Sedimentation at Jetties

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Contract

This report describes work carried out as part of an overall study funded by the Department of Environment under contract PECD 7/6/109, the Department of the Environment's nominated officer was initially Dr R D Thorogood but later Mr P Woodhead. The study was carried out in the Tidal Engineering Department of Hydraulics Research under the management of Mr M F C Thorn by Mr K Mann. This report is published on behalf of the Department of the Environment but any opinions expressed are not necessarily those of the funding department.

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Summary

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This report describes tests made on groups of different numbers and different types of model piles in a laboratory flume in order to ascertain which groupings and pile shapes yield minimum siltation potential.

The work was carried out following a literature review (see HR Report SR 214, Ref 1) of the adverse effects of the construction of jetties in tidal flows and publication of an appendix to the above report which was a summary of drag coefficients of individual pile shapes.

Preliminary tests made with circular piles to establish the passage of flows through piled structures were not continued in the sedimentation phase of the work because of scaling problems due to low pile Reynolds Numbers in the flume.

The work was carried out using bluff-shaped square, hexagonal and octagonal model piles about 12.7mm square in groups in a flume 34.5m long and 0.5m deep. The mean flow velocity was 0.245m/s and the flow depth 0.09m. A series of twenty seven tests was made where sand (d_{50} = 0.150mm) was sprinkled into the flow upstream of the test rig and allowed to settle between the pile array under test. After about five minutes an overhead photograph of the rig was taken to indicate erosion of the sand. These photographs were then analysed to assess the siltation/erosion potential of the various pile groups. The pile groupings varied from square groups at even spacings of 3 'diameters' 6 'diameters' and 9 'diameters' to rectangular groups with 3, 5 and 7 piles either across or along the flume. Flow incidence angles (Θ) of 0, 10, 20, 30, 40 and 45 degrees were used.

The results indicated that square-shaped piles nearly always had less siltation potential than hexagonal and octagonal piles. Closer pile spacings also caused more erosion (less siltation potential) than wider pile spacings with square arrays of 3 x 3 and 5 x 5 piles. The effects of different approach flow angles (incident flow angles) showed that in general siltation potential was greatest at $\Theta = 0°$.

The tests indicated that rectangular-shaped pile arrays with the downflow length greater than the frontal width increased the siltation potential for the arrays tested and also that there was little difference in siltation potential for various frontal widths of arrays for a constant downflow length of array.

It is recommended that a further programme of tests should be made to investigate the effect of irregular pile spacings; different pile sizes; the combined effect of minimising siltation potential and also sideforces on vessels berthed at jetties; effects of reversing and accelerating and

decelerating flows and on-site measurements should be made of siltation (or erosion if possible) at jetties with circular and bluff-shaped piles.

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1 Introduction

Flow regimes in estuaries are typically complex with significant variations in current velocities. At a particular location in an estuary variations occur as the tide rises and falls during the flood and ebb phases of the tide and also through the depth of flow and in some cases complete flow reversal may occur. To construct a jetty in such an environment so that it is optimally aligned with the main tidal flows to cause minimum drag and hence minimum effect on the ever-changing tidal currents and with the minimum amount of siltation is often difficult. Guidance as to how to group and align piles for least detrimental effects should assist engineers in reducing maintenance dredging costs.

Many experimenters have made tests on drag of individual model piles in flumes and some have made tests on the drag coefficients of groups of piles. These are reported on in a literature review associated with this study namely HR Wallingford Report SR 214 - A review of flow obstruction and sedimentation of jetties (Ref 1). The review concluded that although drag coefficients of pile groups have been investigated, the effects of different layouts of pile groups on siltation amongst them had not been examined. Therefore a series of tests was designed to investigate the effect of pile spacing, pile shape, number of piles in group, group layout and flow incidence would have on siltation within pile groups. The effects of changing flow velocities, different pile sizes and the effects of different bed bathymetries were not examined.

It was hoped to produce a manual for design of jetties to minimise siltation after this series of tests but it is now recommended that this should be done after further research. Recommendations for further research are made in Section 5.

2 The flume experimental procedure

The tests were carried out in a horizontal flume 3.66m wide and 34.5m long and 0.5m deep. The experimental test rig was situated 21.5m from the upstream end of the flume (Fig 1) and the flow pumped from a sump which was connected at both ends to the flume. The pile arrays were set into a purpose - built 0.76m diameter circular plate that was flush with the floor of the flume and which could be rotated at 5° intervals.

In order that the velocity field at the test section was uniform across its width, the flow entering the flume was carefully adjusted using baffle plates and weirs until an even lateral flow distribution was obtained. This took a great deal of time and many vertical and lateral profiles were measured. The mean velocity at the measuring rig was 0.245 m/s and the flow depth 0.09 m.

Only one flow velocity was used for the tests as they were of a comparative nature although in reality pile groups are subjected to a whole range of flow and directional variations.

The following test procedure was adopted. A pile grouping was set up in the rig and the flow velocity and water level checked to ensure that the test conditions were consistent. Then a quantity of sand (d_{50} = 0.150 mm) was sprinkled into the flow just upstream of the test rig until an even covering of the spaces between the piles was achieved. Then, after $4\frac{2}{3}$ minutes had elapsed, a photograph was taken from above the test rig. (See Plate 1). In the plate the black base of the test rig is clearly visible as the sand eroded from between the piles left the area of the test rig.

The sand size and the erosion duration used for the tests were arrived at after a series of sensitivity tests so that a measurable amount of erosion took place when the pile groups were in place. The change of erosion with time was not examined in detail in the test series as the tests were of a comparative nature.

Each pile grouping was tested at the following flow incidence angles (Θ):

0, 10, 20, 30, 40 and 45 degrees.

The pile spacing (centre to centre) ranged from 3D to 9D (D = pile diameter or size) which approximates to the range of spacings generally used on jetties in estuaries. The pile shapes tested were square, hexagonal and octagonal. These shapes were chosen for two reasons. Firstly, many researchers (Refs 2 to 11) have used circular piles for research programmes in investigations of drag coefficients but there was always a degree of uncertainty in scaling up the results to full scale field values because of the difference in drag coefficient in the model and nature (see Fig 2) which was caused by the difference in breakaway position on the pile at the very different pile Reynold's Number values. It was therefore considered necessary to use bluff shapes for piles so that the breakaway position was consistent through a large range of pile Reynold's Number values. The values of R_e for the model piles were about 3.1 to 3.6 x 10^3.

The test procedure was carried out on the following pile arrays for 12.7 mm square, hexagonal and octagonal piles on the following pile groups:-

F N S	
3 x 3 x 3D	F = number of piles along the flow lines (downflow direction) flow when $\Theta = 0°$
3 x 3 x 6D	N = number of piles normal to flow when $\Theta = 0°$
3 x 3 x 9D	S = pile spacing (centre to centre)
	D = pile diameter
5 x 3 x 6D	
5 x 5 x 6D	
5 x 3 x 3D	Example of 5 x 3 x 6D array
3 x 5 x 3D	o o o o o
	Flow → o o o o o
3 x 7 x 3D	
7 x 3 x 3D	o o o o o

3 Evaluation of data

The effect of the pile arrays etc on the siltation potential within the groups was deduced in the following manner. Firstly the overhead photographs of the tests were enlarged so that the erosion areas could be defined clearly. The plan area of the area eroded and the pile group were then measured using a digital ground model technique. The eroded area was designated the "scour area" and the plan area of the pile array was designated the 'group area'. The ratio of scour area to group area (Scour Ratio = SR) was then used as a measure of the effectiveness of a particular array in combating siltation. The eroded area included erosion outside, but adjacent to, the pile group and so the scour ratio can be >1. It is clear that this technique has drawbacks for example, in reality scour around a pile may cause a local scour hole that requires armouring or back-filling and the timescale of erosion/siltation is not taken into account but in the context of this research it was considered that it would show areas where siltation would not occur.

4 Test results

4.1 Effects of spacing on square arrays of 3 x 3 piles

(a) <u>Square piles</u>

The curves of scour ratio (SR) against flow incidence angle for square piles for spacings of 3D, 6D and 9D are shown in Figure 3. They show, in general, minimum values of SR at 0° and 45° and the increasing trend between 10° and 40°. At Θ (angle of incidence) = 0° the flow is aligned with the piles and the front row of piles shield those behind; the drag coefficient of those behind is lower than those at the front. As Θ increases more piles are subjected to the full flow stream velocity and this effect increases until 40°. At 45° the front row of piles along two sides of the array produces a partial shielding effect but not so great as at Θ = 0° (Fig 3).

In tests at University of Manchester, Ball and Hall(Ref 10) found a similar shaped curve in their experiments on drag coefficients of circular piles in square arrays with several different pile spacings and numbers of piles. As the spacing increased from 6D to 9D the SR~Θ curve exhibits a less pronounced change in SR because blockage effects are offset as the flow streamlines diverge through the array.

The erosion shows a distinct pattern as the angle of incidence increases, (see Plates 1-6). At Θ = 0° there is little scour downstream of the group and there is still some sand left in-between the piles. As Θ increases scour takes place on the lee side of the group (the top side in the plates) and also downstream of the array but mainly on the bottom side. At Θ = 40° the bed is completely clear between the piles.

Observation of surface floats passing the array indicated that flow passed through the group at low values of Θ. At higher values most of the flow was deflected around the group.

(b) Hexagonal piles

The SR~Θ curves for hexagonal piles are shown in Figure 4. They exhibited a similar pattern to the curves for square piles but as the spacing widens the scour ratio decreases and at 6D there is a less definite double peak shape to the curve.

(c) Octagonal piles

The SR~Θ curves for octagonal piles are shown in Figure 5. These curves are similar to those for both square and hexagonal piles.

Summary

The results indicate that for a 3 x 3 array there will be less likelihood of siltation between the piles for closer spacings and at a spacing of 3D square piles have a higher scour ratio than hexagonal and octagonal piles. This effect is still in evidence at 6D but not at 9D.

The mean values of scour ratio over the range of incidence angle for the three shapes of pile are shown in Table 1 and these confirm the above comments.

If spacings much less than 3D were tested the scour ratio would be unlikely to increase further. As the spacing is decreased the shielding effect of the front piles, especially at 0° and 45°, will increase and there will be less likelihood of vortices forming in the wake of the piles. This will inhibit turbulent velocity fluctuations and hence lift forces on the sand grains, resulting in less erosion of particles and inhibiting particles that are already in suspension in the water column from settling in the pile array.

4.2 Square arrays of different sizes (Spacing 6D)

The tests were made in order to determine whether the scour ratio would decrease with size of pile array because Ball and Hall (Ref 10) had shown a decrease in drag coefficient from a peak of 1.2 for a 5 x 5 group (spacing 8D) to 1.0 for a 9 x 9 group (spacing 8D).

The results of the tests are shown in Figures 6, 7 and 8 and Table 2 for square, hexagonal and octagonal piles respectively. For square piles (Fig 6) the 3 x 3 array has a higher scour ratio over the whole range of incidence angles tested with the average value being 1.18 compared with the mean for the 5 x 5 array of 0.68 (Table 2). With hexagonal piles the difference between 3 x 3 and 5 x 5 arrays is smaller (SR = 0.85 for 3 x 3 and 0.70 for 5 x 5 array) and with octagonal piles the value of SR is the same (0.72).

Examination of the scour photographs (not shown in this report) shows that the scour patterns for the three pile types are similar and they exhibit downflow erosion which increases as the incidence angle increases. Only behind the front piles does the scour hole not join up with the next one downstream - a similar effect to that noticed in the first set of tests. This is attributed to the additional turbulence and drag contributed by the piles in the centre of the array.

The additional erosion potential of the square piles when compared with the hexagonal and octagonal piles is attributed to the additional of blockage produced by them. Figure 9 shows the blockage ratio (projected frontal area of the piles/overall width of the array) for 0° and 45° for square and circular piles (which approximate to octagonal piles) and clearly indicates that the blockage increases with the angle of flow incidence. It is also evident that square piles present much greater blockage at large values of Θ.

Summary

The results indicate that there will be less likelihood of accretion in square arrays of 9 piles (3 x 3) than with those of 25 piles (5 x 5) at a spacing of 6D. They also tend to show that square piles (ie bluff plan-shapes) create greater turbulence than more smoothly-shaped piles and hence less tendency for accretion within the arrays.

