



Hydraulics Research
Wallingford

LABORATORY INVESTIGATION OF MEASURES
TO REDUCE FLUID MUD SILTATION IN DREDGED
NAVIGATION CHANNELS

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ABSTRACT

This three-year research project has been undertaken to establish the conditions under which fluid mud is created, to develop a general theory describing its motion for incorporation in a mud transport model, to test hypotheses on its formation and transport in dredged navigation channels including the development and field trials of a fluid mud meter, and to explore measures designed to minimise channel siltation attribute to fluid mud.

The present report describes the experiments carried out to investigate means of preventing fluid mud inflow to dredged channels. The other project studies have been reported elsewhere (Refs 1-4).

Mono-frequency waves and a constant tidal current were generated. The behaviour of mud supplied from a continuous source area located up-flow of the channel was monitored before and after the installation of impermeable and permeable low-level training walls.

The results confirmed the findings of the earlier two-dimensional tests in respect of the wave and tidal current conditions under which fluid mud is created and transported. They further demonstrated that an impermeable, partially permeable (up to about 30%), low-level training wall was effective in preventing fluid mud inflow to the channel. When increased foreshore levels resulted in over-topping of the wall, the tests indicated that the sudden discontinuity in bed level destroyed the fluid mud layer, dispersing the sediment into general suspension throughout the water column.

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1 INTRODUCTION

1.1 To provide a better understanding of the movement of fluid mud under the action of waves and tidal currents a 3-year research study was formulated with four main objectives:

- (i) To establish by experiment the range of waves and tidal currents under which near-bed fluid mud suspensions are created and transported.
- (ii) To develop a general theory which describes the motion of a fluid mud layer and to incorporate it in an existing mud transport model.
- (iii) To formulate through laboratory studies engineering solutions to inhibit or prevent fluid mud from depositing in dredged navigation channels.
- (iv) To develop and construct a practical field instrument capable of accurate measurement of the flow of fluid mud layers so as to provide benchmark data for the project.

1.2 Objectives (i), (ii) and (iv) have been reported separately in References 1-4. This report describes the laboratory studies undertaken to meet the third objective.

2 THE TEST FACILITY

2.1 An existing basin incorporating a tidal current generator was equipped with a monochromatic wave maker and then moulded to represent a typical muddy foreshore which was virtually level.

Midway between the wave generator and the coastline a pit, 2m square, was excavated in the foreshore and filled with mud. A short distance down-flow of the pit, a trapezoidal channel with side slopes 1:5, bed width 1m, length 10m, was moulded across the foreshore normal to the wave maker, to represent a dredged channel. A diagrammatic layout of the experimental basin is shown in Fig 1.

- 2.2 The height of the foreshore above the basin floor was designed to ensure that the wave maker paddle had an operational water depth of 500 mm, a working depth across the foreshore of 183 mm and a dredged channel depth of 333 mm.

3 TIDAL CURRENT AND WAVE CALIBRATION TESTS

- 3.1 On completion of construction, the mud pit was temporarily filled with closely-packed bricks to the level of the surrounding foreshore and the basin flooded to its operational water depth. Tidal currents were generated and a series of adjustments made to the louvered flow distributors at the ends of the basin (Fig 1) to ensure a reasonably uniform lateral flow distribution across the foreshore. Throughout the period of adjustment, current strength was measured at three depths in the main area of interest at the locations shown on Fig 2. The checks covered a range of flows and although the flow distribution was observed to vary slightly with current strength, the final louvre adjustments ensured that lateral flow variations remained within $\pm 5\%$ of the mean speed over a wide range of discharges.

- 3.2 The performance of the wave generator was examined and wave heights were calibrated over a wide range of

frequencies and paddle stroke settings on several 5m-long traverses in the area of the mud pit.

4 EXPLORATORY MUD STUDIES

- 4.1 An open-bottom settling chamber was used to aid the settlement and consolidation of a mud slurry in the pit. A small measured sample of the mud/saline water mixture was also poured into a standard settling column and topped up with saline water to a depth of 283mm - the same saline water depth as in the 3-D test facility pit. The water salinity was of typical sea water strength - about 30 g/l. After a period of 24 hours measurements were made of the vertical density distribution in the column using a radioactive transmission probe.
- 4.2 After a period of 24 hours the settling chamber was removed from the basin and waves and currents were generated. The density distribution of the mud bed under test was assumed to be identical to that measured in the settling column test. Results from the settling column confirmed that the relative height-relative density relationship for the mud under examination remained unchanged from the sample used in the 2-D wave flume tests (Fig 4, Ref 3). Fig 3 shows a vertical profile of the bed bulk density after 24 hours of settling and consolidation.
- 4.3 The first exploratory test was run mainly to determine the optimum operating conditions for the development and transport of a near-bed turbid layer. Appropriate conditions were achieved with a wave period of 1.71s and a progressive wave height in the area of the mud pit of 0.0241m, combined with a transverse tidal current of 0.16m/s. From first order linear wave theory, the maximum horizontal orbital velocity

generated by the waves was 0.08 m/s. Thus the peak shear stress acting on the mud surface was a summation of the near-bed velocities - 0.24 m/s - a value similar to that which obtained in the 2-D wave/current flume for the formation of a near-bed turbid layer.

4.4 The test conditions just described represent merely one of several combinations of waves and tidal currents conducive to the formation of a near-bed turbid layer. The various relationships between water depth, wave height and wave period in which near-bed horizontal velocities of 0.08 m/s are created are shown on Fig 4, water depths of between 2 m and 4 m being typical of many muddy foreshores through which navigation approach channels are dredged.

