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WOOD BLOCK AND OTHER MEASUREMENTS AT FLAMBEAU TEST FIRE 760-12

by

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SUMMARY

Detailed results of the measurements made by the United Kingdom team at the Project Flambeau test fire 760-12-67 are presented and discussed. The damage to standardised wood blocks increased from the edges of the array to a maximum about midway between the centre and the north-east corner, broadly the region where fire whirls were observed. This increase may well be due to changes in convective heat transfer over the array. Systematic differences in the damage sustained were found between blocks exposed at various positions, facing in various directions; these largely corresponded to differences in the configuration factor of the fuel pile with respect to the block. Peak wind speeds of more than 60 ft/s were registered at ground level within the array by simple 'turn-over' wind gauges. Peak temperatures in the streets exceeded 200°C.

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A.J.M. HESELDEN and M. J. WOOLLISCROFT

1. Introduction

During the Project Flambeau experimental fire 760-12, carried out in September 1967, a team from the United Kingdom made a number of measurements with simple instrumentation. Chief of the devices used was a standardised wood block[1] which could register a wide range of severities of exposure and, under favourable conditions, give a measure of rate of heat transfer. The simplicity of this device permitted its use in large numbers so that readings could be obtained over the whole fuel array.

The results of laboratory experiments with the wood blocks for exposure times in the region of 20 min may be summarised as follows. At very low rates of heat transfer no effect is produced in the block. At constant rates of 0.2-0.5 W/cm^2 the block is undamaged, but a substantial rise in surface temperature occurs, which can be estimated by means of small specimens of temperature sensitive paper cemented to the surface, and this can be used as a measure of heat transfer rate. Above 0.5 W/cm^2 the heat transfer rate can be related to the scorching of the surface by a measurement of reflectivity (up to 1.1 W/cm^2) or to the depth of char (between 1.1 W/cm^2 and some 4 or 5 W/cm^2). Above about 5 W/cm^2 the block is completely destroyed within about 20 minutes. The calibration of the blocks is in terms of a constant heat flux; no calibration has yet been made with a peaked pulse similar to that given in a fire of the Flambeau type.

Other devices employed included a simple 'turn-over' wind gauge, a water calorimeter and simulated roof sections. The data obtained are tabulated for general use. Although the analyses have not yet been completed, sufficient information of interest has emerged so far to warrant this interim report.

2. Measurements

2.1. Wood blocks

Standard blocks 4 in square and 2 in thick of knot free Baltic Redwood (Pinus sylvestris) were exposed in the following positions:-

2.1.1. "Piazza" positions

At the centre of the intersections (called "piazzas") of the channels ("streets") between rows of piles, blocks were placed on the ground facing upwards and held down by means of metal skewer pegs. They were placed in nearly every piazza along the two streets nearest to the edge of the array and in nearly every other piazza in the central area. Blocks could not be laid between rows 10 and 11 since this was a road used by traffic until shortly before ignition. Some blocks were also placed just outside the array in positions corresponding to piazza positions.

Owing to the unusually wet summer much more vegetation had grown up between the piles than usual and care was taken to clear away plants likely to catch fire and affect the response in the blocks.

2.1.2. Vertical blocks round special piles

At heights of 1 and $3\frac{1}{2}$ ft above the ground and either 12 or 21 ft from selected piles, blocks were set up on tubular steel poles with the receiving face (or faces) vertical and facing the centre of the side of the pile. About half these blocks were protected on the sides, rear and top, either by boxing with mineral fibre insulating

board covered with aluminium foil or by an aluminium sheet cover, together with aluminium foil. The standard arrangement is shown in Fig. 1. The piles chosen were those at the corners and the centre of the sides of the array, the five weighed fuel piles (four of which were of milled fuel), the piles fitted with a U.S. Forest Service water calorimeter, and the piles at the intersections of rows C, H, L and Q, and 3, 7, 12 and 16. Blocks were also placed horizontally on the ground in each of the four piazza positions around each of these piles. At the 12-ft position from the five weighed fuel piles, two blocks were installed on each side, one insulated or protected and one double-sided. At each of the other piles a double-sided block was placed next to one of the insulated or protected blocks to compare the responses produced by these two types.

2.1.3. Variation across and along streets

At sixteen locations distributed over the whole array shown in Fig. 3a ten blocks were set up in the standard pattern shown in Fig. 2.

2.1.4. Tower blocks

Blocks were mounted on towers 1, 5, 9 and 13 at various heights facing upwards, downwards and in two directions horizontally (usually east and west). Some blocks were also placed on towers 17 and 18.

2.1.5. Roof sections

A standard arrangement of blocks was set up at each model roof section[2].

2.1.6. Control blocks

Blocks were set up well away from the fire to act as controls.

2.2. Water calorimeters

Simple water calorimeters consisting of a 4-pint aluminium saucepan set in a cylindrical hole in the ground were placed in 16 piazza positions. To reduce heat exchange with the soil the pan was supported about 1 in above the bottom of the hole and about 1 in away from the sides. The hole was lined with thin aluminium sheeting, the annular gap between the top of the saucepan and the top of the cylindrical hole being covered with aluminium foil. The top of the saucepan was approximately at ground level and it was filled to within about 1 in of the top with 3 pints (U.S.) of water, the water surface being left exposed.

2.3. Wind speed indicators

Two versions of a simple ground level wind speed indicator were used. Each consisted of a rectangular sheet steel plate 12 in x 24 in folded on its shorter central axis and placed on the ground with the fold uppermost. One version was designed to overturn at a wind velocity component perpendicular to the fold of 30 ft/s, the other was made of thicker metal with a larger angle of fold and was designed to overturn at 60 ft/s. The correctness of the design calculation was verified for the lower speed indicator in a wind tunnel. The indicators were placed in two lines across the array in the centre of the street between each pair of piles in the columns I and J and rows 9 and 10, so as to respond to the component of velocity along the street. Some were also placed near the south-west corner and two were placed in the gaps between the asbestos sheets around pile Q13, one on the south and one on the north side.

2.4. Thermometers

Ten mercury-in-glass constricted-stem maximum thermometers were placed horizontally in the centres of the streets about 3 in from the ground under shiny aluminium shields so that they would be protected from

radiation from the adjacent piles, but gases could flow freely past them. Horizontal wood blocks were placed on the ground near the thermometers.

2.5. Walled pile

Pile Q13 was surrounded by a wall of asbestos insulating board sheeting 4 ft high held in position on top of an earthbank some 18 in high. The wall was in the form of sheets 8 ft x 4 ft and horizontal gaps 2 ft wide were left between the sheets, i.e. the air inlet area was about 15 per cent of the total wall area. Extra wood blocks were installed around this pile and neighbouring piles (Table 5a).

2.6. Photography

Infra-red and colour photographs were taken at frequent intervals from two sites south of the south-west and south-east corners of the array. Some cine film was also taken from the east side.

3. Results

The results for the wood blocks have been converted to 'equivalent intensities', assuming an effective fire duration of 20 min and neglecting any differences in cooling. By equivalent intensity is meant that constant intensity of radiation which applied for the period of 20 min in still air at about 20°C would give the same response in the block as has actually been measured. Until response in the block can be related to a shaped pulse by a suitable calibration, a period of 20 min was thought to be a reasonable estimate of the effective fire duration at constant intensity. In any case the response in the block is not very sensitive to the duration of exposure. Although equivalent intensity does not necessarily represent accurately the mean intensity over a period of 20 min this treatment enables all the readings (e.g. surface temperature, scorching and char depth) to be brought to a common scale.

At a high enough intensity some blocks developed a glowing hot spot which, fanned by the wind, tended to char away the block. When this process had not entirely consumed the block its occurrence could easily be recognized by the shape of the hollow formed since the hot spot usually developed on the edges and corners and spread radially. There was almost always enough of the original surface left to enable the intensity to be obtained by reflectivity or depth of char, these being fairly constant over the block in the absence of hot spots. However, where a block had burnt completely away it was of course not clear whether it had in fact received an equivalent intensity of at least 4-5 W/cm^2 or a high intensity coupled with charring from a hot spot, possibly fanned by a strong wind. Data for completely burnt-out blocks must, therefore, be used with some caution. The actual behaviour of the blocks can be of direct interest since wood is the material whose ignition and rate of burning are important in fire spread.

A number of blocks were exposed for several days for control purposes under conditions as close as possible to those of blocks set out within the array, but some distance from the fire area. After the tests the moisture content of the control blocks, as determined by the change in weight since leaving the United Kingdom, was about 12 per cent for blocks placed horizontally on the ground and about 10 per cent for blocks placed vertically $3\frac{1}{2}$ ft above the ground. These moisture contents are very close to that during calibration, so that no allowance for any change of sensitivity should be necessary.

After the test the reflectivity of the surface of the control blocks was on average about 48 per cent - substantially less than that before exposure, apparently because of some action of the strong sunlight.

The damage incurred by the wood blocks is given in Figs 3a and 4a and Tables 2a, 3a, 4a, 5a, 6a and 7a, and the equivalent intensities are given in Figs 3b and 4b and Tables 2b, 3b, 4b, 5b, 6b and 7b. The results of the other measurements are given in Tables 8 and 9.

4. Discussion

4.1. Wood blocks near ground

Following exploratory plots of the data, a regression of the form

$$\ln I = ax + bx^2 + cy + dy^2 + exy + f$$

has been fitted to the data from the piazza blocks, where I is the equivalent intensity in W/cm^2, a, b, c, d, e and f are constants (regression coefficients) and x and y are the distances from the north and west sides of the array respectively, expressed in numbers of rows.

The coefficients obtained are given in Table 10; all are highly significant. If $\ln I$ is imagined plotted vertically above the array, then this equation represents a quadric surface, the intersection with any vertical plane being a parabola and with a horizontal plane an ellipse.

Figure 5 shows contours of constant intensity, portions of ellipses with axes inclined at 39° to the numbered series of rows. The intensity rises from the sides of the array to a maximum value of 1.35 W/cm^2 near G14, about half-way between the centre of the array and the north-east corner.

