Hydraulics Research
Wallingford

MEASUREMENT OF FLUID MUD LAYERS -

Field Instrument Developments

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This report describes the work carried out under Contract No. DGR/465/36, funded by the Department of Transport from April 1982 to March 1984, thereafter by the Department of the Environment. Any opinions expressed in this report are not necessarily those of the Funding Departments. The DoE (ESPU) nominated officer was Dr R P Thorogood. The instrument development and the field trials were carried out by members of the Hydraulics Research (HR) Field Studies Section, headed by Mr C B Waters. The development project was supervised by Mrs M P Kendrick in the HR Tidal Engineering Department under the management of Mr M F C Thorn. The report is published with the permission of the Department of the Environment.

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ABSTRACT

Results from field measurements obtained during port development studies in certain turbid coastal locations suggested that relatively weak wave activity over shallow muddy areas can create a near-bed layer of fluid mud which is transportable by modest tidal currents into dredged navigation channels, harbours and berthing areas.

Subsequent laboratory flume studies carried out on the local mud confirmed this hypothesis.

To monitor the movement of a near-bed turbid layer it is necessary to know the thickness, density, speed and direction of movement within precise limits. It is desirable also to know how the layer moves in relation to the water column above. To meet these requirements, field instrumentation has been developed at HR.

This report describes the instrumentation and the results obtained during field trials of the equipment.

1 INTRODUCTION

Fluid mud is universally recognised as a major source of silting in ports. It can be formed in a variety of ways - by rapid deposition of suspended sediment during periods of slack water; by agitation dredging; by salinity-density differences during lock operation; by shipping activity; or by wave action over coastal mud banks. Once formed, it may flow under the influence of gravity and hydrostatic forces and finally settle and consolidate in navigation channels and dredged berths producing considerably higher siltation rates than those solely attributable to direct deposition from suspension.

A few years ago a study was carried out to determine the optimum layout of a major port enlargement and redevelopment project (Ref 1). Included in the terms of reference were the determination of the siltation mechanism for the existing port and the prediction of siltation rates and dredging requirements for the redeveloped port and offshore approach channel. Results from a 20-month field programme demonstrated that neither fluvial nor marine sediments fully suspended in the flow could account for the scale of siltation experienced.

It was observed from field records that when moderate wave activity occurred, near-bed suspended loads increased. A laboratory flume study was carried out on local mud and it was found that under certain wave conditions a highly-concentrated, turbid layer developed just above the bed which could be transported by relatively weak tidal currents. Using local wind records, hindcasts were made to determine the height, period and frequency of occurrence of waves capable of generating a turbid layer. The movement of the layer was determined from tidal flow path data. The results demonstrated that siltation on the scale that occurred in the port could be explained by the existence of such a turbid layer.
Although the laboratory tests were crude, the results were taken into account in the formulation of a siltation mechanism and the construction of a conceptual model which yielded siltation rates in sufficiently close agreement with those being experienced in the port to justify attempts to predict siltation following port development.

It was, however, acknowledged that the range and combination of wave and tidal conditions under which the turbid layer could form had not been fully explored. It was also appreciated that although existing equipment could measure the in-situ density of muddy deposits, no instrumentation had yet been developed to confirm the formation and record the movement of a fluid mud layer in nature.

This report describes the development of instrumentation designed to meet the measurement objectives. A field trial of the measurement system, carried out on the river Avon, near Bristol, is described.

2 INSTRUMENTATION

The underwater package shown in Plate 1 consists of a 3m-long streamlined rod fitted with a fin and suspended from an electro-mechanical cable. At the lower end of the rod is attached a nuclear transmission probe, shown in more detail on Plate 2. This is fitted with a 50mm diameter electromagnetic current meter to monitor fluid movement on the probe axis. At the upper end of the rod, clear of the near-bed sediments, a watertight housing contains a precision pressure-sensing depth transducer, a twin-axis inclinometer to indicate the attitude of the rod, and a compass. The underwater unit weights approximately 50 Kg which enables it to penetrate low-density material under its own weight.

The outputs from the sensors are taken by cable to an inboard readout unit. The depth measuring system can resolve to ± 1cm over the range 0-30m and the depth is read from a digital LED display. The inclinometer measures pitch and roll attitudes over the range $\pm 10°$ with a resolution of $\pm 1°$ and is read from twin analgoue meters. The x and y components of flow are indicated on analogue meters and the output from each channel may be connected to a chart or magnetic tape recorder.

