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FIRE AND THE MOTOR CAR
RESULTS OF TESTS ON THE PROPAGATION OF FIRE IN PARKED CARS

by

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MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

As our City streets become more congested by the presence of the ever increasing number of motor vehicles, the problem of mass parking becomes more acute. Probably the most economical method of dealing with the problem is the use of multi-storey car parks, either of the ramp type or multi-storey buildings having mechanical parking machinery.

The multi-storey car park as a building type probably lends itself to system building more readily than any other type of building structure. To achieve economic design in construction the use of light and slender members with dry joints has advantages. Such design methods are at present inhibited by the relatively high standard of fire resistance required by building regulations. Under the regulations car parks of this kind are classified as "storage buildings".

The storage of goods and materials takes many forms; in some a high fire hazard is involved and in others there is little or no hazard. A multi-storey car park is intrinsically a rather special type of storage building which is unlikely to be used for other storage purposes. It is therefore reasonable to ask what are the fire risks inherent in such a specialised storage building? If these fire risks are shown to be low, then it may be reasonable to require a lower standard of fire resistance than is needed in storage buildings generally, and this would result in substantial economic advantages.

In order to provide some answer to this question of fire risks in multi-storey car parks the experiments, which are the subject of this paper, were undertaken. It should be noted that they relate only to a car park in the narrow sense, i.e. a building which provides waiting space only for cars and not facilities for repairs, fuelling, and such ancillary services.

THE FIRE RISK

Before considering the structural requirements of these buildings it is desirable to consider the possible risk that is involved in the close confining of a large number of motor vehicles. Statistics of the incidence of fire in motor vehicles in use and at rest show that the risk of fire is within the region of 1 per 1000 vehicles at risk per year. The incidence of fire associated with modern parking methods is likely to be substantially less than this figure. When considering the fire risk associated with motor vehicles it is unwise to compare the risk to a series of parked cars with that of the large extensive and expensive fires that have occurred in the motor car industry. In the case of car factories, the materials used in the construction and finishing of the building, together with factory materials forms a large part of the combustible material available to contribute to the fire.

It has now become accepted that some assessment of the severity of a possible fire in a building can be made from a knowledge of the amount and type of fuel present, coupled with some details of the building.

In considering these factors it is necessary to state for the fuel present, the calorific value of the various constituent items, the total then being expressed in heat units (Btu's) and referred to as the fire load for the building.

In order to take account of the size of the building, however, the quantity 'Fire Load Density'[1] is used, which is the fire load per unit floor area, and in order to simplify the units this quantity is frequently expressed in terms of the equivalent weight of wood per unit of floor area. Using this idea then 'Fire Load Density' is referred to in pounds per square foot (lb/ft^2).

The fire load associated with the average motor vehicle consists of the car body, upholstery, tyres, oil and the petrol in the tank. For one vehicle these items may appear to present a considerable hazard, but in relation to the cubic content of the building and the floor area occupied by the vehicle, the amount of combustible material involved presents a comparatively low fire load density.

An investigation of the combustible components of two motor vehicles (Appendix I) showed that a saloon model with an engine capacity of approximately 1100 cc had, when its fuel tank was full of petrol, a fire load of 4.3 million Btu, whilst a larger model with an engine capacity of approximately 1500 cc had a fire load of 5.6 million Btu.

When these figures are converted to the wood equivalent and related to the area on which each car stands, a fire load density of 8.35 lb/ft^2 and 8.6 lb/ft^2 respectively is obtained.

However, in the context of car parks the parking area allowed for each car is considerably larger than the area on which the car stands and may range from a maximum of 290 sq.ft to a minimum of 200 sq.ft. Taking the maximum density (200 sq.ft per car) and the larger vehicle as the most severe condition, the fire load density for a car park would be in the region of 3.5 lb/ft^2. For a fire load density of this magnitude it would normally be suggested that a fire resistance of $\frac{1}{2}$ hour would be required in the structure in order to be able to resist a complete burn-out of the combustible contents of the building.

PURPOSE OF THE INVESTIGATION

This suggested relation between the possible fire severity and the required fire resistance in the building is based on the assumption that a fire in one car would spread to others and that eventually the total contents of the building would become completely involved in fire and in order to test the likelihood of this occurring three experimental fires were proposed in which nine cars would be parked in a specially erected building.

Moreover, since the problem of the parking of the motor vehicle is becoming an ever increasing problem it is clear that desirable features of a multi-storey car park would be speed of erection and the possibility of demountability. The fire resistance at present required for such structures can have an inhibiting effect on the use of structural steelwork which as a structural media lends itself to prefabrication and rapid erection. In addition, therefore, to studying the pattern of fire development the temperatures would be measured inside the experimental building and in structural steel members placed in suitable positions.

DESCRIPTION OF THE TEST ASSEMBLY

The building specially erected for the tests consisted of a steel scaffolding structure 60 x 30 ft (approx) with a corrugated iron roof placed on a concrete ramp similar to that of a typical multi-storey car park. An insulated ceiling of wood wool slabs approximately 7 ft above the floor was erected over the central area below the truss lines to simulate the effect of the deck above and on the two long sides ventilation was restricted to approximately 50 per cent by non-combustible cladding suspended from the roof structure. The two ends of the building were left open for two of the tests but were completely closed in for the third. The plan and cross-section of the building are shown in Figs 1a and 1b Plate No.1 shows the general layout of the building and the cars in position before the commencement of the first test.

The minimum number of cars which was considered necessary to establish the most congested parking conditions was nine cars laid out in three parallel rows of three. The cars selected for the test were typical vehicles as complete as possible, i.e. having tyres, upholstery and a tank capable of holding petrol. All vehicles were fuelled with five gallons of petrol and combustible materials were placed inside the cars to represent items of personal luggage. As has already been stated, the spacing of vehicles can influence the fire load conditions. The spacing selected was considered to be the minimum which could be tolerated in the car park of the type under consideration, and the actual spacing between individual cars in the three tests is shown in Fig.2.

To determine with reasonable accuracy the pattern of fire development it was considered necessary to carry out three tests with a different type of vehicle in the central position for each experiment. Structural steel members were placed in central positions close to the ignited car, and since the weight of steel section, its shape and cross-sectional area will all have an influence on the temperature rise of the steel from a given source of heat, several typical size steel members were used.

These were as follows:

1 - 10 in x 10 in x 72 lb/ft run universal column
1 - 8 in x 8 in x 35 lb/ft run universal column
2 - 4 in x 4 in x $6\frac{1}{2}$ lb/ft run square hollow section
1 - 3 in x $1\frac{1}{2}$ in x $4\frac{1}{2}$ lb/ft run beam (joist)

and were placed in the positions shown in Fig. 1a.

PRELIMINARY TEST

The methods by which a car can become ignited are not considered to be numerous but probably the two major causes are electrical faults and the careless disposal of matches and cigarette ends within the vehicle.

For the purpose of the investigation it was necessary to ensure that a sustained fire was produced and that the ignition method adopted was reproducible. From a test on a single vehicle it was found that the introduction of a small tray containing approximately 20 fluid ounces of petrol placed under the drivers seat and ignited electrically by remote control was a satisfactory method and this procedure was used in the three subsequent tests.

It was appreciated that the vehicles available for the tests were non-runners and that petrol lines and carburettors were not charged. Nevertheless the method of ignition described above was considered to more than compensate for this slight deficiency in practical fire hazard conditions of parked vehicles.

METHOD OF TEST

The procedure during the three tests was similar with the exception that in the third test the two ends of the structure were closed in by screens to reduce the ventilation to the minimum that would be tolerated in a building of this character; the purpose being to establish whether or not the pattern of fire development would be significantly changed by reducing the ventilation in this way. Plates 2 and 3 show the structural alterations used for Test 3.

The centre car (see Fig.2) was ignited and the fire allowed to develop naturally and to continue to burn until it had either burnt itself out or the temperatures reached had fallen to an insignificant level, at which point the Fire Service, who were in attendance at all three tests, extinguished the remaining burning materials. As far as was practicable with the vehicles available the windows were closed on the assumption that security would expect such conditions to be found in the car park. However, for the ignited car the drivers window was left half open. At the completion of each test the burnt-out car was moved to the least vulnerable position and the assembly repositioned for another test with, as near as possible, identical test conditions. The weather conditions were similar for all three tests and could be said to be fairly typical. Wind speeds within the range of 6-12 m.p.h. and gusts of a maximum 18 m.p.h. were experienced. Conditions could therefore be said to be those which would be experienced in a multi-storey building.