4.3 Effect of downflow length of array (N) on siltation potential

The effect of the downflow length (N) of arrays on siltation potential was considered in a series of tests utilising 3 x 3, 5 x 3 and 7 x 3 arrays, all with a spacing of 3D. The results are shown in Figures 10, 11 and 12 and in Table 3.

In general there is little difference between the overall values of SR for different pile types except for the 3x3 array where the square piles appear to create greater erosion potential at higher values of Θ. There is, however, a marked difference in the scour ratios between the array sizes. As an indication of this Table 3 shows the mean value of the scour ratio over 0-45° (SR) for each group size viz 1.85 for 3x3, 1.41 for 5x3 and 1.24 for 7x3 groups.

Examination of the photographs of the tests (not shown here) shows that for all types of pile there is little erosion in the downstream half of the pile array at Θ = 0 due to the blockage effect of the piles and reduction of flow velocity acting on successive piles in the arrays. As Θ increases and the incident flow diverges as it hits the angled piles and spreads through the array more erosion occurs. For the 5x3 and 7x3 arrays results are very similar and when Θ > about 30° the pile arrays are virtually free of siltation for all pile shapes.

Summary

The main finding of these tests was that the siltation potential of 3x3 arrays was smaller than that for 5 x 3 and 7 x 3 arrays.

Square-shaped piles appeared to provide a smaller siltation potential than hexagonal and octagonal piles.

4.4 Effect of transverse width of array (N) on siltation potential

The effect of frontal width of pile groups (N) on siltation potential was assessed in tests with arrays of 3 x 3, 3 x 5 and 3 x 7 piles with a spacing of 3D and constant downflow length of 3 piles. The results are shown in Figures 10, 13 and 14 and in Table 4.

In general there is little difference in scour ratio for hexagonal and octagonal piles with the different pile groups but square piles produce less siltation potential ie higher scour ratios.

Table 4 indicates that the scour ratio decreases with increased frontal width of the group and therefore the siltation potential increases.

In Figures 10 - 14 the scour ratio increases as Θ increases for all types of pile and this trend was confirmed by the photographic evidence which showed that the square piles produced 100% erosion within the pile groups at 0° and remained so with increased values of Θ. This effect was less clear with hexagonal piles and the array did not have 100% scour until $\Theta = 40°$. With octagonal piles clearance did not occur until $\Theta = 45°$.

Summary

The siltation potential of the groups was shown to be least for small groups and for square piles. This finding accords with other tests in this series.

5 Discussion, conclusions and recommendations

The tests carried out in this work utilised the following

a) three bluff-shaped pile types
b) regular pile groupings and spacings (always square)
c) several values of L/B for the jetties
d) one flow speed and depth of flow
e) one pile size
f) varied angles of flow incidence (Θ)
g) one sediment type
h) horizontal bed (of flume)

Although this list may seem fairly comprehensive it does not fully cover the vast range of different conditions that may be experienced in a real estuary where currents are constantly changing in magnitude and direction, water depths vary tidally, piled structures often have different lateral and longitudinal spacings between piles, circular piles are often used, bed bathymetry varies from site to site and bed sediments, and that in suspension in the estuary, also vary considerably.

Notwithstanding the relative simplicity of the present series of tests compared with real conditions, several findings have become apparent and provide guidelines for the design of jetties with the object of minimising deposition within the structure.

Although some preliminary tests were made originally to establish the passage of flows through different pile arrangements using circular piles these experiments were not continued into the sedimentation phase of the work because of scaling problems due to incorrect Reynolds Number values and incorrect drag coefficients when compared with prototype or real values. This is unfortunate as jetties appear to have more circular piles than bluff-shaped piles as used for these tests. In order to obtain high Reynold's Number values for models a wind tunnel would have to be used.

The results of the tests show that for arrays of 3 x 3 piles with a spacing of 3D (regardless of pile-type), there was less likelihood of siltation within the group than with spacings of 6D and 9D. They also showed that, in general, the erosion potential between the piles increased as the angle of incidence (Θ) increased up to about 40°. Arrays of square piles were less prone to siltation than those with multi-sided piles (hexagonal and octagonal) which indicates that circular piles would be much more prone to siltation.

The results of tests with different incident flow angles tend to indicate that pile arrays should not be placed in-line with the dominant flow (Θ = 0°) direction if the major requirement is that siltation should be kept to the minimum. However, sideforces exerted on vessels berthed at the jetties by the diverging flows through the pile groups at higher values of Θ, probably preclude these pile group orientations. Tests carried out by Ball and Hall (Reference 10) showed that the drag coefficient of square groups of circular piles has a minimum at 0°, ie. flow parallel to the array, rising to a maximum at about 12 - 18° with a second peak at about 30 - 40°. They suggested that pile groups should be aligned with the dominant flow direction to keep the Cd low.

For square arrays with a spacing of 6D the results showed that there was less potential for siltation with 3 x 3 arrays than for 5 x 5 arrays. Square-shaped piles had a smaller tendency for siltation than less bluff-shaped piles. For octagonal piles (similar to circular piles) the scour ratio was similar for both sizes of array indicating that there is probably little to choose between the two groups for minimising the siltation potential for most jetties.

Tests indicated that increasing the downflow length of pile groupings increased the siltation potential for the arrays tested. This may be attributed to reduction in free-stream flow velocity as it passes through the longer arrays. Square-shaped piles had the smallest siltation potential of the types tested.

The effect of different frontal widths of array on siltation potential was shown to be relatively small (Section 4.4) for pile groups with a downflow length of 3 rows of piles although the smallest group probably had the lowest siltation potential. Once again square piles showed greater potential for erosion than hexagonal and octagonal piles.

The results have indicated that further research should be carried out to establish

a) the effect of different diameter/size piles (Ball, Ref 11 suggests that designers should contemplate fewer, larger size piles rather than many smaller piles)

b) irregular pile spacings

c) combined effect of sideforces on vessels and siltation - the results obtained here suggest that siltation will be maximised for minimum sideforces

d) effects of sediment-laden flow in reversing and accelerating and decelerating tidal flows. All these tests were made with constant uni-directional flows and experience of real estuaries suggests that siltation/erosion potential may vary with reversing and varying flows especially at angles of incident flow greater than 0°

e) the full size (prototype) effects of siltation with circular and bluff-shaped piles should be assessed by undertaking measurements at a jetty that experiences siltation (and erosion if possible) so that model results may be compared with them.

6 Design guidance

In terms of lowest siltation potential the following points may be made from these results:

a) 3 x 3 pile groups with a spacing of 3D showed less likelihood of siltation than at spacings of 6D or 9D.

b) as the flow divergence angle increases siltation potential falls up to $\Theta°$ = 40°. This indicates that piles groups should not be in line with the dominant flow; however, side forces exerted on vessels at higher values of $\Theta°$ have to be taken into account.

c) in general square piles have a smaller siltation potential than circular piles.

d) for square pile arrays at 6D spacing 3 x 3 pile groups showed a lower siltation potential than 5 x 5 groups.

e) siltation potential increases with increasing downflow length of array - thus small groupings appear best along with square-shaped piles.

f) frontal width of pile arrays appears to have no effect on siltation potential for groups of downflow length of 3 rows of piles.

Overall comments

Square piles are probably the best for minimum siltation around the piles - circular ones are probably the worst.

Small groups of piles are better than large groups.

The effect of reducing siltation as $\Theta°$ increases is offset by greater side-forces on vessels.

Frontal width the group has no effect on siltation potential for small groups of piles.

7 Acknowledgements

The first part of the experimental work was undertaken by Mr A P Addison under the supervision of Mr R Atkins who also analysed all the data. Mr O J Garrett carried out the second part of the experimental work.

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Tables

Table 1 Mean values of scour ratio - 3 x 3 arrays

Spacing	Square	Hexagonal	Octagonal	$\overline{SR}$
3D	2.04	1.76	1.70	1.83
6D	1.18	0.85	0.72	0.92
9D	0.32	0.43	0.21	0.32

Table 2 Mean values of scour ratio - spacing 6D

Group	Square	Hexagonal	Octagonal	$\overline{SR}$
3x3	1.18	0.85	0.72	0.92
5x5	0.68	0.70	0.72	0.70

Table 3 Mean values of scour ratio for 3x3, 5x3 and 7x3 arrays - spacing 3D

Group	Square	Hexagonal	Octagonal	$\overline{SR}$
3x3	2.08	1.76	1.70	1.85
5x3	1.49	1.29	1.44	1.41
7x3	1.32	1.23	1.17	1.24

Table 4 Mean values of scour ratio for 3x3, 3x5 and 3x7 arrays - spacing 3D

Group	Square	Hexagonal	Octagonal	$\overline{SR}$
3x3	2.08	1.76	1.70	1.85
3x5	1.54	1.58	1.80	1.64
3x7	1.62	1.47	1.38	1.49