This regression was derived from data from all piazza blocks, except those

(i) Outside the array (ii) Around the milled fuel piles (iii) Around pile Q13 (walled Pile) (iv) Burnt completely away; since

the intensity at these special positions was known or suspected to be different from that of the rest of the positions.

Piazza blocks giving intensities substantially different (outside the range ± 2 standard deviations of the residual - roughly the 95 per cent confidence limits) from those predicted from the regression were found at the positions given in Table 11.

In piazza positions around three of the milled fuel piles the intensity was substantially higher than average, presumably because their rate of burning was much higher than that of the wildland fuel piles.

Figure 6 shows that almost all the burnt out piazza blocks, which give equivalent intensities much higher than average, were in the north-east of the array. Spalling of boulders and severe "scouring" of the ground between piles were also noted in this area (Fig. 6) although these observations have not been made systematically.

It is broadly in this region that fire whirls were noted by Woolliscroft, stationed on the north side of the array, who saw fire whirls between about A10 and the north-east corner, and by Thomas and Rothermel, on the east side, who saw whirls a few piles from the edge of the array between the centre of the east side and the north-east corner.

The remainder of the wood block data has not yet been analysed in any detail but exploratory plots show that in general the equivalent intensity at the blocks in other positions, viz. across streets, both horizontally on the ground and vertically 1 ft or 3½ ft above the ground, also increased from the edges to a maximum value in the north-east of the array. There are some anomalies, e.g. high intensities in the

street between D4 and D5. The intensities at these other positions are generally much higher than those of nearby piazza blocks but are well correlated with them. First approximations to the relations obtained are given in Fig. 7, which should be regarded as provisional.

The question naturally arises, what mechanism is responsible for damage to the blocks and, particularly, what causes intensity, to rise from the sides to a maximum at around G14? Some of the blocks were damaged in a way which suggests very strongly that radiation was the predominant heat transfer process. For example, some of the blocks were more severely damaged on one side or face than on an adjacent perpendicular side or face. Again in some cases, notably in the channel between pile L8 and M8, (Fig. 4b) the horizontal blocks nearest the piles were more damaged than those in the centre of the aisle, whilst vertical blocks showed the most damage on the sides facing the nearest pile. In some cases, e.g. D14/E14, E2/F2, M4/M5, P2/Q2 and O12/P12 there is a distinct gradient of intensity across the streets. This indication of radiation transfer is, on the whole, more obvious nearer the sides of the array, particularly on the south and west sides, it is not consistent over the whole array. It is hard to see how the observed range of intensities, from about 0.2 W/cm^2 near the south-west corner to about 1.35 W/cm^2 at the maximum near G14 could be entirely accounted for by differences in radiation.

A possible explanation is the modification of the heat balance of the blocks caused by convection transfer between the block and an air current which becomes hotter as it progresses further into the array.

Street gas temperature measurements are not yet available apart from the few values for peak temperature given in Table 9; however Countryman[3] notes that in previous fires of this type the temperature of air reaching the interior flames may exceed 1000°F (550°C).

Calculations of the heat balance at the receiving surface of the blocks under various conditions suggest that the data are reasonably consistent with a model in which all the piles of the array radiate similarly and the gases flowing between the piles become hotter as they approach the effective centre of the fire, in this case moved to the north-east by the south-westerly wind. On the outskirts of the fire the blocks would be cooled by the cold inflowing air, but as this air progressed further into the array and became hotter less heat could be lost by convection from a block heated by radiation and its response would therefore increase. Eventually a stage might be reached where the gases were hotter than the surface of the block.

With this hypothesis systematic differences between the various positions around any given pile are due largely to different configuration factors between the block and adjoining fuel piles, (Table 12).

In still cool air the front surface of a vertical block receiving a constant intensity of radiation of 0.4 W/cm^2 heats up after about 20 min to a temperature of about 150°C. Most of this incident energy is lost by reradiation and convection from the receiving surface, only some 0.1 W/cm^2 flows into and can affect the block, so that it will be seen that if the cooling conditions are substantially changed, for example, by increasing the temperature and velocity of gases passing over the block, large changes can occur in the response of the block.

4.2. Wood blocks mounted on towers

Table 7 shows that equivalent intensity generally decreased with height. Most of the lower blocks on towers 5 and 9, well inside the array, were burnt away, the highest blocks were most affected on the down-facing side.

4.3. Milled fuel and single pile burns

Data for two single burns of milled fuel and two of wildland fuel are given in Tables 6a, 6b and 6c. Although there is very little data comparison of the average equivalent intensities in Table 6c suggests:-

(1) Single milled fuel piles gave higher intensities than single wildland fuel piles.

(2) The milled fuel pile on the edge of the array (at S9) gave intensities similar to those of the single milled fuel pile.

(3) Milled fuel piles well within the array gave much higher intensities than those of the single milled fuel pile, in accordance with the piazza block results noted in Section (4.1.).

4.4. Thermal conditions round walled pile (Q13)

Equivalent intensities at piazza blocks and at vertical blocks round the walled pile were not significantly different from those at corresponding positions around nearby ordinary fuel piles.

4.5. Water calorimeter

The amounts of water evaporated and the equivalent intensities are given in Table 8 assuming no heat loss and an effective exposure time of 20 min. The initial amount of water was 48 U.S. fluid oz. and

the exposed surface area was about 250 cm^2. The apparent equivalent intensities are much higher than those of the piazza blocks, probably a reflection of substantial mass transfer to the air flowing over the free liquid surface.

4.6. Wind indicators

The results of the wind indicators given in Table 9 and Fig. 8 show that peak ground level wind speeds were generally between 30 and 60 ft/s, except near the fire whirl region in the north-east where peak speeds exceeded 60 ft/s.

The gauges nearest the west and south edges and the south-west corner were almost all unaffected. In the line between the mid-points of the north and south sides the 30-ft/s gauges were tipped over and the 60-ft/s gauges remained standing except for one near C9 which was moved 30 ft.

In the line between the mid-points of the west and east sides many of the gauges were not merely tipped over but in the east half of this line were moved bodily distances of up to 50 ft. This corresponds to the fire whirl area. In the west half the 30-ft/s gauges were generally overturned and the 60 ft/s remained standing.

5. Summary and conclusions

(i) Satisfactorily measurable responses were obtained in the wood blocks placed horizontally on the ground at the centres of intersections of streets ("piazzas"), but in some other positions the incident intensity was higher and a rather large proportion of blocks was burnt completely away so that only a lower limit to intensity could be obtained.

(ii) As in most simple devices of this type the response in the block depends on the magnitude of the heat losses and these should be estimated for a more accurate interpretation of the results.

(iii) It is desirable that a calibration of the blocks in terms of a suitably shaped pulse of heat transfer should be carried out.

(iv) The effective net heat transfer to the wood blocks, which can represent combustible material initially unignited, increased markedly from the edges to a centre in the north-east of the array, the area in which fire whirls were observed. The data are in accordance with a hypothesis postulating that all fuel piles radiated similarly and that the temperature of gases flowing along the streets increased substantially from the edges of the array to the fire centre.

(v) Least damage occurred to blocks placed on the ground at the centres of intersections of streets, whilst most damage occurred to vertical blocks facing the centres of the sides of fuel piles, these differences being broadly of the magnitude expected from differences in the configuration factor of the pile with respect to the block.

(vi) It is hoped that when analyses are complete it will be possible to determine those areas within the array where ignition of specimens in various positions with respect to the fuel piles would have occurred.

(vii) Milled fuel piles burnt both singly and within the array gave higher intensities than wildland fuel piles in similar situations.

(viii) Peak wind speeds of more than 60 ft/s and peak temperatures exceeding 200°C were recorded at ground level in the streets near to the area of fire whirl activity.

6. Acknowledgement

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7. References

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TABLE 1

Conversion of measured damage to equivalent intensity

An equivalent time of 20 min. has been assumed

Initial reflectivity taken as 48 per cent

Damage	Equivalent intensity W/cm^2	Damage	Equivalent intensity W/cm^2
U	<0.2	1C	1.3
1P	0.2	2C	1.5
2P	0.3	3C	1.6
3P	0.4	4C	1.7
4P 46R	0.5	5C	1.8
5P 39R	0.6	6C	1.9
28R	0.7	7C	2.0
21R	0.8	8C	2.1
15R	0.9	9C	2.2
10R	1.0	10C	2.3
7R	1.1	11C	2.5
('OR'	1.1)	12C	2.7
		13C	3.0
		14C	3.3
		15C	3.5
		20C	4.2
		25C	4.5
		30C	4.7
		BO (Double-sided)	>4.5
		BO (Single-sided)	>5

Notes: U denotes no response

nP denotes blackening of n sensitive papers

mR denotes scorching of the surface to a reflectivity of m per cent

pC denotes charring of the surface to a depth of p mm

BO denotes block was burnt away completely

OR denotes surface judged by eye to have a very low reflectivity but without any charring.

TABLE 2a

Response in vertical blocks placed around piles at corners and along sides of array

Pile	12 ft from pile $3\frac{1}{2}$ ft above ground				21 ft from pile 1 ft above ground			
	N	E	S	W	N	E	S	W
A1	No values given since pile did not burn							
A9	20C -	BO -	OR -	BO -	- -	OR -	BO -	BO -
A10	OR -	- -	BOA -	BOI -	35R 34R	- -	BOA -	- -
A18	BO -	41R -	BOI -	18CA -	1P -	2P -	19RI -	1CA -
J18	BO -	BO -	18CI -	BOA -	BO -	32R 35R	BOI -	BOA -
S18	BOA -	47R 42R	3P -	3PI -	ORA -	3P -	1P -	4PI -
S10	BO -	- -	4P -	24R -	13R -	- -	2P -	3P -
S1	25CI -	3PA -	2P -	32R 36R	35RI -	2PA -	1P -	- -
J1	14RI -	BO -	3PA 33R	4P -	43RI -	BO -	3PA -	1P -

Notes:

(1) For meaning of symbols see Table 1 and note 4 below.