The transmission probe (Plate 2) consists of two vertical stainless steel tubes connected by 130mm-long horizontal cross-bars forming an 'H'-shaped assembly. Near the lower pointed end of one vertical tube is a 3-millicurie (1.1×10^8Bq) Barium 133 radioactive source have a half-life of 8 years. The source is mounted within a lead collimator to produce a narrow beam of gamma-rays directed across the gap between the two tubes. The second vertical tube contains the radiation detector. Attenuation of the narrow gamma-ray beam in the source-to-detector interspace is a function of the bulk density of the medium within that space. Density measurements with a vertical resolution of a few millimeteres are possible so long as the probe is held vertical, i.e. the gamma-ray beam remains horizontal. This feature is particularly useful when measuring the density profiles of highly stratified layers.

Output displays and high voltage for the nuclear detector are provided by a scaler/ratemeter. Radiation readings are indicated in analogue form on the unit's ratemeter display. A more precise radiation measurement is made by counting for a pre-set time period (typically 3 seconds) the incoming radiation pulses. The cumulative counts in the elapsed time are displayed on a liquid crystal display.

The readout unit is powered by an internal rechargeable battery, providing eight hours of continuous use.

The radiation counts may be converted into equivalent sediment densities by reference to a calibration curve. The individual density-depth profiles may then be plotted.

The plotting procedure is semi-automated, using a programmed microcomputer which contains the relevant calibration information. With this unit it is necessary only to key in the radiation counts together with the appropriate depths. The profiles are then automatically plotted on a graph plotter.

In order to give precise elevation control of the measurement head when operating over the side of the boat, a motion-compensating handling system was devised. The system, shown in Plate 1, consists of a light aluminium alloy framework carrying a pivoted beam which is sprung-loaded using heavy-duty rubber cords. The beam carries two sets of pulleys, one coaxially with the pivot, the other 1 metre outboard of the pivot. Three electrically-driven winches are mounted on the framework, each holding 35 metres of 4mm-diameter stainless steel wire rope. The outer winches control the raising and lowering of a 200kg sinker weight supported on the two wires which are spaced 450mm apart. In operation the sinker weight is lowered to the sea bed and the two guide wires are tensioned against the rubber cords. The control winch raises and lowers the measurement package on the guide wires. The instrument mounting brackets displace the probe about 300mm away from the sinker thus allowing measurements to be taken in an undisturbed region of the tubid layer. The handling system compensates for a vertical motion of the vessel of up to 90 cms.

3 CALIBRATIONS

(a) Density probe

The transmission probe was calibrated in the laboratory using a series of samples covering the density range 1.0 to 2.0 g cm^{-3}. Calibration tubs contained clear water at the low density end of the range, compacted sand at the high density end and stable calcium chloride solution in the middle of the range. With careful calibration a measurement accuracy of ± 0.01 g cm^{-3} may be achieved. In the field a calibration check is made using clear water.

(b) Electromagnetic current meter

The electromagnetic current meter was calibrated in a 2m diameter annular flume of cross-section 300mm by 300mm. An electrically driven rotating arm was used to move the current meter head around the flume at controlled speeds in the range 0 to 0.5 ms^{-1}. The current meter head was connected by cable to the readout unit and the x and y outputs recorded on a twin-channel chart recorder. The current meter was calibrated initially with the flume filled with clear water. The calibration procedure was then repeated with the flume containing a well-mixed water/silt solution. The density of this fluid was determined from samples taken at the time of calibration. Calibrations were carried out in a range of fluid densities up to a maximum of 1.2 g cm^{-3}.

It was found that the instrument sensitivity remained virtually constant at a value of 200 mV/m/s at fluid densities up to 1.15 g cm^{-3}. At higher densities the sensitivity decreased and at a density of 1.2 g cm^{-3} there was a reduction in sensitivity of some 25 per cent.

The velocity measurement resolution was approximately 1cm per second.

4 FIELD MEASUREMENTS

The results of a field trial of the basic measuring system, carried out on the River Avon near Bristol in 1984, were published in an interim project report (Ref 2). At this stage of the project, the measuring head was suspended from a conventional davit on the attendant boat and was subject therefore to vertical and horizontal movements induced by motions of the boat. These induced movements of the probe prevented the accurate elevation control necessary for detailed profiling in the fluid mud layer. As a result of the problems encountered during the initial field trial, the motion-compensating handling system, described earlier in this present report, was developed.