Figures

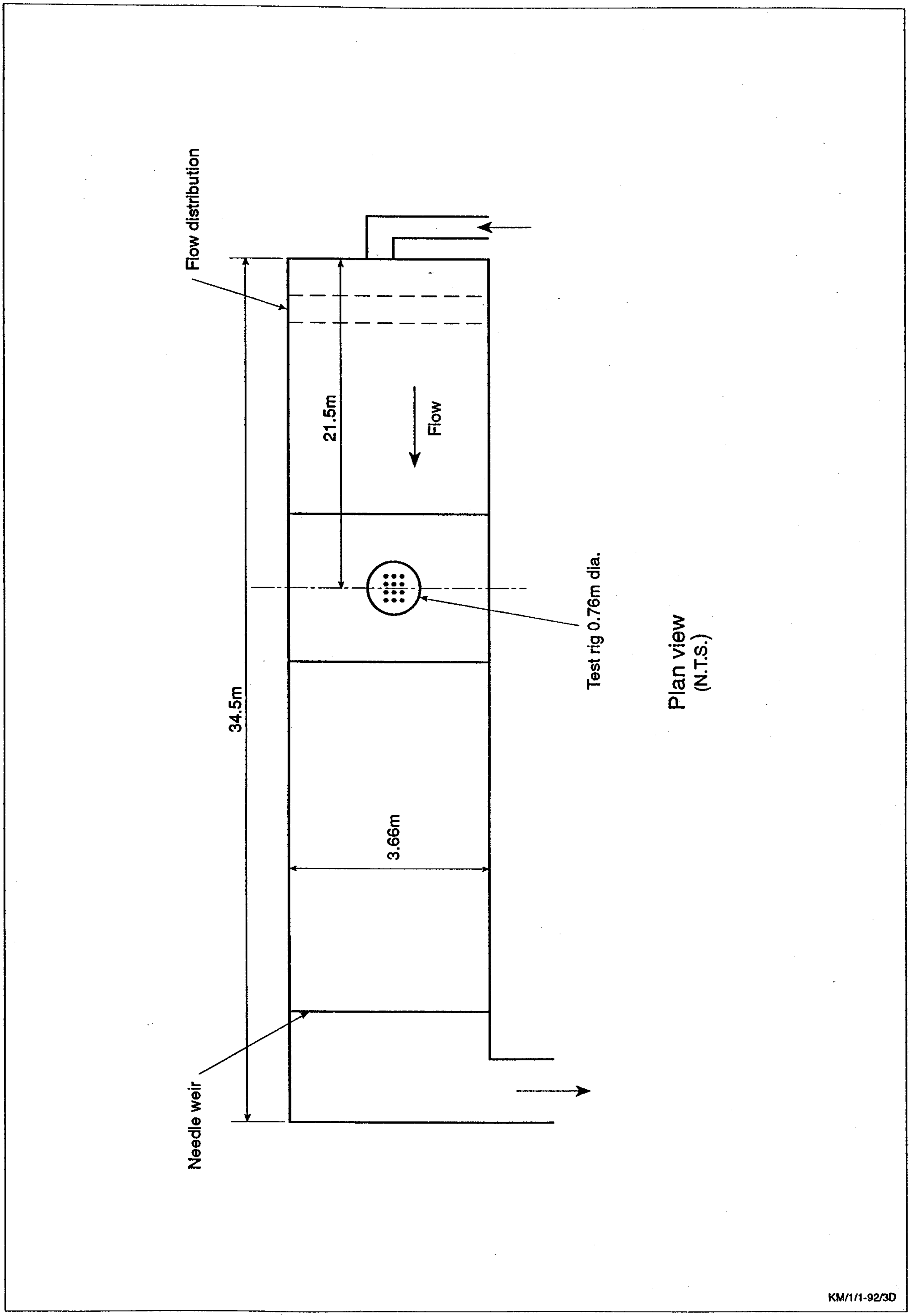

Fig 1   Layout of flume and test rig

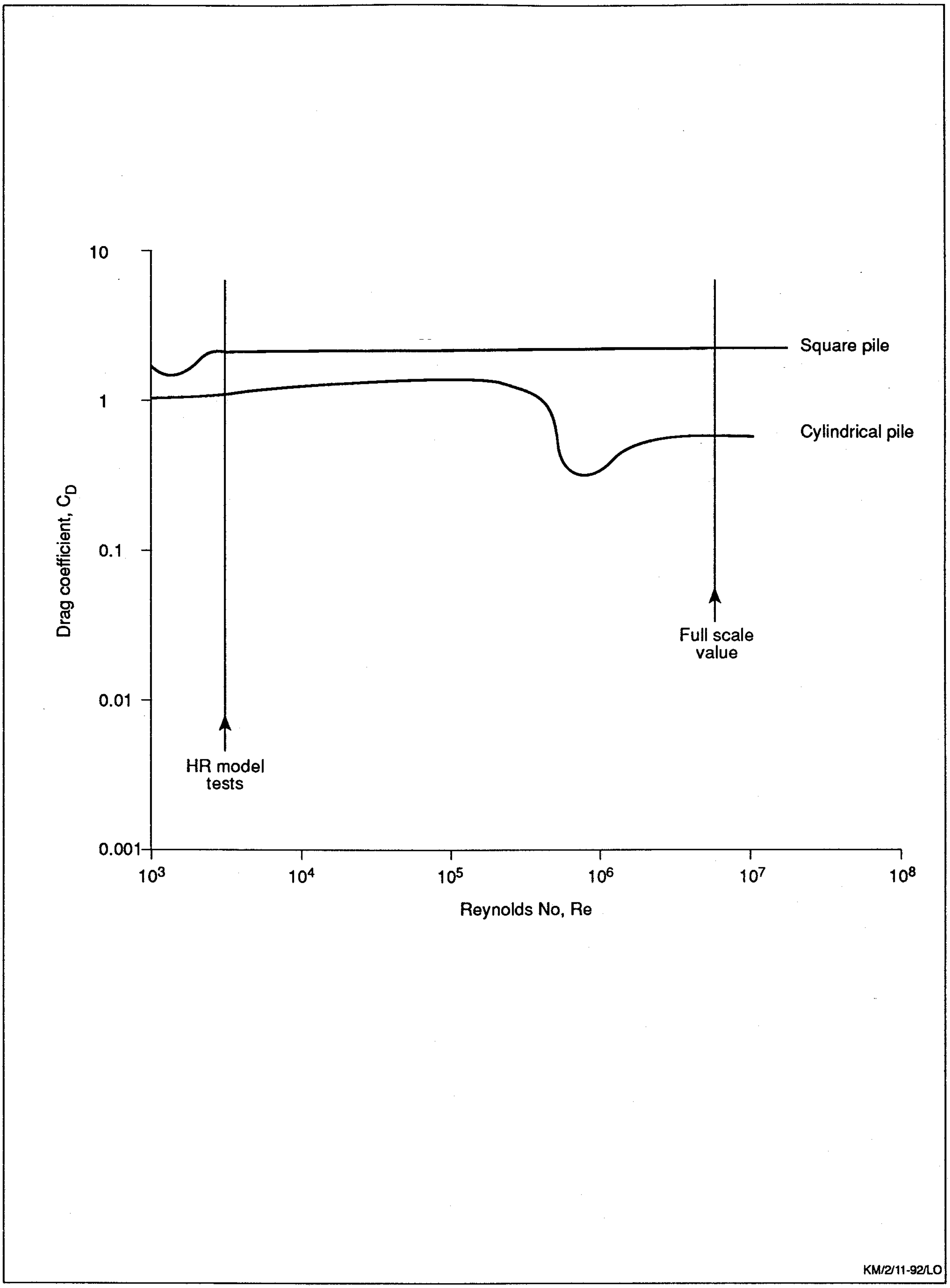

Fig 2 Drag coefficients of model and full scale

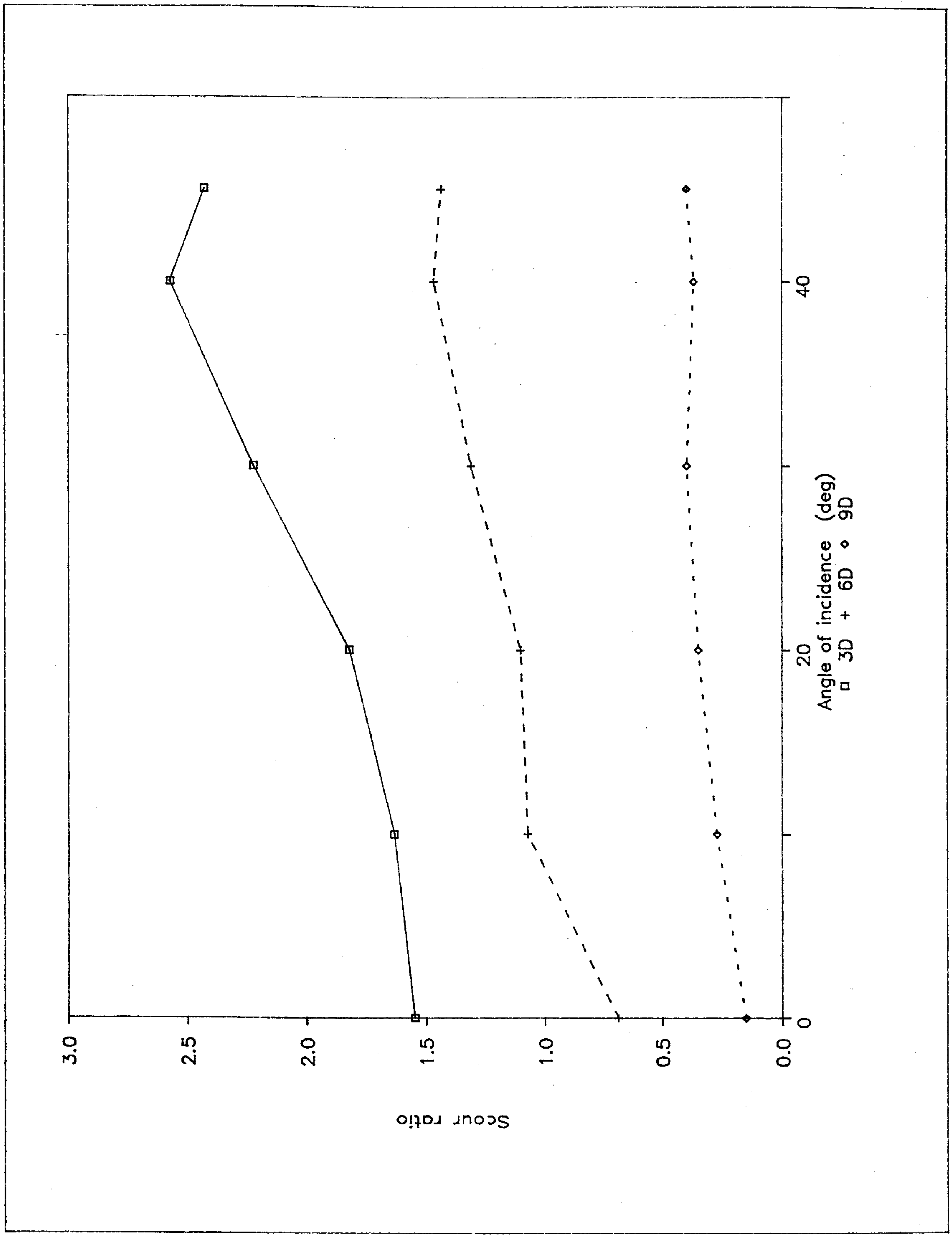

Fig 3 Effect of spacing on 3 x 3 arrays of square piles

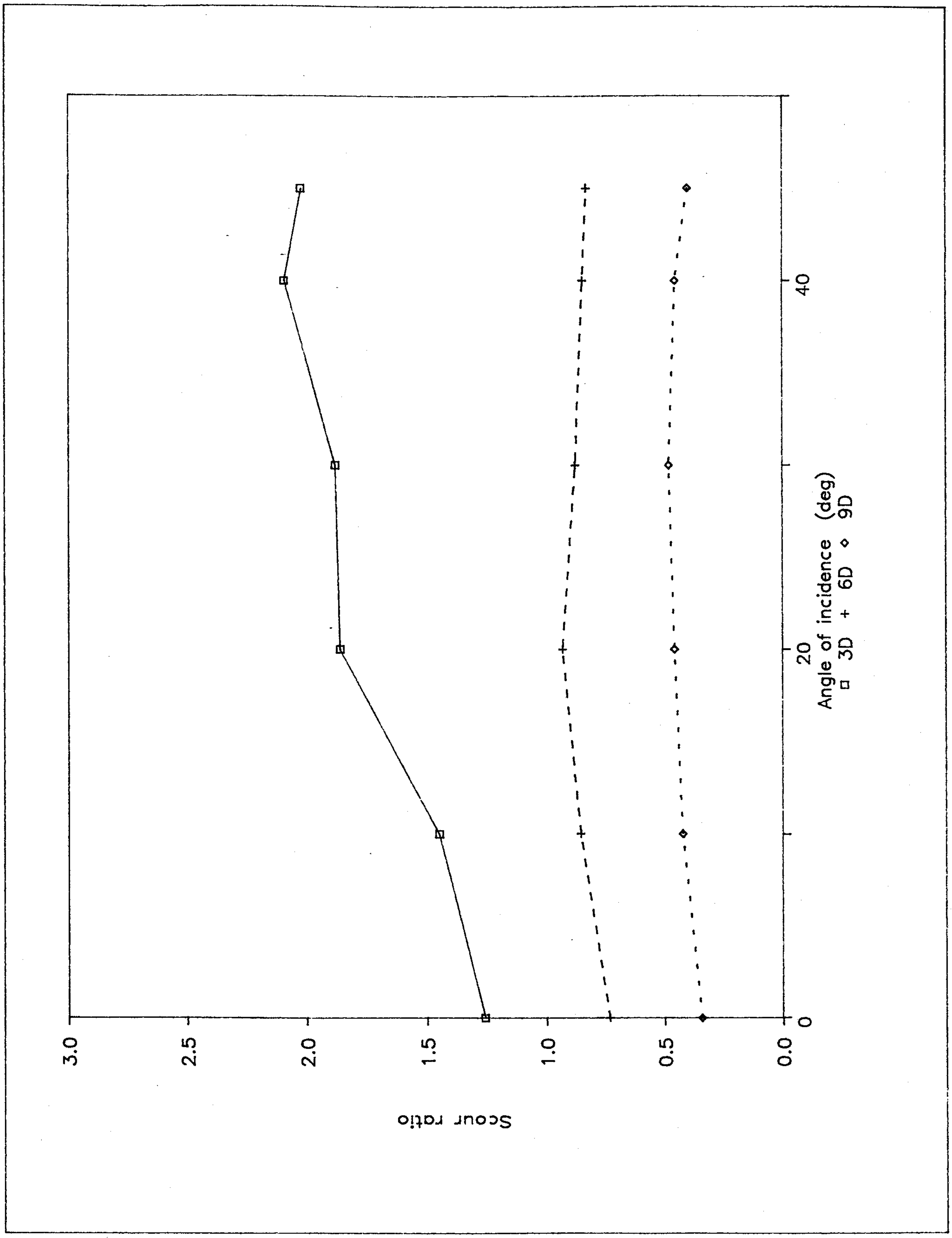

Fig 4 Effect of spacing on 3 x 3 arrays of hexagonal piles

