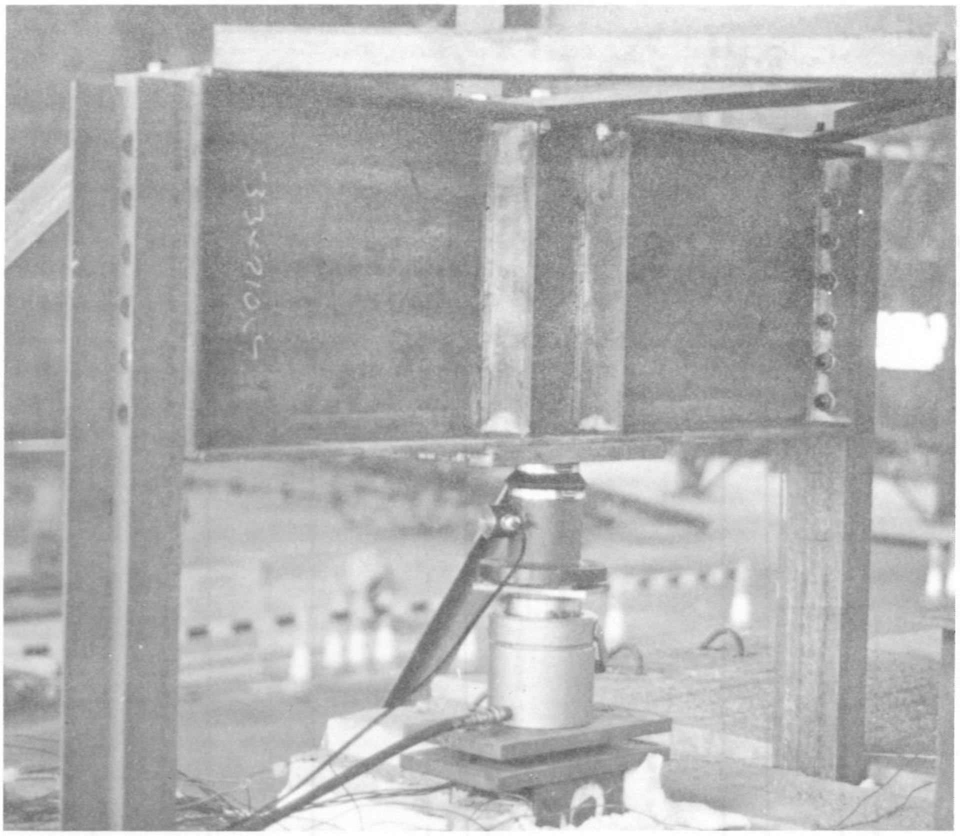


LOADING AND SECONDARY STEEL FRAME LAGGED WITH CERAMIC FIBRE BLANKET

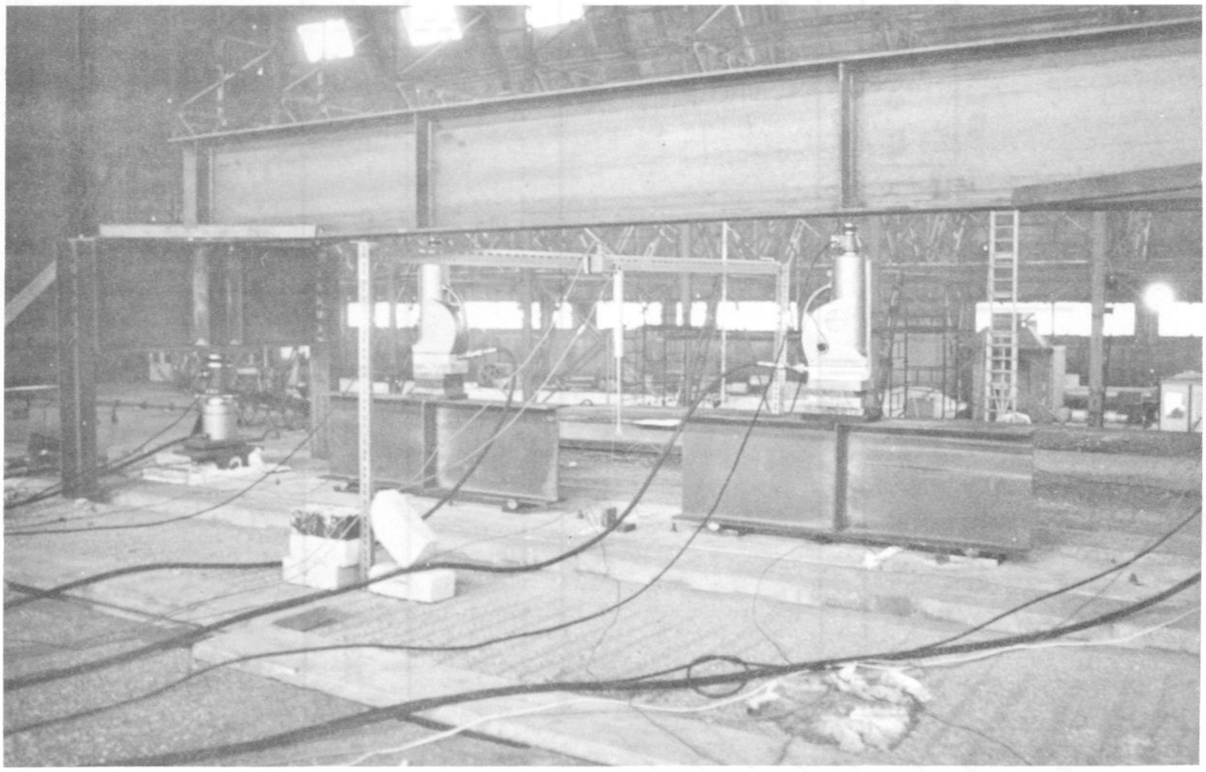
FIG. 4



SCHEMATIC REPRESENTATION OF LOADING POINTS FIG. 5
(R2/5020)