MEASUREMENTS MADE DURING THE TESTS

Three important aspects of the fire pattern were studied during the tests.

(a) The temperature attained by structural steel members placed around and above the ignited car.

Temperature measurements were made on the steel columns 24 in from the base and 6 in below the false ceiling level. Fig. Nos 1-3 of Appendix 2 shows the average steel temperatures attained by the structural steel elements.

(b) The temperature of the flammable gases under the suspended ceiling.

Their temperatures were measured by means of thermocouples placed 12 in below the suspended ceiling and the average gas temperature above the ignited car are shown in Fig Nos 4-6 of Appendix 2.

(c) The radiation from the ignited car to adjacent parked vehicles.

To obtain radiation measurements the usual instrumentation would be the use of radiometers but a simple satisfactory method is the use of softwood blocks[2], placed on cars surrounding the ignited vehicle. The blocks 7 cm x 7 cm x 4.5 cm thick were placed on the outside of the cars surrounding the one ignited with one square face vertical and pointing towards the ignited car. After the fire an average of heat transfer to the blocks during the period of fire when the burning was intense was assessed by the depth to which charring had occurred or by the change in the reflectivity of the surface of the block or by the colour change in pieces of temperature sensitive paper cemented to the surface of the block. A duration for the intense burning period was derived from observations made at the fires. The position of the blocks and the radiation intensities obtained are shown in Appendix 3.

VISUAL OBSERVATIONS DURING THE TESTS

The pattern of fire growth and the speed at which the fire developed was dependent to a considerable extent upon the type of vehicle involved. Test No.1 in which a large luxury type saloon was ignited was by virtue of the solid construction slow in development and spread whilst in Test No.2 a Utility Van with a lightly constructed body and a fabric panel in the roof produced a more rapid development than in the previous test. Test No.3, the final test in the series, where a soft top small saloon was used as the ignited car produced the most rapid development as there was little other than the fabric top to restrict the upward development of the fire.

Plate No.4 shows the progress of the fire in test No.1 at approximately 5 minutes from the commencement of the test and Plate No.5, the state of the car at the completion of the test.

The tendency of fire to spread to adjacent vehicles was closely watched during the progress of all three tests. The two methods of possible ignition, namely by radiation and direct flame impingement were observed. Whilst paint blistered and ignited on the adjacent vehicles to either side in both Test Nos 2 and 3, sustained burning was not maintained. It may be seen from the radiation measurements set out in Appendix 3 that the intensity of radiation was generally low. Window glazing in the cars adjacent and on either side retained its integrity in all the tests and by so doing reduced the possibility of fire spread to the combustible interior of the adjacent cars.

One of the major hazards which was considered a possibility was disruption of the petrol tank and the flowing of petroleum under other cars in the vicinity via the sloping concrete ramp. In no case did this occur in spite of the fact that in Test No.2 the position of the spare wheel and other combustibles which were completely burnt away was situated directly above the tank containing five gallons of fuel. It was observed that the method of burning of the fuel when ignited, was via the filler cap and the connecting pipe which melted and the fuel burnt from this source only. From a knowledge of the disposition of combustible materials adjacent to fuel tanks, in the three tests, it is considered very unlikely that an explosion or disruption of a petrol tank would take place. A pressure build-up sufficient to cause disruption of the tank could, we feel, not take place as all tanks are provided with a pressure release either in the filler cap or by other means. Plate No.6 shows the burning fuel at the filler pipe in Test No.3.

DISCUSSION OF RESULTS

The close confining in a building of large numbers of motor vehicles which in themselves contain a considerable quantity of potentially flammable material has been considered to represent a fire hazard. In the majority of cases the ceiling level is low and experimental work in other fields has shown the presence of the ceiling to be a substantially contributing factor in fire spread. The tests described here were designed to show how fire would develop and spread should one occur in a car park. The results showed that the development, even with the fairly rigorous igniting source, was slow in terms of normal fire development in combustible materials, and that depending upon the type of vehicle the fire was contained within it for a considerable time before breaking out and in any way menacing adjacent cars.

Even when the fire was at full development the temperatures recorded were relatively low and a critical condition for any form of non-combustible structural element was never reached. The maximum temperatures recorded only persisted for a very short period of time.

In Tests 2 and 3 the ignited car burnt out completely and the intensity of the fire in these tests was quite severe owing to the fact that part of the external body of these cars was combustible and a considerable quantity of combustible material was deliberately placed inside them to represent items of personal luggage. If the ignited car had been of plastic fabrication it seems unlikely that a more intense fire would have resulted but if a car adjacent to the one on fire has a plastic body then it is just possible that the fire might spread to that vehicle but spread beyond it is unlikely unless other cars with plastic bodies are also adjacent.

It seems probable that fire will not spread to adjacent cars by radiation particularly when, for security reasons, the windows are likely to be closed. Sustained ignition would only take place if no attempt is made to extinguish the car on fire. In fact, as the action of the fire brigade at the conclusion of the tests showed, the extinction of a burning car is a comparatively simple matter.

CONCLUSIONS

An outbreak of fire within a single parked vehicle is unlikely to result in uncontrollable fire-spread within the car park or in serious damage to the structure of the building.

REFERENCES

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1. GRIFFITHS, Lynda G. and HESELDEN, A. J. M. The use of wooden blocks as simple radiometers. F.R. Note No.648. Feb. 1967.

ACKNOWLEDGEMENTS

The success of these tests was due to the close collaboration between and the hard work of many people and the authors wish to record their thanks to all concerned. In particular they are grateful to Mr. G. A. Pentecost, Borough Engineer and Surveyor of the London Borough of Barnet and his staff for locating such an ideal site and for providing and transporting the vehicles; to Messrs. Camus Ltd., for permission to use the site; to Messrs. Turner Scaffolding Ltd., for the speed in the erection and demolition of the building; to the London Fire Brigade, J. Division, who were in attendance at all the tests and who ensured the safety of all those present and extinguished the fires at the end of each test; and to Mr. A. Silcock and the other members of the Structural Fire Protection Section of the Fire Research Station who carried out so successfully, the not inconsiderable volume of work in organising and ensuring the smooth running of the test programme. Finally, we wish to thank Mr. Coiley and his staff who worked long hours under difficult conditions to prepare each test on time.

APPENDIX 1

List of combustible materials present in two typical family saloon type cars

A. Medium saloon (engine capacity approx. 1100 cc)

Material (generic description)	Weight (lb)	Btu.	Equivalent weight of wood (lb)
Polyurethane	18.3	219,600	27.4
P.V.C.	17.4	161,646	20.2
Wood	31.3	250,400	31.3
Cotton	13.25	117,925	14.8
Rubber	105	1,785,000	224
Petrol (full tank)	72.25	1,445,000	180.6
Oil	10	190,000	23.7
Alcohol	3	28,800	3.6
Paint	5	50,000*	6.25
Nylon	3	30,000*	3.75
Polyester	0.5	5,000*	0.625
Total	279	4,283,371	536.225

Area of enclosing rectangle 61.7 sq.ft
Percentage of combustibles in weight of car 15.4 per cent.

B. Large saloon (engine capacity approx. 1500 cc)

Material (generic description)	Weight (lb)	Btu.	Equivalent weight of wood (lb)
Polyurethane	71.2	854,400	106.8
P.V.C.	34.9	324,221	40.5
Wood	14.08	112,640	14.08
Cotton	14.9	132,610	16.5
Rubber	101.2	1,720,400	215
Petrol (full tank)	85	1,700,000	212
Oil	13.87	263,530	32.9
Underseal	22.5	342,000	42.7
Paint	18	180,000*	22.5
Total	375.65	5,629,801	702.98

Area of enclosing rectangle 78 sq.ft.
Percentage of combustible in weight of car 16.8 per cent.

*Assumed values

APPENDIX 2

Log of tests

Test No.1. Wind S-SW 10-12 m.p.h.

Gusts up to 18 m.p.h.

Time	Observation
0.00	Fire started.
8.30	Flames seen coming out of off-side front window
12.30	Windscreen broken
21.00	Interior of car completely alight
23.00	Flames coming out of all windows licking against a false ceiling
30.00	Black smoke and flames seen under bonnet
36.00	Gradual reduction in fire intensity with no spread whatsoever to adjacent cars apart from blistering of paint.
45.00	Water on, fire out.

Test No.2. Wind S-SW 6-9 m.p.h.

