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JOINT FIRE RESEARCH ORGANIZATION

DEVELOPMENT OF A ROOF TEST

by

C. T. WEBSTER

Summary

A test has been developed to assess the resistance of a roof to penetration by fire from outside.

This and a second test to measure the resistance of the outer surface to spread of flame are described and a number of test results are given.

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Fire Research Station,
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Herts.

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INTRODUCTION

Development of a fire test for roofs was started by the Building Research Station in 1936 and this work has since served to give some guidance in the framing of Byelaws. Experiments were discontinued at the outbreak of the war but in the last two years they have restarted.

The Byelaws require that roofs should afford protection against the penetration of fire to the inside of a building from a burning building in the neighbourhood.

The present paper describes two tests. In the first of these radiation representing the heat from a neighbouring building on fire is applied to the specimen under test. The time for which the roof will resist the penetration of fire to the inside is measured. In the second test the radiation varies across the roof so that information can be gained as to the circumstances in which a roof will spread flame across its surface.

FIRE PENETRATION

Test conditions

Roofs may be exposed to conditions of varying degrees of severity. For example, a roof exposed to a warehouse fire would have to resist severe exposure for much longer than one exposed to a domestic building on fire, and different distances of separation would produce different levels of radiation on the roof. It is, however, expected that in general, any one level of radiation intensity would grade roofs in the same order and different exposure risks could be dealt with by the specification of different requirements or gradings for different purposes. A level of intensity suitable for this purpose has been chosen on the following grounds.

If a building is exposed to a nearby fire there would be no point in demanding that it be better protected from radiation by its roof than by its windows. This means that a roof need not resist penetration by radiation and burning brands and resist flame for a time significantly longer than the time after which the same radiation will cause a room with a typical area of window opening to ignite spontaneously. The duration of the severe part of a fire in a domestic building is approximately half-an-hour, and it is suggested that a roof exposed to a domestic building on fire need not resist radiation for much more than this. The intensity required to ignite a room through the window might therefore be a suitable radiation level for the test and although information of this kind for full-scale has not yet been obtained, a model lined with fibre insulating board, (1) and containing furniture was found to ignite in about half-an-hour when the intensity was 2.3 $w\ cm^{-2}$ for a 33 per cent window opening and 0.9 $w\ cm^{-2}$ for a 100 per cent window opening. By interpolation an intensity of 1.3 $w\ cm^{-2}$ would be required for a 50 per cent window opening. For the test it is convenient to use a level of intensity of 1.46 $w\ cm^{-2}$. This is the radiation from a fire at 1,000°C incident 25 feet above ground level on a roof at 45° pitch facing a facade 50 feet square with 50 per cent window opening across a roadway of 45 feet, see Figure 1.

The principal relevance of a fire test for roofs is to roofs in cities where the exposure risk is greatest because buildings are closer together and in these circumstances there is no reason to distinguish between roofs on account of their pitch since on a low building surrounded by larger ones and on a high building surrounded by smaller ones the pitch of the roofs is largely irrelevant. For these reasons all roofs were tested at one pitch namely 45°.

The hazard from burning brands is increased by wind blowing on to the roof. This produces positive pressure on the outside of the roof and tends to drive the flames from a brand into any cracks or fissures such as the gaps between tiles. It was decided that a wind of 15 mile per hour, (Beaufort Scale No.4 a moderate breeze,) would be representative in value.

To simulate this suction was applied to the undersurface. This corresponds to 1.5 mm difference in pressure between the upper and lower side of the roof.

It was considered that a luminous gas flame would be a convenient and repeatable method of simulating a burning brand. A 9 in. luminous flame from a $\frac{3}{8}$ in. orifice was selected. When this flame was played on either slate or tile roofs and suction applied on the lower side flame approximately 2 in. long could be seen on the lower side.

In the penetration tests this flame was applied for one minute five minutes after the start of the test and moved over the surface of the specimen.

APPARATUS

The apparatus developed for carrying out the roof tests is shown in Figure 2. It consists of a square radiant panel supported at an angle of 45° on a vertical frame and consists of four 1 ft square gas fired surface combustion panels with their centres at the corners of a square of 19 in. side. This is the optimum spacing for obtaining uniform radiation on the specimen.

Between the vertical legs of the frame a 2 ft wide track supports the trolley which conveys the roof specimen to the radiation panel. The trolley carries a frame for supporting the specimen at 45° so that in the test the roof is parallel with the radiant panel and the position of the trolley is such that the distance of the roof from the surface combustion heaters is 23 inches. A cover with a mica window is fixed to the lower side of the frame and suction is applied by connecting an extraction fan to the cover. To provide an air seal so that air is drawn through the upper surface of the roof, the specimen (Figure 3) is framed round the edges with asbestos wood so that a flat bearing surface is obtained and this rests on asbestos millboard laid round the frame on the trolley. Gaps between edges of the specimen and the asbestos wood are plugged with cement mortar.

The suction under the roof is measured by a gauge of the type shown in Figure 4. The slope of the side tube is 1 in 10 and the movement of the coloured water for 1.5 mm water pressure is 1.5 cm.

The radiation intensity incident on the specimen is monitored by 4 copper asbestos disc thermocouples [5] placed symmetrically at a distance of 6 in. in front of the surface combustion panels in the corners of a square of 2 ft side. The gas supply to the panels is controlled by a governor so that once the intensity of radiation is adjusted it remains constant for at least 4 hours. The frame for supporting the thermocouples is shown in Figure 5. When the radiation intensity incident on the roof is at the correct value of 1.46 watt cm^{-2} for the penetration tests the output from each of the monitoring discs is 25.5 MV. With each disc giving the same output the distribution of radiation intensity over the roof is that shown in Table 1 below.