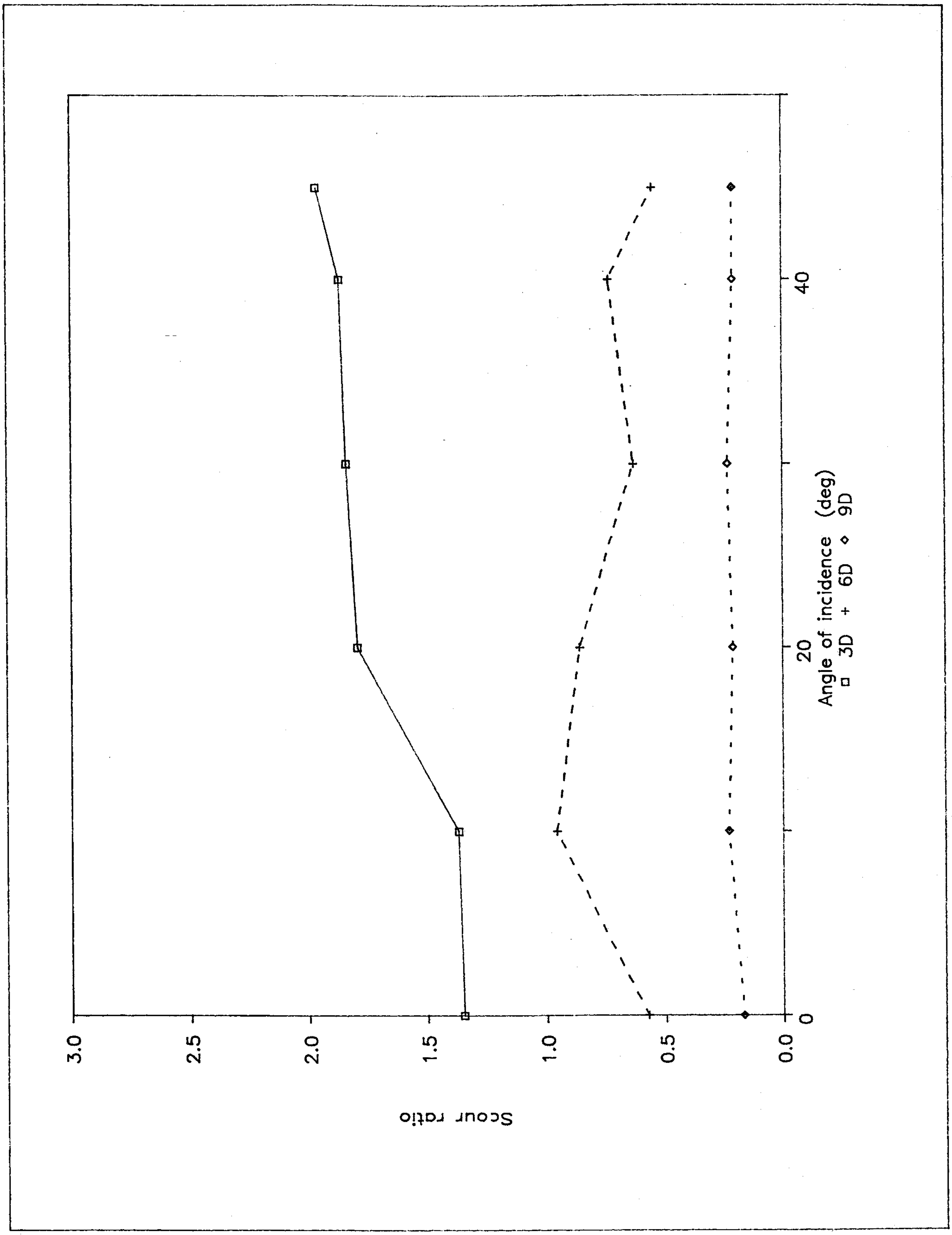

Fig 5 Effect of spacing on 3 x 3 arrays of octagonal piles

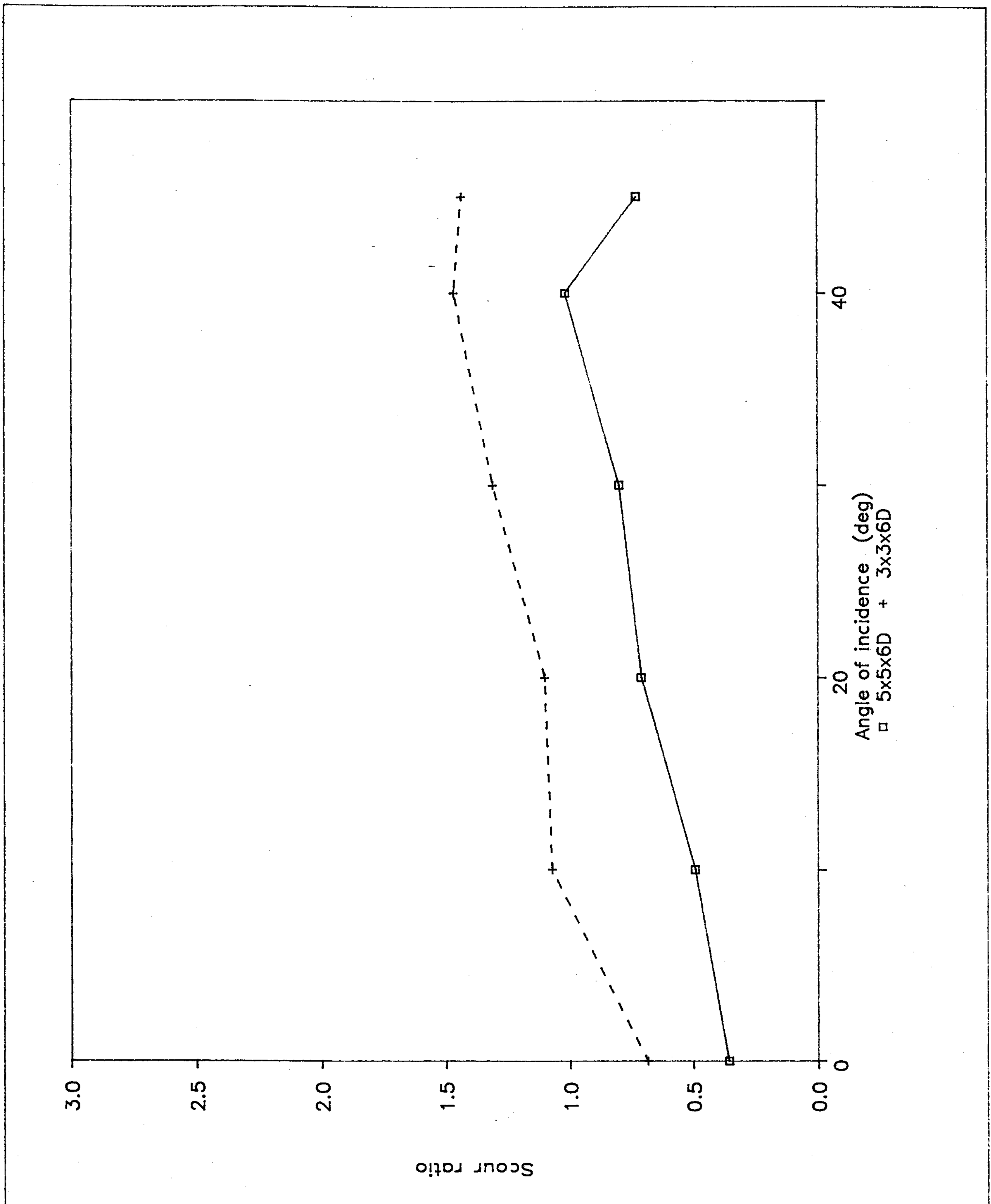

Fig 6 Effect of size of square array.
s = 6D. Square piles

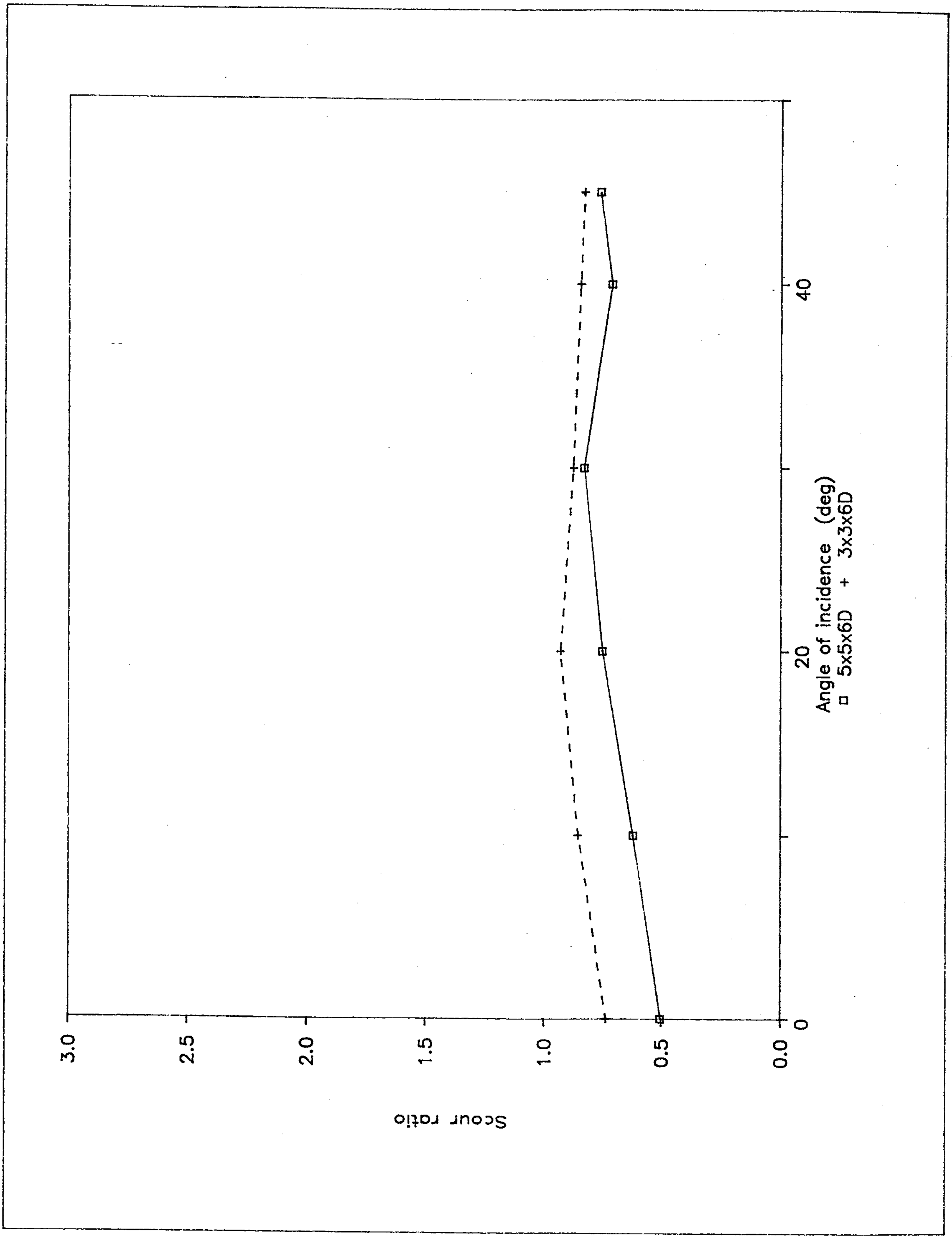

Fig 7 Effect of size of square arrays.
s = 6D. Hexagonal piles