Time	Observation
0.00	Fire was started in the centre car but did not spread and was found to be extinguished after 15 minutes. The fire was restarted by lighting some wood and wood-wool in a cardboard box behind the rear seat of the car.
0.00	Fire started
5.00	Area behind rear seat well alight
12.00	Flames seen to be coming out of windows and licking against the false ceiling
14.00	Aluminium roof melted, car completely alight
15.00	External paintwork on both cars immediately to either side of the one on fire, alight
18.00	Flaming on paintwork on adjacent cars ceased
20.00	Near side rear tyre alight
21.00	Fire in engine compartment
25.00	Gradual decrease in fire intensity
35.00	Water on, fire out.

Test No.3.

Time	Observation
0.00	Fire started
2.30	Fire seen to have burst through fabric section of the car roof
3.30	Windscreen fallen out
5.50	External paintwork well alight on car to left of burning centre car
6.30	Paint to car on left-hand side ceased to flame
7.00	Fire in engine compartment
8.30	Fire beginning to decrease in intensity
10.00	Fire seen in the boot of the car
22.00	Fire seen to be coming from petrol filler cap
45.00	Fire still coming from petrol filler. Remainder of car virtually burnt out
48.00	Water on, fire out.

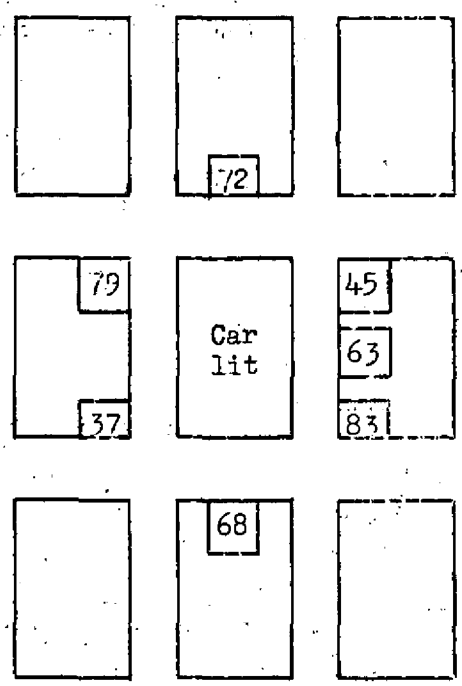
APPENDIX 3

Radiation wood block measurements

Test No.1.

One block, placed on the rear wing of the car immediately to the North of the car that was lit, registered an average intensity of radiation of 0.06 to 0.1 cal $cm^{-2}s^{-1}$. The intensity on all other blocks was less than 0.06 cal $cm^{-2}s^{-1}$.

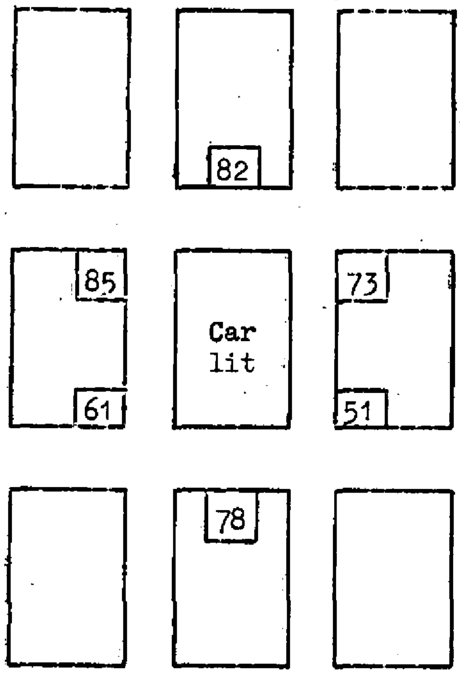
Test No.2.



Time of intense burning taken to be 20 min. (This time is less than that required by the block to attain temperature equilibrium and the estimates of intensity of radiation obtained from the surface temperature measurements will therefore be too low)

Block	Intensity from reflectivity change cal $cm^{-2}s^{-1}$	Intensity from depth of charring cal $cm^{-2}s^{-1}$	Intensity from surface temperature cal $cm^{-2}s^{-1}$
72	0.23		
45	0.17		
63	0.32	0.31	
83	0.14		0.06 - 0.1
68	0.11		0.06 - 0.1
37	0.11		0.06 - 0.1
79	-	0.6	

Test No.3.



Time of exposure taken to be 20 min. (see note on Test No.2)

Block	Intensity from reflectivity change cal $cm^{-2}s^{-1}$	Intensity from depth of charring cal $cm^{-2}s^{-1}$	Intensity from surface temperature cal $cm^{-2}s^{-1}$
82	0.1	No charring	0.06 - 0.1
73	0.12		
51	0.11		0.06 - 0.1
78	0.12		0.06 - 0.1
61	0.15		
85	0.11		0.06 - 0.1

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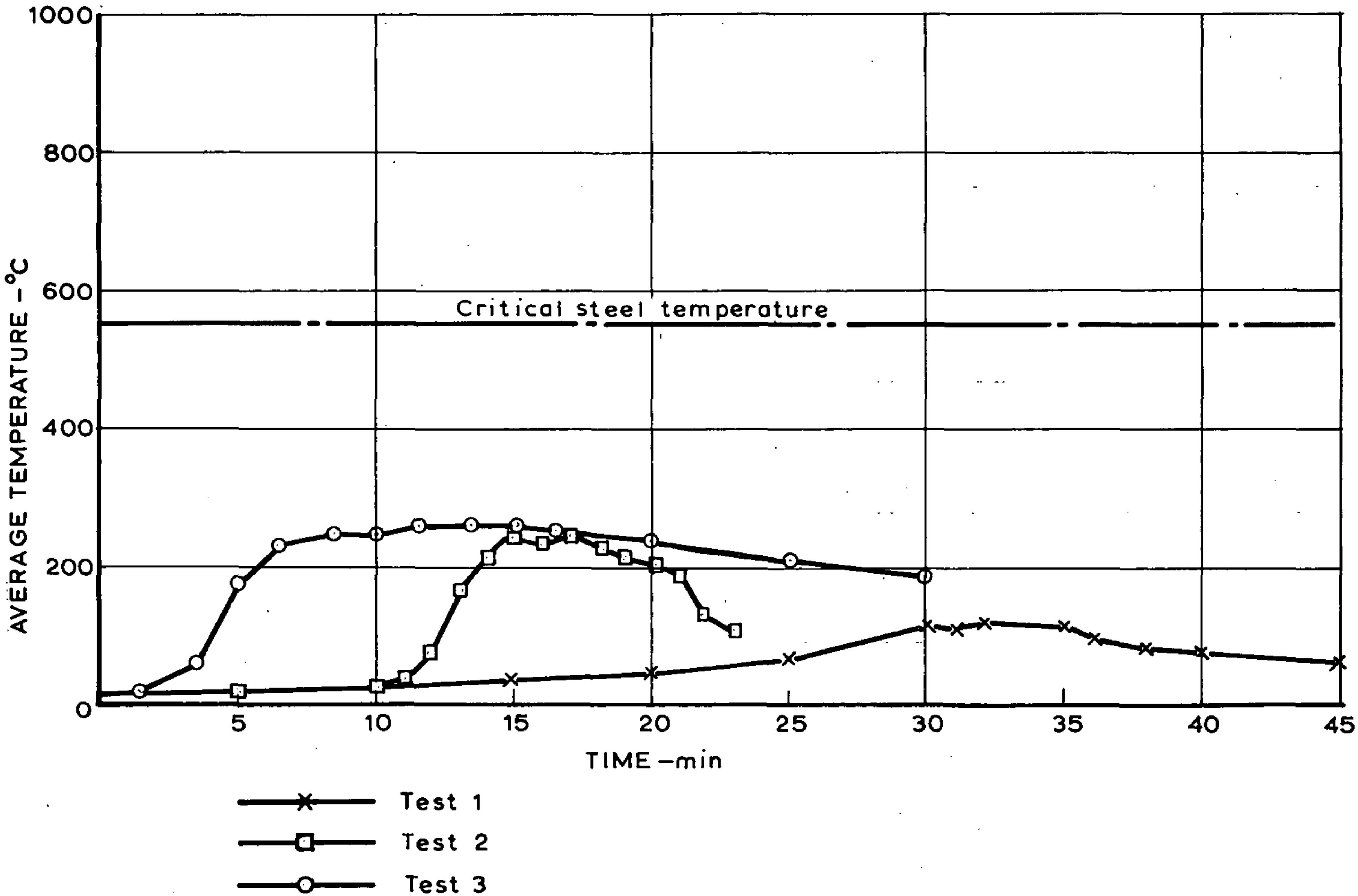
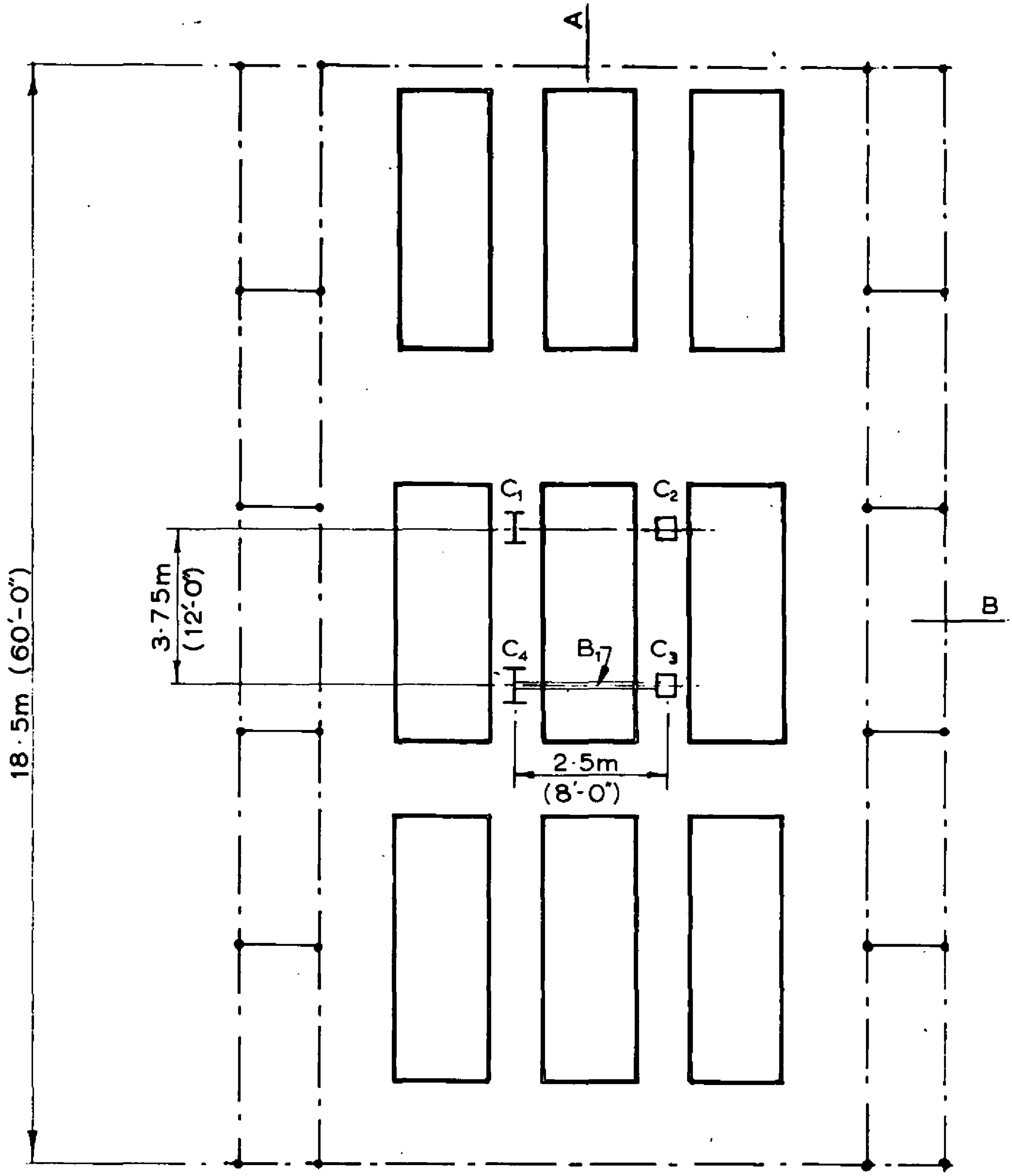