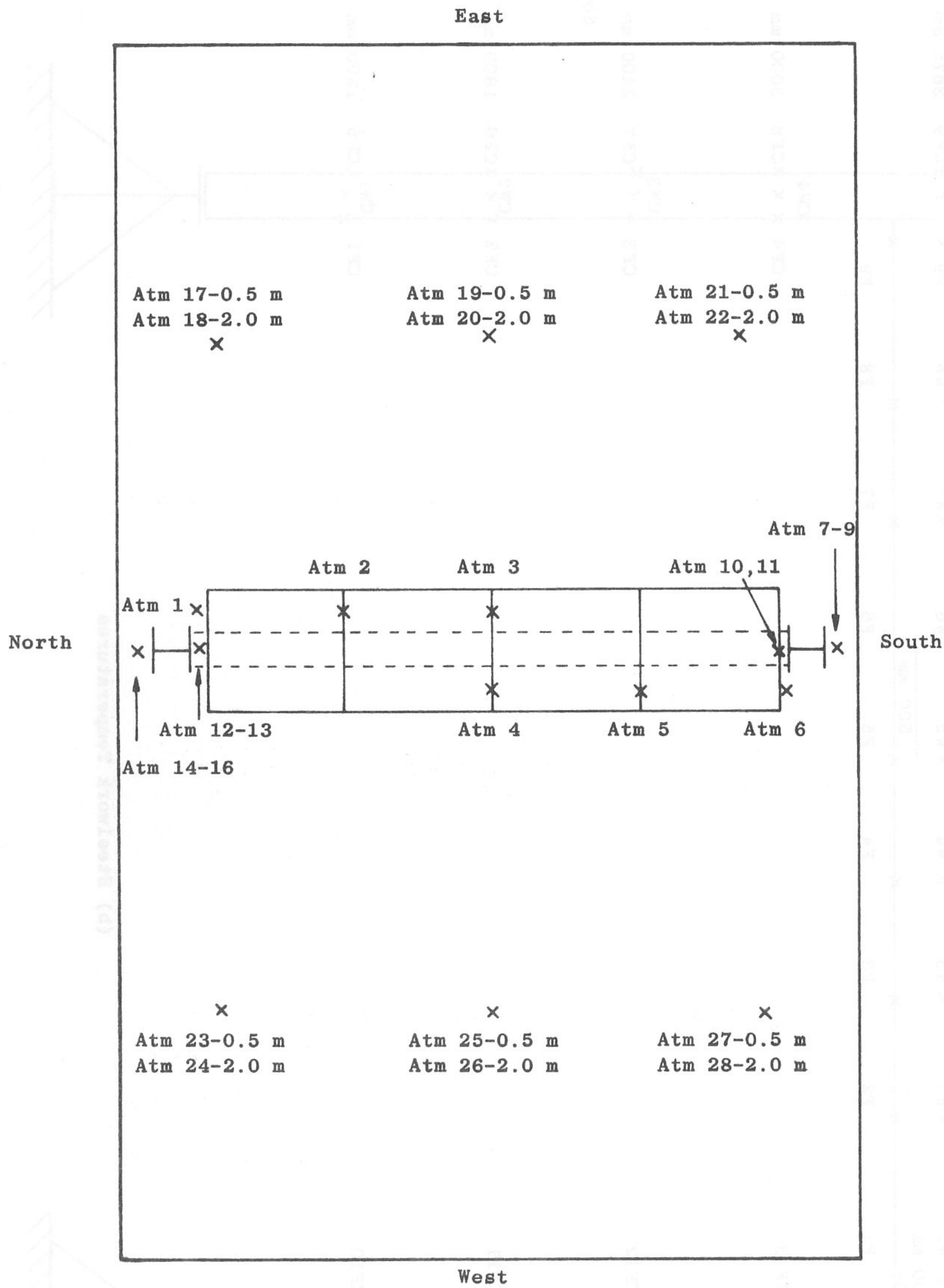


Column



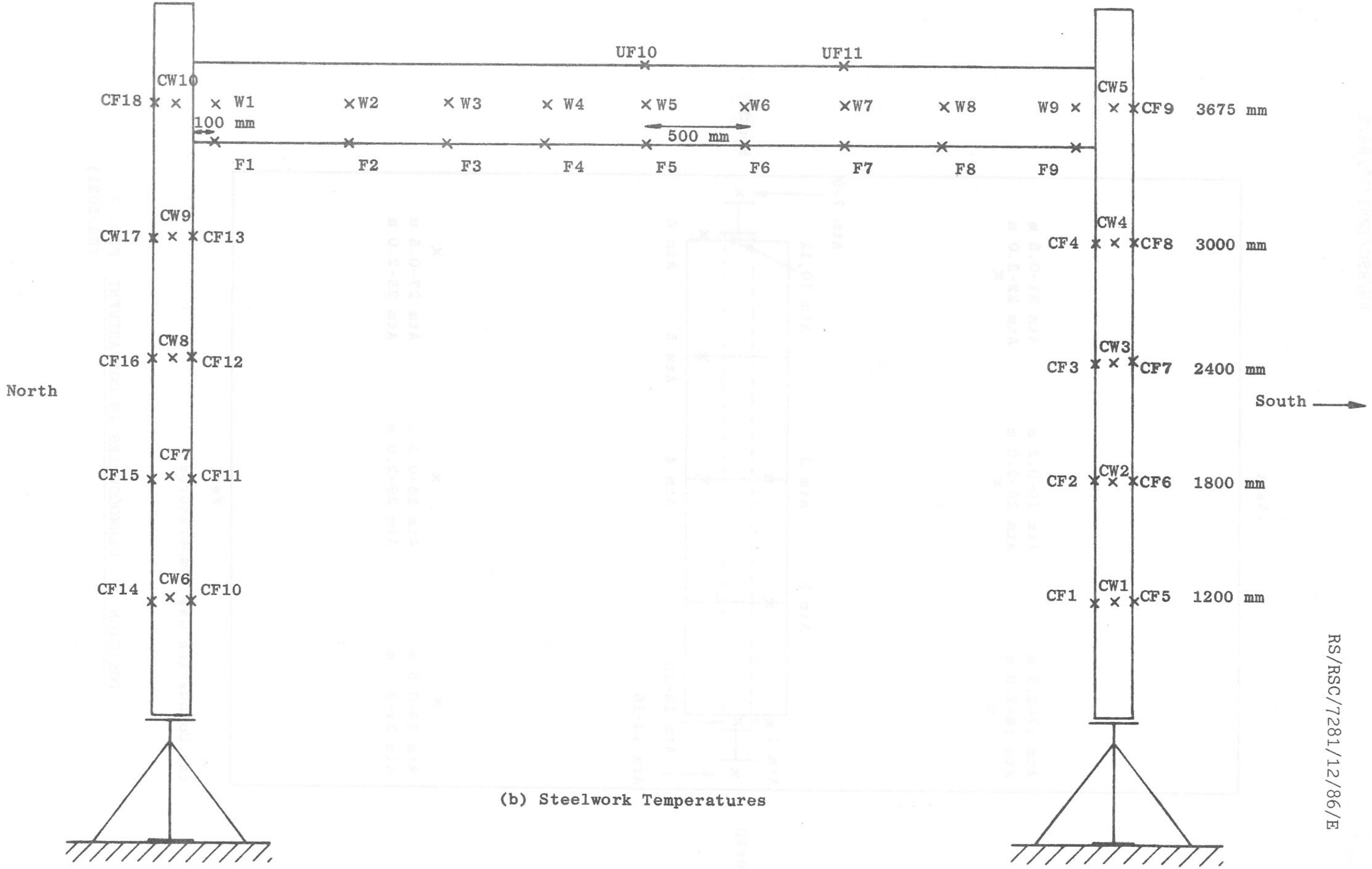
Beam

LOADING ARRANGEMENT USED IN FIRE TEST FIG. 6



(a) Combustion Gas Temperatures

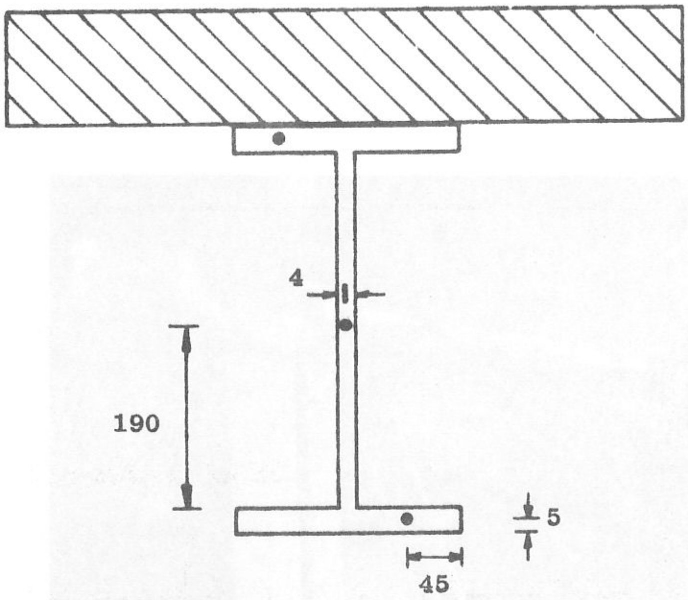
POSITION OF THERMOCOUPLES IN COMPARTMENT FIG. 7
(R2/5021)



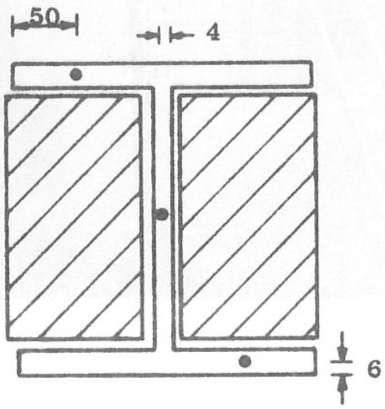
(b) Steelwork Temperatures

POSITION OF THERMOCOUPLES IN COMPARTMENT FIG. 7 (Continued)
(R2/5022)

Dimensions in mm



406 x 178 mm x 54 kg/m Universal Beam



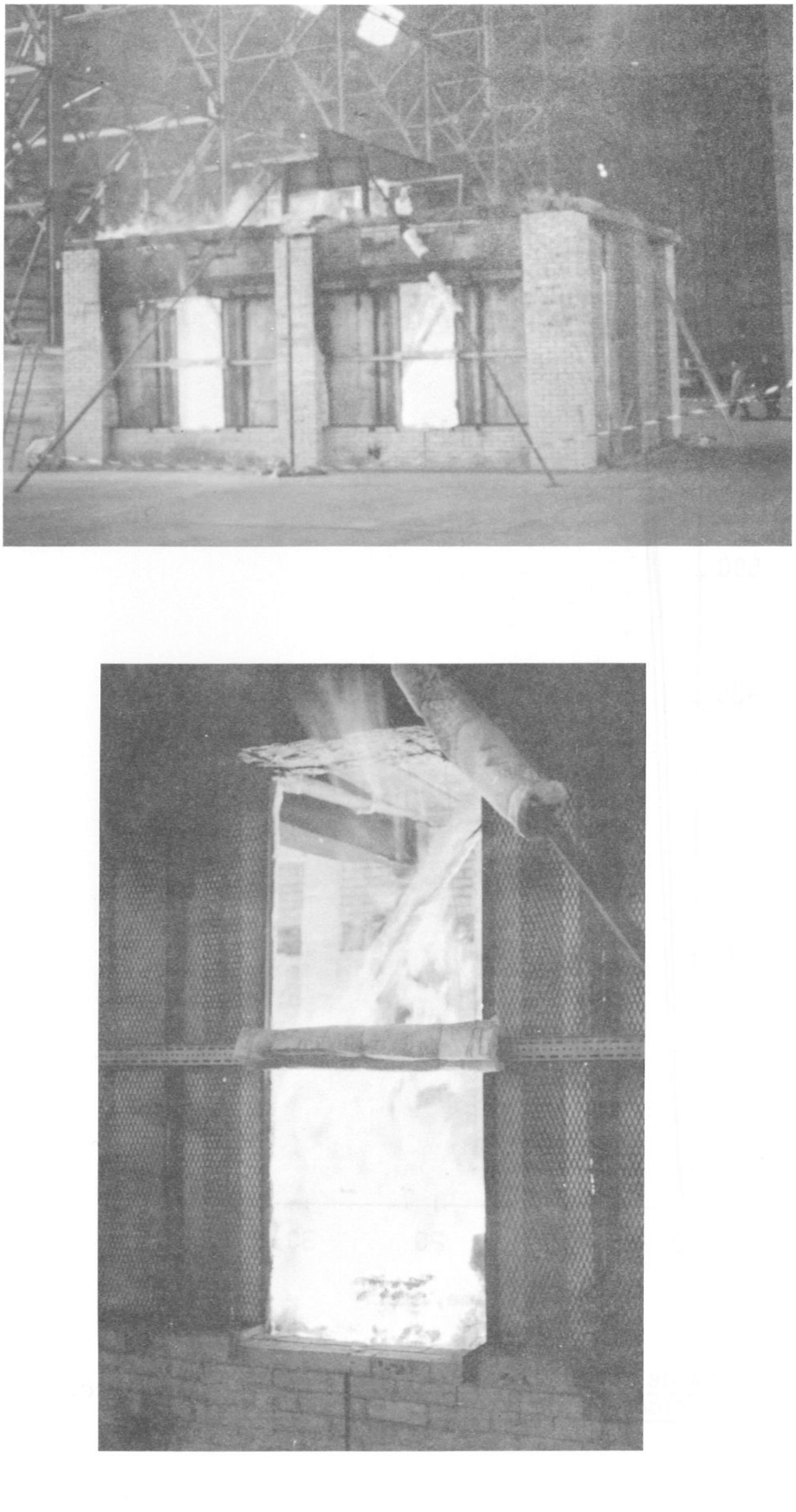
203 x 203 mm x 52 kg/m Universal Beam

(c) Location of Thermocouples in Steelwork

POSITION OF THERMOCOUPLES IN COMPARTMENT FIG 7 (Continued) (R2/5023)