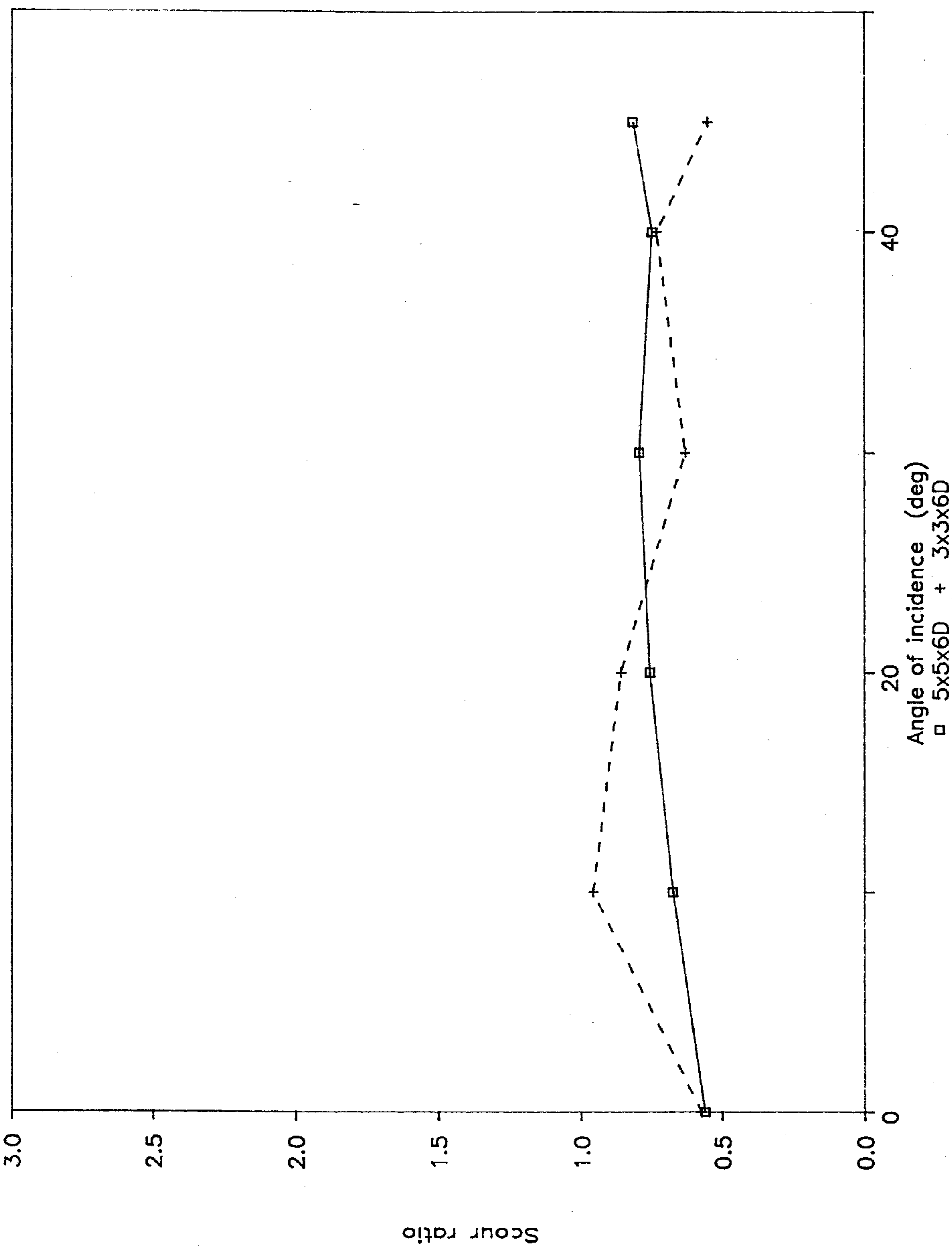

Fig 8 Effect of size of square arrays.
s = 6D. Octagonal piles

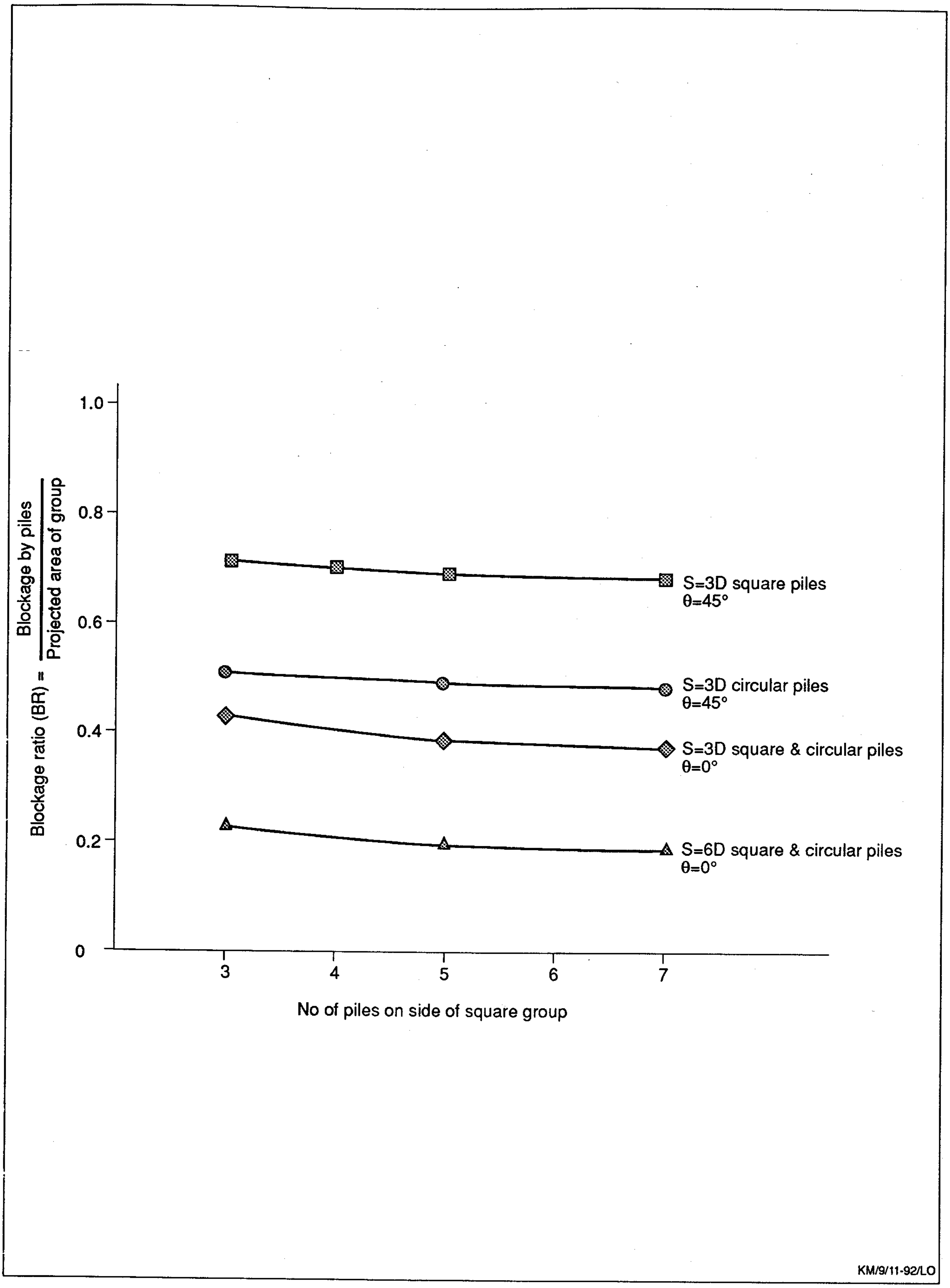

Fig 9 Blockage ratio of square groups of piles

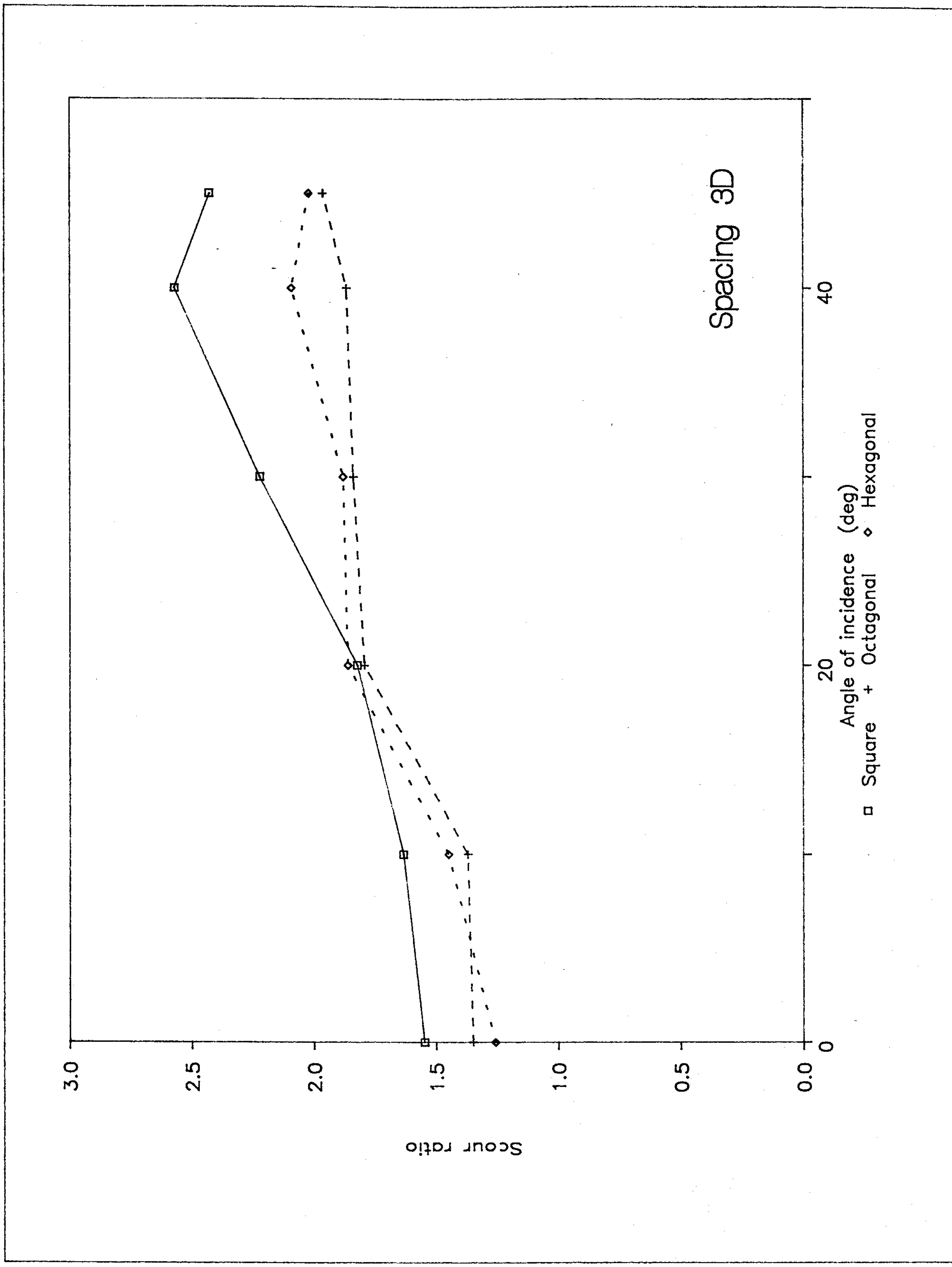

Fig 10 Effect of downflow length of array.
3 x 3 arrays

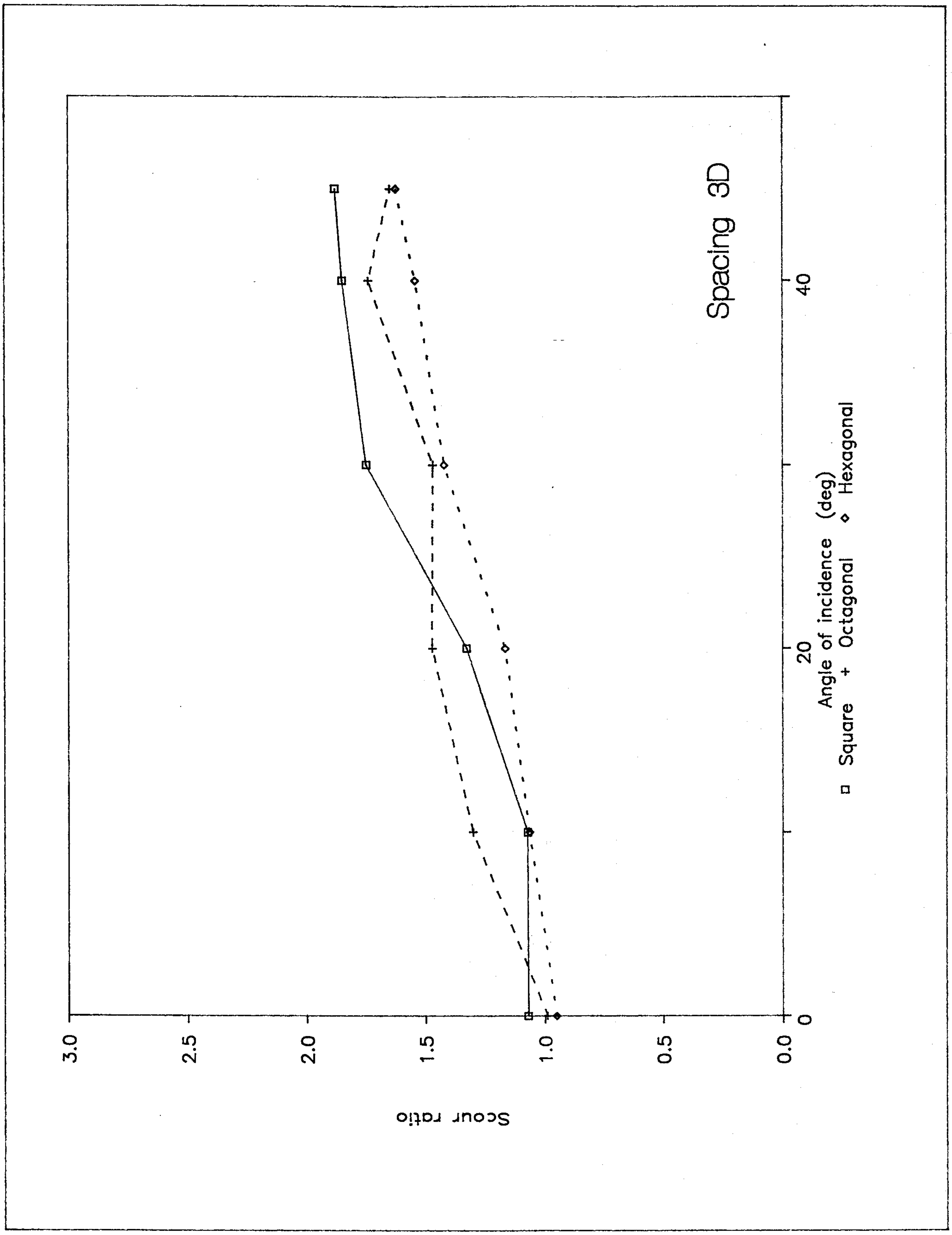

Fig 11 Effect of downflow length of array.