(2) Each block faced the centre of the side of the pile.

(3) For any given pile, the value on the first line of the table is the response on the side of the block facing the pile. The value on the second line is the response on the side facing away from the pile, when known.

(4) All blocks were two-sided except those which had the sides, top and back protected with aluminium sheet and foil (marked A), or with mineral fibre board insulation (marked I).

(5) One extra double-sided block was set up at each pile at a height of $3\frac{1}{2}$ ft next to one of the 12 ft I or A blocks. Apart from some cases where the double-sided block was burnt out while the single-sided block was less severely damaged the response in those blocks was very similar and accordingly the result for the single-sided block has been given.

TABLE 2b

Equivalent intensity at vertical blocks placed around piles at corners and along sides of array

Pile	12 ft from pile $3\frac{1}{2}$ ft above ground				21 ft from pile 1 ft above ground			
	N	E	S	W	N	E	S	W
A9	4.2 -	> 4.5 -	1.1 -	> 4.5 -	- -	1.1 -	- -	- -
A10	1.1 -	- -	> 5 -	- -	0.6 0.6	- -	> 5 -	- -
A18	> 4.5 -	0.6 -	> 5 -	4.0 -	0.2 -	0.3 -	0.8 -	1.3 -
J18	> 4.5 -	> 4.5 -	4.0 -	> 5 -	- -	0.7 0.6	> 5 -	> 5 -
S18	> 5 -	0.5 0.6	0.4 -	0.4 -	1.1 -	0.4 -	0.2 -	0.5 -
S10	> 4.5 -	- -	0.5 -	0.8 -	0.9 -	- -	0.3 -	0.4 -
S1	4.5 -	0.4 -	0.3 -	0.7 0.6	0.6 -	0.3 -	0.2 -	- -
J1	0.9 -	> 4.5 -	0.4 0.7	0.5 -	0.5 -	- -	0.4 -	0.2 -

Values are in W/cm^2

TABLE 3a

Response in vertical blocks placed around seventeen piles within array

Pile	12 ft from pile $3\frac{1}{2}$ ft above ground				21 ft from pile 1 ft above ground			
	N	E	S	W	N	E	S	W
C3	29RI	BOA	BO	BO	4PI	22CA	BO	BO
C7	BOA	BO	BOI	BO	1CA	BO	BOI	-
C12	BO	BO	BOI	BOA	BO	BO	BOI	BOA
C16	ORA	BOI	BO	BO	BOA	BOI	OR	BO
H3	21R 50R	BO -	34RA 16R	BOI -	34R 12R	BO -	5PA -	BOI -
H7	No results available							
H12	BOI	BOA	BO	BO	BOI	BOA	BO	-
H16	BO	BOA	BOI	BO	BO	BOA	BOI	BO
L3	32R 27R	BO -	30RI 44R	ORA -	4P -	11R 11R	5PI -	BOA -
L7	12CA	24C	1CI	BO	BOA	1C	1CI	BO
L12	BO -	BOI -	BOA -	BO -	BO -	BOI -	BOA -	BO -
L16	BO -	BO -	BOA -	11RI -	BO -	BO -	BOA -	ORI -
Q3	28RA -	18CI -	12R 12R	BO -	17RA -	17RI -	BO -	BO -
Q7	BO -	40RA -	ORI -	BO -	BO -	46RA -	BOI -	BO -
Q12	BO -	OR -	ORA -	45RI -	BO -	BO -	BOA -	13RI -
Q16	- -	12R 30R	10R -	4PA -	ORI -	BO -	BO -	16RA -
E9	BO -	BO -	OR -	BO -	1C -	1C -	OR -	BO -

Notes: As for Table 2a

TABLE 3b

Equivalent intensity at vertical blocks placed around seventeen piles within array

Pile	12 ft from pile $3\frac{1}{2}$ ft above ground				21 ft from pile 1 ft above ground			
	N	E	S	W	N	E	S	W
C3	0.7 -	> 5 -	> 4.5 -	> 4.5 -	0.5 -	4.3 -	- -	- -
C7	> 5 -	> 4.5 -	> 5 -	> 4.5 -	1.3 -	- -	> 5 -	- -
C12	> 4.5 -	> 4.5 -	> 5 -	> 5 -	- -	- -	> 5 -	> 5 -
C16	1.1 -	> 5 -	> 4.5 -	> 4.5 -	> 5 -	> 5 -	1.1 -	- -
H3	0.8 0.5	> 4.5 -	0.6 0.9	> 5 -	0.6 1.0	- -	0.6 -	> 5 -
H12	> 5 -	> 5 -	> 4.5 -	> 4.5 -	> 5 -	> 5 -	- -	- -
H16	> 4.5 -	> 5 -	> 5 -	> 4.5 -	- -	> 5 -	> 5 -	- -
L3	0.7 0.7	> 4.5 -	0.7 0.5	1.1 -	0.5 -	1.0 1.0	0.6 -	> 5 -
L7	2.7 -	4.5 -	1.3 -	> 4.5 -	> 5 -	1.3 -	1.3 -	- -
L12	> 4.5 -	> 5 -	> 5 -	> 4.5 -	- -	> 5 -	> 5 -	- -
L16	> 4.5 -	> 4.5 -	> 5 -	1.0 -	- -	- -	> 5 -	1.1 -
Q3	0.7 -	4.0 -	1.0 1.0	> 4.5 -	0.9 -	0.9 -	- -	- -
Q7	> 4.5 -	0.6 -	1.1 -	> 4.5 -	- -	0.5 -	> 5 -	- -
Q12	> 4.5 -	1.1 -	1.1 -	0.5 -	- -	- -	> 5 -	0.9 -
Q16	- -	1.0 0.7	1.0 -	0.5 -	1.1 -	- -	- -	0.9 -
E9	> 4.5 -	> 4.5 -	1.1 -	> 4.5 -	1.3 -	1.3 -	1.1 -	- -

Values are in W/cm^2

TABLE 4a

Response in vertical blocks placed around weighed fuel piles

Pile	12 ft from pile 3½ ft above ground								21 ft from pile 1 ft above ground			
	N		E		S		W		N	E	S	W
	S	D	S	D	S	D	S	D	S	S	S	S
05	BO -	BO -	12C -	BO -	25C -	- -	BO -	BO -	1C -	- -	BO -	- -
S9	BO -	BO -	14R -	50R 24R	42R -	- -	20C -	BO -	BO -	40R -	3P -	BO -
09	BO -	BO -	BO -	BO -	1C -	- -	BO -	BO -	BO -	BO -	BO -	BO -
J9	BO -	BO -	BO -	BO -	BO -	BO -	14C -	BO -	BO -	BO -	BO -	15C -
J8	OR -	OR -	2C -	BO -	9R -	OR 18C	BO -	BO -	13R -	14R -	BO -	BO -

Notes: (1) For meaning of symbols see Table 1.

(2) Each block faced the centre of the side of the pile.

(3) S stands for a single-sided block, the sides, top and back being protected with mineral fibre board insulation. D stands for double-sided block. In these piles a single and a double-sided block were set up close together on each side.

(4) For any given pile the value on the first line is the response on the side of the block facing the pile. The value on the second line is the response on the side facing away from the pile, when known.

TABLE 4b

Equivalent intensity at vertical blocks placed around weighed fuel piles

Pile	12 ft from pile $3\frac{1}{2}$ ft above ground								21 ft from pile 1 ft above ground			
	N		E		S		W		N	E	S	W
	S	D	S	D	S	D	S	D	S	S	S	S
05	>5 -	>4.5 -	2.7 -	>4.5 -	4.5 -	- -	>5 -	>4.5 -	1.3 -	- -	>5 -	- -
S9	>5 -	>4.5 -	0.9 -	0.5 0.8	0.6 -	- -	4.2 -	>4.5 -	>5. -	0.6 -	0.4 -	>5 -
09	>5 -	>4.5 -	>5 -	>4.5 -	1.3 -	- -	>5 -	>4.5 -	>5 -	>5 -	>5 -	>5 -
J9	>5 -	>4.5 -	>5 -	>4.5 -	>5 -	>4.5 -	3.3 -	>4.5 -	>5 -	>5 -	>5 -	3.5 -
J8	1.1 -	1.1 -	1.5 -	>4.5 -	1.0 -	1.1 4.0	>5 -	>4.5 -	0.9 -	0.9 -	>5 -	>5 -

Values are in W/cm^2

TABLE 5a

Response on vertical blocks placed near pile Q13 (Asbestos-walled pile)

Pile	Vertical blocks							
	12 ft from pile $3\frac{1}{2}$ ft above ground				21 ft from pile 1 ft above ground			
	N	E	S	W	N	E	S	W
Q13	9R	44R	11R	0R	40R	30R	0R	39R
P13	B0	B0	-	-	20C	B0	-	-
Q14	B0	31R	-	-	B0	4P	-	-
R13	-	-	19R	14R	-	-	B0	15C

Notes

(1) For meaning of symbols see Table 1.

(2) Each value in the table is the response produced on the side of the block facing the pile named, the block being opposite the centre of the side.