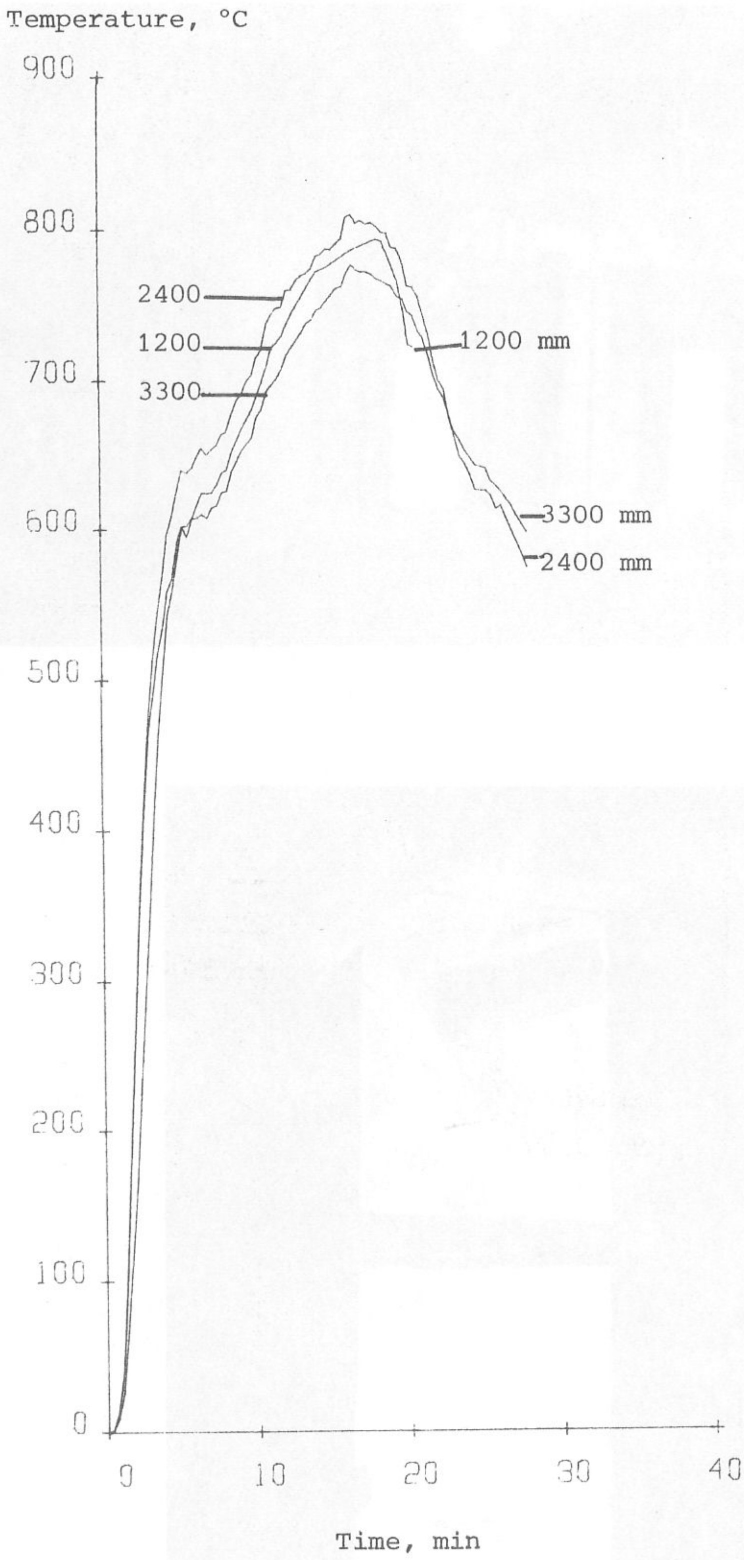
FRS DISPLACEMENT TRANSDUCER FIXTURE FOR MONITORING THE DEFLECTION OF THE BLOCKED-IN COLUMN