TABLE 1

Distribution of radiation intensity over a roof in the penetration test

Distances from centre inches	12	6	Centre	6	12
watt cm^{-2}	1.42	1.5	1.46	1.5	1.42

Results of penetration tests

The results of penetration tests on various roofs are shown in Table 2. In the tests on the zinc covered roofs one coat of black paint was applied to the exposed surface to simulate the conditions likely to be seen in practice through corrosion and deposition of soot.

TABLE 2

Results of penetration tests on roofs
Moisture content of wood 12 per cent

Type of Roof	Test Period hour	min.	Type of Failure
Timber Deck $\frac{7}{8}$ in. square edge Boarding. Two Layers Organic Base Felt. Underlayer 25 lb saturated felt. Finish, 40 lb self finished felt.		8 12 $9\frac{1}{2}$ 13 9	Failure by flaming " " " " " " " " " " " "
As above but with asbestos Base Felt.	1 1 1 2 1	12 12 21 00 6	Failure by flaming " " " " " " Failure by glowing " " flaming
Timber Deck $\frac{7}{8}$ in. square edge Boarding. One layer of 25 lb zinc with underlayer of 25 lb Saturated organic Base Felt.	3 3	10 40	Did not fail " " "
As above with dull black finish on roof.	2 1 3 2	31 34 00 17	Failure by flaming " " " " " " " " "
One layer sheet lead 6 lb/sq.ft without a join laid on one layer of 25 lb saturated bitumen felt on $\frac{7}{8}$ in. nominal square edge boarding.	1	0 50 45	Failure by flaming " " " " " "

TABLE 2 (cont'd)

Type of Roof	Test Period hour	min.	Type of Failure
Western Red Wood Shingles on Battens		5	Failure by flaming
		6	" " "
		6	" " "
Corrugated Asbestos Cement on purlins.	3	30	Did not fail
Corrugated metal protected with Bitumen ($4\frac{1}{4}$ lb/sq.yd $1\frac{1}{2}$ lb felt sq.yd)	2	00	Did not fail
	2	00	
Clay tiles on Battens with reinforced Bitumen Felt Underlay.	3	6	Failure by flaming
	3	35	Did not fail
	3	13	Failure by flaming
	3	40	Did not fail
	4	00	" " "
Slates on Battens with Reinofrced Bitumen Felt Underlay.	3	20	Failure by flaming
	2	50	" " "
	3	00	" " "

SURFACE SPREAD OF FLAME

Test Conditions

The main requirement in the part of the test concerned with spread of flames on the outside of the roof is to determine the minimum radiation intensity at which a combustible material when used on a roof will ignite from a small source and tend to propagate flame. A simple method of determining this value is to ignite the hot end of a roof sample subjected to radiation which varies in intensity along the length of the specimen.

The point at which flaming ceases may be regarded as defining the minimum intensity of supporting radiation required for ignition of a roof by a burning brand. It is preferable to let the flaming spread down the roof because if as in practice the flames spread upwards then the roof is subjected to additional heat in front of the flame and a measure of the minimum intensity of radiation for ignition is not obtained. This then permits the results to be interpreted in terms of actual building configuration and distances.

Apparatus

For the spread of flame test only the two upper surface combustion heaters are used. When these heaters are correctly adjusted the two copper asbestos thermocouples opposite the heaters give an E.M.F. of 25.5 M.V. The distribution of radiation intensity over the roof surface, with the monitoring thermocouples giving an output of 25.5 M.V., is shown in Figure 6.

Results of surface spread of flame tests

Because of the small range of non-proprietary roofs with combustible surfaces it was decided to make a series of tests on bitumen felt laid on 1 in. nominal square edge boarding. The results of the tests and details

TABLE 3

Surface spread of flame on bitumen felts. Radiation intensity as in Figure 6

Type of Roof	Specimen No.	Distance of spread of flame inches
Single layer of self finished 40 lb bitumen felt asbestos base on $\frac{7}{8}$ in. thick wood deck.	1	18
As No. 1 but with underlayer of 25 lb saturated bitumen felt asbestos base.	2	20
As No. 2 but with underlayer of 25 lb saturated bitumen felt organic base.	3	20 20 23 Mean = 21
Single layer of self finished 40 lb bitumen felt organic base on $\frac{7}{8}$ in. thick wood deck.	4	33
As No. 4 but with underlayer of 25 lb saturated bitumen felt organic base.	5	34 34 34 Mean = 34
As No. 4 but with underlayer of 25 lb saturated bitumen felt asbestos base.	6	33 $31\frac{1}{2}$ Mean = 32
Corrugated metal protected with bitumen ($4\frac{1}{4}$ lb/sq.yd $1\frac{1}{2}$ lb felt sq.yd)	7	9

of the felts are shown in Table 3 from the table it may be seen that the results are consistent, the organic base felts spreading a distance ranging from 32 to 34 inches and asbestos base felts 18 to 23 inches. These results appear to be independent of the underlay; the same result was obtained whether the felt was laid direct on the wood decking or laid on a felt with a different base for example asbestos base on organic base felt. In Figure 7 a curve is shown of the final distance of spread of flame down a roof covered with asbestos base felt. The intensities from the curves at various points on this curve are given as determined in Figure 6. It may be seen that the intensity along the line to which flame spread is practically constant round the curve indicating that distance of spread of flame is mainly a function of radiation intensity.