(3) Extra blocks were placed around pile Q13, 12 ft from the pile on either side of the blocks facing the centre of the pile. The responses on the side facing Q13 were:-

North side	13R	W	of	Centre	12R	E	of	Centre
East side	5P	N	"	"	4P	S	"	"
South side	B0	E	"	"	B0	W	"	"
West side	0R	S	"	"	B0	N	"	"

TABLE 5b

Equivalent intensity at vertical blocks

placed near pile Q13 (Asbestos - walled pile)

Pile	Vertical blocks							
	12 ft from pile $3\frac{1}{2}$ ft above ground				21 ft from pile 1 ft above ground			
	N	E	S	W	N	E	S	W
Q13	1.0	0.5	1.0	1.1	0.6	0.7	1.1	0.6
P13	>5	>5	-	-	4.2	>5	-	-
Q14	>5	0.7	-	-	>5	0.5	-	-
R13	-	-	0.8	0.9	-	-	>5	3.5

Values are in W/cm^2

TABLE 6a

Wood block data for single piles of fuel

Fuel	Test	Vertical block 12 ft from pile $3\frac{1}{2}$ ft above ground				Vertical block 21 ft from pile 1 ft above ground				Horizontal block in 'piazza' position			
		N	E	S	W	N	E	S	W	NE	SE	SW	NW
Milled lumber	760-12A* 29-8-'67	-	-	-	-	12R	10R	20C	BO	-	-	-	-
	J9 After 760-12	14C	OR	28C	BO	16R	14R	21C	15C	U	3P	15R	40R
Wild-land	21/9**	-	23C	56R	-	11C	42R	4P	54R	2P	U	-	5P
	June '67***	-	-	-	-	19C	14C	44R	58R	-	-	-	-

Notes: In these tests the initial reflectivity was about 70 per cent so that some slight modification is required before the calibration data of Table 1 can be employed here.

*Vertical blocks 4 ft from pile and $3\frac{1}{2}$ ft above ground were burned away on N, E and W sides.

**A vertical block 4 ft from pile $3\frac{1}{2}$ ft above ground on S side gave 24C.

***Vertical blocks 4 ft from pile $3\frac{1}{2}$ ft above ground gave BO on N and E sides, 42C on S side and 39 C on W side.

TABLE 6b

Equivalent intensities for single fuel piles

Fuel	Test	Vertical block 12 ft from pile $3\frac{1}{2}$ ft above ground				Vertical block 21 ft from pile 1 ft above ground				Horizontal block in piazza position			
		N	E	S	W	N	E	S	W	NE	SE	SW	NW
Milled lumber	760-12A 29-8-67	-	-	-	-	1.0	1.1	4.2	>5	-	-	-	-
	J9 After 760-12	3.3	1.1	4.6	>5	0.9	1.0	4.2	3.5	<0.2	<0.4	0.9	0.7
Wild-land	21/9	-	4.4	0.6	-	2.5	0.7	0.5	0.6	0.3	<0.2	-	0.6
	June '67	-	-	-	-	4.1	3.3	0.7	0.6	-	-	-	-

Values are in W/cm^2

TABLE 6c

Average equivalent intensities around milled-lumber piles and single piles of wild-land fuel

Fuel	Test and pile	Vertical blocks		Piazza block
		12 ft from pile $3\frac{1}{2}$ ft above ground	21 ft from pile 1 ft above ground	
Milled lumber	760-12 J9	> 4.6	> 4.6	1.1
	760-12 09	> 4	> 5	1.1
	760-12 05	> 4.3	> 3	1.0
	760-12 S9 (Edge of plot)	~ 2.7	> 2.7	0.5
	760-12a 29/8/67 (Single pile)	-	~ 2.8	-
	J9 Single pile burnt after 760-12	~ 3.5	2.4	0.5
Wild-land fuel	21/9 (Single pile)	~ 2.5	1.1	~ 0.3
	June '67 (Single pile)	-	2.2	-

Values are in W/cm^2

TABLE 7a

Response in wood blocks mounted on towers

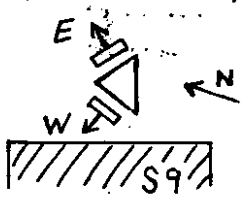
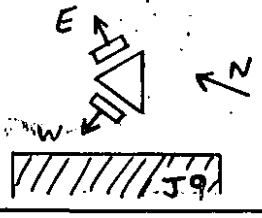
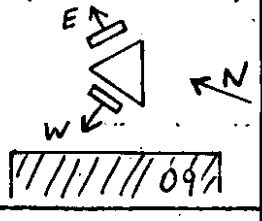
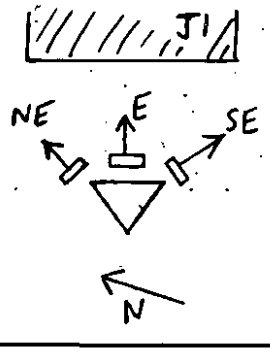
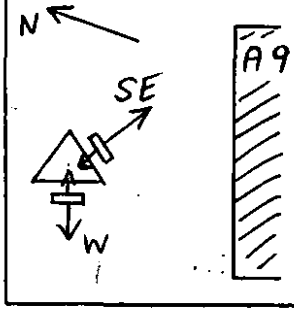
Tower	Height ft	Up facing	Down facing	West facing	East facing
1 (E side of S9) 	$3\frac{1}{2}$	3P	1P	15C	9R
	7	3P	1P	-	0R
	20	-	-	27R	17R
	50	U	25C	4P	4P
	80	U	11R	3P	3P
	100	U	40R	3P	4P
13 (E side of O5)	Tower collapsed. All blocks burned out.				
9 (E side of J9) 	7	B0	B0	B0	B0
	20	B0	B0	B0	B0
	50	B0	B0	B0	1C
	80	B0	8R	28R	36R
	100	3P	14R	4P	4P
5 (E side of O9) 	$3\frac{1}{2}$	-	-	B0	0R
	7	-	-	B0	0R
	20	B0	B0	B0	0R
	50	2P	B0	32R	44R
	70	1P	0R	46R	44R
18 (W side of J1) 	0 (Horizontal on ground at base of tower)	U	-	-	-
	10	-	-	-	U (Facing E) U (Facing NE)
	50	-	-	-	2P (Facing E) 1P (Facing SE)
17 (N side of A9) 	0 (Horizontal on ground at base of tower)	U	-	-	-
	10	-	-	U (Facing W) U (Facing NW)	U (Facing E) 1P (Facing SE)
	50	-	-	1P (Facing W) 1P (Facing NW)	U (Facing E) 2P (Facing SE)

TABLE 7b

Equivalent intensities for blocks mounted on towers

Tower	Height ft	Equivalent intensity W/cm^2			
		Up facing	Down facing	West facing	East facing
1 (E side of S9)	$3\frac{1}{2}$	0.4	0.2	3.5	1.0
	7	0.4	0.2	-	1.1
	20	-	-	0.7	0.9
	50	<0.2	4.5	0.5	0.5
	80	<0.2	1.0	0.4	0.4
	100	<0.2	0.6	0.4	0.5
13 (E side of 05)	Tower collapsed				
9 (E side of J9)	7	>4.5	>4.5	>4.5	>4.5
	20	>4.5	>4.5	>4.5	>4.5
	50	>4.5	>4.5	>4.5	1.3
	80	>4.5	1.0	0.7	0.6
	100	0.4	0.9	0.5	0.5
5 (E side of 09)	$3\frac{1}{2}$	-	-	>4.5	1.1
	7	-	-	>4.5	1.1
	20	>4.5	>4.5	>4.5	1.1
	50	0.3	>4.5	0.7	0.5
	70	0.2	1.1	0.5	0.5
18 (W of J1)	0	<0.2	-	-	-
	10	-	-	-	<0.2(E) <0.2(NE)
	50	-	-	-	0.3(E) 0.2(SE)
17 (N of A9)	0	<0.2	-	-	-
	10	-	-	(<0.2(W) (<0.2(NW)	<0.2(E) 0.2(SE)
	50	-	-	(0.2(W) (0.2(NW)	<0.2(E) 0.3(SE)

TABLE 8

Water evaporated and equivalent intensities of water calorimeters

	Water evaporation[1] U.S. fluid oz.				Equivalent intensity[2] W/cm^2			
	C	H	L	Q	C	H	L	Q
16	18	28	27	9	5.9	8.2	7.9	3.9
12	24	24	28	16	7.3	7.3	8.2	5.5
7	35	22	-	-	9.7	6.8	-	-
3	0	0	8	6	<1.9	<1.9	3.7	3.2

Notes

(1) Calorimeters held 48 fluid oz. initially.

(2) Assuming no heat less and effective exposure time of 20 min.

(3) Negligible evaporation occurred from a control calorimeter exposed under similar conditions but some distance from the fire.

TABLE 9a

Wind gauge results

Location		60 ft/s gauge	30 ft/s gauge	Maximum thermometer °C	Horizontal wood block	
					Response	Equvalent intensity W/cm^2
A	9/10	Up	Down			
B	9/10	Up	Down	Broken		
C	9/10	30 ft to NE	Down			
D	9/10	Down*	Down*			
E	9/10	Up	Down			
F	9/10	Up	Down	Broken	9C	2.2
G	9/10	Up	Down			
H	9/10	Up	3 ft to N			
I	9/10	Up	Down			
J	9/10	Up	Down	Broken		
K	9/10	Up	Down			
L	9/10	Up	Down	~ 230	1C	1.3
M	9/10	Up	Down			
N	9/10	Up	Down	202		
O	9/10	Up	Down			
P	9/10	Up	Up	75	7C	2.0
Q	9/10	Up	Down			
R	9/10	Up	Down			
S	9/10	Up	Up			

*Possibly knocked over by a falling rock

TABLE 9 (b)

Wind gauge results (Cont'd.)

Location		60 ft/s gauge	30 ft/s gauge	Maximum thermometer °C	Horizontal wood block	
					Response	Equivalent intensity W/cm²
18	I/J	Down	Down			
17	I/J	50 ft to N	Down	Glass softened	13C	3.0
16	I/J	Lost	12 ft to N			
15	I/J	Down	27 ft to E			
14	I/J	Up	Down			
13	I/J	12 ft to N	12 ft to N			
12	I/J	12 ft to S	Down			
11	I/J	Up	Down	> 220	20R	0.8
10	I/J	12 ft to N	12 ft to N			
9	I/J	Up	3 ft to E			
8	I/J	Up	2 ft to E			
7	I/J	Up	4 ft to E			
6	I/J	Up	2½ ft to E	Broken	12R	1.0
5	I/J	Up	Down			
4	I/J	Up	Down	Broken	18R	0.8
3	I/J	Up	Down		44R	0.5
2	I/J	Up	Up			
1	I/J	Up	Up			

TABLE 9 (c)

Wind gauge results (Cont'd.)