A further field trial of the complete measuring system was carried out on the River Avon during a neap tide period in March 1987. The measuring equipment was assembled on a 12m long Rotork Sea-Truck barge, which proved to be an ideal vessel for this type of operation. The measurement location, near Shirehampton (Fig 1), was chosen after carrying out an echo-sounding survey of the river channel below Sea Mills reach. This survey was undertaken using a Raytheon 719D sounder operating at a frequency of 208 kHz. At Shirehampton a mud layer some 0.5m thick was clearly indicated on the echo-sounder trace.

The vessel was anchored and measurements taken over a five hour period from mid-ebb through low water and into the onset of the flood tide.

The fluid mud profiling system was successfully operated during the three hour period from mid-ebb to low water. During this time four density/velocity profiles were recorded in the fluid mud layer. The results of these measurements are shown in Fig 4.

The profiling system operated satisfactorily throughout the measurement period. It was noted however that the signals from the electromagnetic current meter were rather noisy when measuring within the fluid mud layer. This effect had not been so apparent during the laboratory calibrations of the meter. Despite the noisy signal the mean velocities were easily determined from the recorder trace.

The motion-compensating system appeared to operate satisfactorily although the actual motion of the barge was fairly minimal in the calm conditions prevailing during the experimental period. Control of the elevation of the measuring head to within one or two centimetres was easily achieved.

Throughout this tidal period the velocity within the water column above the mud layer was monitored using a direct-reading impeller-type current meter. In addition, the level of the surface of the mud layer, as indicated on the Raytheon echo-sounder, was recorded. The results of these supplementary measurements are shown in Figures 2 and 3.

It is seen that the maximum near-surface velocity of about 0.65 m/s occurred at mid-ebb. The change of current direction at the onset of the flood tide occurred near the bed soon after low water whereas the flow at the surface continued in the ebb direction for a further ninety minutes. During this transition period the alignment of the barge in the river channel was very erratic, being influenced in part by a light down-channel breeze. This instability of the barge prevented operation of the fluid mud profiling system during this stage of the tide.

5 CONCLUSIONS AND RECOMMENDATIONS

The development of a field instrumentation system for the measurement of density and velocity profiles in fluid mud layers has been completed successfully.

A number of measurement profiles were obtained during a short field trial carried out on the River Avon, near Bristol.

The noise levels on the output signals from the electromagnetic current meter were unexpectedly high. An improvement in the quality of these signals is required before routine usage of the profiling equipment.

Although the motion-compensating system appeared to operate satisfactorily it is recommended that further field trials are carried out in less tranquil conditions.