4.5 In a water depth of 2 m, low, locally-generated waves with periods of between 2 s and 4 s would fluidize the mud surface, as would longer-period waves arriving from a more distant disturbance. In 4 m of water the shorter-period waves are tending towards deep-water waves and the height required to form a fluid layer is unreasonably high.

4.6 During these exploratory tests two observations were made.

- (i) Fluid mud transported across the foreshore was destroyed at the leading edge of the dredged approach channel and the sediment load was thrown into suspension. This observation was important because it indicated that only a small interruption to flow was required to destroy the near-bed turbid layer.
- (ii) The period of entrainment and transport of mud from the pit was of limited duration and once the level had been eroded by some 15 mm, the

fluid mud was trapped within the pit area and sediment could only be transported as a fully suspended load.

4.7 The following modifications were therefore made to the basin.

- (i) The dredged channel section was changed from a trapezoidal shape (Fig 1, Section (a)) to a less abrupt transition having no angles (Fig 1 Section (b)).
- (ii) The pit was fitted with a false floor having a mud-tight seal round the edges and a jacking system to allow the floor to be raised in incremental stages so that the mud would remain at, or near the level of the surrounding foreshore.

4.8 Following these modifications, a new mud bed was settled into the pit and then examined under wave and current action with the false floor raised in small increments of 1.5 mm at regular five-minute intervals. This resulted in the formation and near-bed transport of fluid mud from the pit, across the foreshore, and into the dredged channel.

4.9 Although it was desirable to continue the test by regularly replenishing the pit with settled mud, the procedure adopted before the start of the first test was not repeated because it would have resulted in loss of valuable experimental time during the period of settlement and bed consolidation. Instead, trials were carried out in which the pit was successively filled with different thick mud slurries of known density, the experimental basin refilled with water, and testing begun immediately. The mud slurries used had densities of 1.2 t/m^3 , 1.15 t/m^3 and 1.17 t/m^3 , the last slurry behaving under the action of waves and

tidal currents in a manner virtually identical to that observed in the exploratory test with mud which had been settled into the pit from suspension and left to form a bed (mean density, 1.16 t/m^3). It was the last slurry tested (density 1.17 t/m^3) that was therefore used in all subsequent tests.

5 MAIN MUD STUDIES

5.1 Following the procedure outlined above, the first of the main tests was carried out. During each run, water samples were taken at half hourly intervals from three verticals on the foreshore (upstream of the mud sample, upstream of the channel and downstream of the channel) and another in mid-channel. At the end of the run, when the top of the false floor of the pit was within a few millimetres of the surrounding foreshore level, the basin was carefully drained and the saline water stored in an adjacent sump for re-use. Overhead photographs were taken of the mud distribution on the foreshore and in the dredged channel and note was made of the mud thickness at known points on a grid.

5.2 The false floor was lowered, the mud pit refilled with mud slurry, and the water slowly returned to the basin for a second run, repeating the observations and sampling carried out during and at the end of the first run. This procedure was repeated for a third run.

5.3 Test 1 - unobstructed foreshore. Plate 1 (a), (b), (c) shows the distribution of the mud on the foreshore and in the channel at the end of the first second and third runs respectively. Tidal currents are generated along the shore (from top to bottom on the

photographs) while waves are generated offshore and travel onshore (from right to left).

5.4 The progressive build-up of mud on the up-flow side slope and in the bottom of the channel is clearly visible, the spread over the foreshore having a component in the direction of tidal flow and an offshore component against the direction of wave travel.

5.5 Test 2 - impermeable training wall. An impermeable, low-level, vertical training wall 38 mm high was installed across the foreshore on the up-flow side of the dredged channel to create an obstruction in the lower layers of flow. For the conditions under test, the works represented a wall height-to-water depth ratio of about 0.2.

5.6 The mud distributions at the end of three runs are shown on Plate 2(a), (b) and (c). At the end of the first run (Plate 2 (a)), the distribution on most of the foreshore is quite similar to the corresponding stage of the previous test (Plate 1 (a)). The main differences are confined to the zone immediately up-flow of the training works where the obstruction created by the wall prevented the fluid mud from flowing into the dredged channel and resulted instead in a seaward extension of the deposit. The plate shows no evidence of mud deposition in the channel at this stage.

5.7 Photographs (b) and (c) (Plate 2), taken at the end of the second and third runs respectively also show no channel deposition. However, although the seaward extension of the deposit up-flow of the wall is intensified, comparison with Plate 1 (b) and (c), reveals that mud is now spreading landwards also.

5.8

By the end of the third run, the mud bed at the training wall, down-flow and seaward of the pit, had built up to within a few millimetres of the wall crest (Plate 2 (c)). The turbidity of the water during the third run prevented accurate observations of the mud behaviour but at this point it is believed that the near-bed layer approaching the wall was thrown into suspension by local increases in turbulence near the wall crest and further down-flow.

5.9

To investigate the performance of the training wall once the foreshore had reached wall crest level, a fourth run was carried out. At the end of the run, the plan distribution of the mud over the foreshore was similar to that at the end of the third run (Plate 2 (c)) but the depth of deposition had increased. Material had over-topped the wall along a 1 m - long frontage but there was still no evidence of deposition in the dredged channel. As expected, following the observation made during the exploratory tests (Section 4.6), the increased turbulence down-flow of the wall was sufficient to break up the near-bed layer and entrain it in the surrounding flow.

5.10

Test 3 - permeable training wall. For this test, the low-level wall was removed and replaced with a permeable screen of similar dimensions having a uniform distribution of voids yielding an overall permeability of 37.5%.

5.11

The mud distributions at the end of each of three runs are shown on Plate 3 (a), (b) and (c). During the second and third runs, (b) and (c), the mud bed thickness just seaward of the pit increased sufficiently for the overburden pressure to force the mud through the voids, but there was no significant deposition of material on the channel side slope and nothing on the bed of the channel.