Location	60 ft/s gauge	30 ft/s gauge
S4/S5	Up	-
S3/S4	Up	Up
S2/S3	Up	Down
S1/S2	Up	Up
R1/S1	Up	-
Q1/R1	Up	-
P1/Q1	Up	Up
O1/P1	Up	Up
South side of Q13	-	Down
North side of Q13	-	Down

TABLE 10

Parameters of quadric regression on piazza block data

Parameter	Value	Standard error
a	0.154	0.0279
b	-0.00822	0.00121
c	0.231	0.0291
d	-0.00763	0.00142
e	-0.00281	0.00107
f	-1.836	

Residual standard error 0.434

Degrees of freedom 196

TABLE 11

Piazza blocks giving intensities substantially different from those predicted from the regression

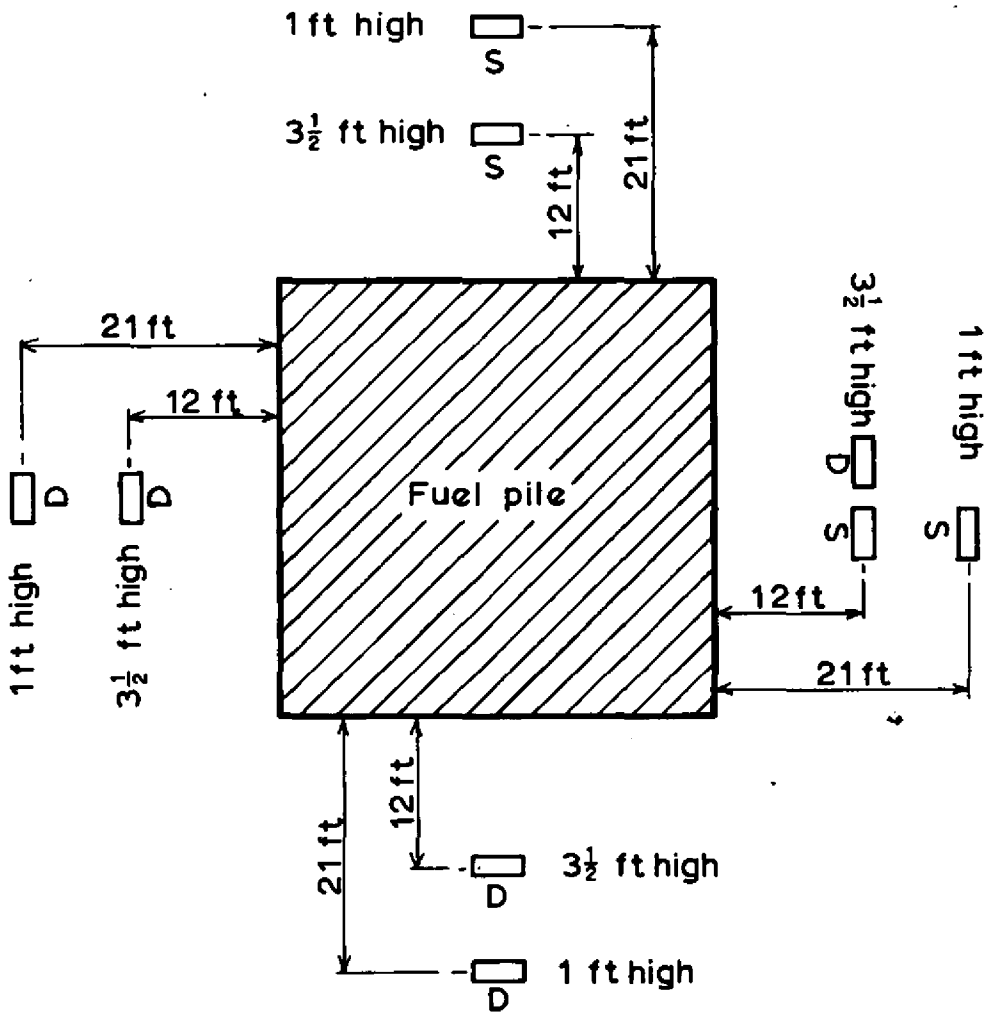
Position	Equivalent intensity W/cm^2		Suggested reason for deviation
	Observed	Predicted from regression	
A16	>5	1.0	Fire whirl activity
A18	>5	1.0	
F17	>5	1.25	
H17	3.5	1.25	
B16	>5	1.1	
G16	>5	1.3	
I16	>5	1.25	
E14	>5	1.3	
C13	>5	1.2	
B12	>5	1.0	
08	2.1	0.7	Proximity of milled fuel pile
S9	1.1	0.4	
05	2.1	0.55	
G2	<0.2	0.5	Proximity of unignited piles
I2	0.2	0.5	
P14	>5	0.7	Random variation
I6	2.1	0.85	
G5	4.0	0.75	
B3	1.1	0.4	
C5	1.5	0.6	
Q15	0.2	0.6	
H5	0.2	0.7	

TABLE 12

Configuration factors and intensities for various positions of wood blocks

Fuel pile assumed to be the sole radiator, i.e. radiation from the flames neglected.

Position	Configuration factor	Configuration factor relative to that at piazza position	Equivalent intensity relative to that at piazza position
Piazza	0.06	1	1
Horizontal block on ground at street centre.	0.12	2	1.5-2
Horizontal blocks on ground - mean across street.	0.20	3.3	2-3
Vertical block 1 ft above ground at street centre.	0.26	4.0	2.5-3.5
Vertical blocks 1 ft above ground - mean across street.	0.28	4.6	~ 3.5
Vertical block $3\frac{1}{2}$ ft above ground at street centre.	0.28	4.3	3.5-5
Vertical block $3\frac{1}{2}$ ft above ground at piazza position.	0.04	2.1	1.1
Vertical block $3\frac{1}{2}$ ft above ground in plane of edge of piles facing across piazza.	0.06	1.5	1.2



S-Single sided block
D-Double sided block

PLAN

FIG.1. STANDARD ARRANGEMENT OF VERTICAL BLOCKS AROUND SELECTED PILES

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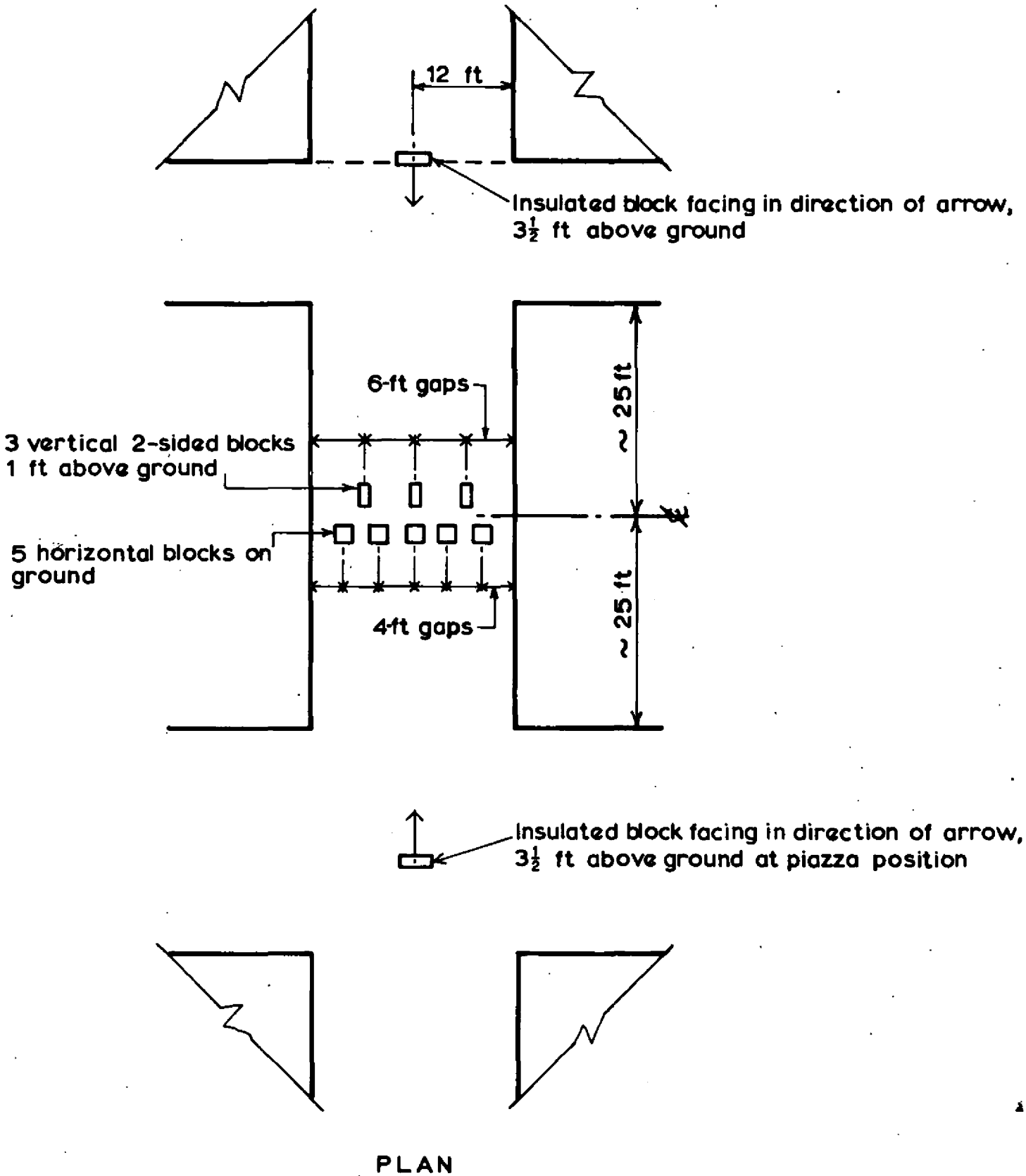