6 REFERENCES

1 HR Report No. EX 879 - Port of Belawan, Indonesia, Third report on hydraulic studies. June 1980.

2. HR Report No. SR 44 - Monitoring of a near-bed turbid layer. March 1986.

FIGURES

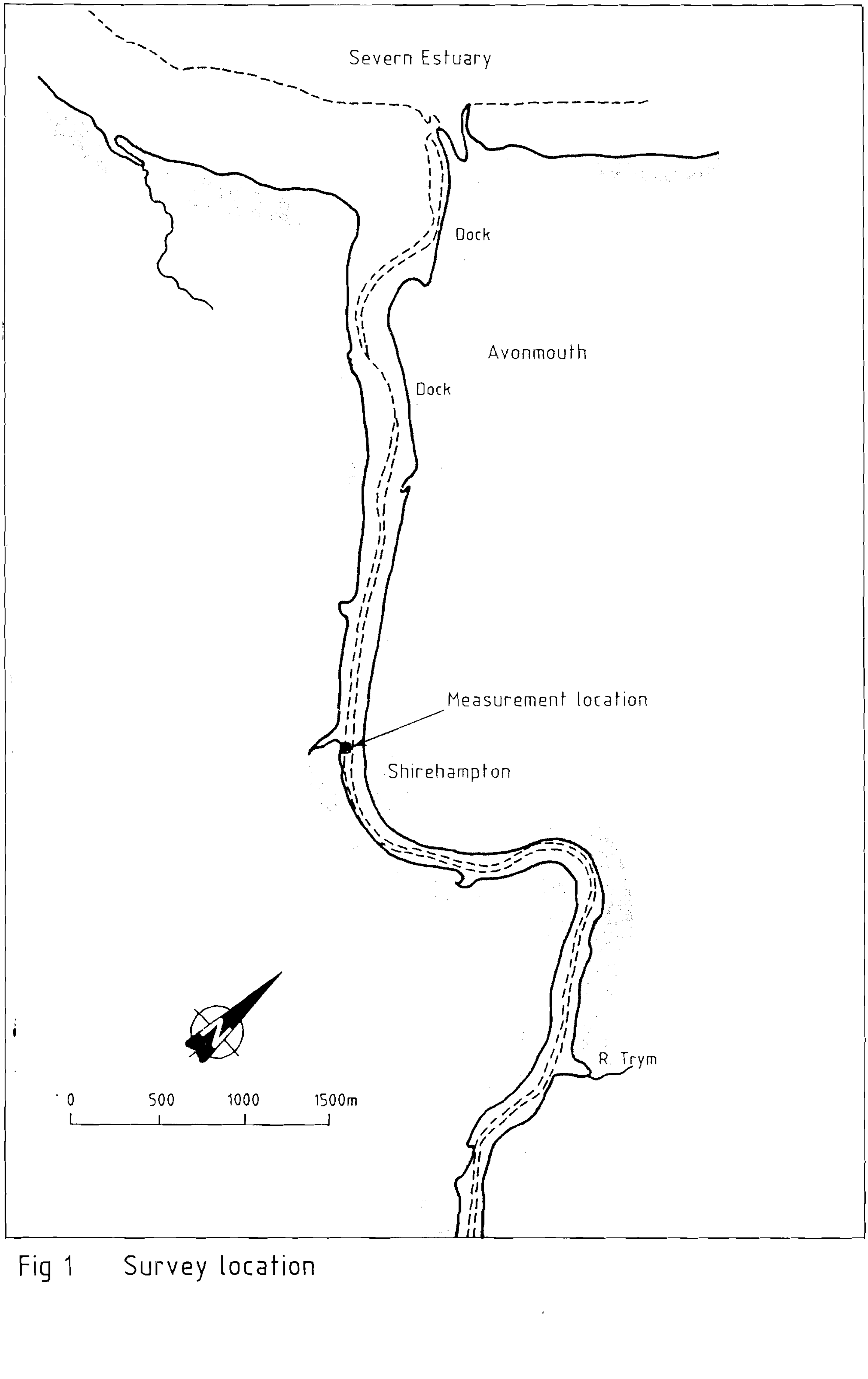

Fig 1 Survey location