FIG.1. AVERAGE STEEL TEMPERATURES FOR COLUMNS IN TESTS 1 AND 2, AND BEAM IN TEST 3



C_1 – 26·7cm x 25·8cm x 107 kg/m (10" x 10" x 72 lb/ft)

C_2, C_3 – 10·3cm x 10·3cm x 9·7 kg/m (4" x 4" x 6½ lb/ft)

C_4 – 20·6 cm x 20·4 cm x 52 kg/m (8" x 8" x 35 lb/ft)

B_1 – 7·75 cm x 3·8 cm x 6·7 kgm (3" x 1½" x 4½ lb/ft)

FIG. 1a. PLAN SHOWING THE POSITION OF STEEL MEMBERS, CARS AND TEMPORARY SCAFFOLDING

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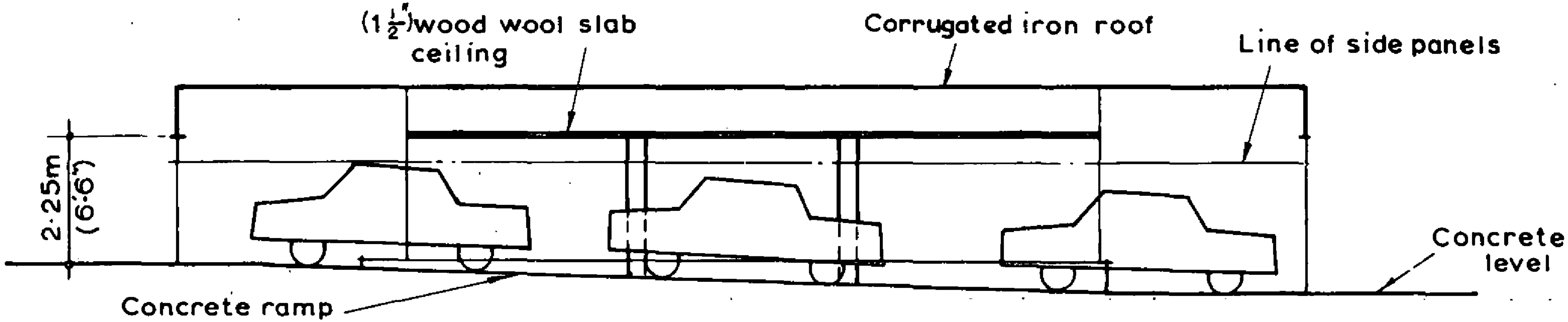
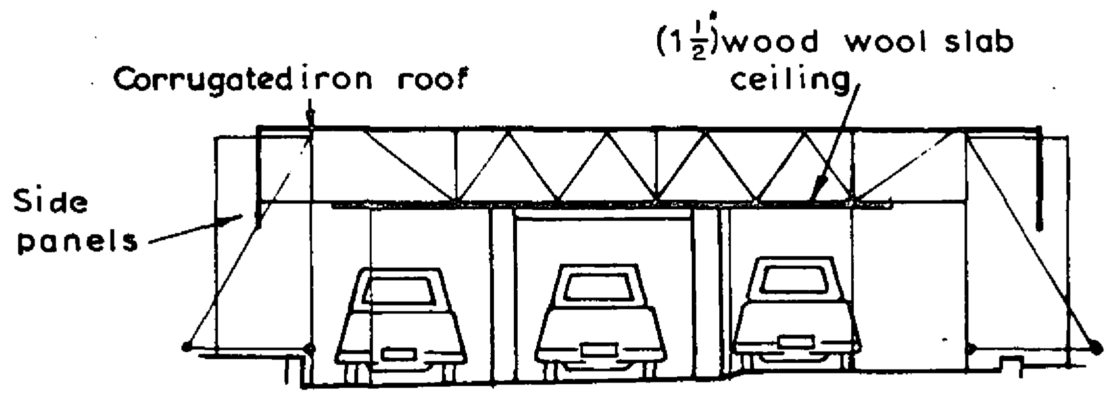