5.12

A comparison of Plates 2 and 3 suggests that a low-level wall with some degree of permeability would be virtually as effective as an impermeable wall in preventing the near-bed transport of fluid mud into a dredged channel.

6 SUSPENDED SEDIMENT

6.1

Throughout the series of studies there was a progressive build-up in the amount of sediment in suspension. Depth-averaged concentrations up-flow of the mud pit and down-flow of the dredged channel are shown on Fig 5. The area between the up-flow and down-flow concentration curves divided by the run duration provides a mean value of turbidity increase for the run. For the three tests, the following mean values were obtained:

<u>Test</u>	<u>Average increase in</u> <u>depth-mean concentration</u> (m/gl)
1. No works	14.8
2. Impermeable wall	26.2 (34.8 during 4th run)
3. Permeable wall	18.9

6.2

The movement of sediment from the near-bed layer to the general body of water above therefore appears to increase with: (a) an increase in obstruction to near-bed flow, and (b) an increase in the quantity of sediment overtopping the wall.

7 DISCUSSION OF RESULTS

7.1

Although the mud thickness at the end of each run was measured on a grid, little use could be made of the data because it proved to be impossible to obtain

enough samples for laboratory determination of bed density. Sampling damaged the bed too severely and so this operation had to be restricted to the end of each test. When plotted, the results demonstrated a random distribution of dry weight densities in the range $350 \text{ kg/m}^3 - 450 \text{ kg/m}^3$. It was therefore not possible to prepare a realistic estimate of sediment weight on any part of the foreshore.

7.2

No completely satisfactory explanation has been found for the marked offshore component in the direction of movement of the near-bed turbid layer, i.e. opposite to that of the approaching waves. Dyed water injected into the study area demonstrated that under the combined action of waves and tidal currents, residual flow took a course perpendicular to the dredge channel, i.e. it moved in the direction of the tidal current. Granular material placed on the bed just downstream of the mud pit was also transported in the direction of the tidal current. However, since the entire series of tests produced remarkably consistent results, the mud distribution must be regarded as genuine.

7.3

One possible cause of the offshore spread might have been a turbidity current generated by variations in bed density, although it is difficult to explain the repeatability of movement of the mud centroid given such a random density distribution of the mud bed. Another possibility might have been the influence of gravity had there been any gradient between foreshore and wave maker, but the foreshore in the study area was in fact level. The behaviour of both the dye and the granular material suggest that the correct explanation will not be discovered through an examination of the water movements alone, but will be found only after further investigation of the properties of the mud itself.

8 CONCLUSIONS & RECOMMENDATIONS

1. The experiments in the wave basin confirmed the results of the earlier two-dimensional tests that under the combined action of waves and tidal currents a fluid mud layer can be created and transported near the bed with little vertical mixing.
2. Sudden discontinuities in foreshore level which affect the boundary layer initiate flow separation and disperse the near-bed layer into general suspension.
3. A low-level, impermeable training wall can prevent the inflow of fluid mud to a dredged channel: if foreshore accretion reaches wall crest level, the near-bed layer is destroyed and sediment is entrained to be transported as fully suspended load.
4. A low-level training wall having a permeability of up to about 30% could provide a high degree of protection to a dredged channel from the inflow of fluid mud.
5. In order to increase confidence in extrapolating these small-scale laboratory studies to full scale, further site measurements should be carried out to provide more information on the thickness of near-bed turbid layers encountered in the field.
6. The laboratory studies should be extended to establish the optimum combination of wall height/water depth ratio and wall permeability to minimise cost whilst maintaining adequate channel protection from fluid mud siltation.

9 REFERENCES

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2. H R Report No SR 129. Measurement of fluid mud layers - field instrument developments. March 1987.
3. H R Report No SR 88. Laboratory experiments on a near-bed turbid layer. June 1987.
4. H R Report No SR 84. An analysis of the behaviour of fluid mud in estuaries. March 1986.