Discussion and conclusions

Table 4 summarises the results, the roofs are arranged in ascending order of merit from 1 to 9. The order of arrangement is based on two principles:-

1. The roof should resist penetration by heat for the longest possible time.

2. There should be minimum spread of flame on the surface.

The order of the roofs in Table 3 agrees with the Model Byelaws and general experience. Tile, slate, and zinc roofs have been long known to give a reasonably satisfactory performance when exposed to a neighbouring fire. Copper roofs though not tested may be expected to give much the same performance as zinc roofs. Lead gives an inferior performance to zinc because the metal melts where it bulges through thermal expansion. Roofs inferior to asbestos based bitumen felts such as organic based bitumen felts, unless covered with incombustible materials such as gravel one-half inch thick or bituminous macadam, are excluded by the Model Byelaws. Wood shingles are near the bottom of the table of results and this position is in agreement with the views of the Fire Grading of Buildings Committee in their Report [6] which states, 'The data we have available on the fire risks of cedar shingle-roofs in America, where they have been extensively used, form a record of disastrous conflagration involving whole townships'.

Though not yet tested a concrete roof constructed as a floor slab is probably the best type of roof. It is well known that this type of construction will resists heat in fire resistance tests even when directly exposed to flame for several hours. Other tests have shown that asphalt mastic, a roof surfacing sometimes used on concrete slab roofs, will not spread flame even at higher intensities than those used in this investigation.

The test described is intended only for conditions implied in the Byelaws, so that the behaviour of roofs when exposed to fire on the underside has not been studied. Nevertheless a need may be felt for some information on this aspect of roof behaviour. In this connexion data could be provided by other methods for example the "Spread of Flame" Test [7] or a new test [8] at present under development, which measure the contribution of the inner roof lining to the growth of fire while the Fire Resistance Test can measure the ability of the roof to prevent penetration of the roof from inside the roof.

REFERENCES

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2. Bevan, R. C. and Webster, C. T. Investigations on Building Fires, Part III. Radiation from Building Fires. National Building Studies Technical Paper No.5 1950 H.M. Stationery Office.

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4. British Standard Code of Practice CP3 - Chapter V 1952 Loading. The Council for Codes of Practice for Buildings.

5. Webster, C. T. and Gregsten, M. J. A disc type Radiometer. Instruments in Industry Vol.3, No. 23.

6. Post-War Building Study No. 29 Fire Grading of Buildings Part I General Principles and Structural Precautions London 1946, H. M. Stationery Office.

7. Fire Tests on Building Materials and Structures. British Standard No. 476 : 1953.

8. Hird, D and Karas, G. C. A method for classifying the fire hazard of internal linings and their treatments.

TABLE 4

Summarised results of fire tests on roofs

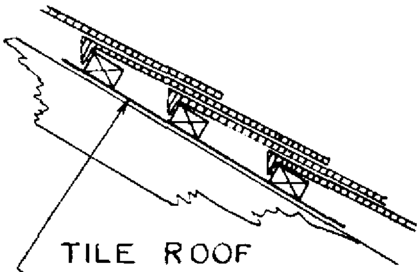
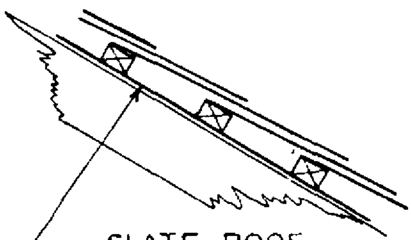
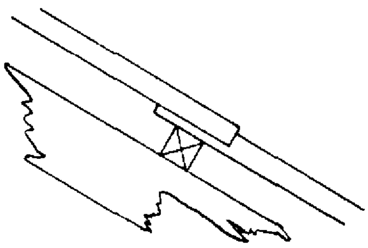
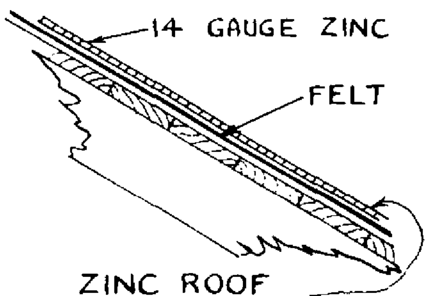
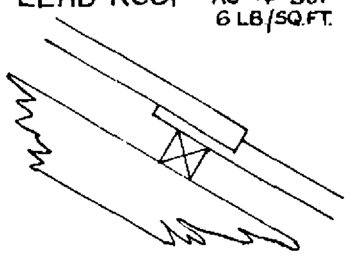
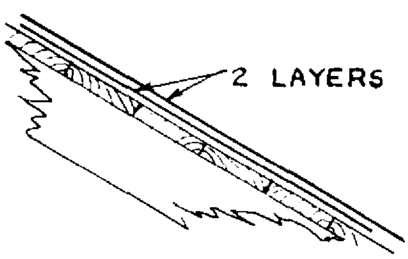
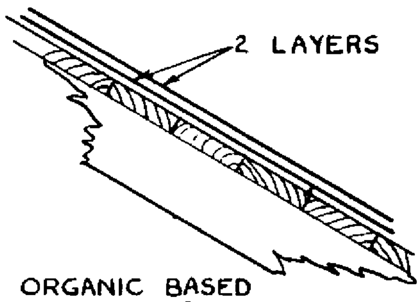
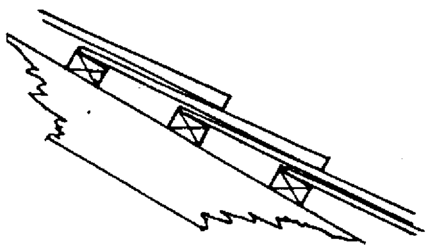
Type No.	Section of roof	Average time for penetration hour min.	Distance of spread of flame inches
1	 TILE ROOF; REINFORCED BITUMEN FELT.	over 3½ hrs.	No spread
2	 SLATE ROOF; REINFORCED BITUMEN FELT.	3 - 5	No spread
3	 CORRUGATED ASBESTOS CEMENT	over 3½ hrs.	No spread
4	 14 GAUGE ZINC; FELT; ZINC ROOF	(Bright surface) over 3½ hrs.	
5		(Black painted surface) 2 - 23	No spread
6	LEAD ROOF (AS 4 BUT WITH 6 LB/SQ.FT. LEAD	52	No spread
7	 BITUMEN COATED CORRUGATED IRON	over 2 - 00	9
8	 2 LAYERS; ASBESTOS BASED BITUMEN FELT. ON TIMBER DECK.	1 - 22	20