SECTION A



SECTION B

FIG.1b. SECTIONAL ELEVATIONS SHOWING ROOF AND POSITION OF CARS

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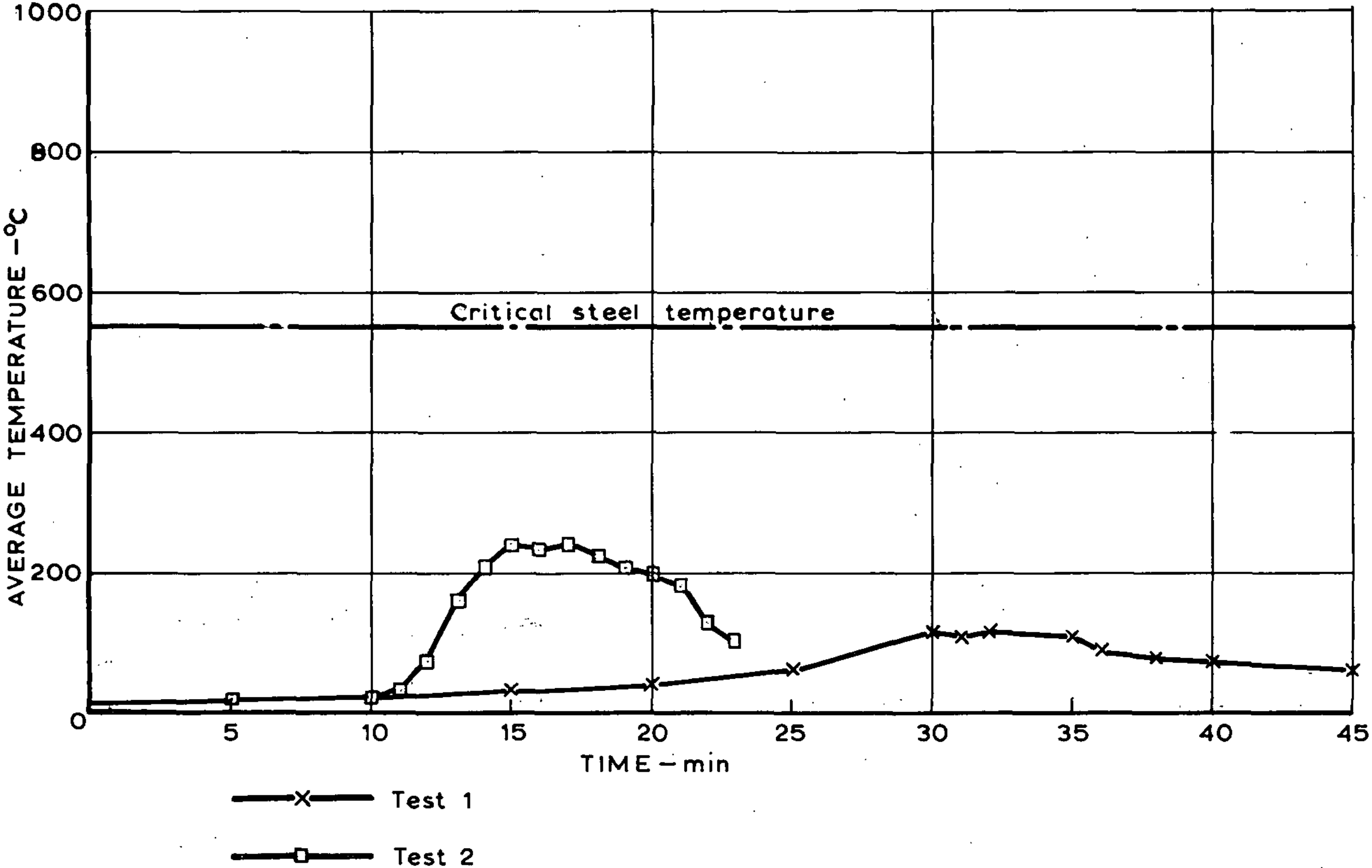
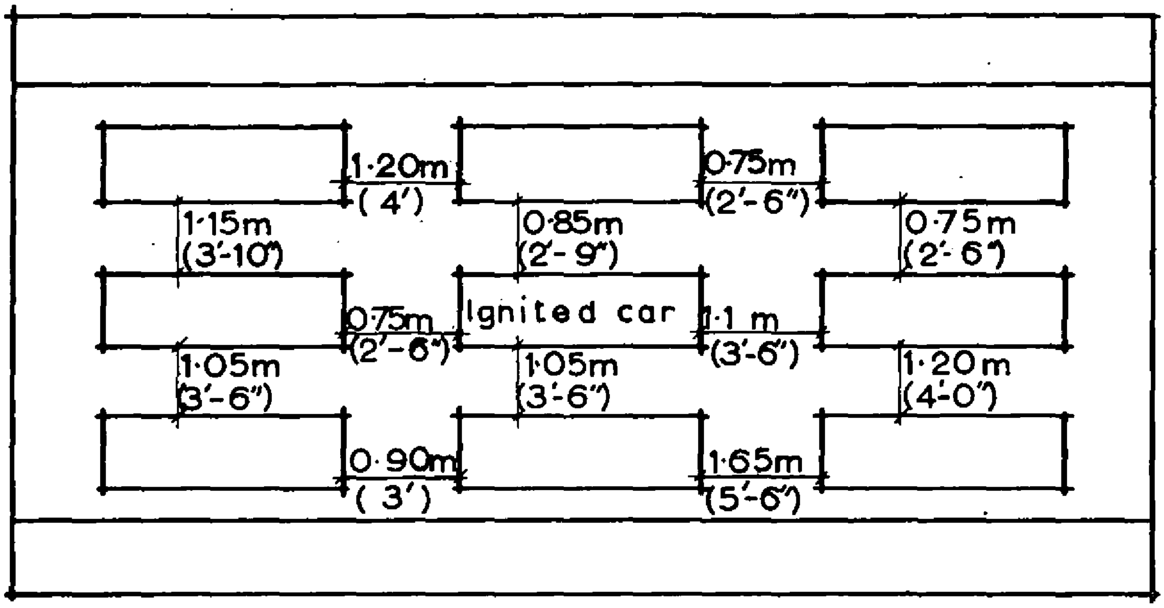
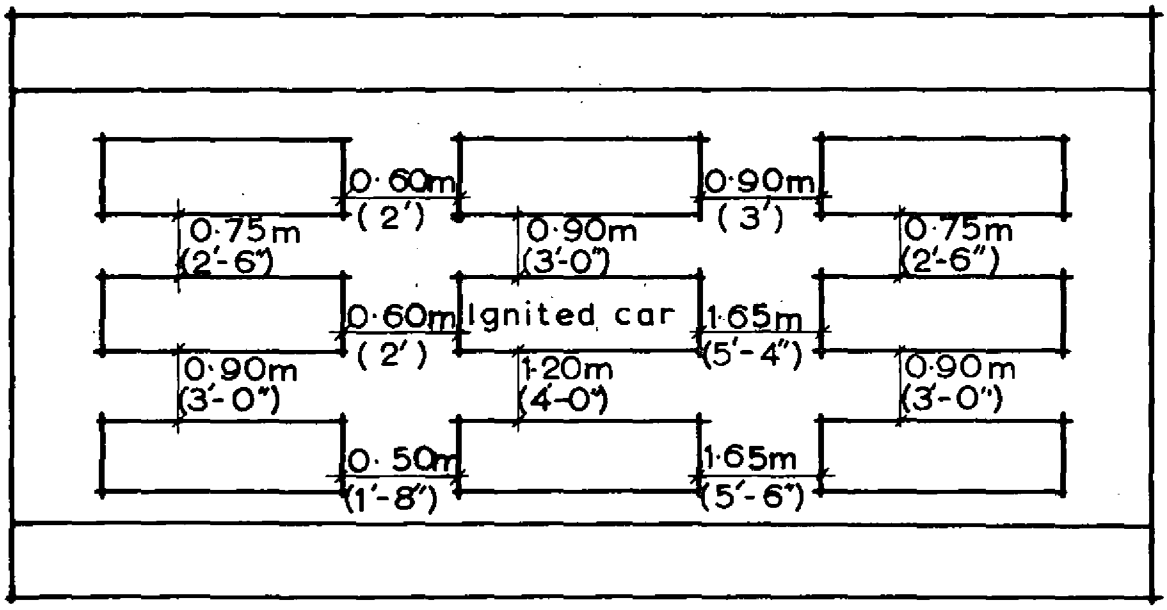