FIG. 8



FIRE TEST IN PROGRESS

FIG. 9

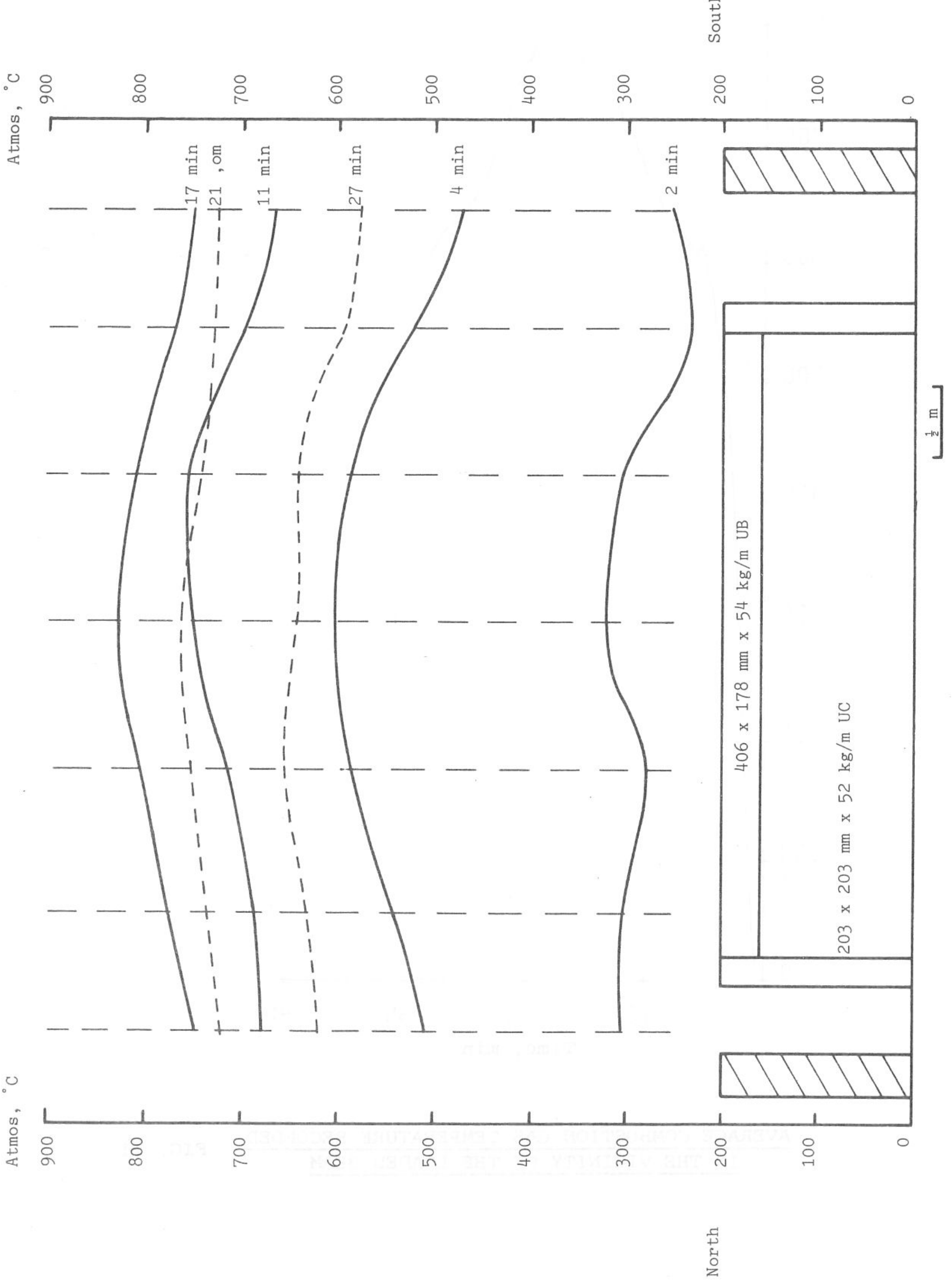


CHANGE IN COMBUSTION GAS TEMPERATURE WITH HEIGHT IN THE VICINITY OF THE COLUMNS

FIG. 10

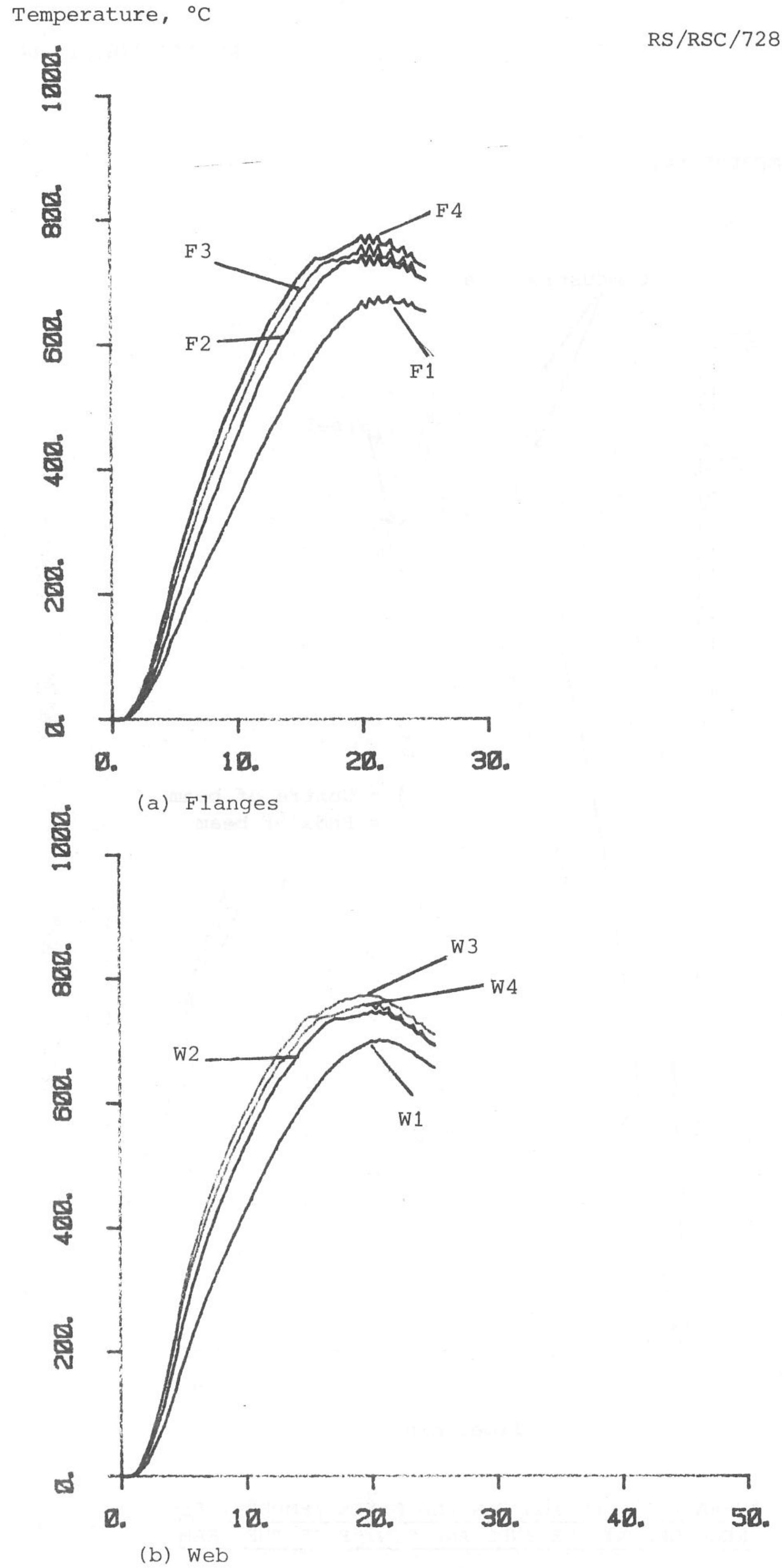
AVERAGE COMBUSTION GAS TEMPERATURE RECORDED IN THE VICINITY OF THE LOADED BEAM

FIG. 11

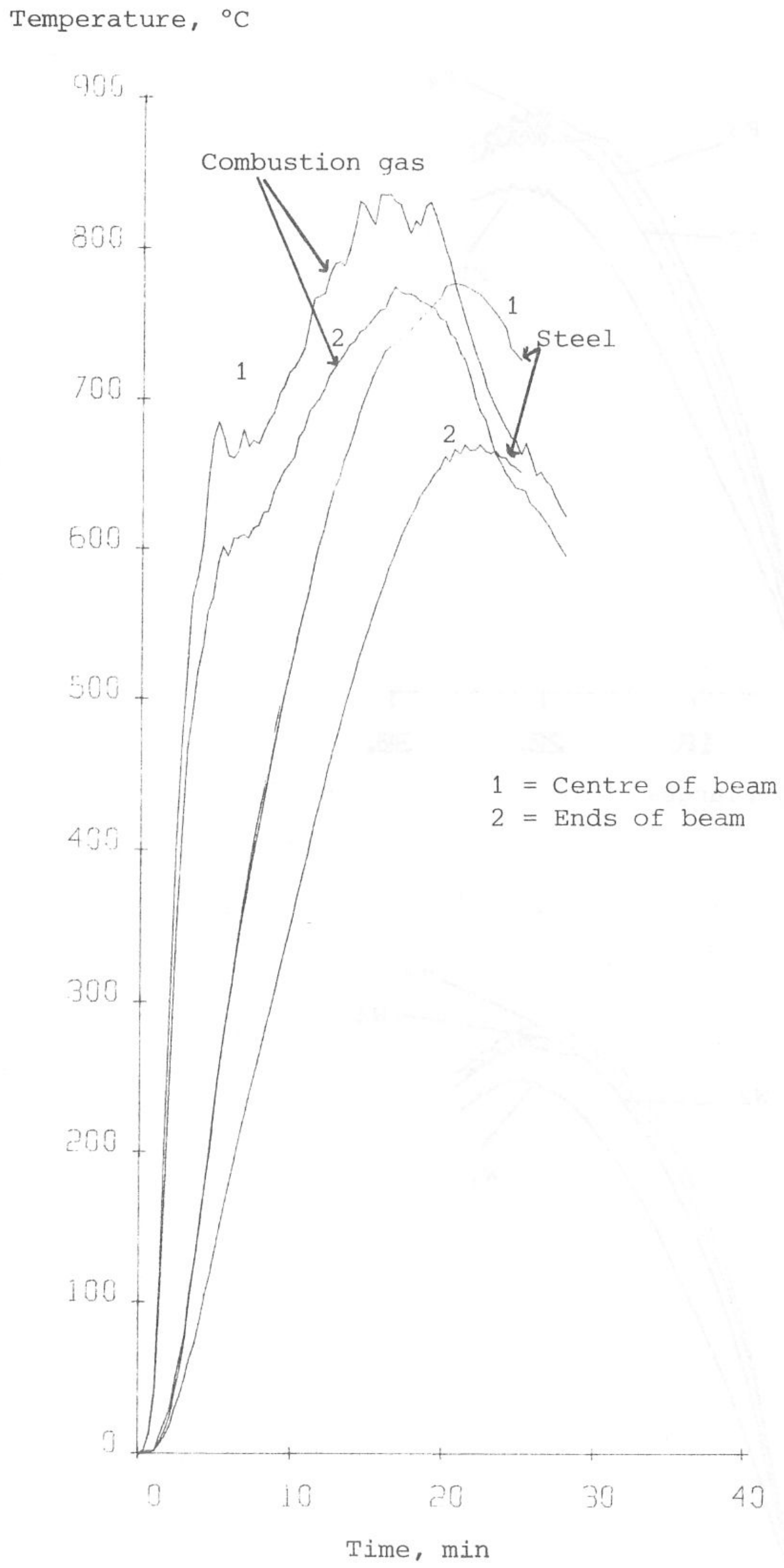


COMBUSTION GAS TEMPERATURE PATTERNS ESTABLISHED IN THE VICINITY OF THE LOADED STRUCTURE

FIG. 12
(R2/5312)