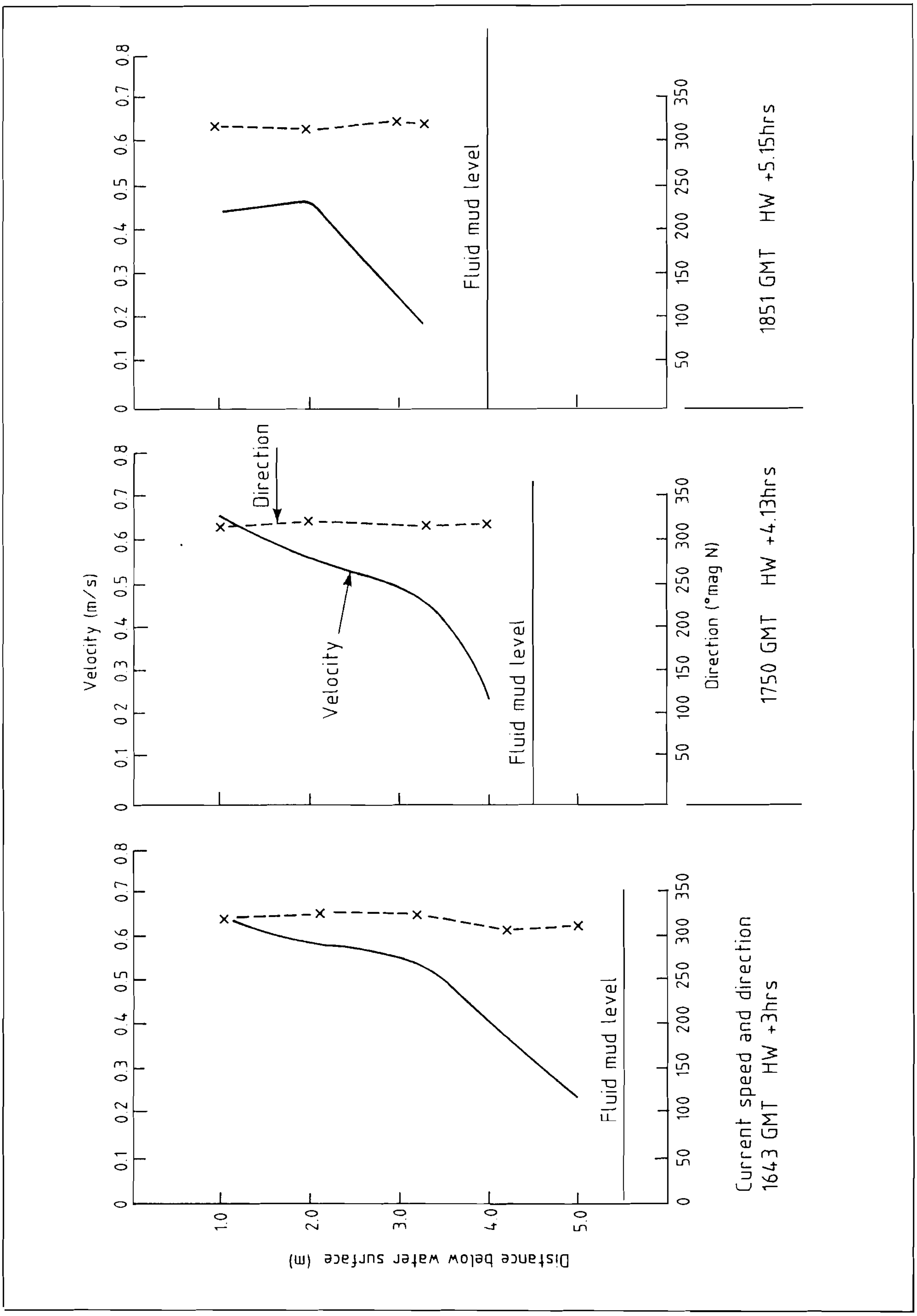

Fig 2 River Avon, Pill (Shirehampton) 9-3-87. Velocity profiles during ebb flow

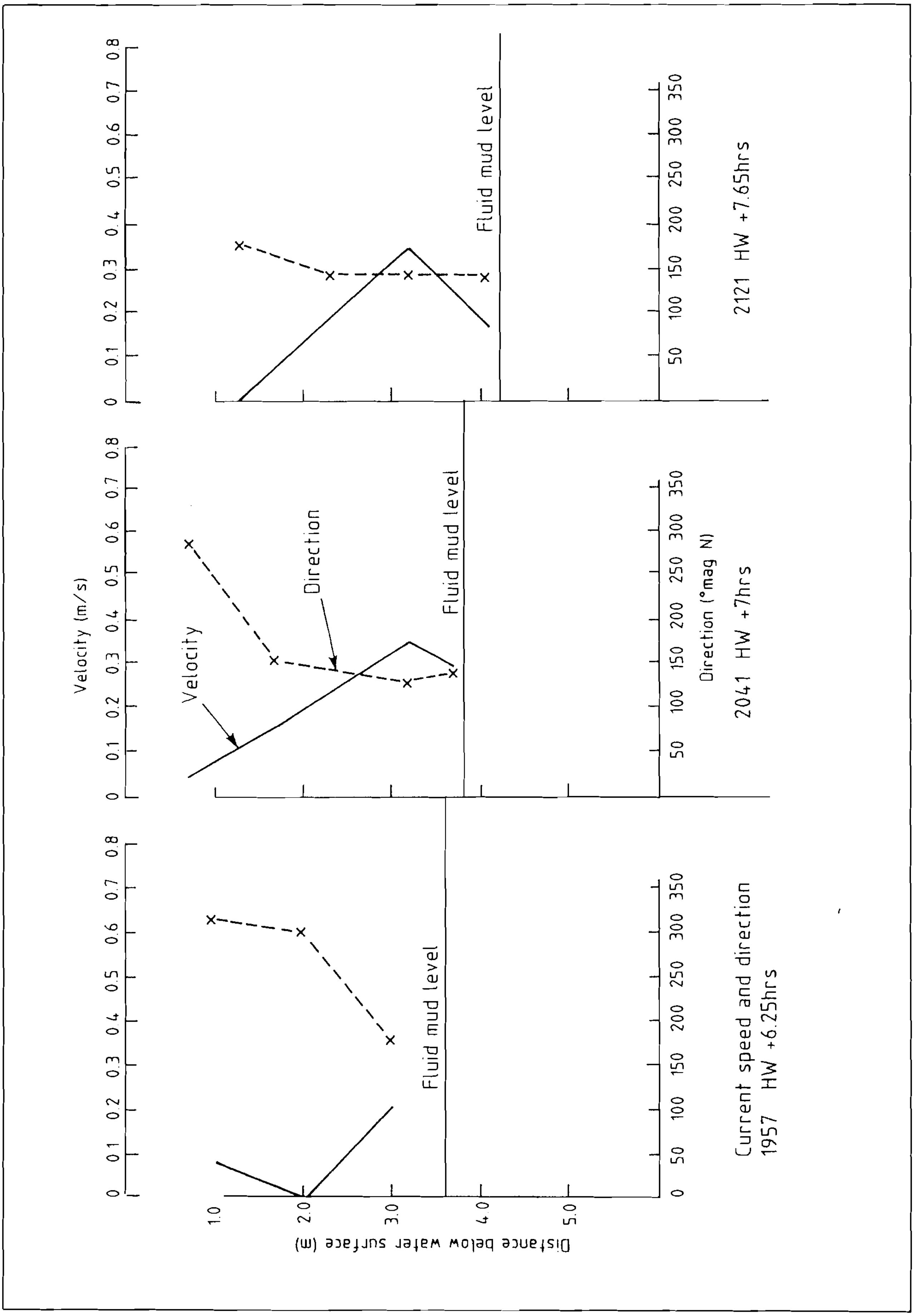

Fig 3 River Avon, Pill (Shirehampton) 9-3-87. Velocity profiles, onset of flood tide.