5 x 3 arrays

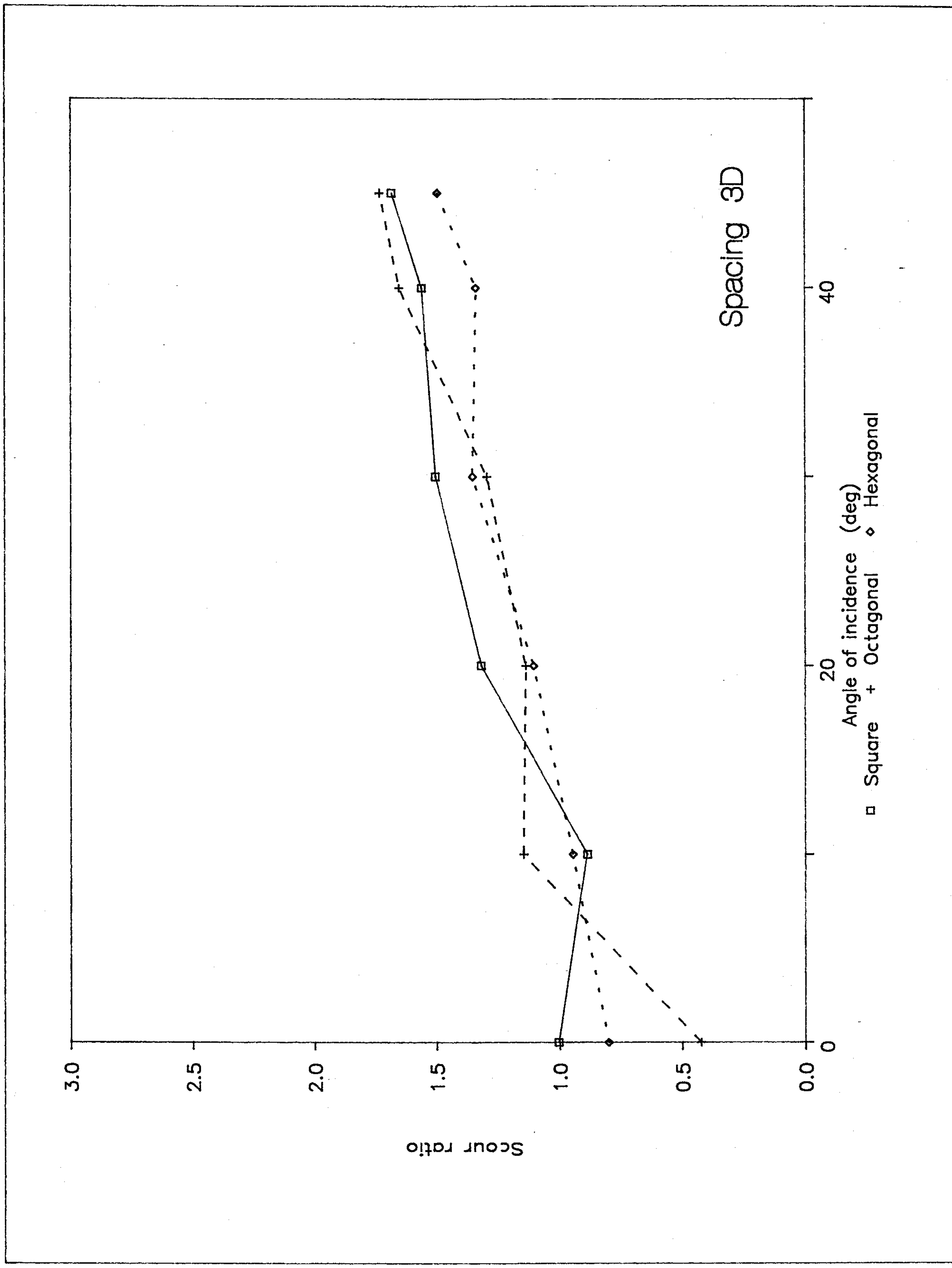

Fig 12 Effect of downflow length of array,
7 x 3 arrays

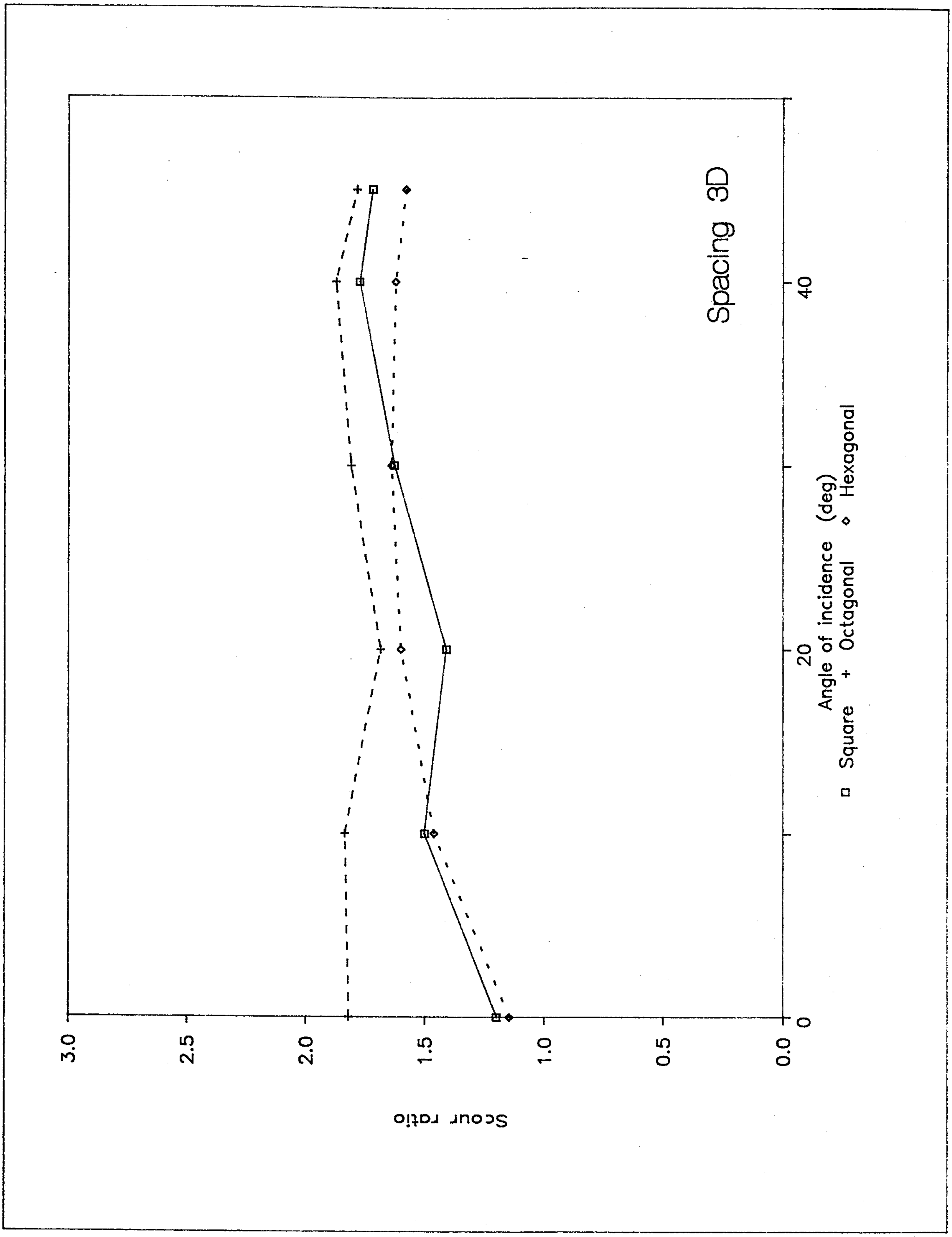

Fig 13 Effect of transverse width of array.
3 x 5 arrays

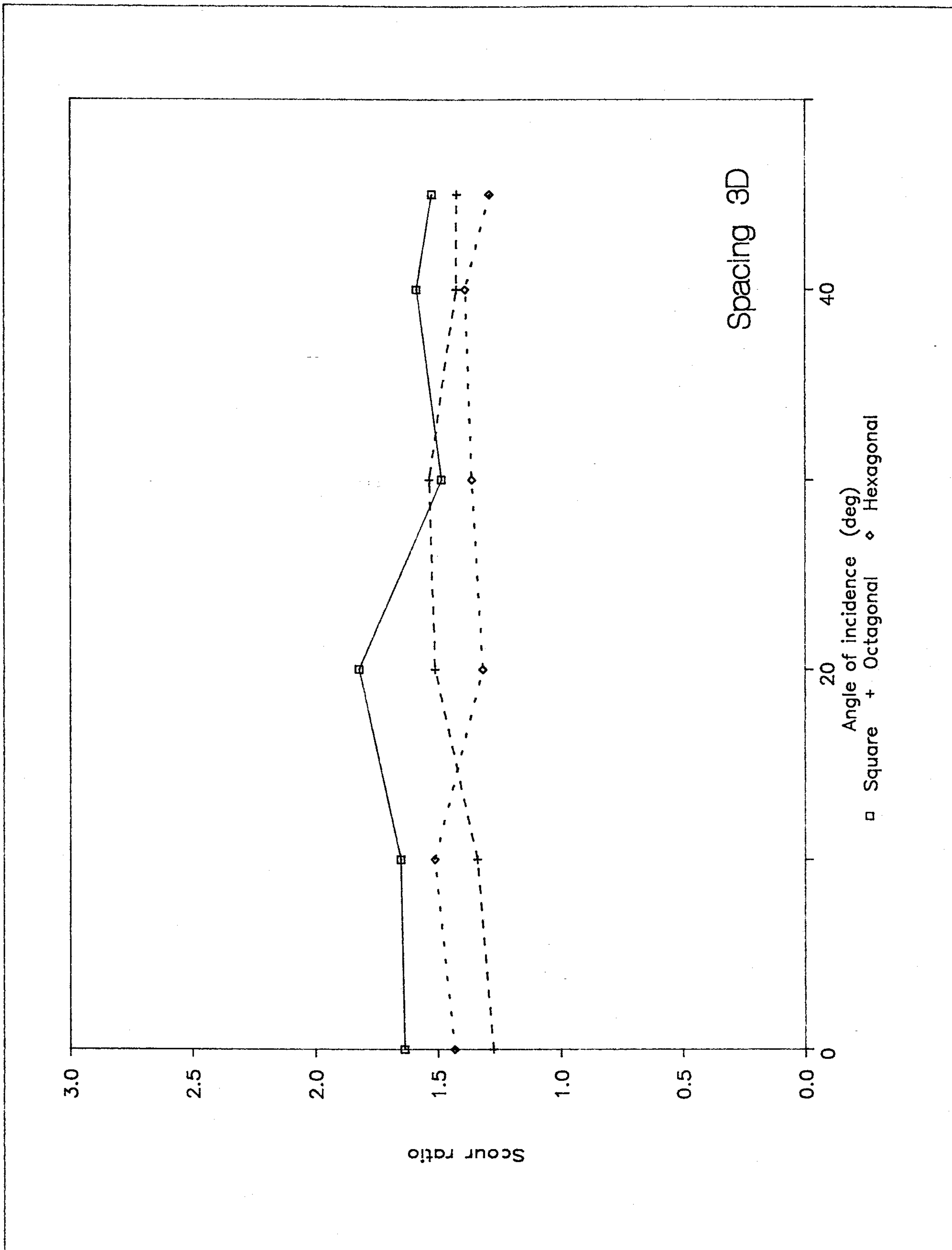

Fig 14 Effect of transverse width of array.
3 x 7 arrays

Plates