FIGURES

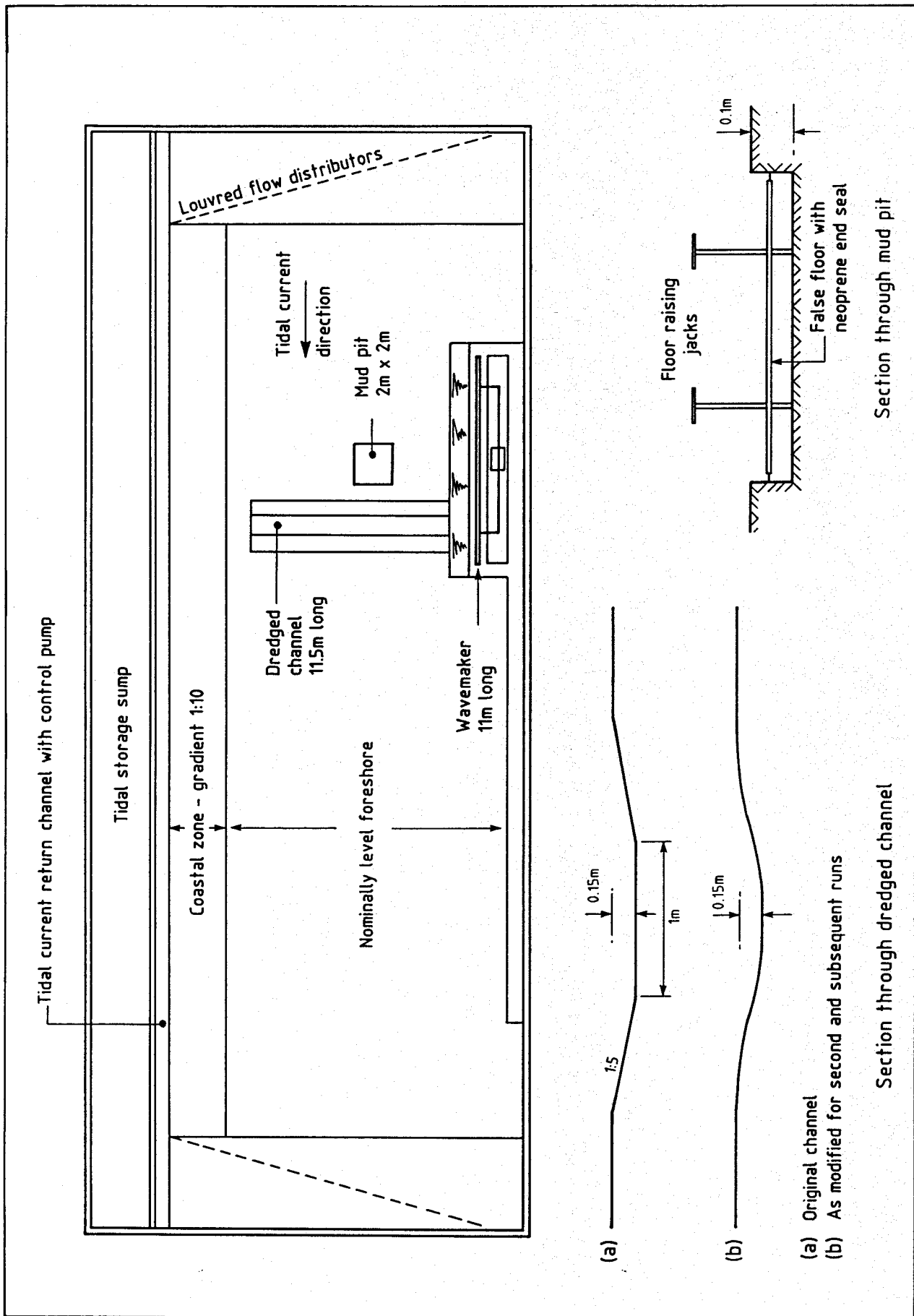


Fig 1 Layout of experimental basin

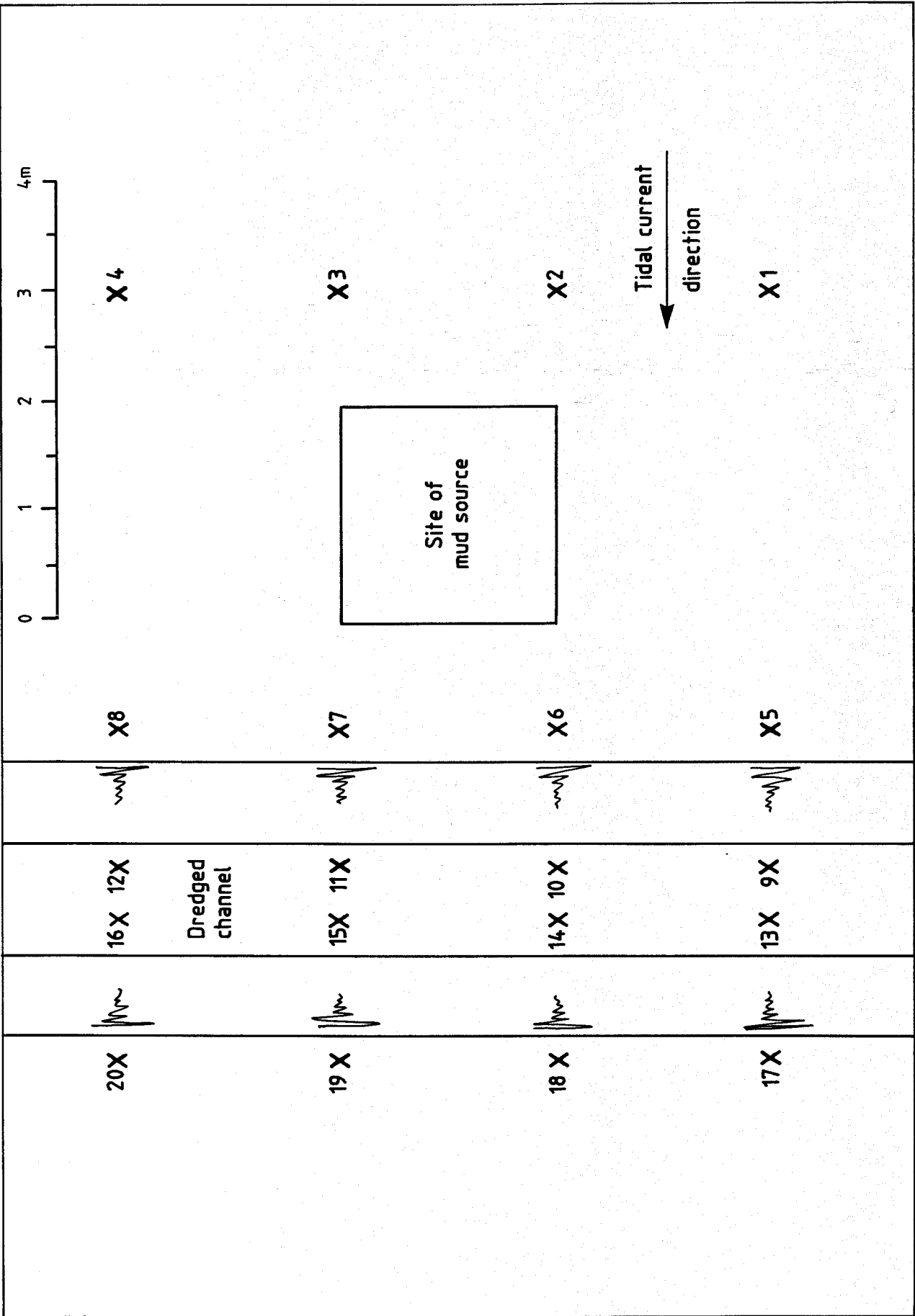