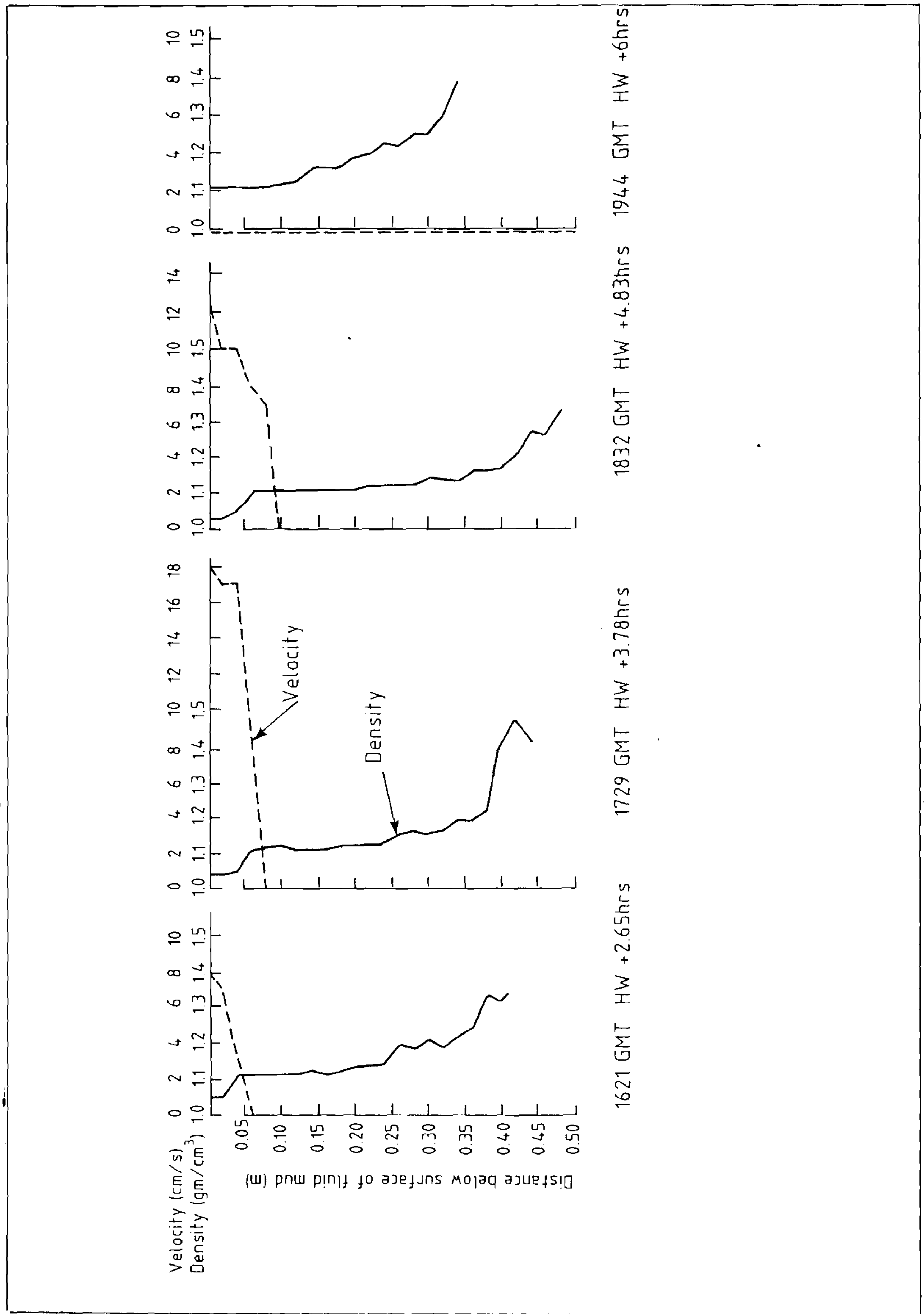

Fig 4 River Avon, Pill (Shirehampton) 9-3-87. Fluid mud density profiles during ebb flow