TABLE 4 (CONT'D)

Summarised results of fire tests on roofs

Type No.	Section of roof	Average time for penetration hour min.	Distance of spread of flame inches
9	 ORGANIC BASED BITUMEN FELT. ON TIMBER DECK	11	33
10	 WOOD SHINGLES	6	Not measured

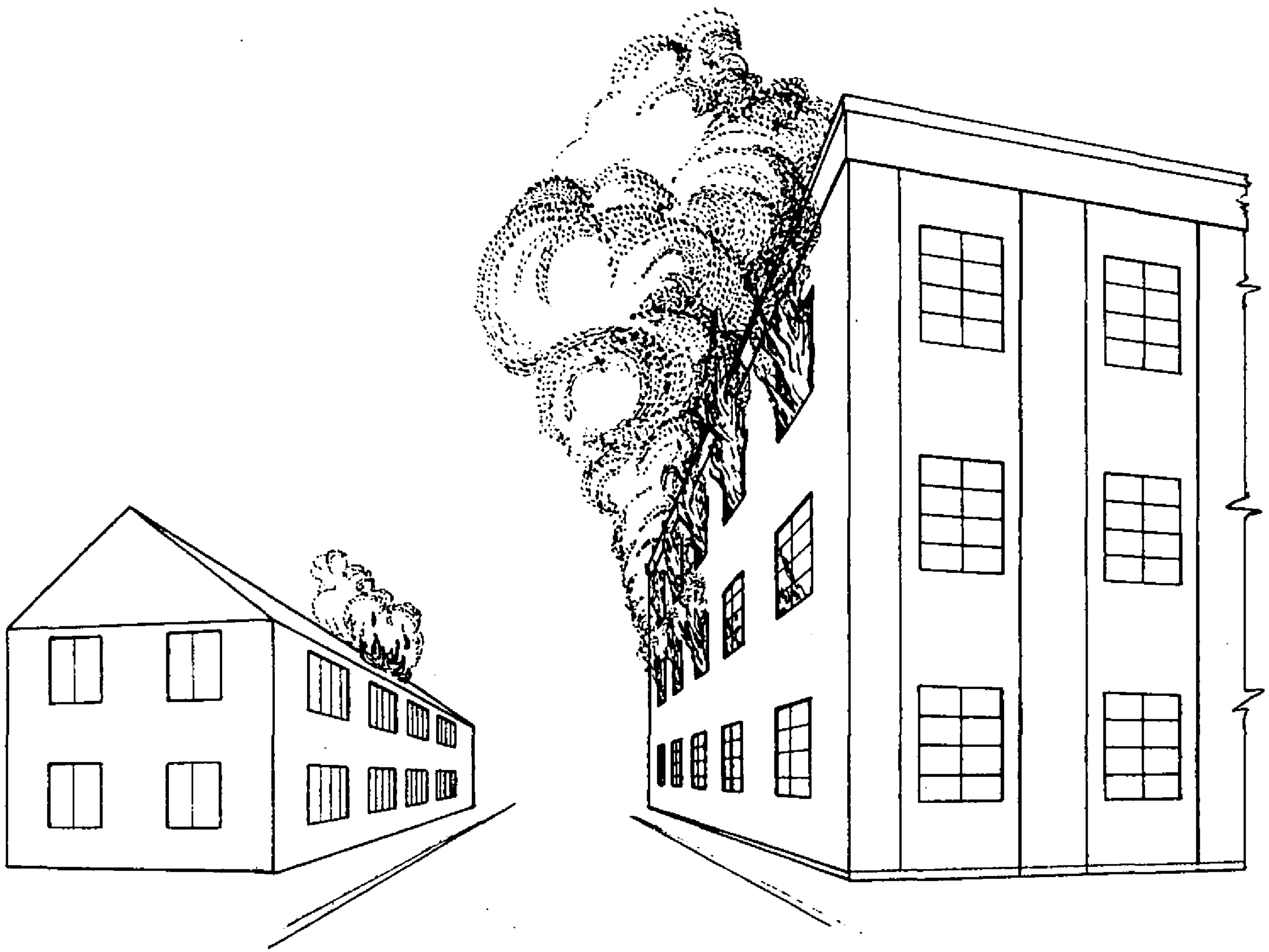


FIG. 1. EXTERNAL FIRE EXPOSURE HAZARD OF A ROOF

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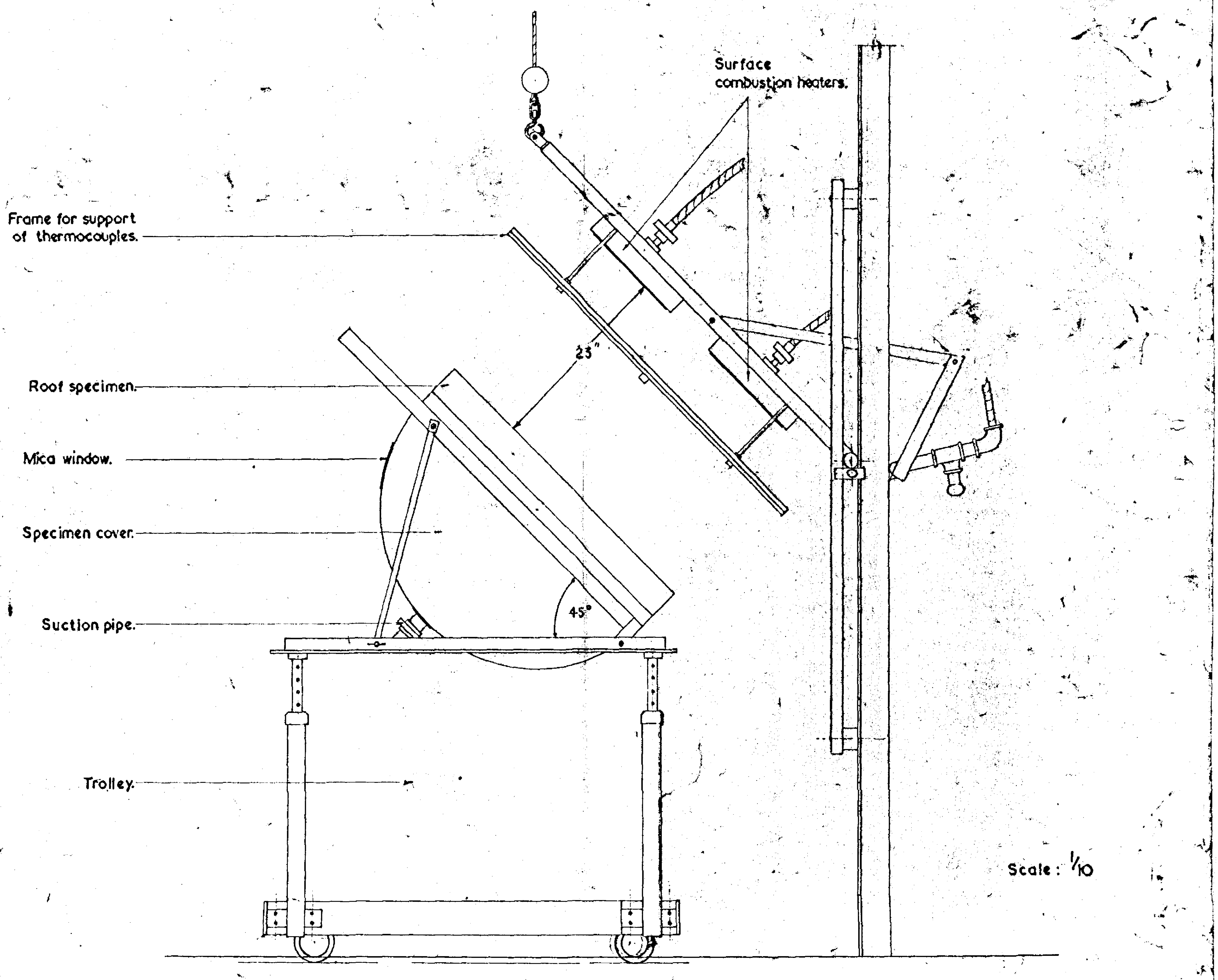

FIG. 2. ROOF TEST APPARATUS.