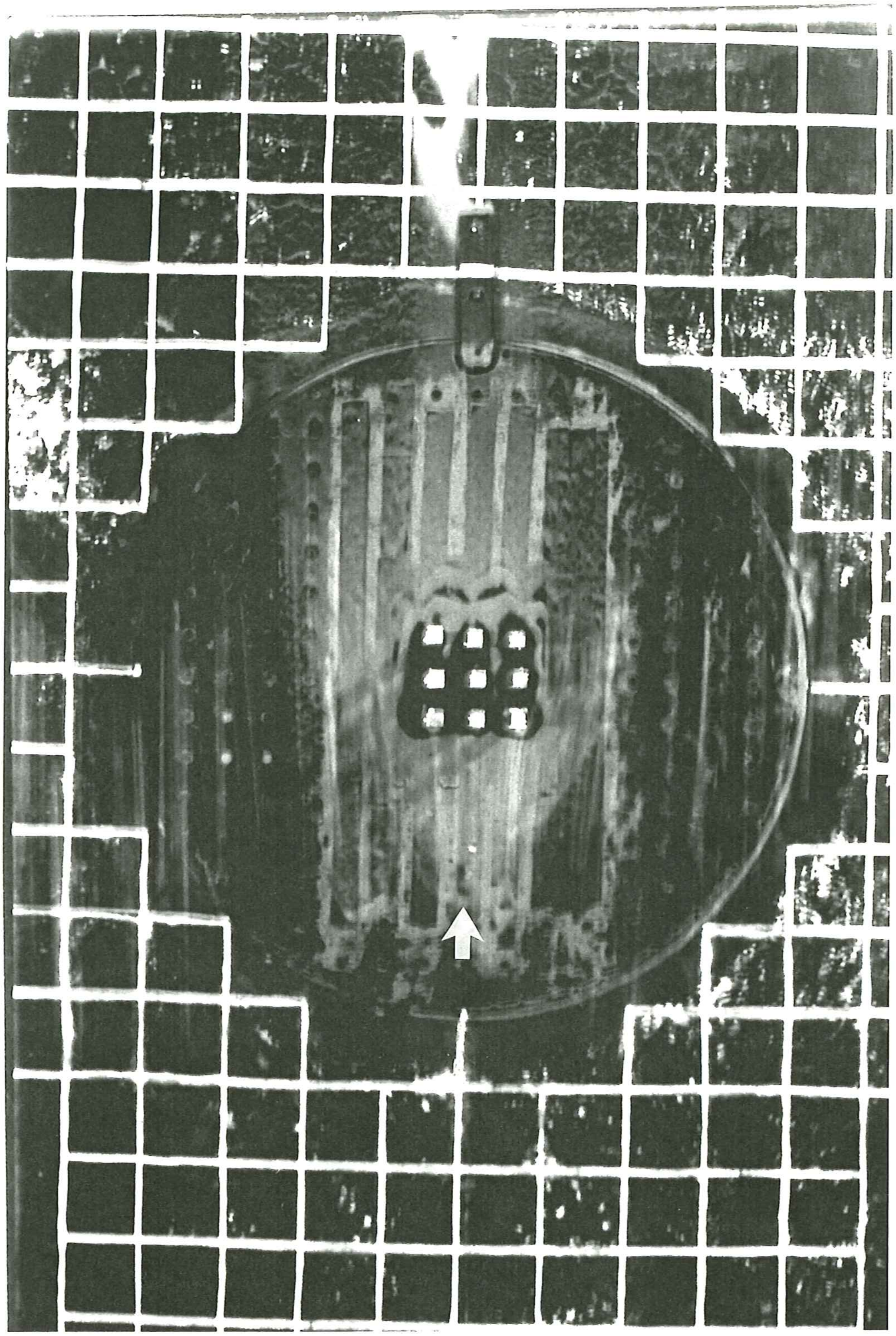

PLATE 1 EROSION PATTERN

3 X 3 X 3D GROUP SQUARE PILES $\Theta = 0^{\circ}$

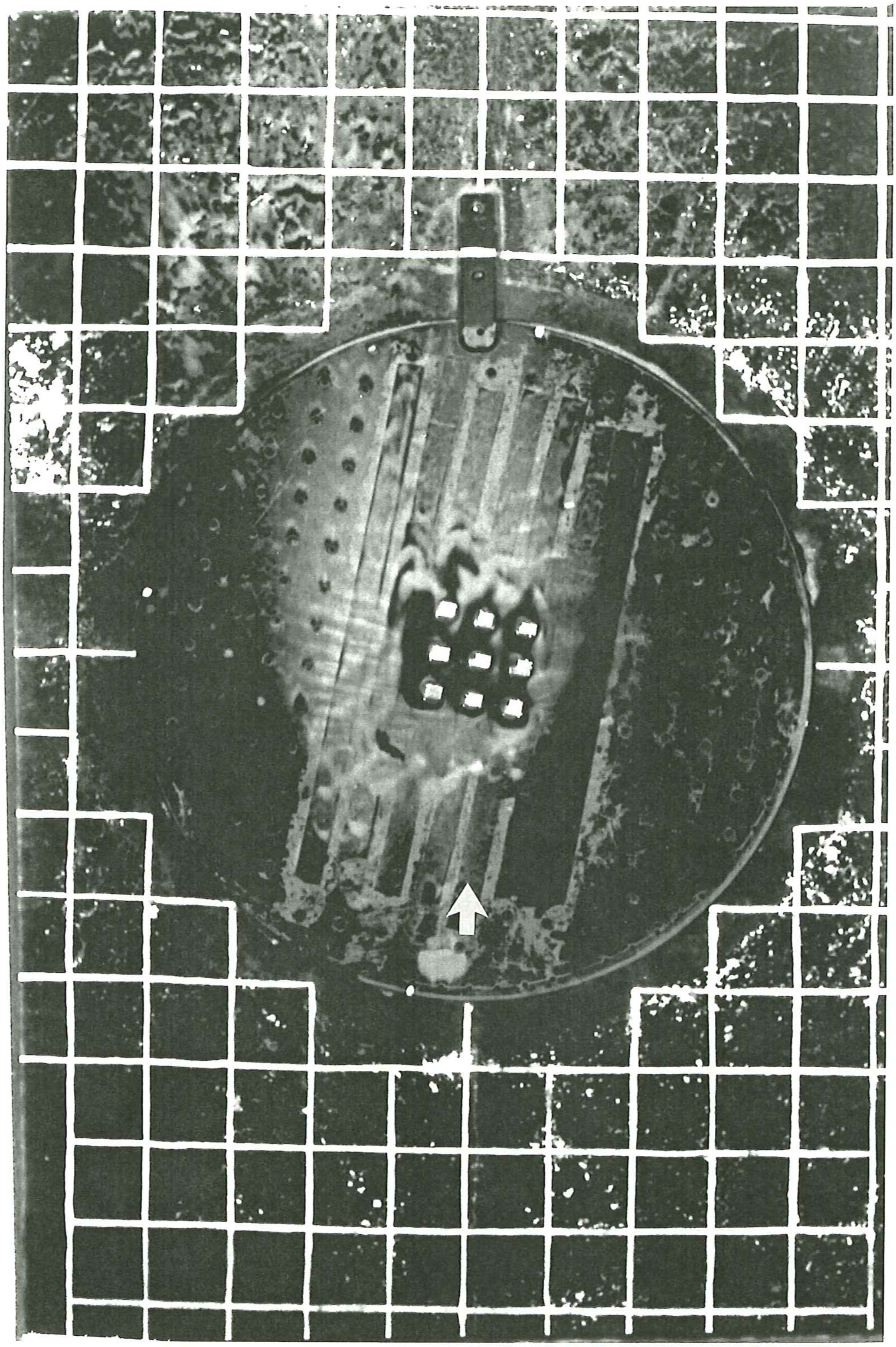

PLATE 2 EROSION PATTERN

3 X 3 X 3D GROUP SQUARE PILES $\Theta = 10^{\circ}$

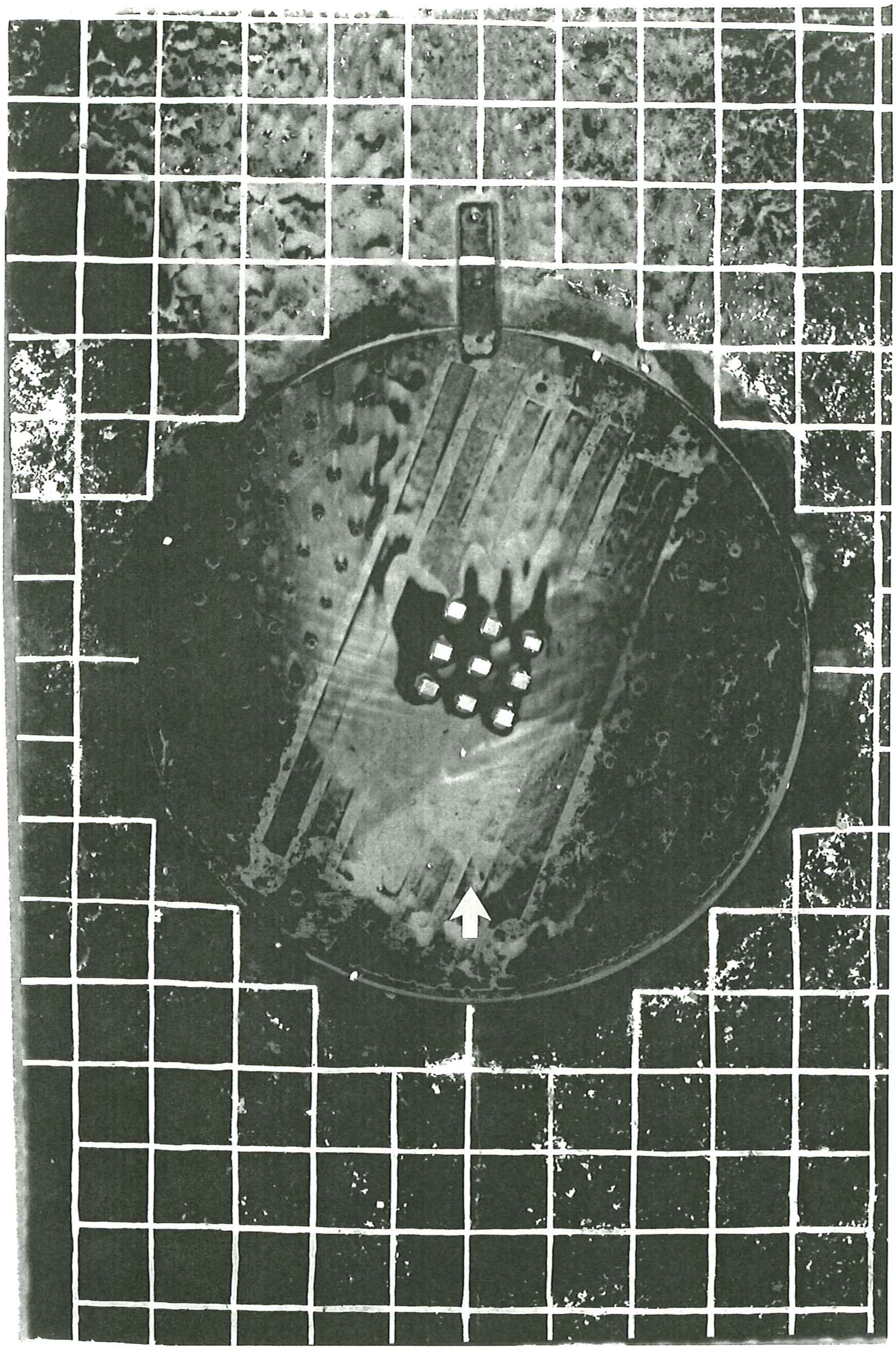

PLATE 3 EROSION PATTERN

3 X 3 X 3D GROUP SQUARE PILES $\Theta = 20^{\circ}$