PLATES

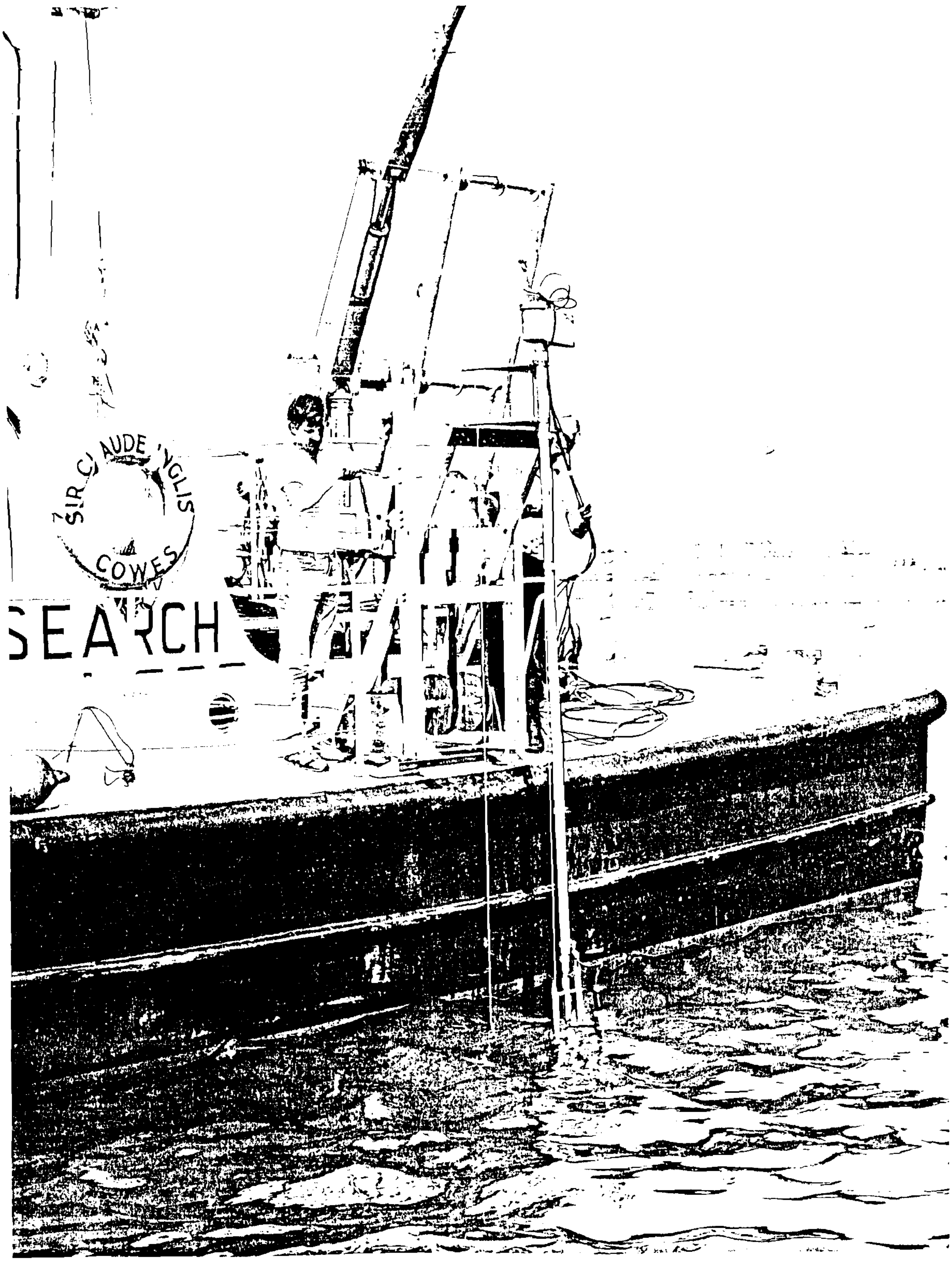

PLATE 1 The underwater measurement array and handling system.