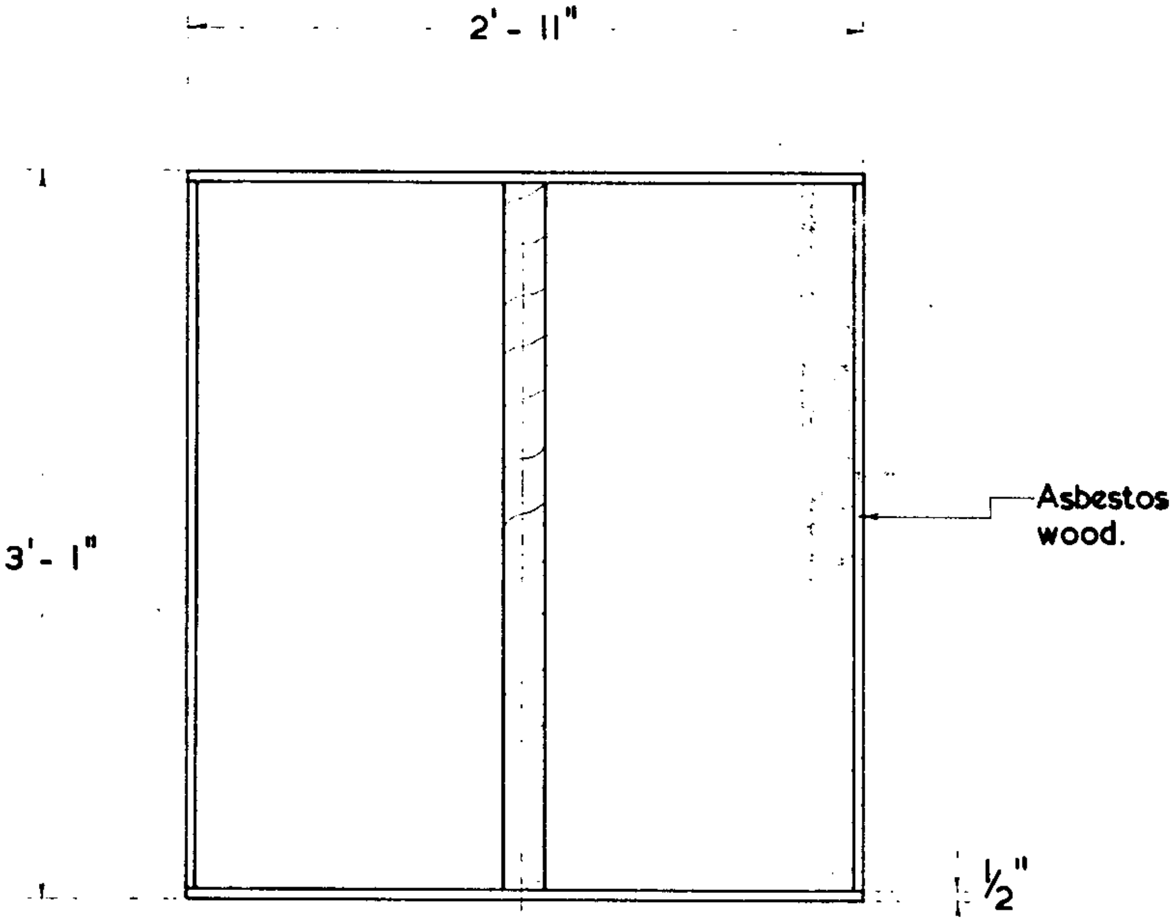

FIG. 3. UNDERSIDE OF SPECIMEN WITH FRAMING.

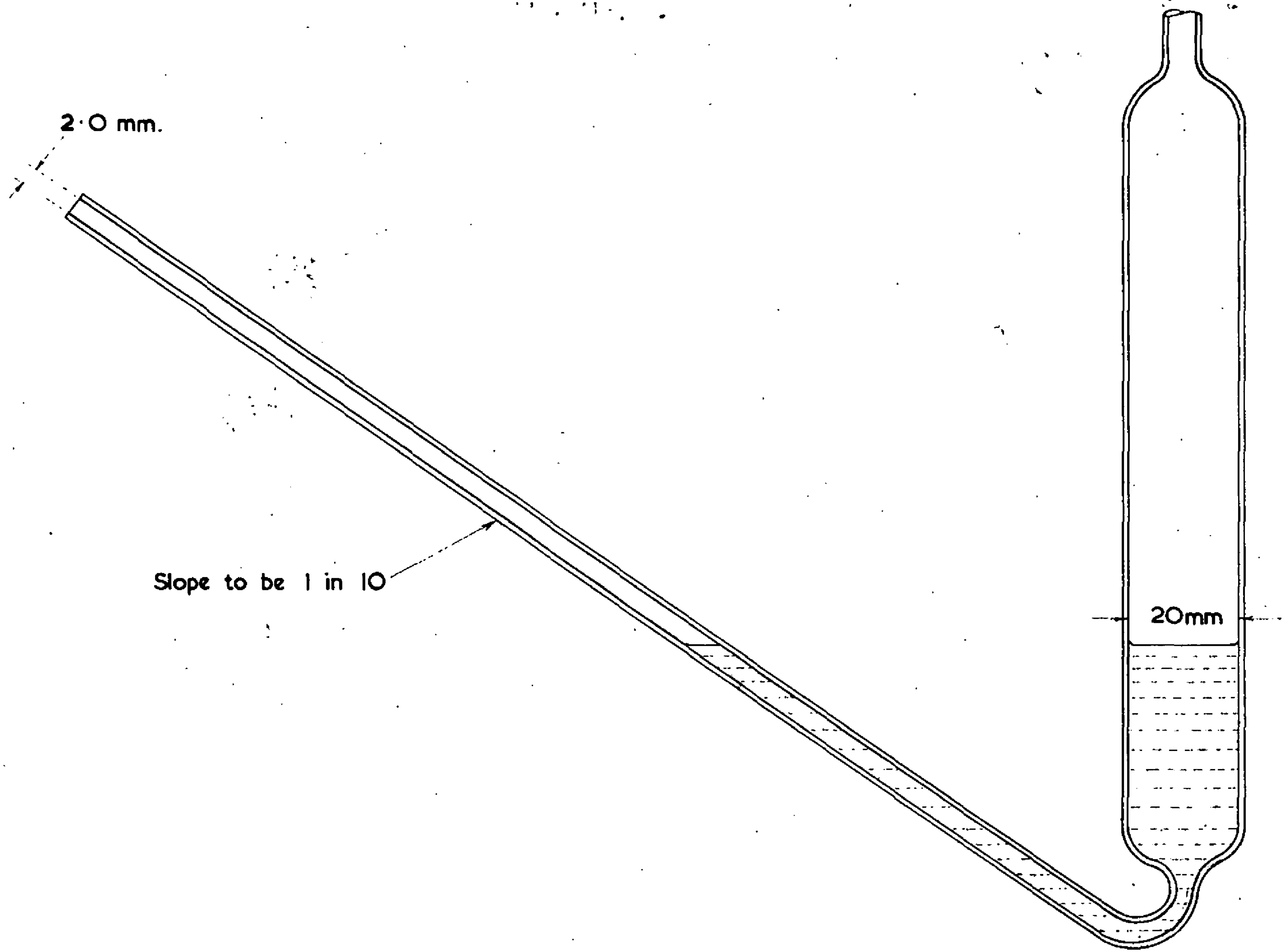

FIG. 4.