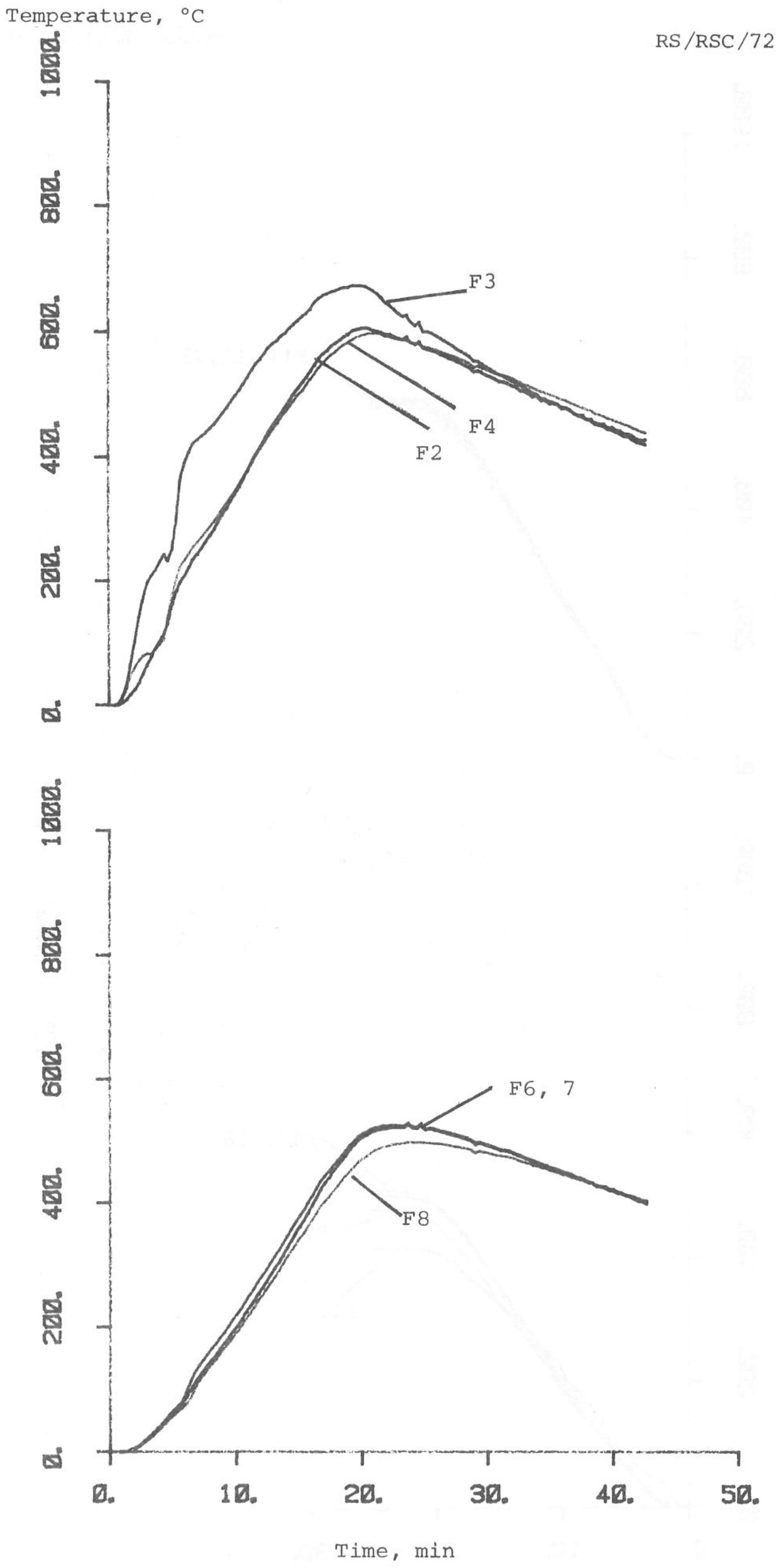


STEEL TEMPERATURES MEASURED IN BEAM FIG. 13



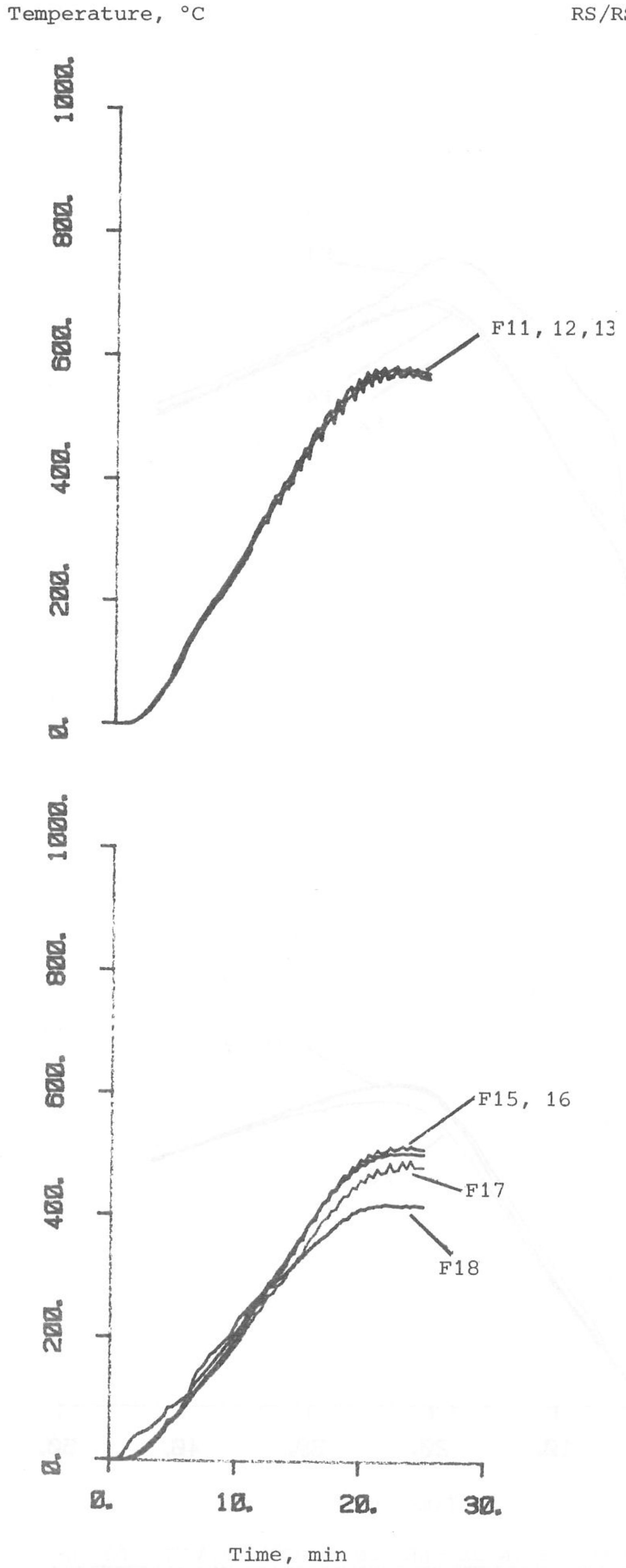
AVERAGE COMBUSTION GAS AND STEEL TEMPERATURES RECORDED AT THE ENDS AND CENTRE OF THE BEAM

FIG. 14



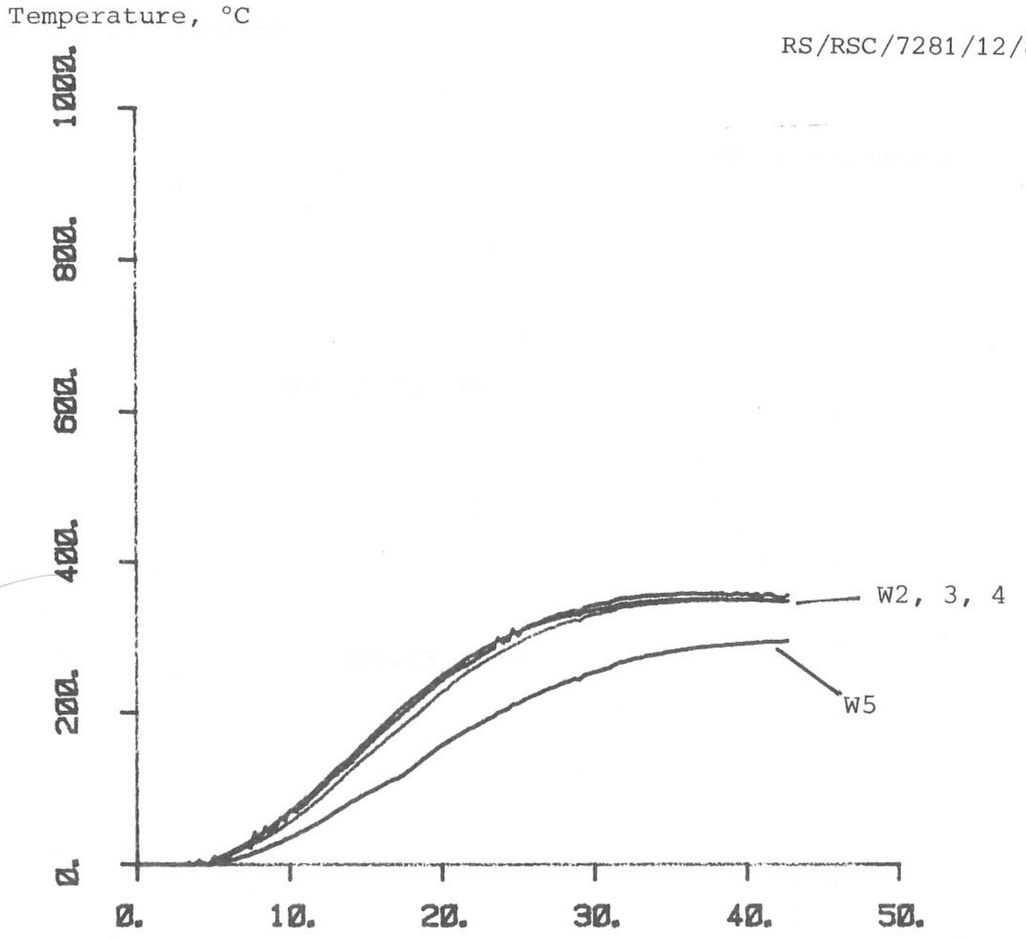
STEEL TEMPERATURES IN BLOCKED IN COLUMN ADJACENT TO THE SOUTH WALL OF THE COMPARTMENT