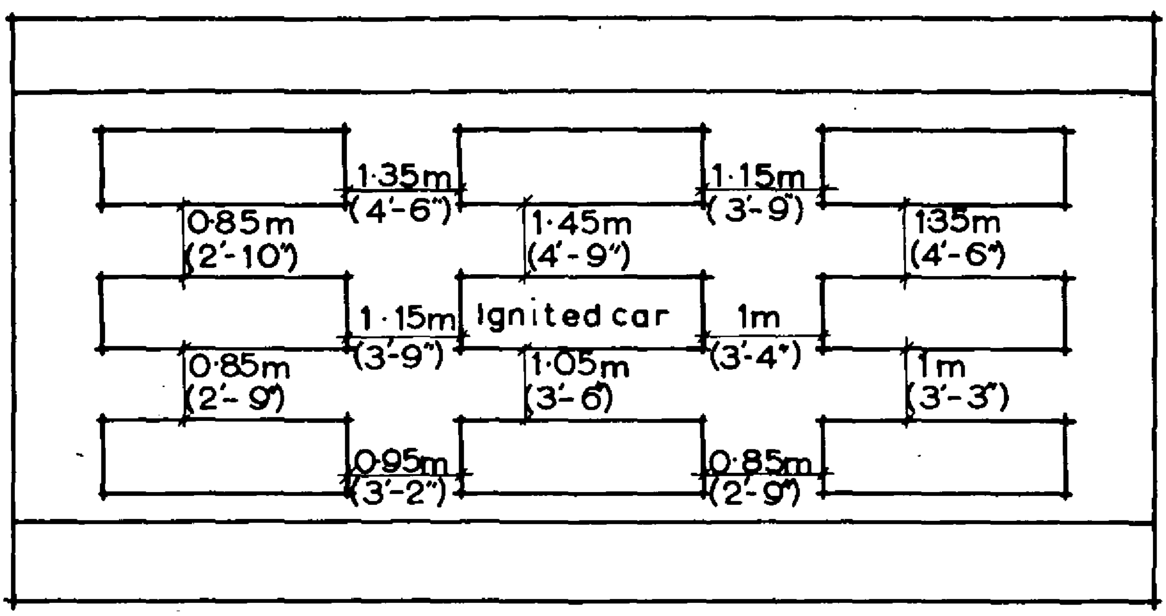
FIG. 2. AVERAGE TEMPERATURE OF STEEL COLUMNS IN TESTS 1 AND 2



TEST 1



TEST 2



TEST 3

FIG. 2. POSITION AND SPACING OF CARS FOR THREE TESTS

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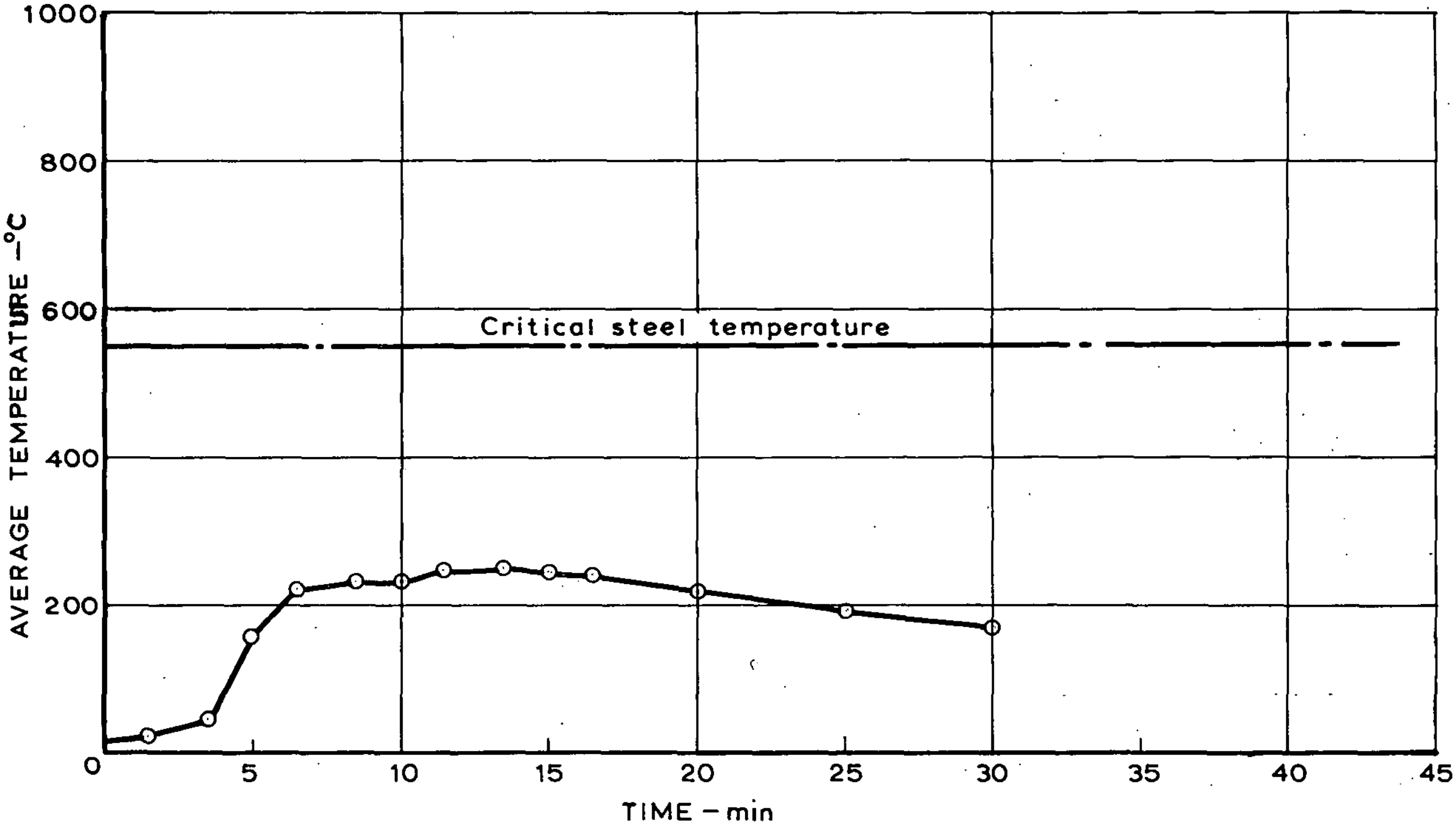

FIG.3. AVERAGE TEMPERATURE OF STEEL BEAM IN TEST 3

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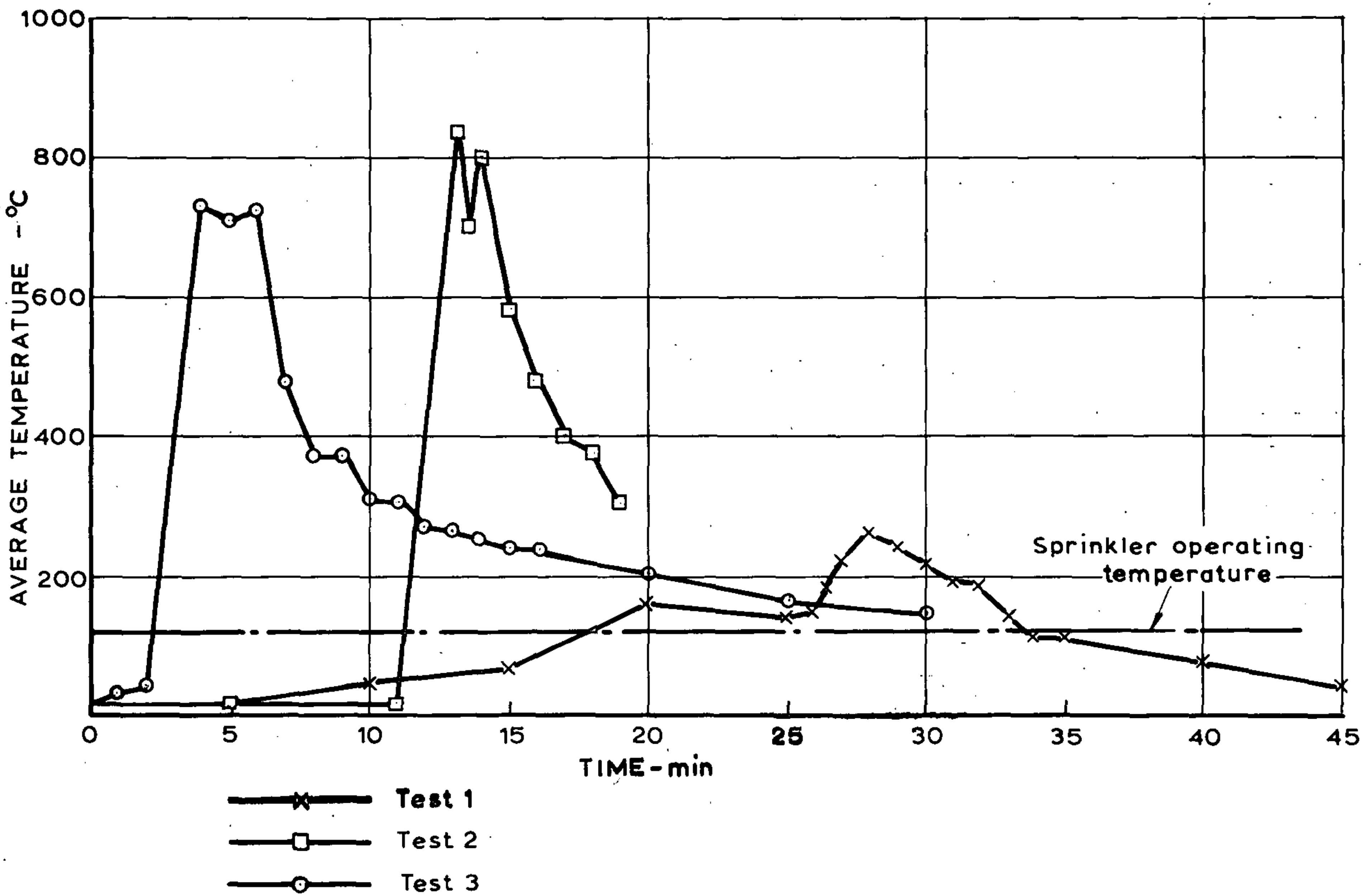