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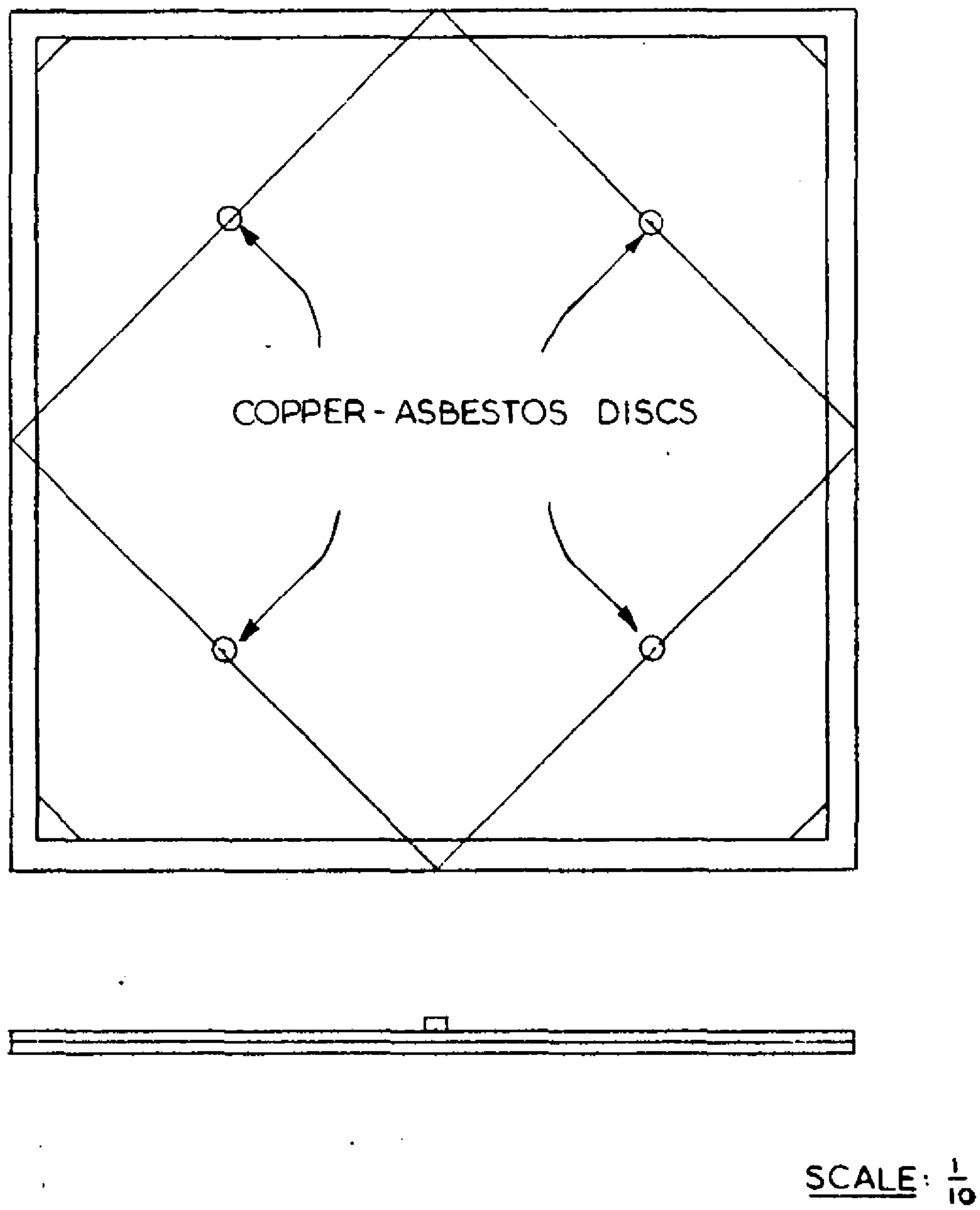