FIG. 15

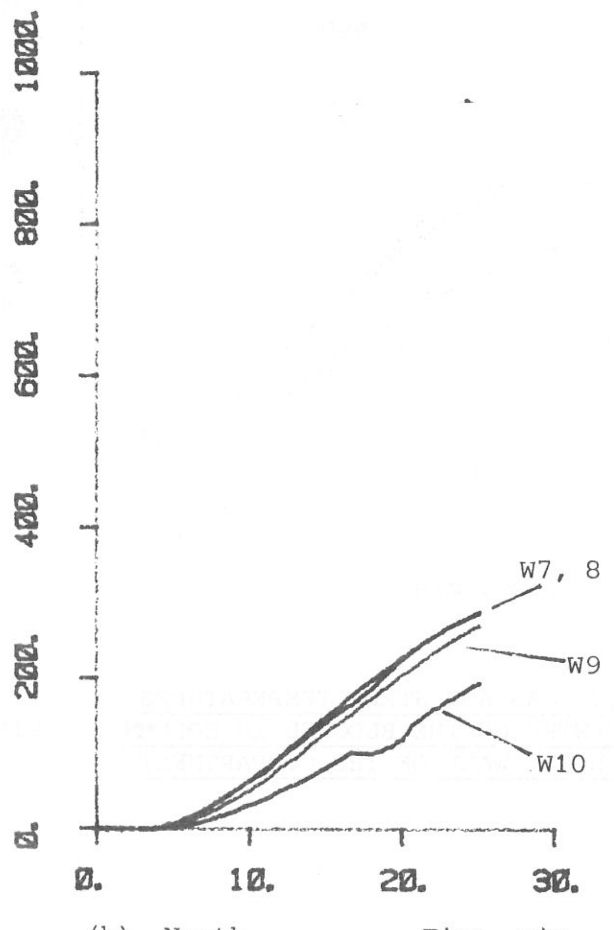


STEEL TEMPERATURES IN BLOCKED IN COLUMN ADJACENT TO THE NORTH WALL OF THE COMPARTMENT

FIG. 16

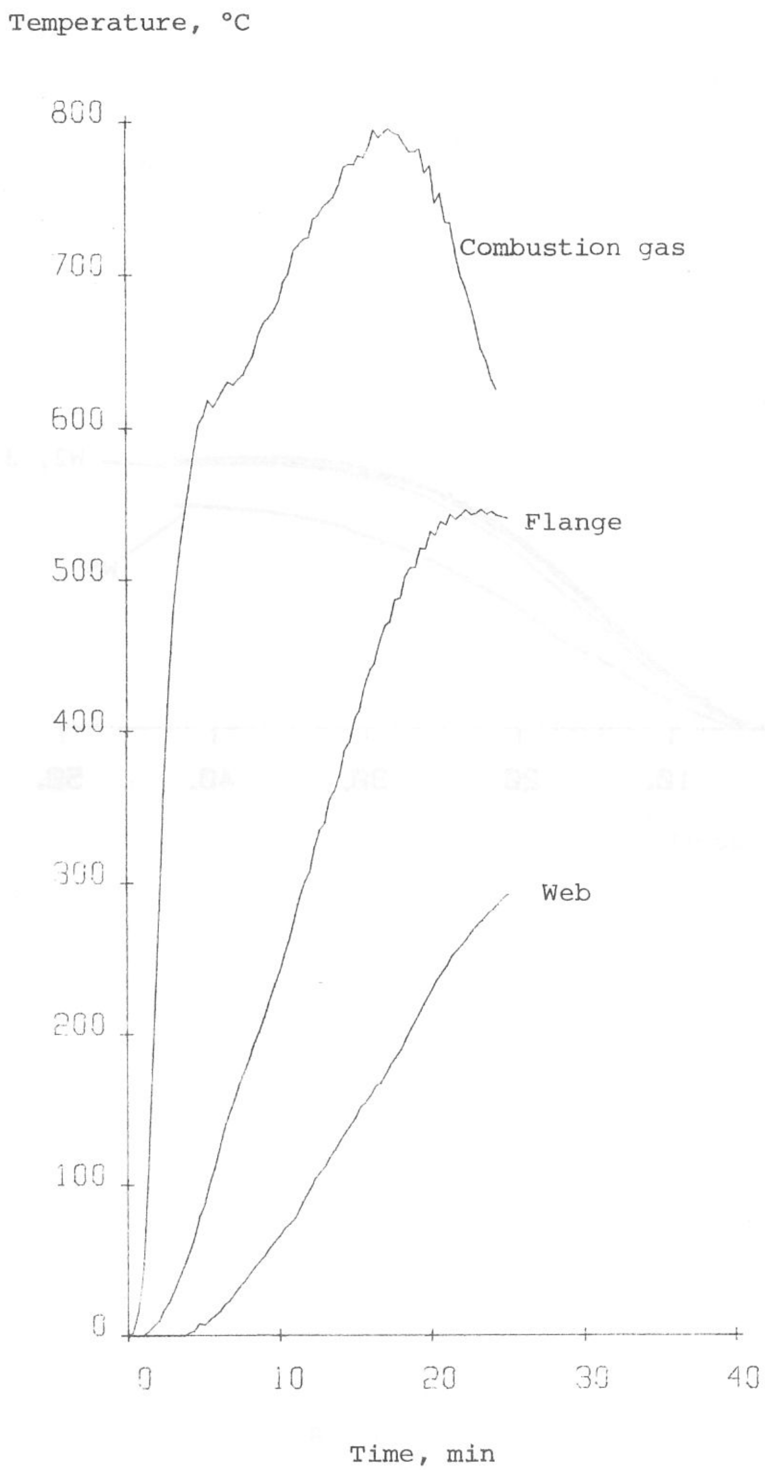


(a) South



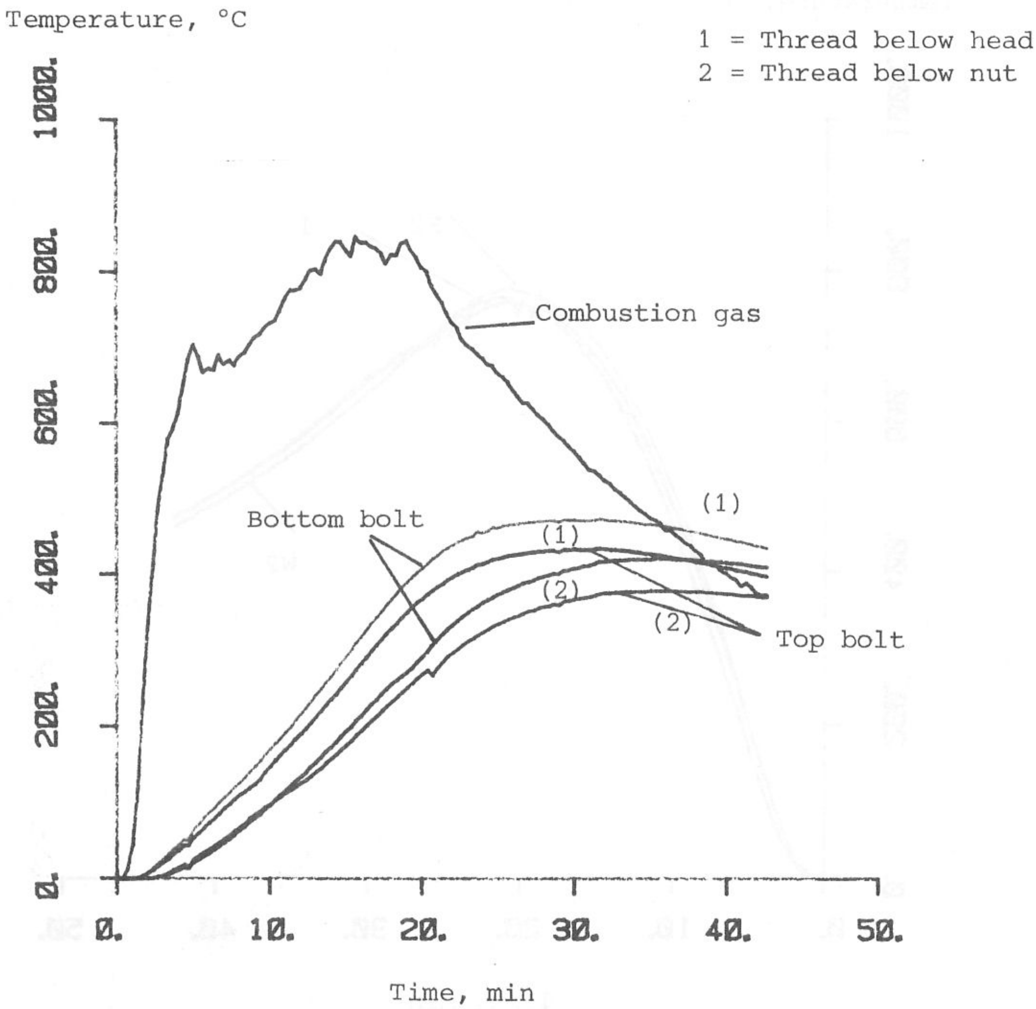
(b) North

STEEL WEB TEMPERATURES IN BLOCKED IN COLUMNS FIG. 17

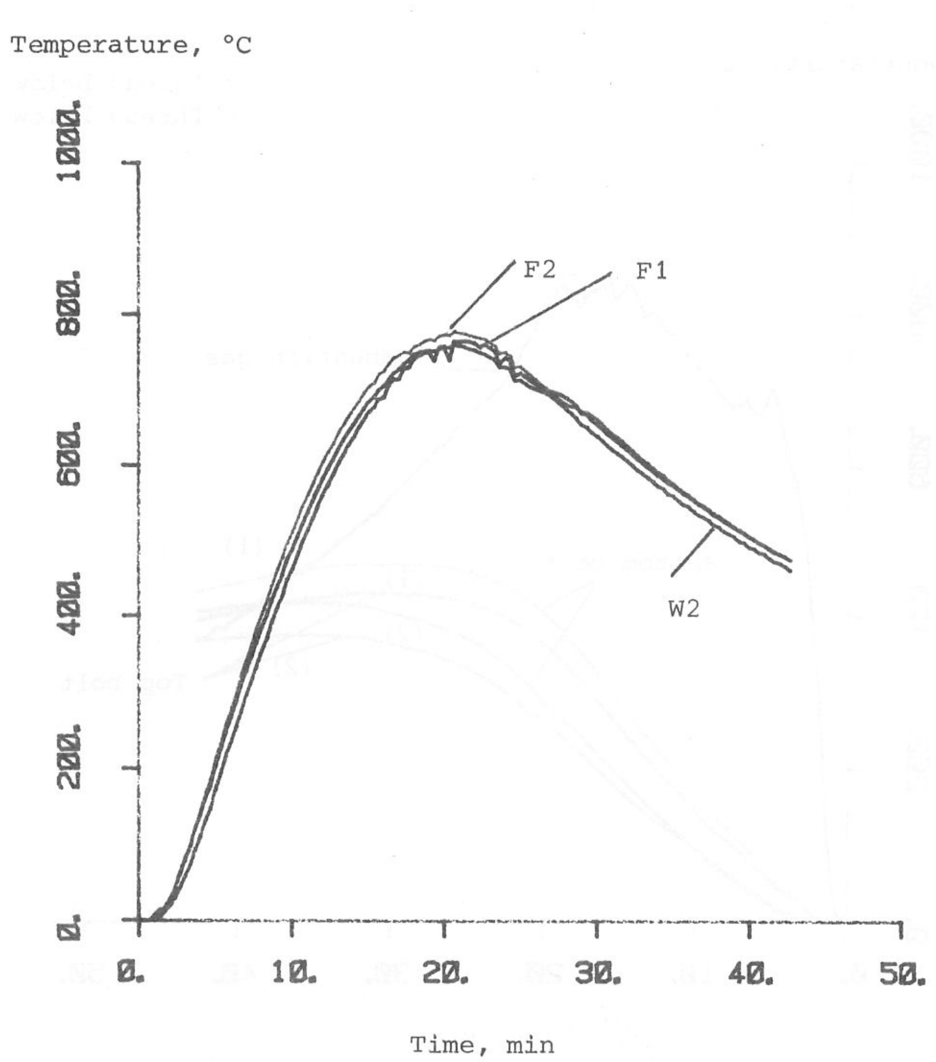


AVERAGE COMBUSTION GAS AND STEEL TEMPERATURES RECORDED AT THE CENTRE OF THE BLOCKED IN COLUMN ADJACENT TO THE NORTH WALL OF THE COMPARTMENT