Fig 2 Current meter positions

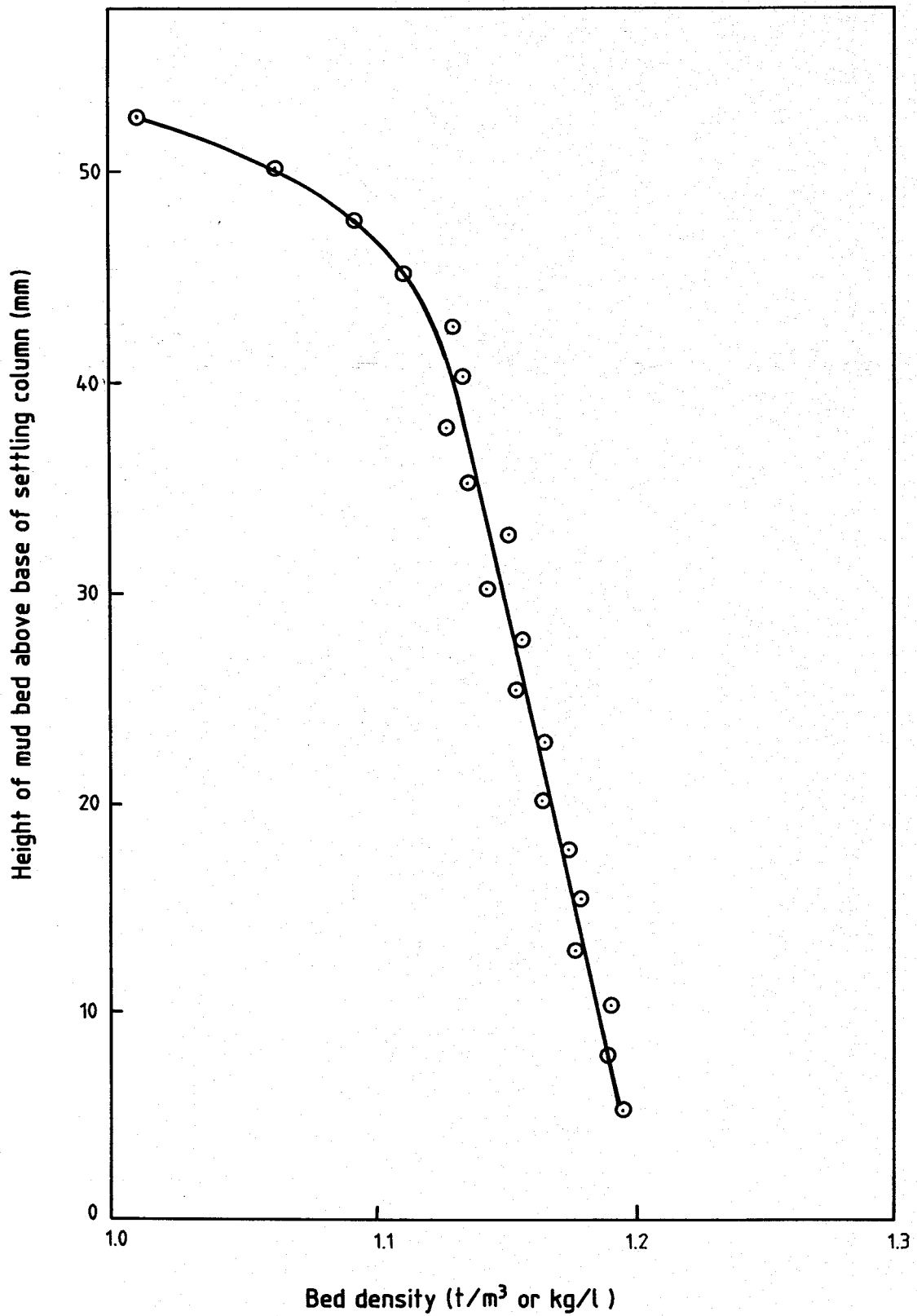


Fig 3 Bulk density of settled mud after 24 hours