FIG. 5. COPPER ASBESTOS DISCS FOR MONITORY RADIATION INTENSITY

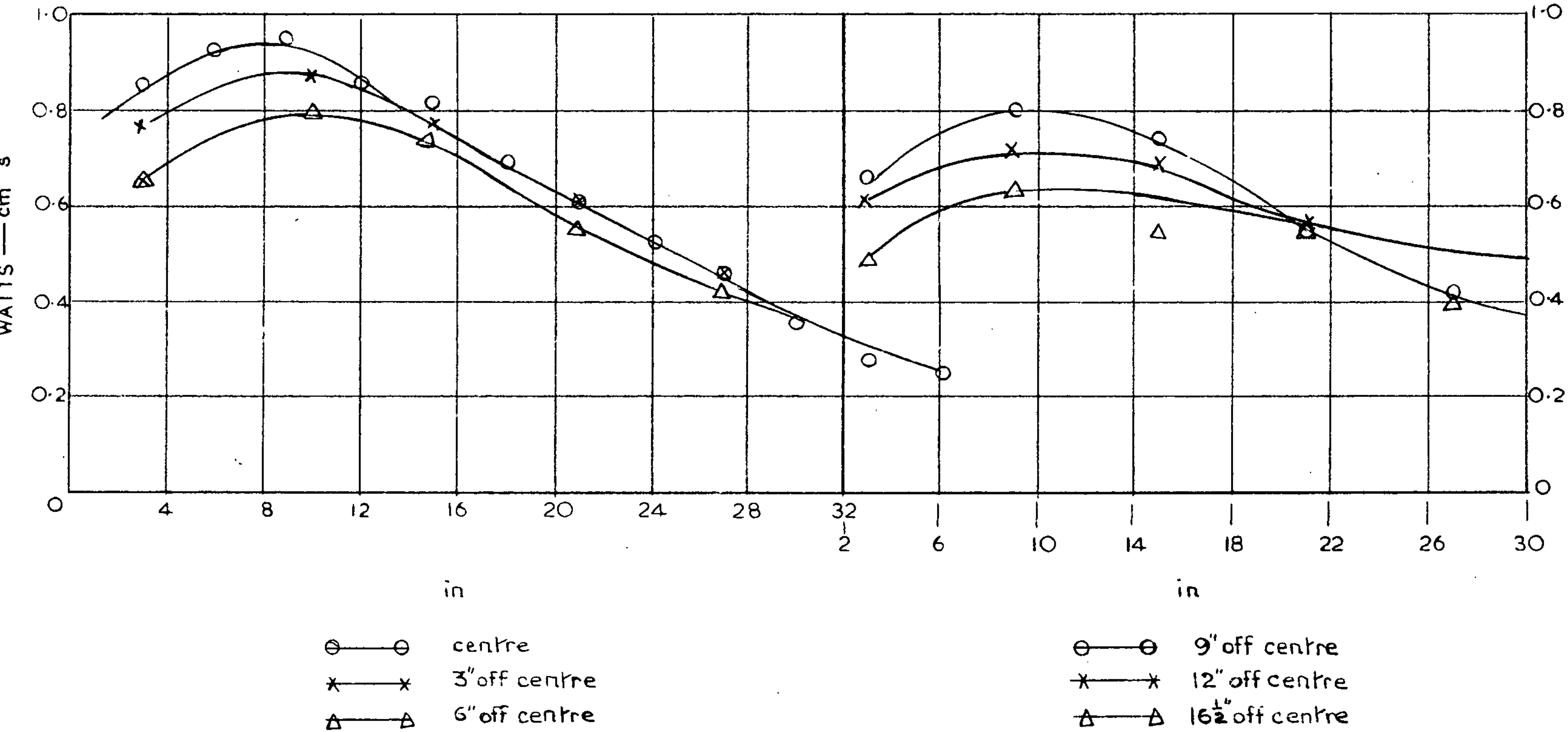

FIG. 6. RADIATION INTENSITIES ON ROOF IN SPREAD OF FLAME TEST

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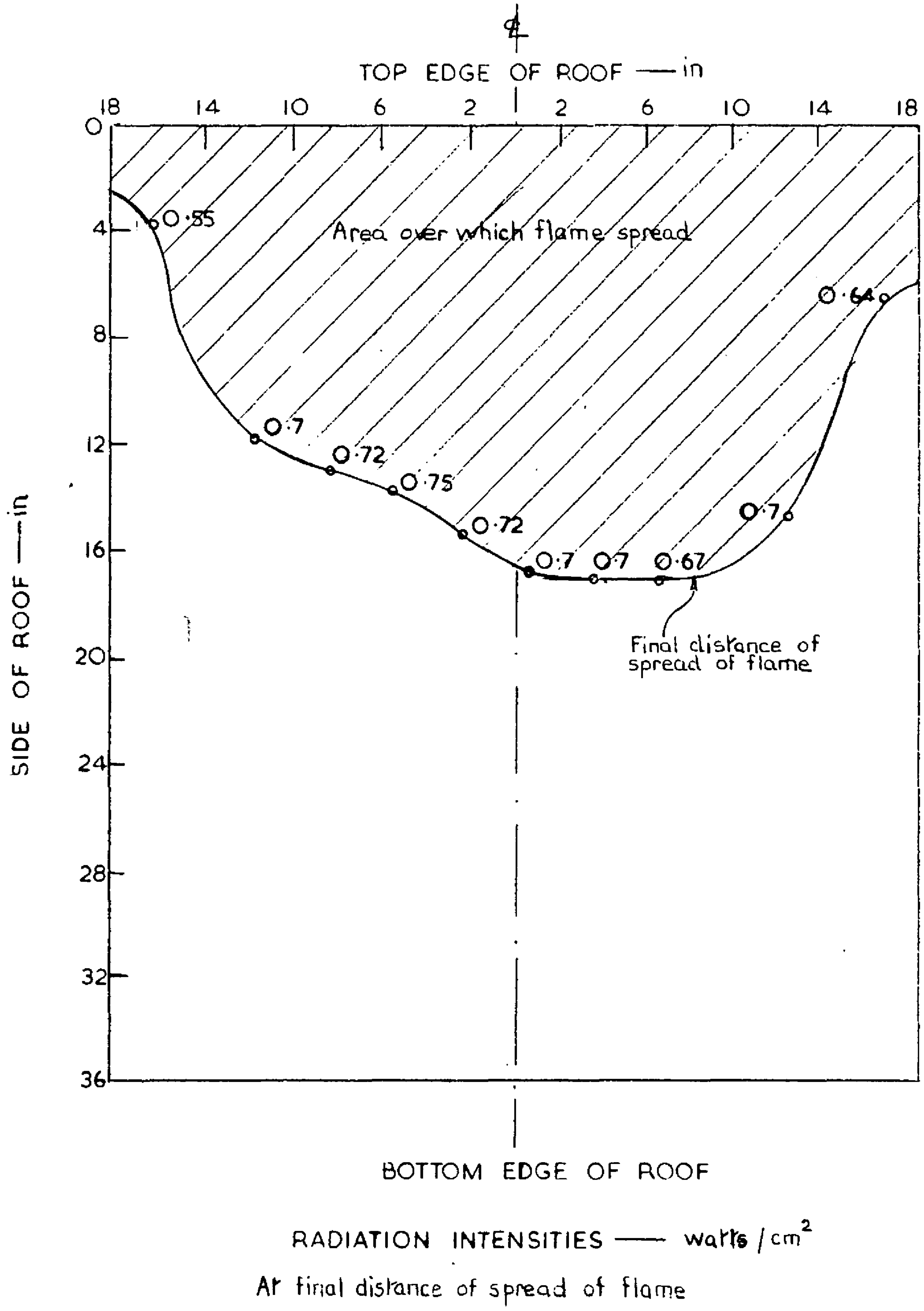

FIG. 7. FINAL DISTANCE OF SPREAD OF FLAME ON SPECIMEN ROOF COVERED WITH ONE LAYER OF ASBESTOS BASE BITUMEN FELT