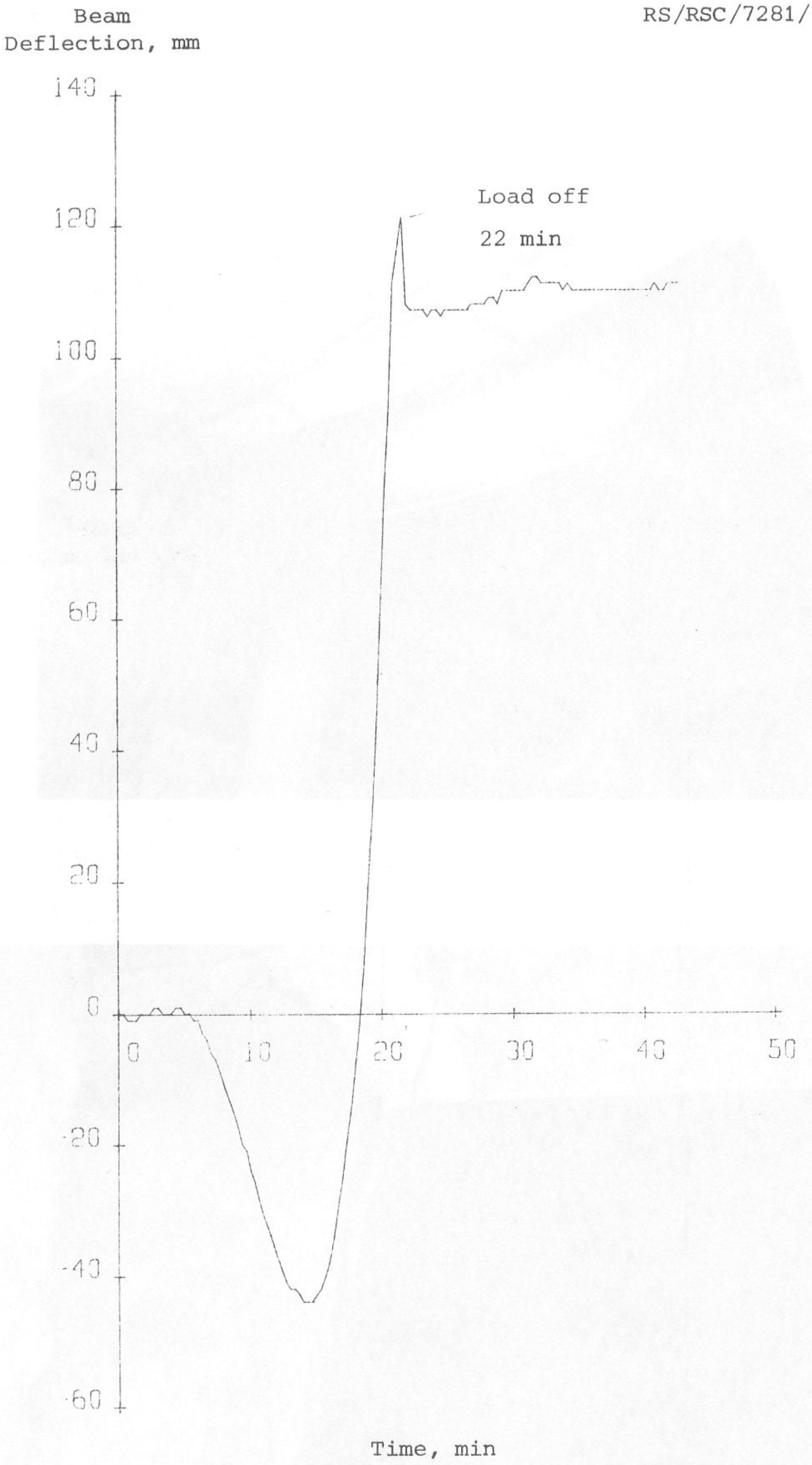
FIG. 18



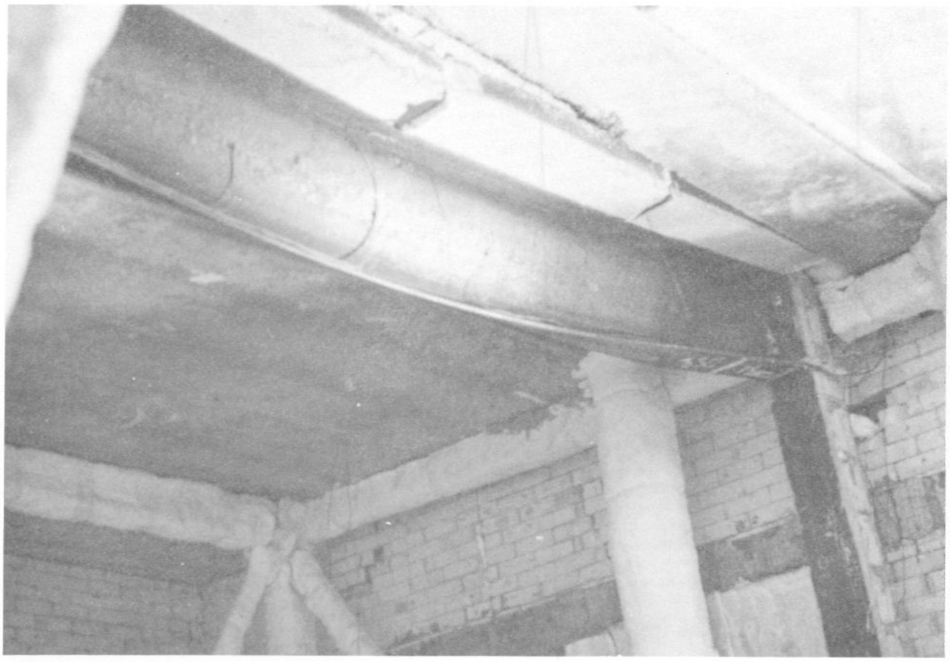
TYPICAL TEMPERATURE PROFILES IN BOLTS FIG. 19



STEEL TEMPERATURES IN INDICATIVE COLUMN FIG. 20



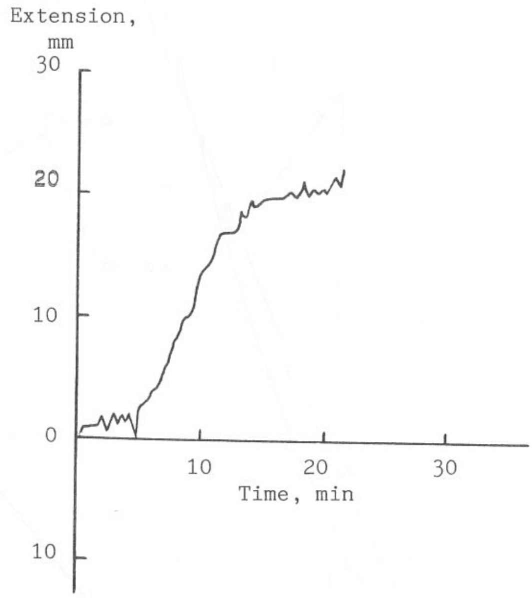
CENTRAL VERTICAL DEFLECTION RECORDED ON THE BEAM DURING THE TEST FIG. 21



(a)

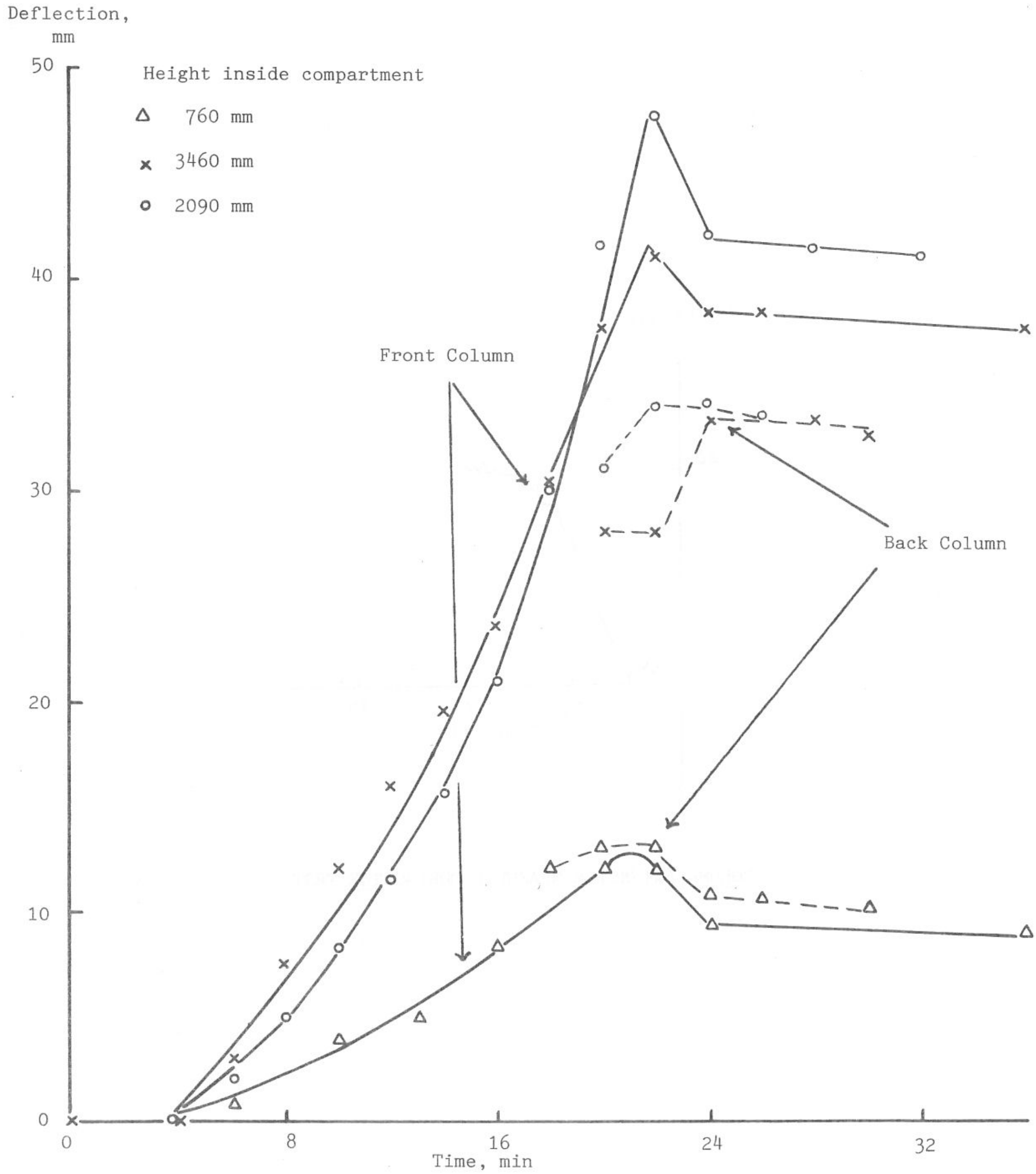
(b)