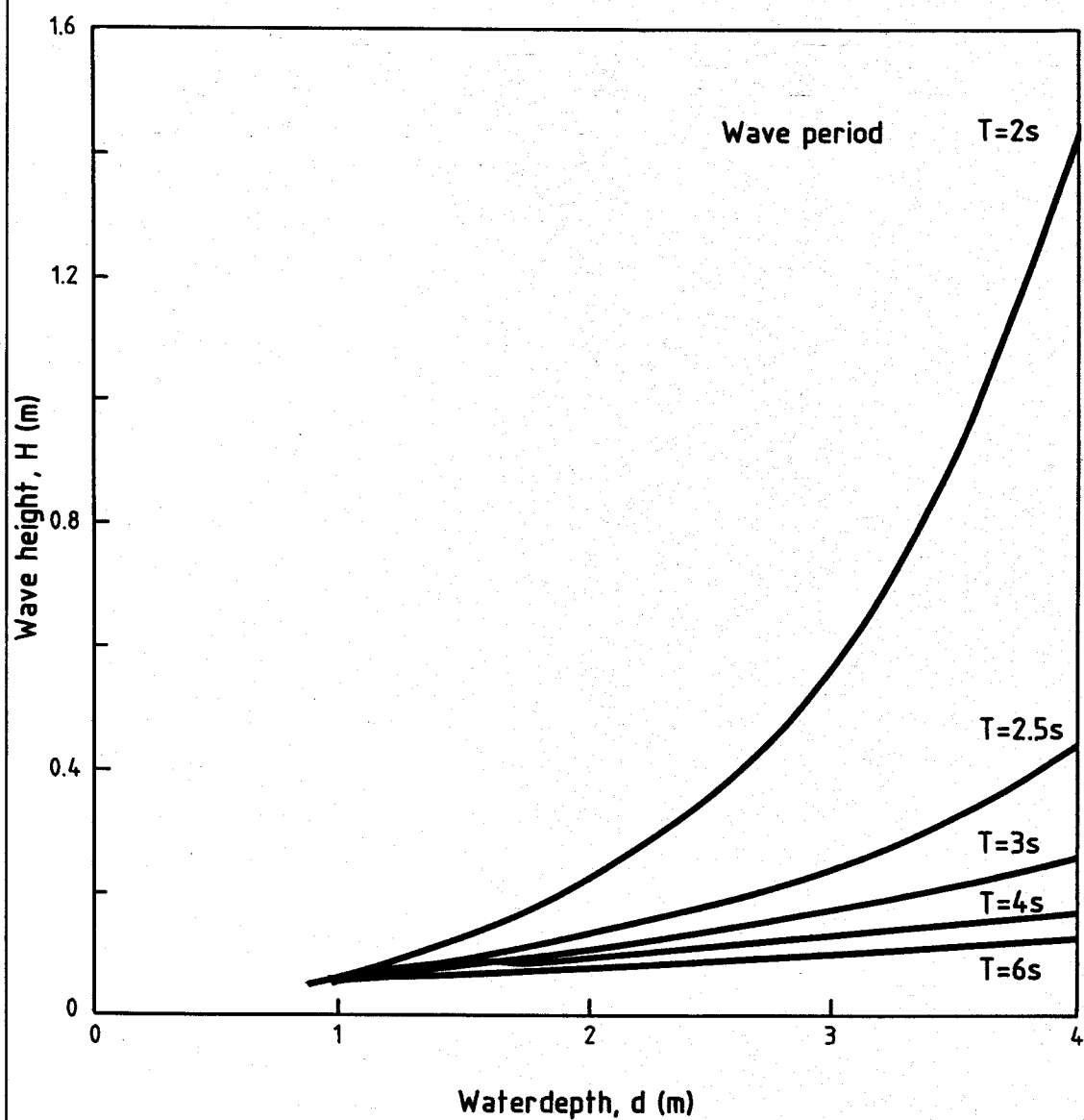


Fig 4 Relationship between wave height, wave period and water depth for creation of near-bed horizontal velocity of 0.08m/s