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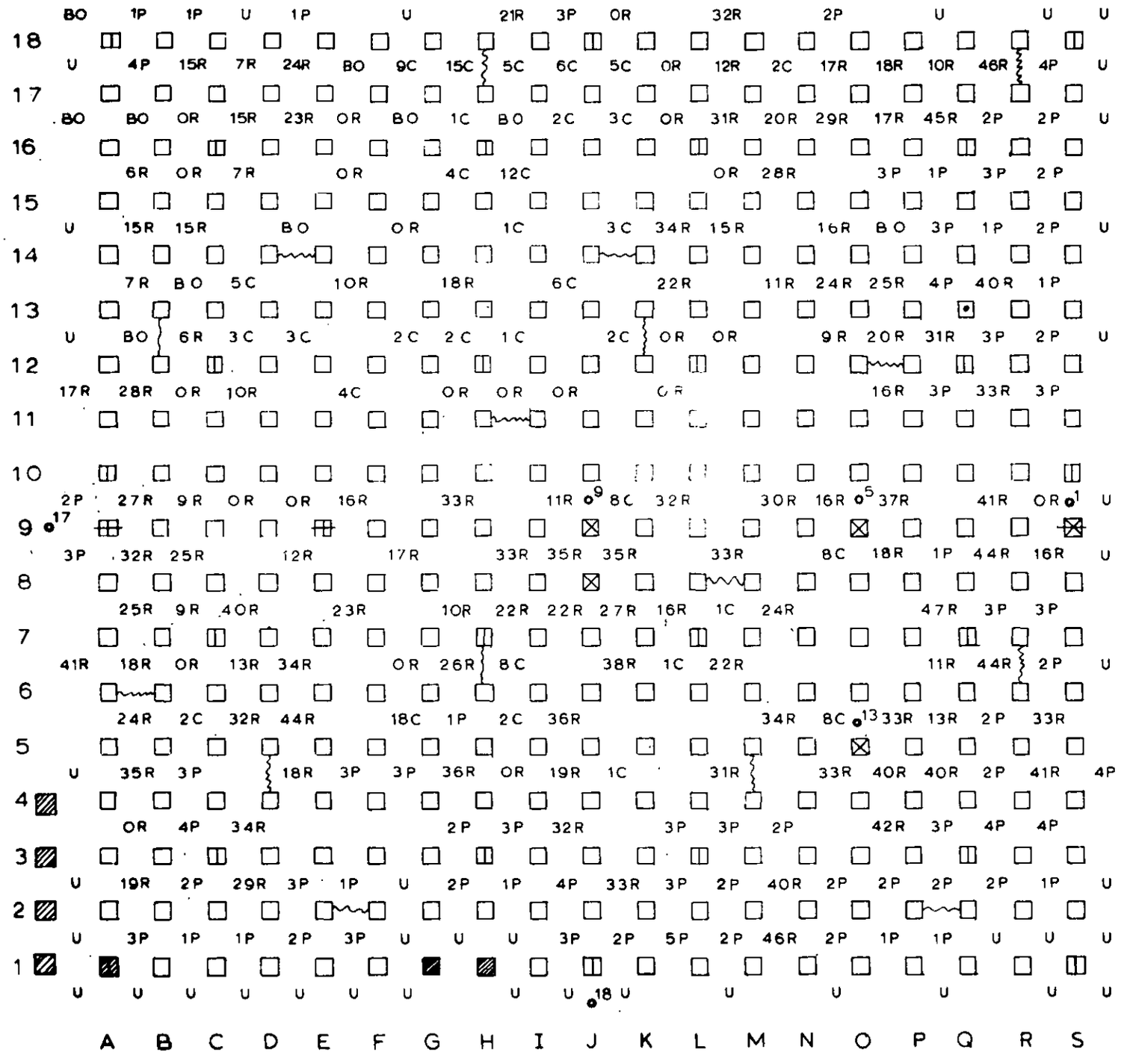
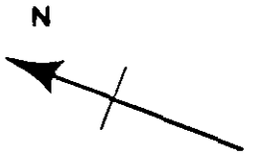
FIG. 2. STANDARD PLAN ARRANGEMENT OF BLOCKS ACROSS AND ALONG STREETS





For meaning of symbols see table 1.

KEY

- Weighed pile
- Water calorimeter
- Unignited pile
- Asbestos-walled pile
- Pile with pattern of vertical blocks
- Pattern of street blocks
- Tower with wood blocks

FIG. 3a.
RESPONSE IN HORIZONTAL BLOCKS AT PIAZZAS.

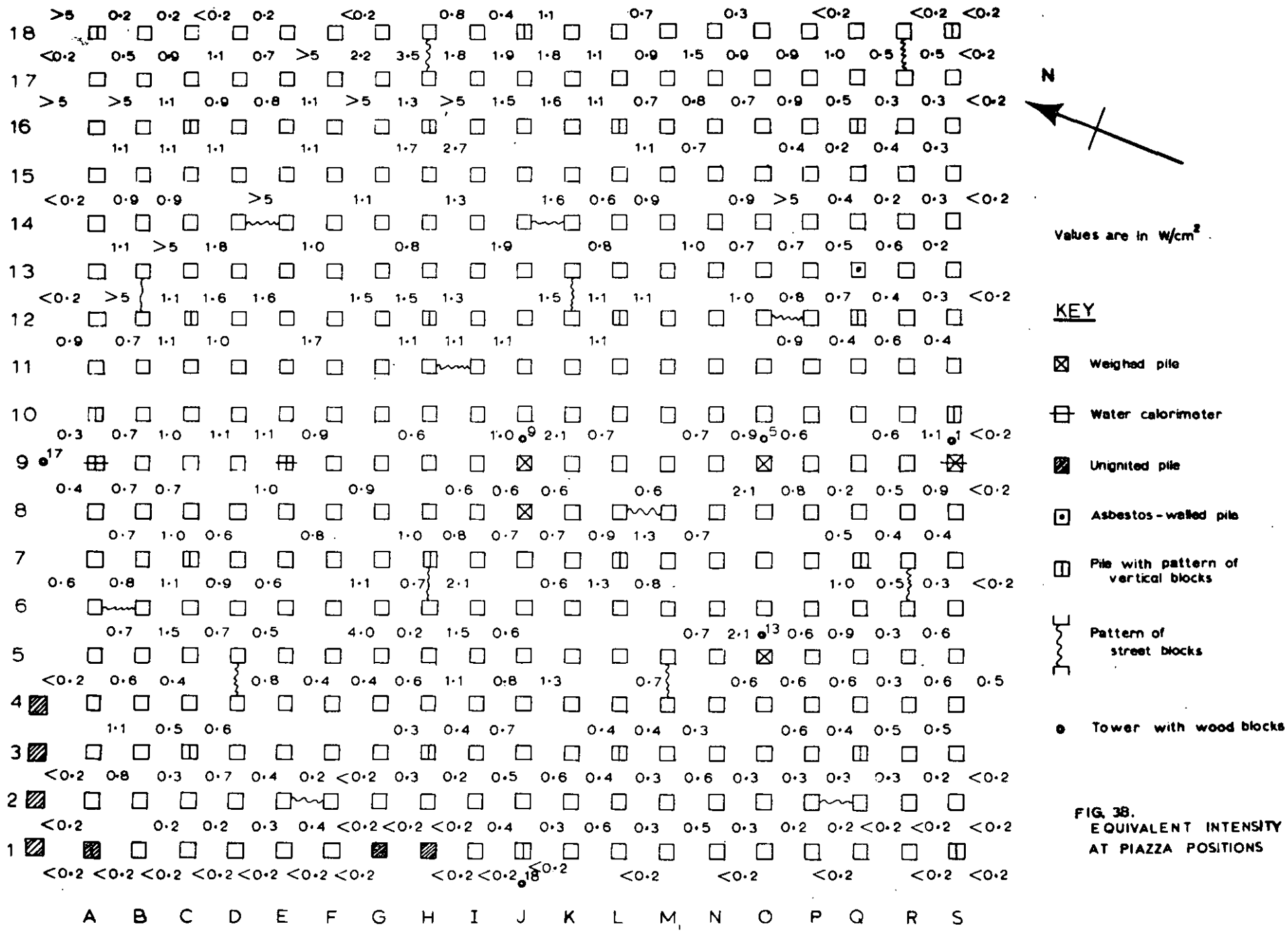
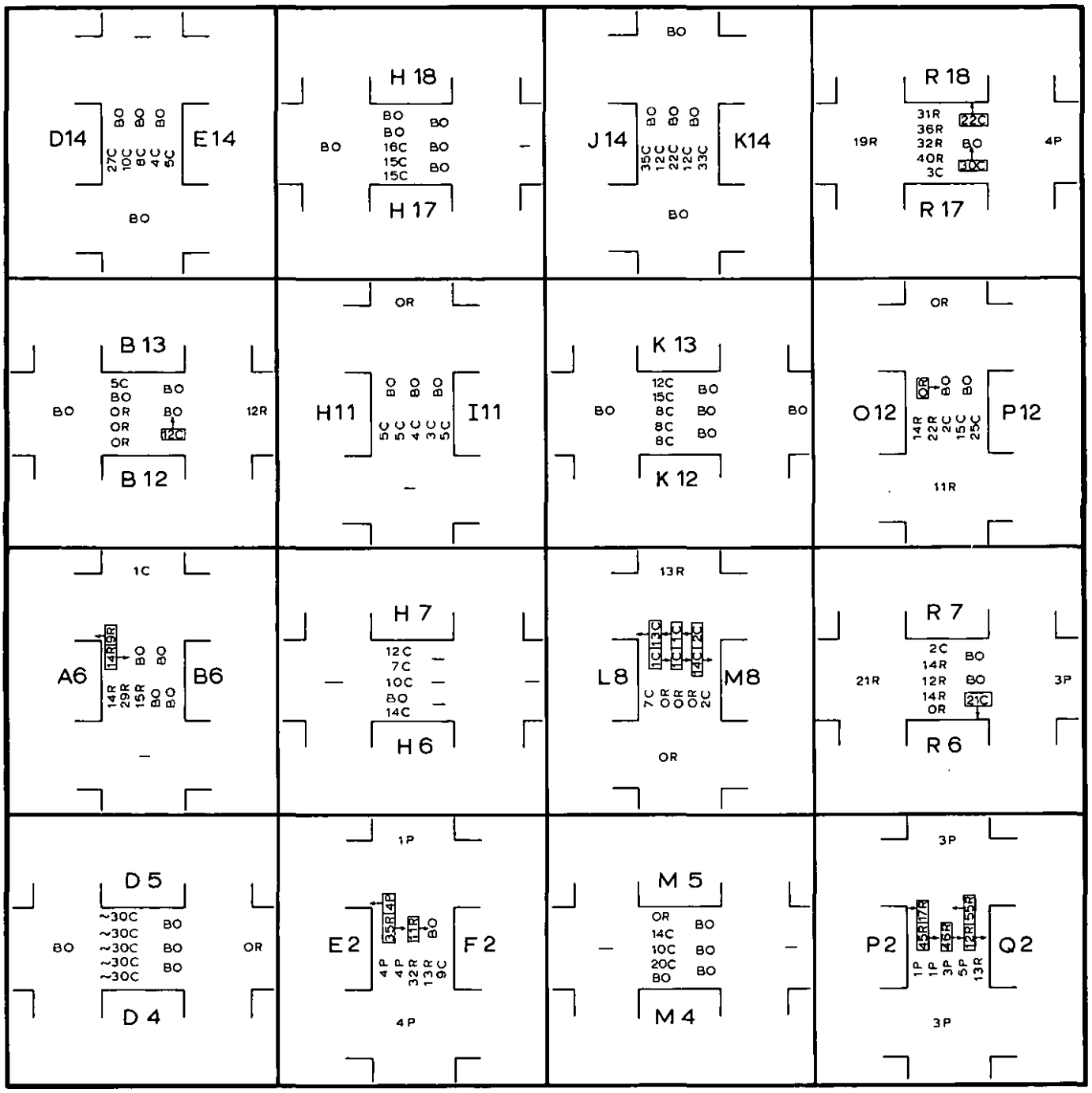