FIG.4. AVERAGE GAS TEMPERATURE ABOVE CENTRE CAR IN TESTS 1,2 AND 3

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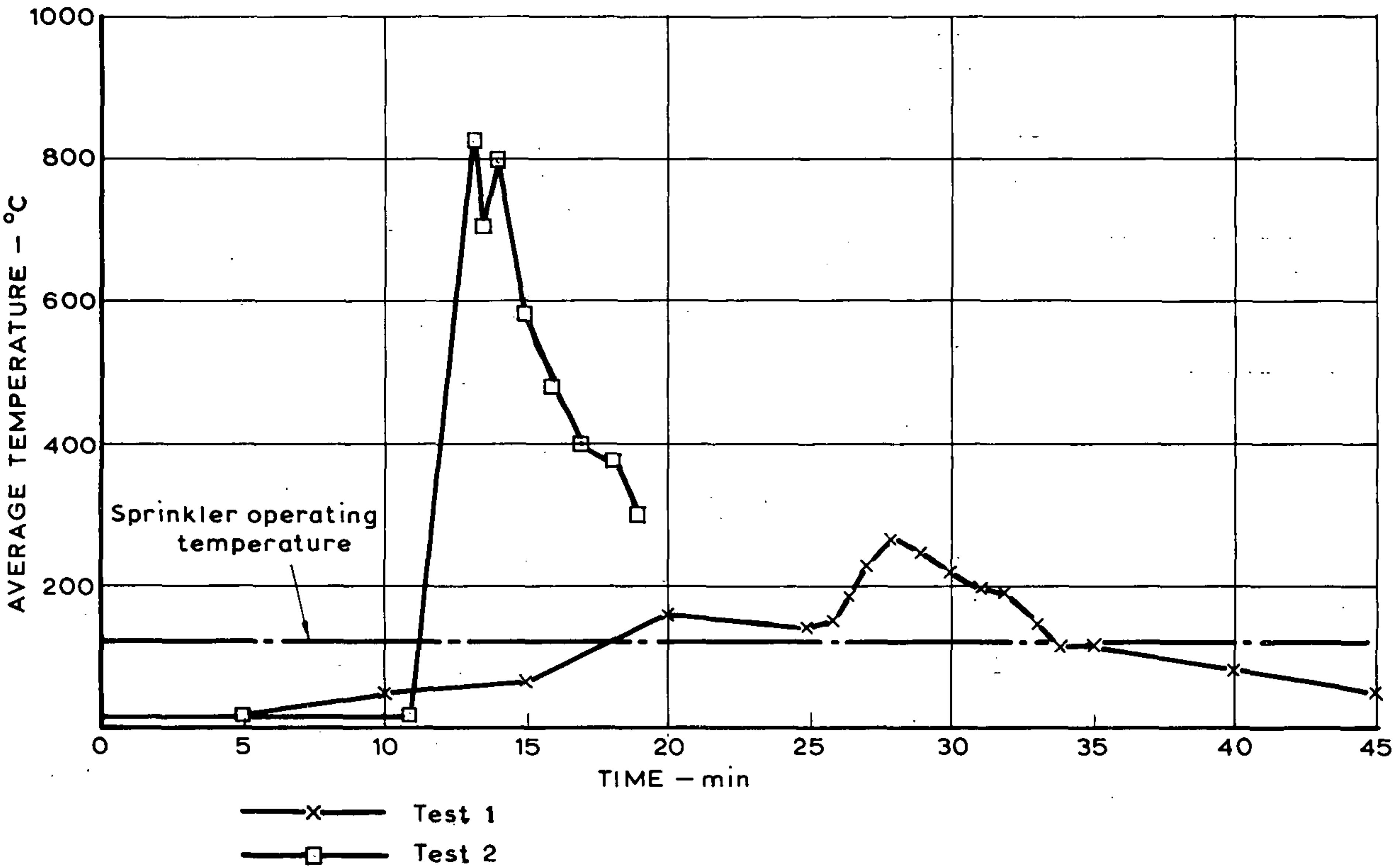

FIG.5. AVERAGE GAS TEMPERATURE ABOVE CENTRE CAR IN TESTS 1 AND 2

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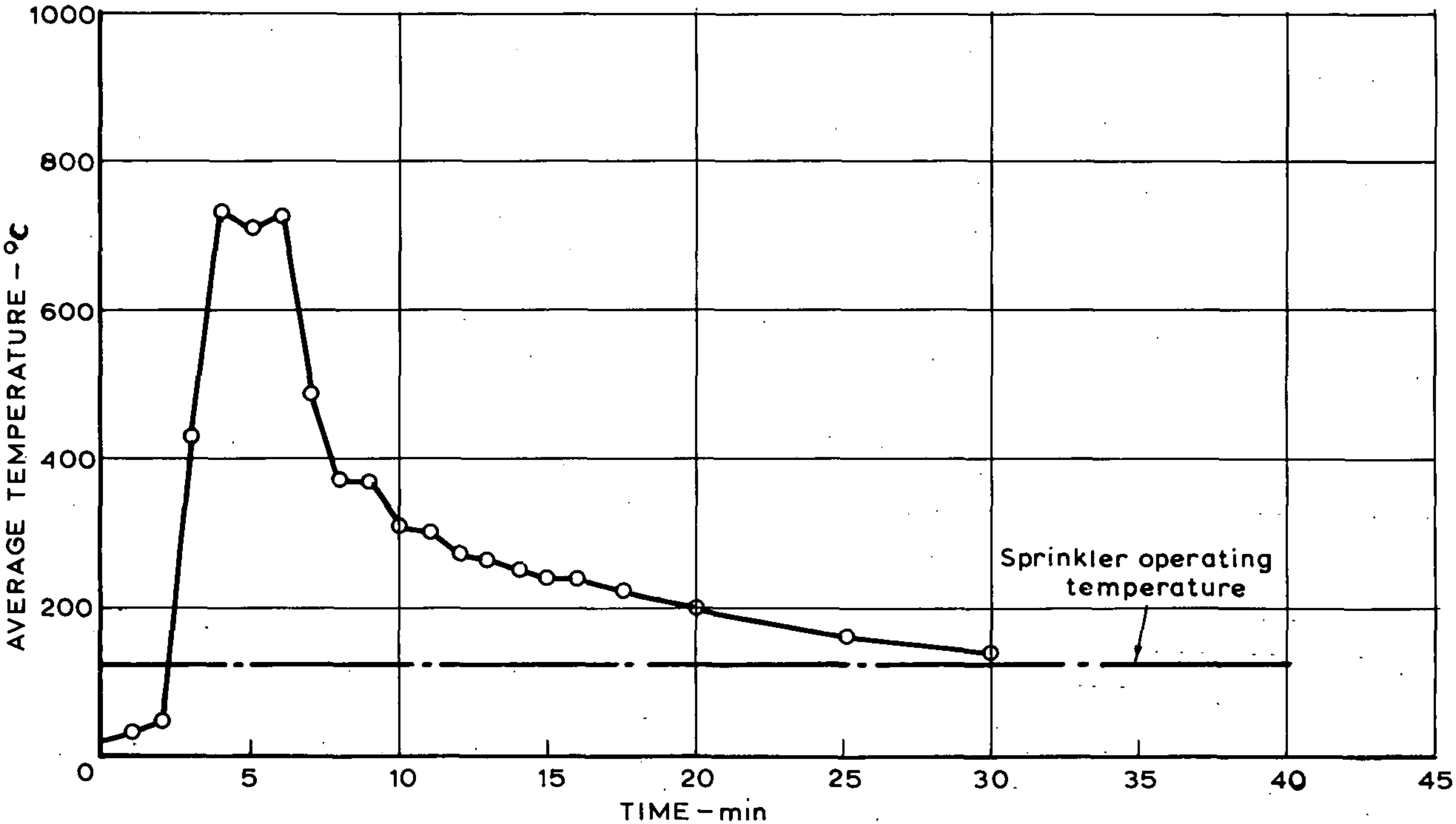