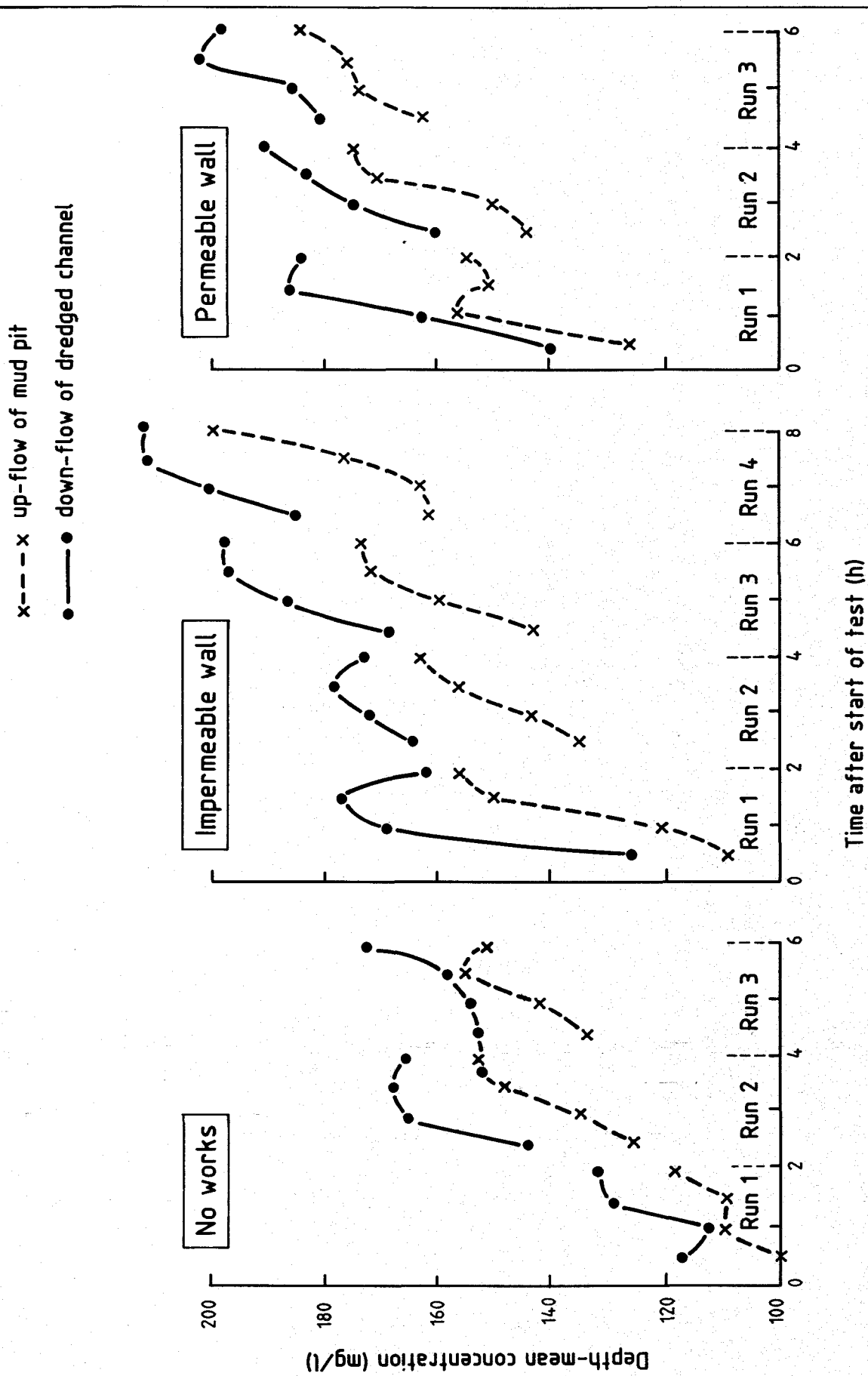
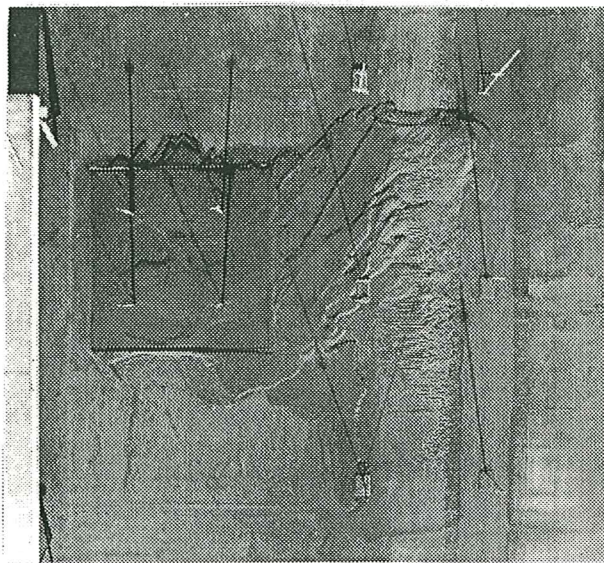
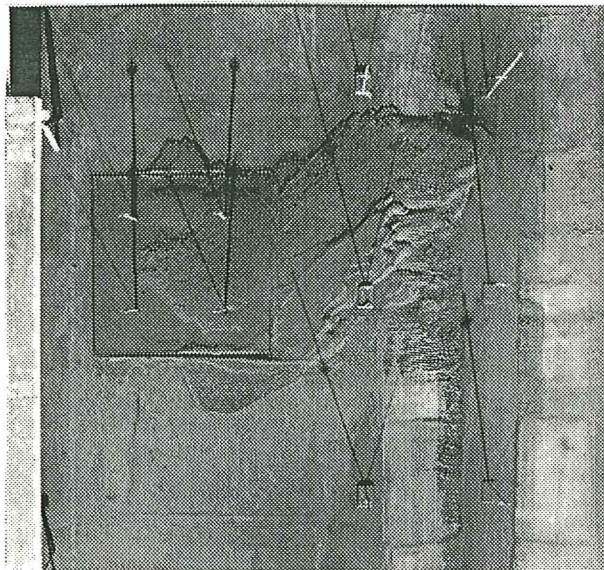