FIG. 38.
EQUIVALENT INTENSITY AT PIAZZA POSITIONS

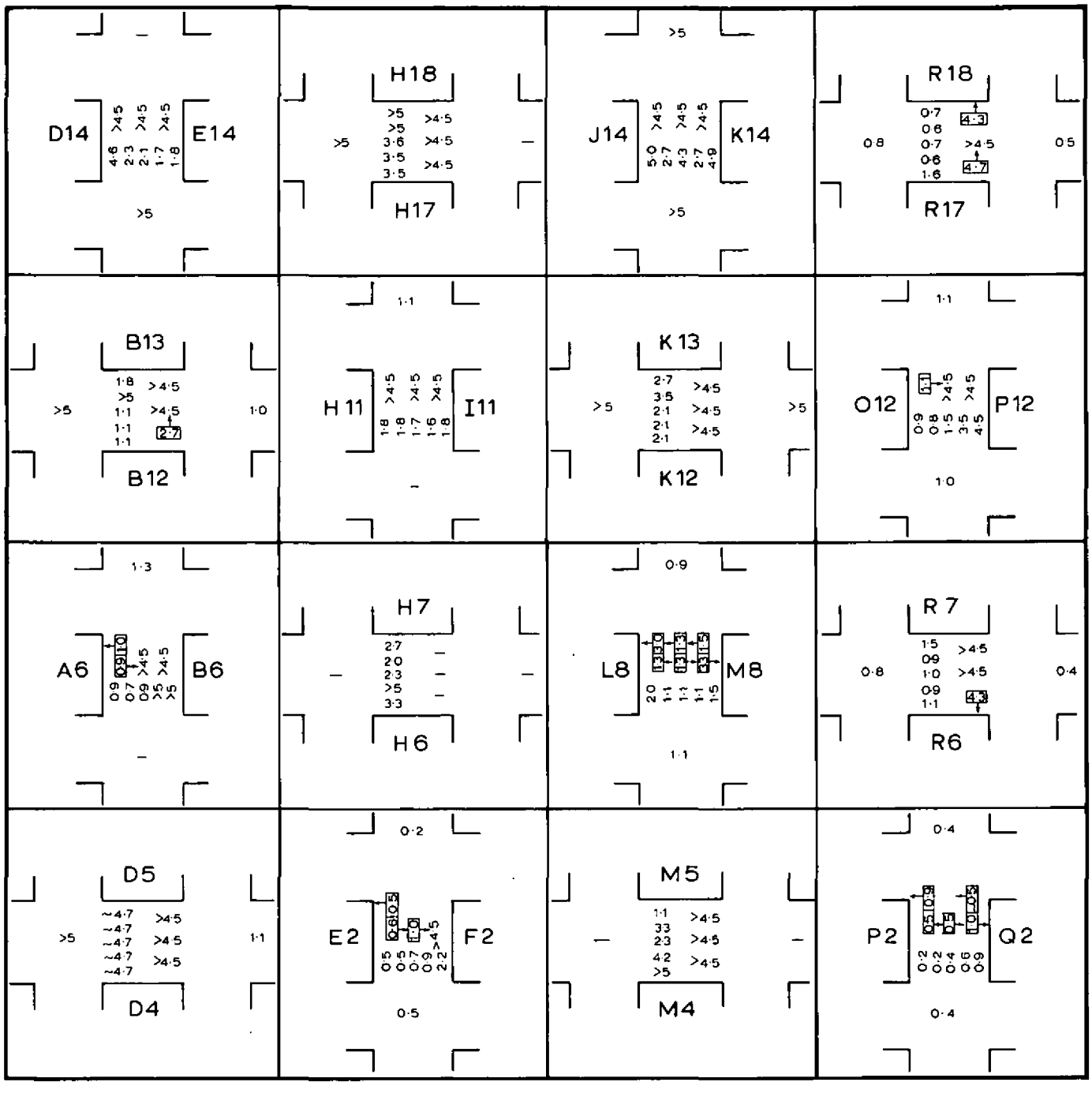


N

For explanation of positions see Figs 2 and 3a

For meaning of symbols see Table1

FIG.4a. RESPONSE IN STREET BLOCKS



For explanation of positions see Figs 2 and 3a

Values are in W/cm²

FIG.4b. EQUIVALENT INTENSITY AT STREET BLOCKS

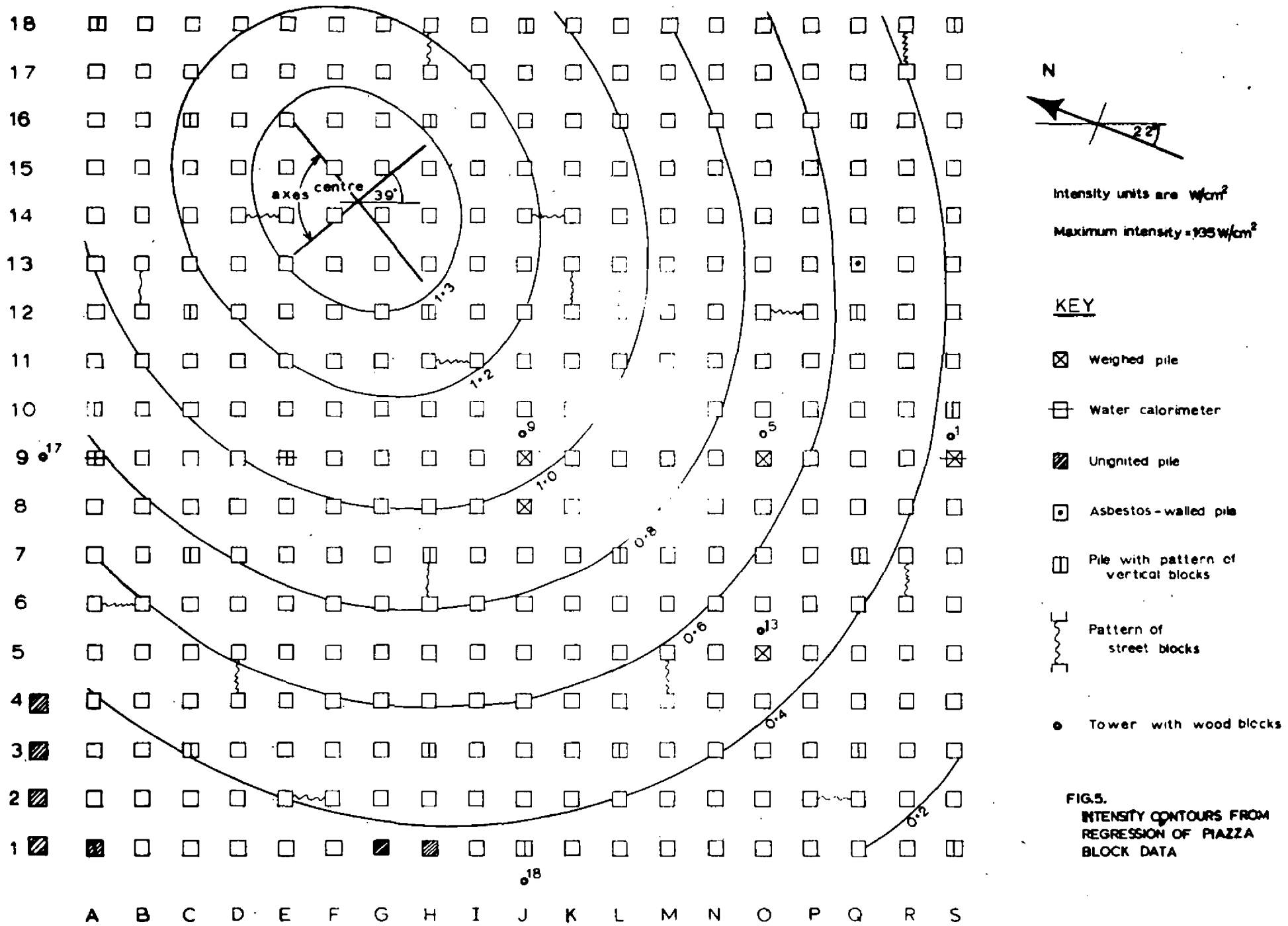
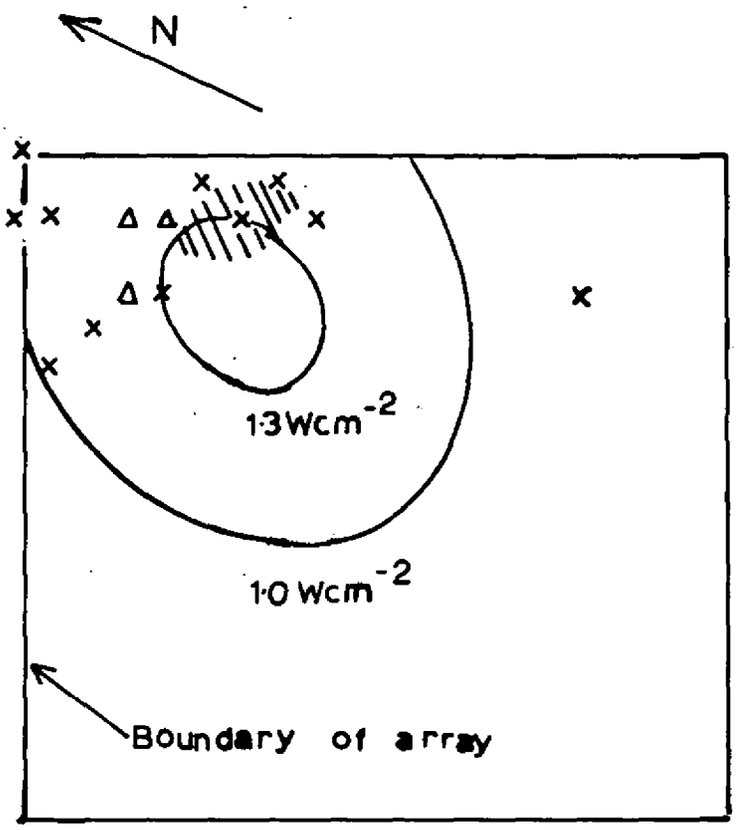