CONDITION OF THE TEST BEAM ON COMPLETION OF THE FIRE TEST FIG. 22



COLUMN EXTENSION MEASURED DURING THE TEST

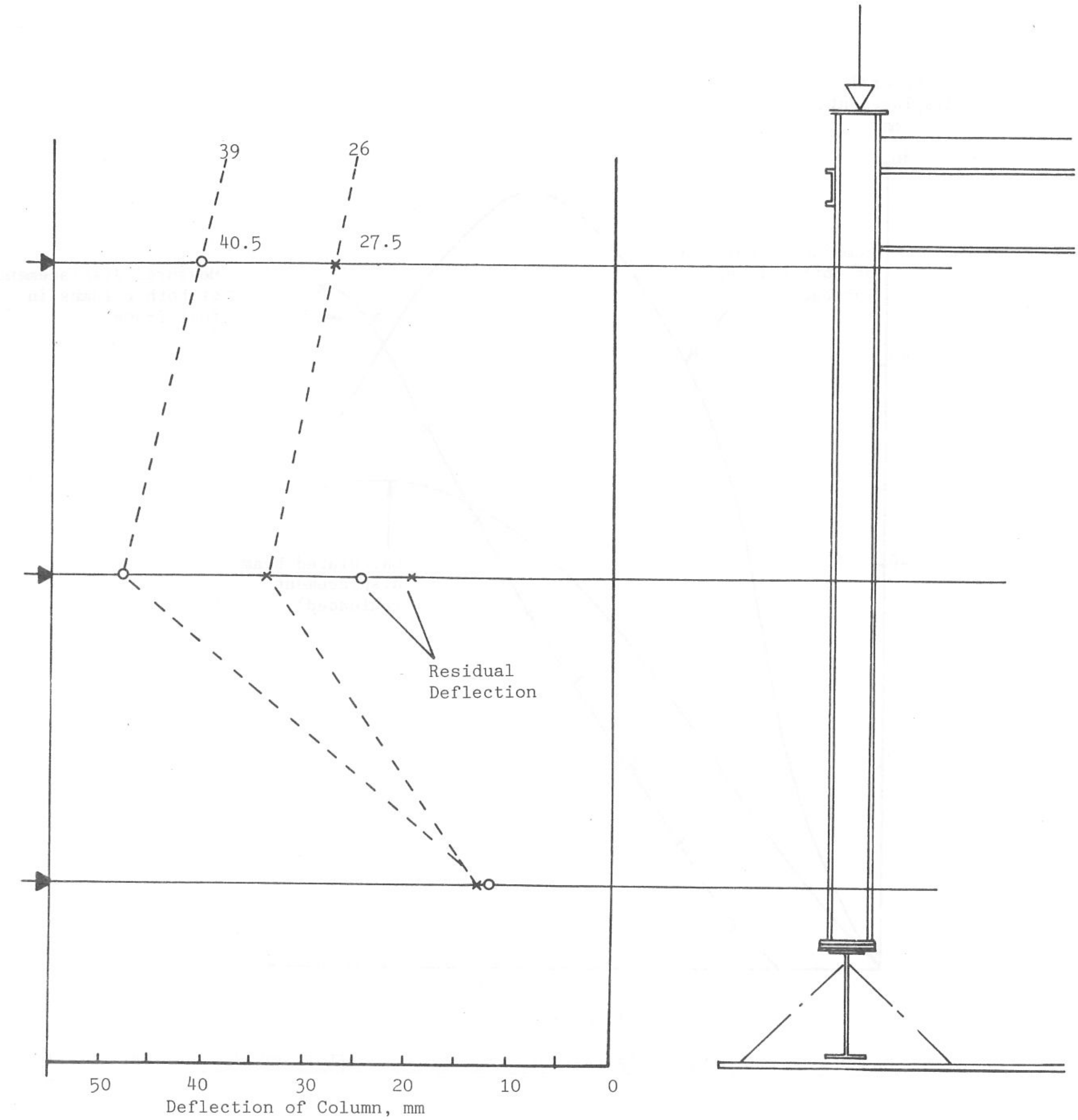
FIG. 23
(R2/5313)



Beam length 4553

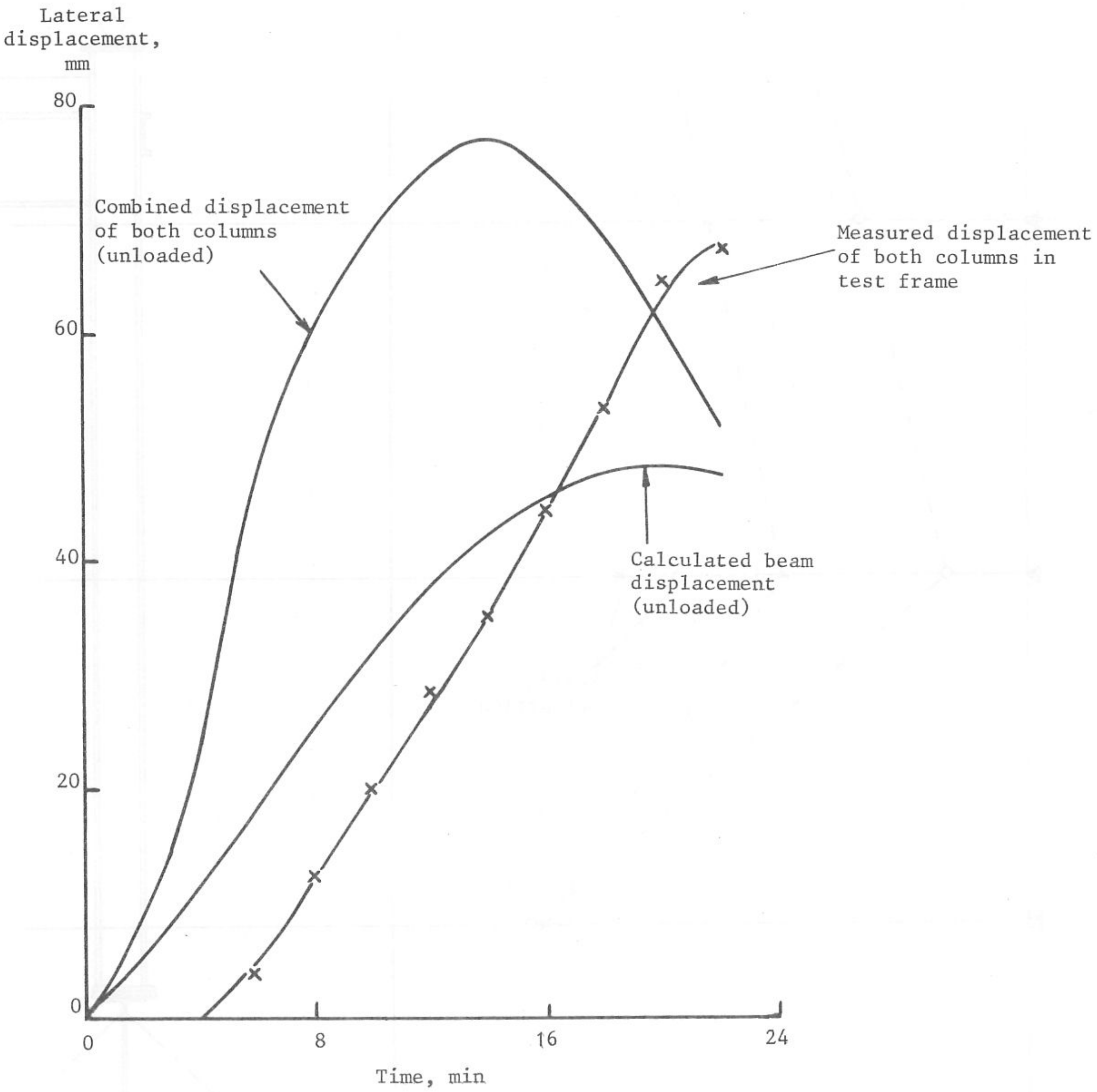
LATERAL DEFLECTION OF BLOCKED-IN COLUMNS MEASURED BY THE FRS DURING THE TEST

FIG. 24
(R2/5314)



LATERAL DEFLECTION OF BLOCKED-IN COLUMNS AFTER 22 MINUTES

FIG. 25
(R2/5315)



CALCULATED AND MEASURED LATERAL DISPLACEMENT OF STEEL FRAME IN FIRE TEST

FIG. 26
(R2/5316)

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