Fig 5 Change in suspended sediment concentration across test area

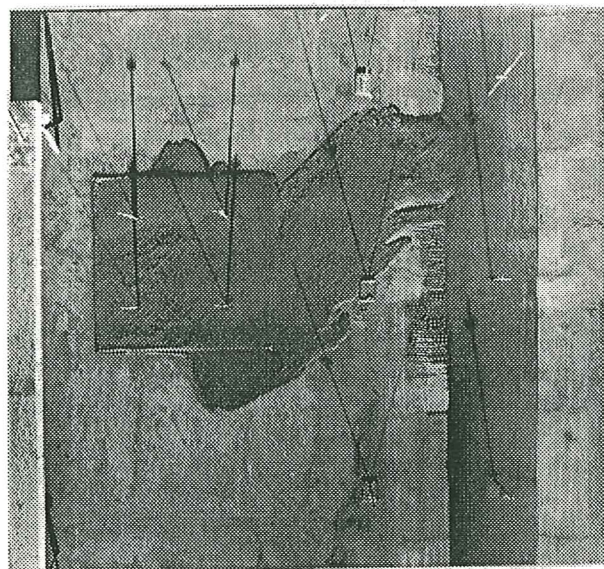
PLATES



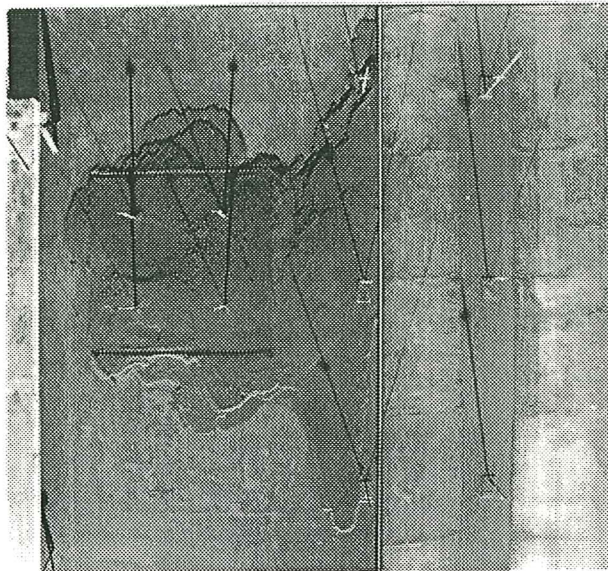
(c) Run 3



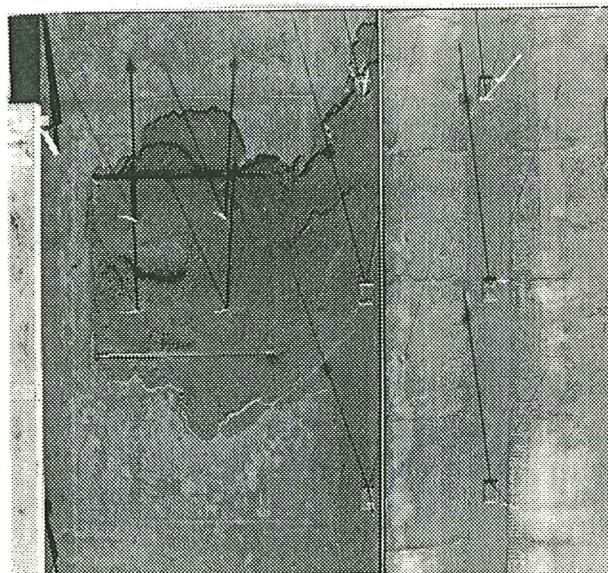
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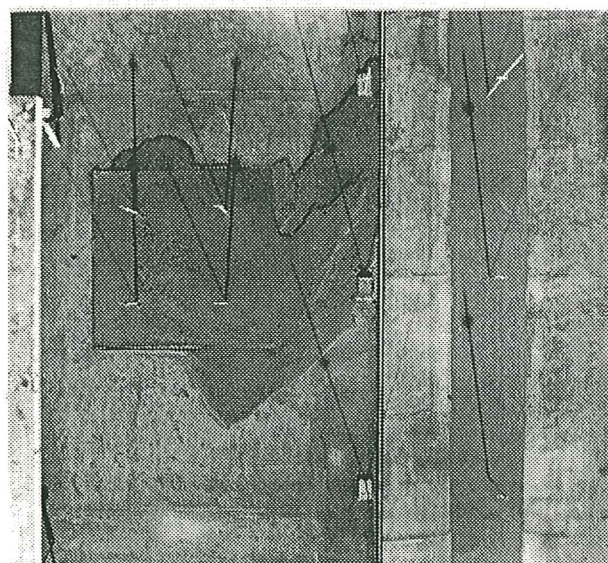
(a) Run 1



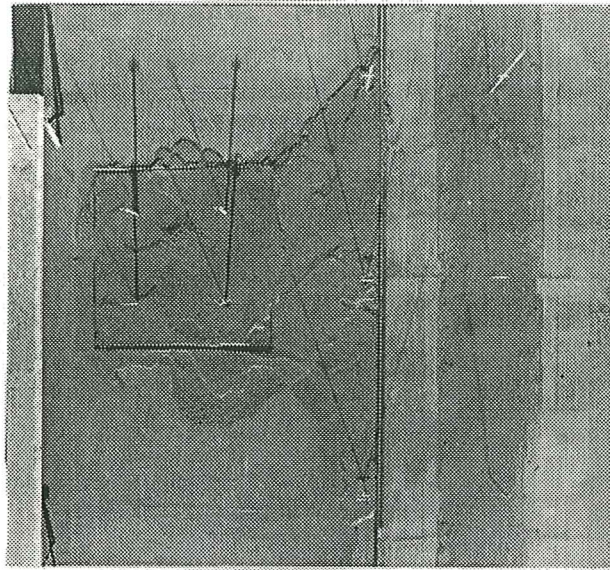
(c) Run 3



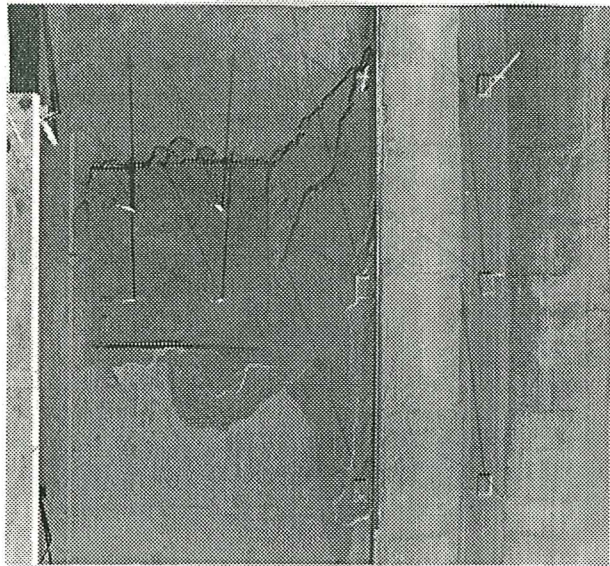
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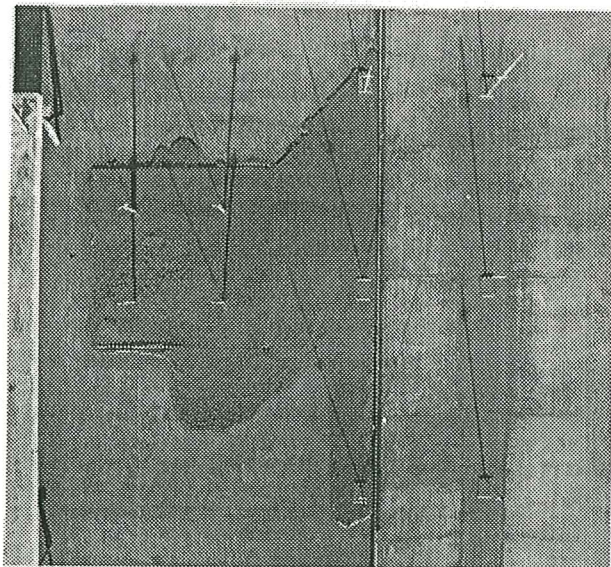
(a) Run 1



(c) Run 3



(b) Run 2



(a) Run 1