FIG.5.
INTENSITY CONTOURS FROM REGRESSION OF PIAZZA BLOCK DATA



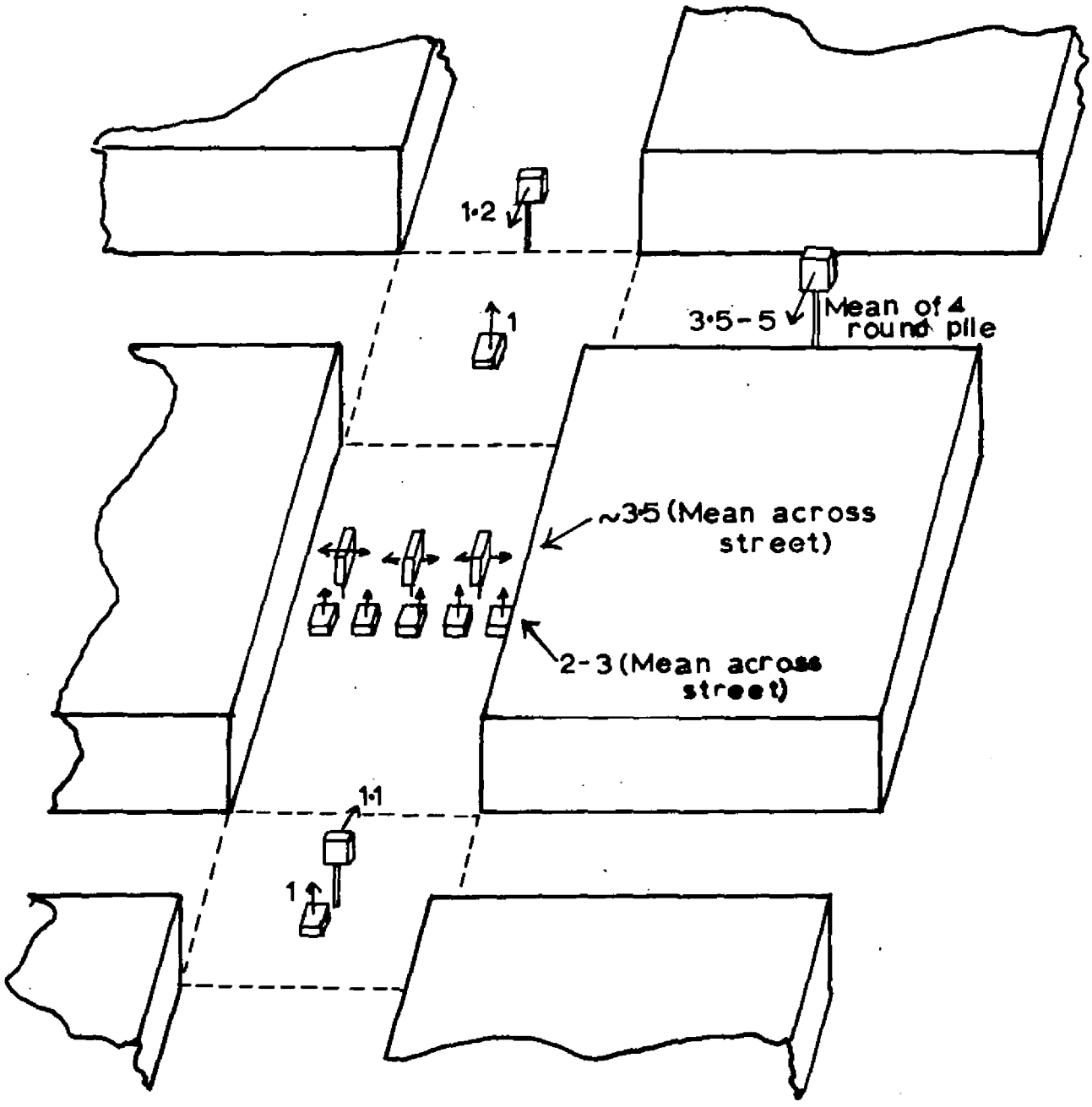
Curves plotted are contours of intensity from quadric regression of piazza block data

X Piazza block burned away

△ Spalling of boulders noted

\\\ Severe scouring of ground noted

FIG. 6. AREAS OF SEVERE DAMAGE



Each value is an equivalent intensity, averaged over whole array, relative to that at the piazza position.

FIG.7. RELATIVE INTENSITY AROUND A FUEL PILE.

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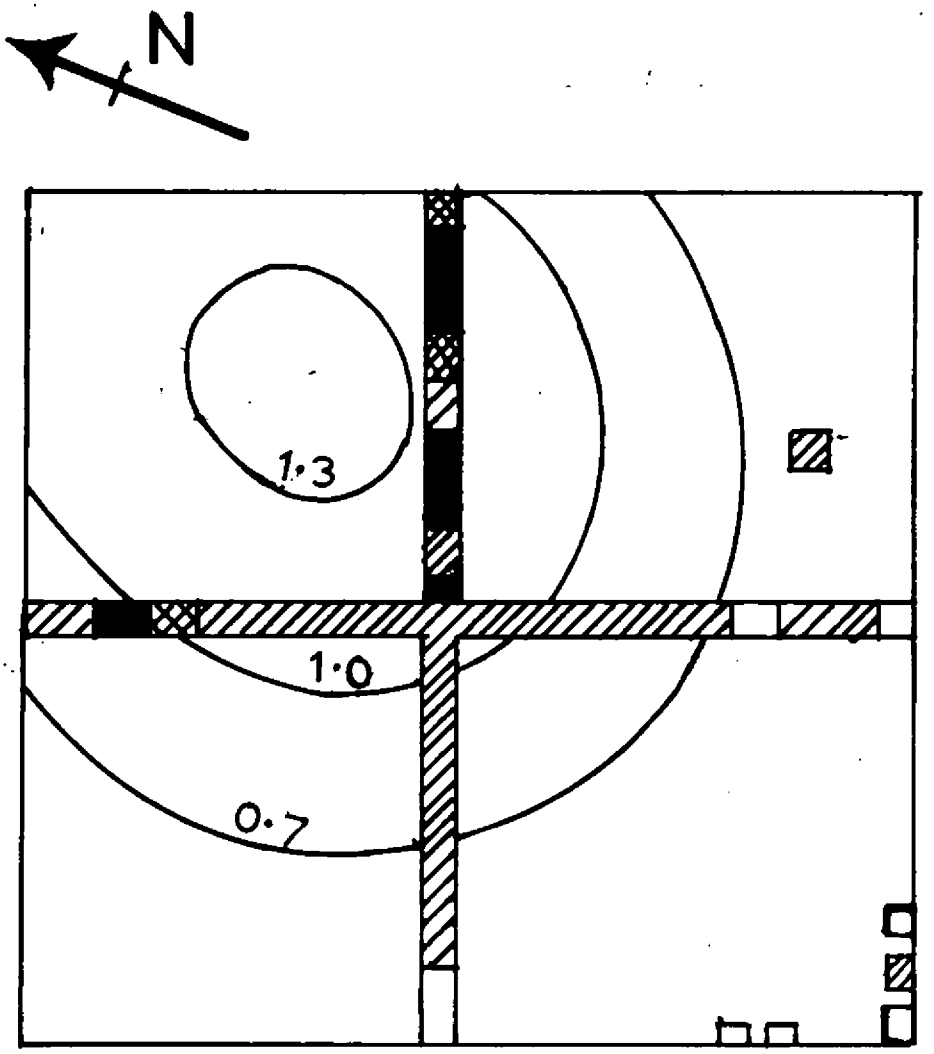

Wind speed (W) < 30ft/s

30ft/s < W < 60ft/s

W > 60ft/s

W >> 60ft/s (Gauge moved at least 12ft)

Contours are equivalent intensity from piazza block regression ($W cm^{-2}$)

FIG.8. WIND GAUGE RESULTS

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