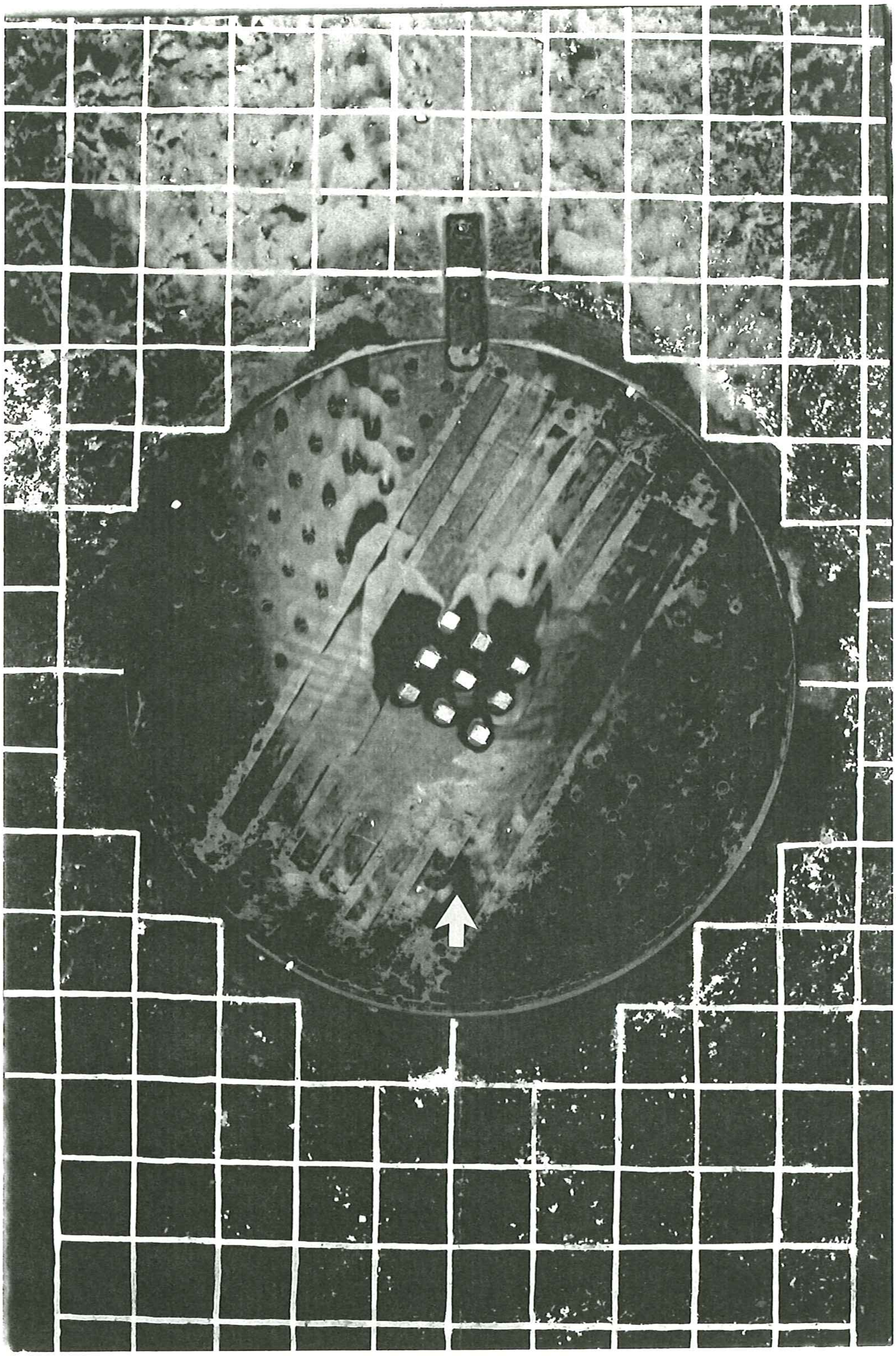

PLATE 4 EROSION PATTERN

3 X 3 X 3D GROUP SQUARE PILES $\Theta = 30^{\circ}$

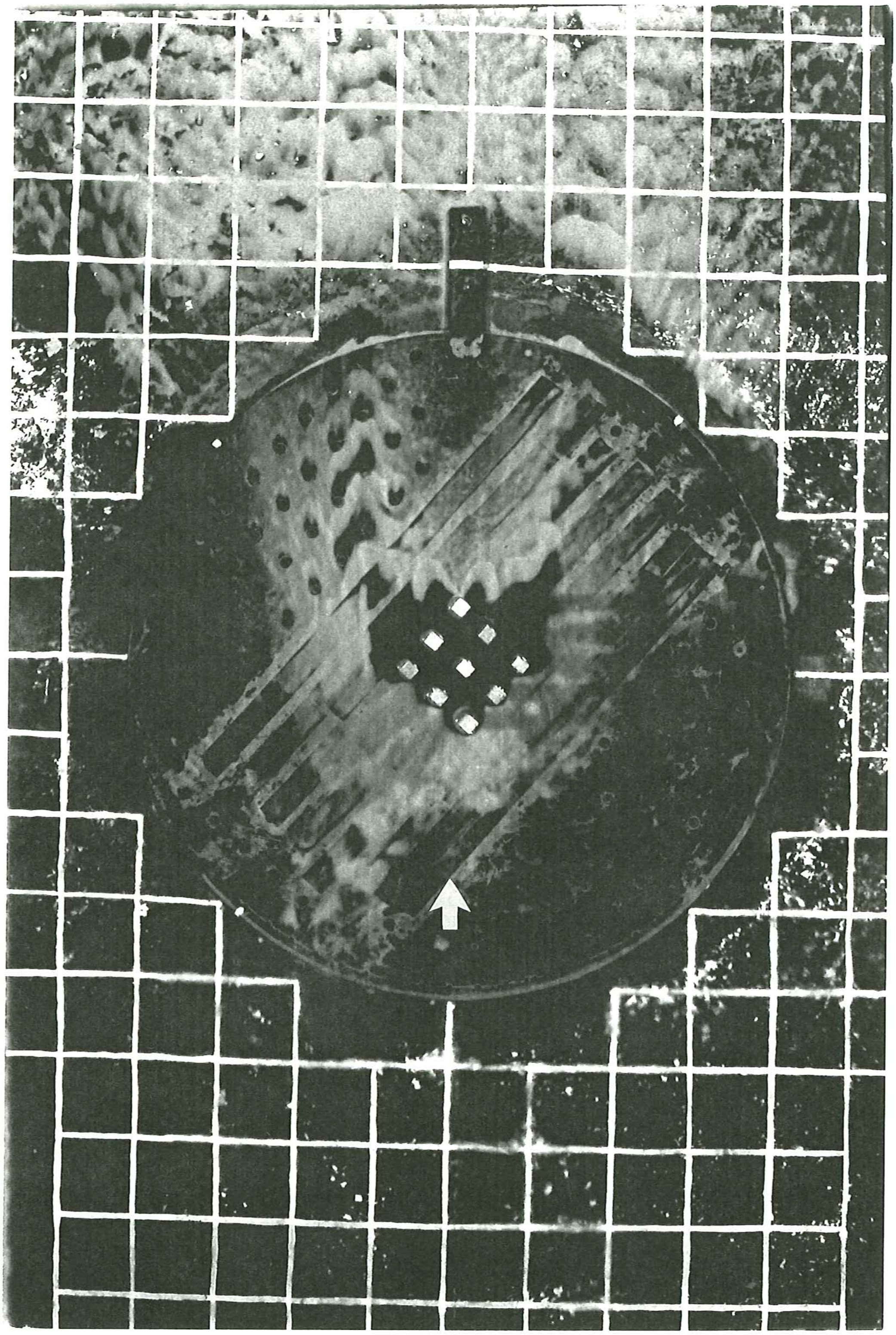

PLATE 5 EROSION PATTERN

3 X 3 X 3D GROUP SQUARE PILES $\Theta = 40^{\circ}$

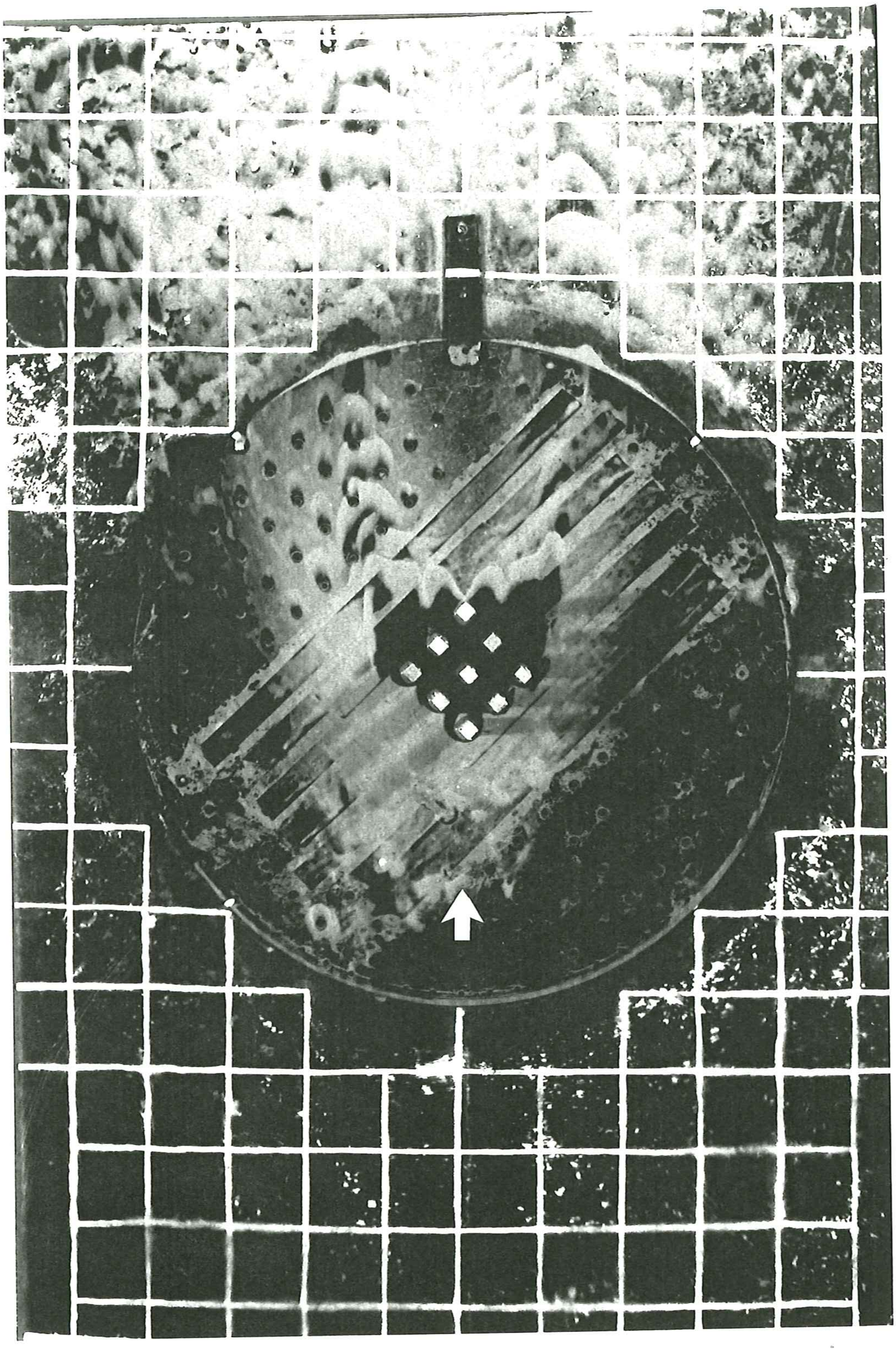

PLATE 6 EROSION PATTERN

3 X 3 X 3D GROUP SQUARE PILES $\Theta = 45^{\circ}$