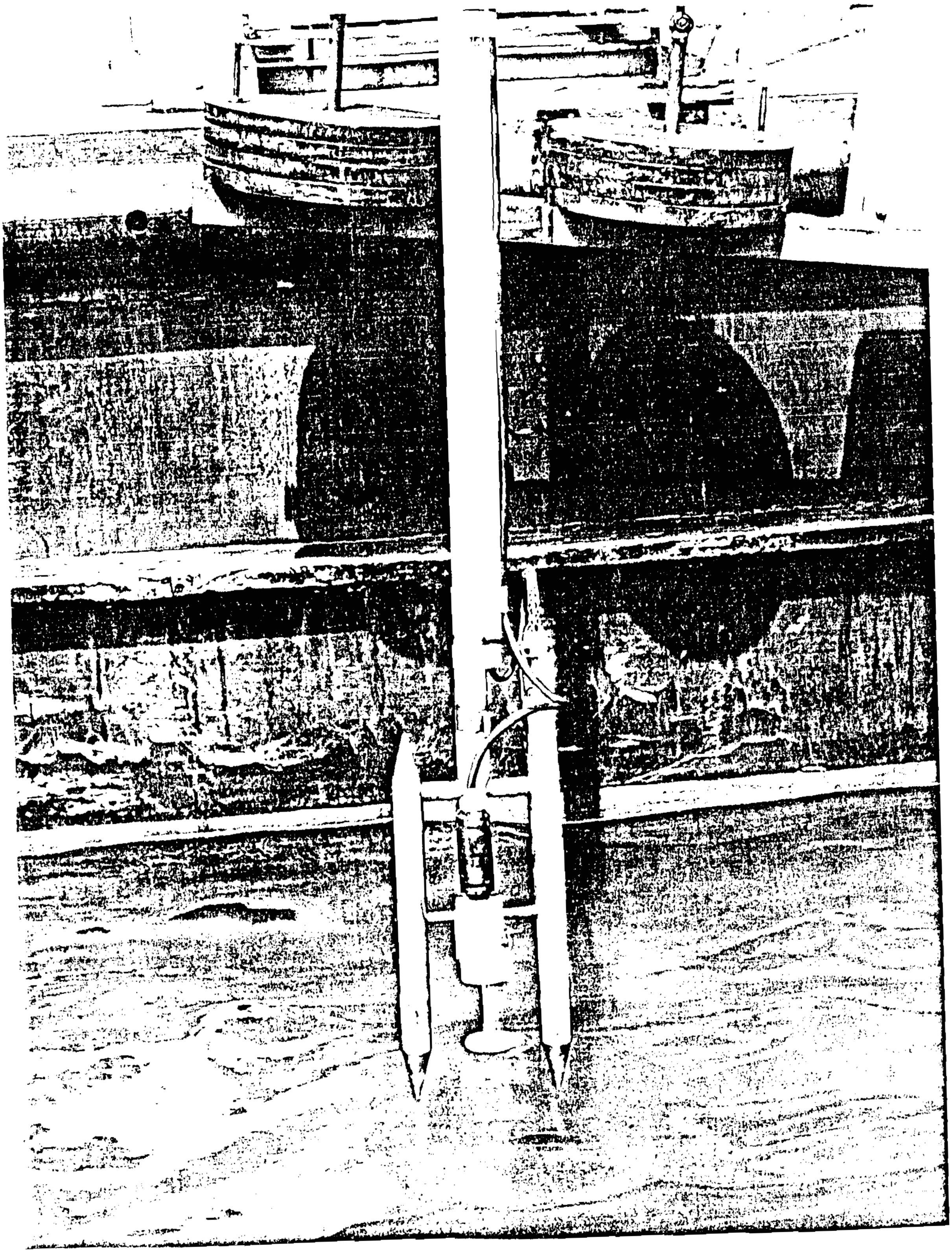

PLATE 2 The measuring head