FIG. 6. AVERAGE GAS TEMPERATURE ABOVE CENTRE CAR IN TEST 3

A

B

GENERAL LAYOUT OF CARS IN POSITION
BEFORE FIRST TEST

PLATE 1

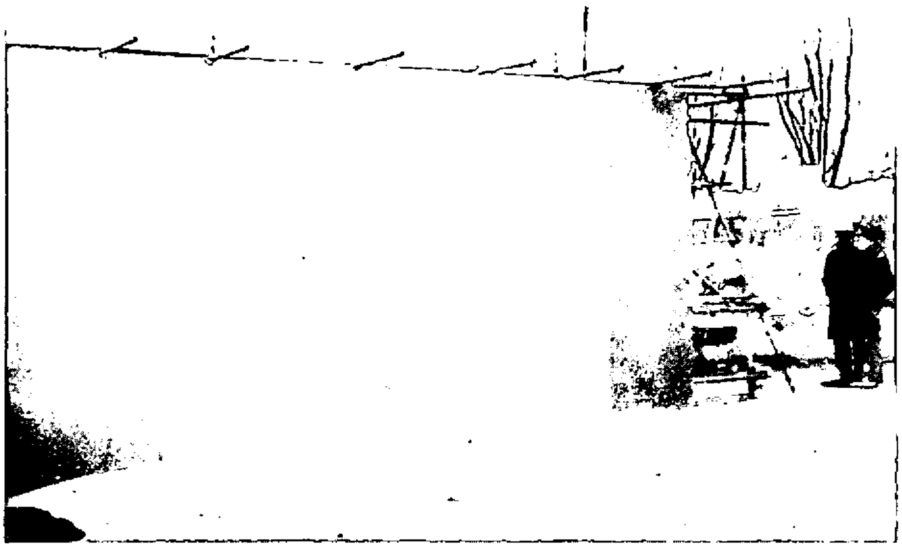


PLATE 2

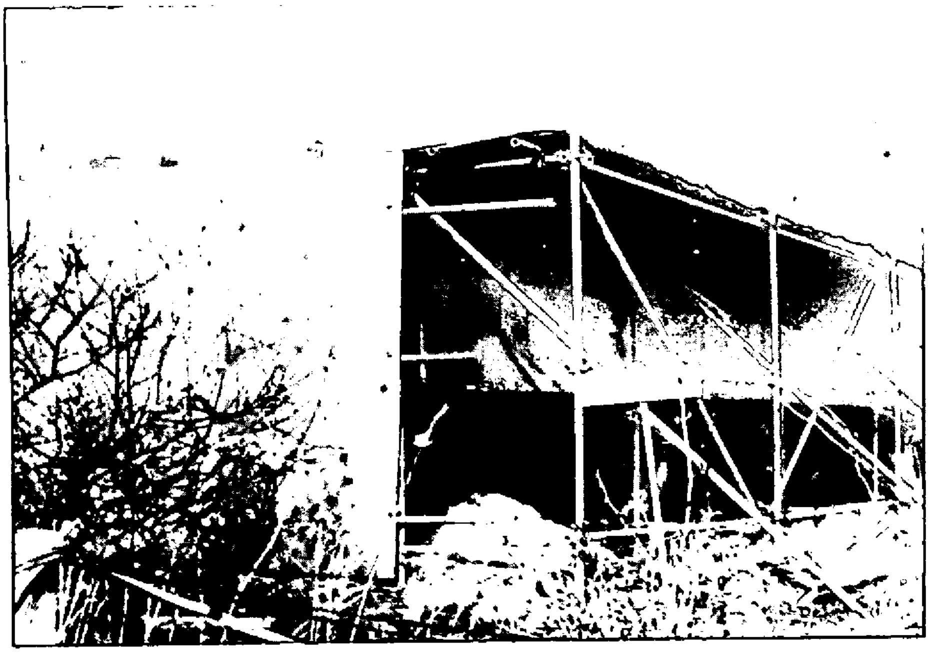
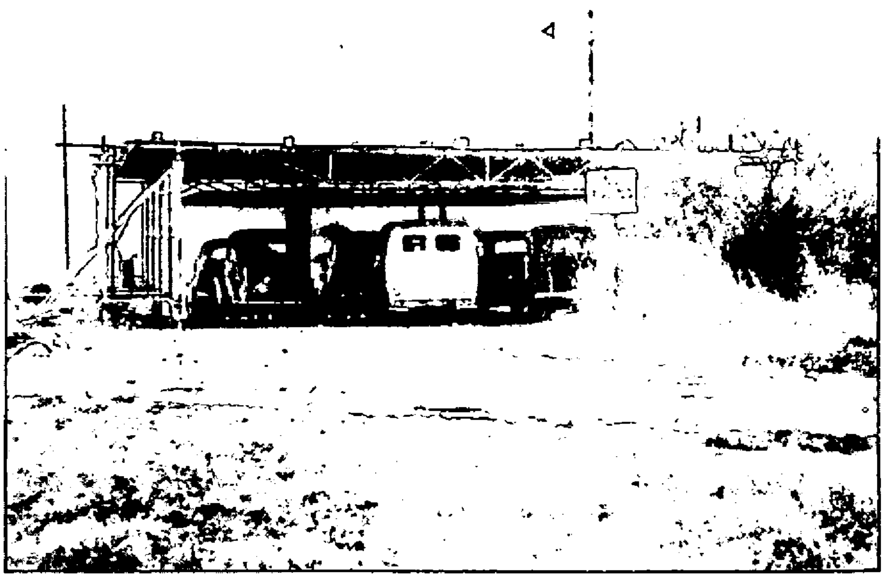


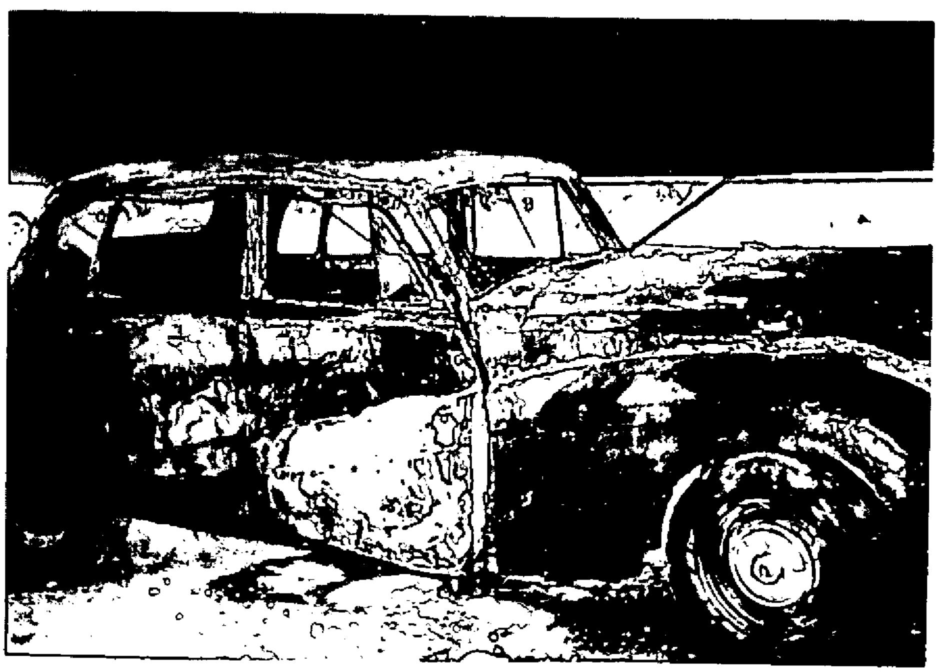
PLATE 3

STRUCTURAL MODIFICATIONS FOR TEST 3



TEST 1   5 min AFTER START

PLATE 4



STATE OF IGNITED CAR AT END OF TEST 1

PLATE 5

BURNING FUEL AT FILLER CAP PIPE
DURING TEST 3

PLATE 6