MONITORING OF A NEAR-BED TURBID LAYER

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CONTENTS

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

SUMMARY

A few years ago HR carried out a study to determine the optimum layout of a major port enlargement and redevelopment project. 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. A major field exercise was mounted to establish tidal movements, salinity, suspended load, river discharge, wind and wave activity under all seasonal conditions. These data, together with dredging records, a series of hydrographic survey charts covering many years and additional observations from a physical model were used to investigate the siltation mechanism. Results from the field demonstrated that neither fluvial nor marine sediments fully suspended in the flow could account for the scale of siltation experienced at riverside berths and in the tidal basin.

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. It was further established that this layer was capable of being 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 but no field equipment was available to confirm or refute the 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 also desirable to know how the layer moves in relation to the water column above. To meet these requirements, an instrument has been developed at HR. It was tested in the tidal reaches of the Bristol River Avon and results from the study have established the existence of such a turbid layer and indicated that its direction of flow is dependent on other factors in addition to water movement in the column above.

INTRODUCTION

In 1980 Hydraulics Research (HR) produced the final report (Ref 1) on hydraulic studies for a major port development project located in a muddy estuary. The studies were planned on the information available at the time, the main objectives being to explain the prevailing mechanism of siltation and to predict future siltation following various stages of port development.

Existing data included various reports, earlier surveys, dredging records, some tidal levels and observations on local conditions by port personnel. A point frequently made was that although a particular reach of the port approach channel experienced siltation throughout the year, depth deterioration became more rapid in the short, wet season when river flow increased. It was inferred from this that fine sediments suspended in the flow and transported down the river provided the main deposition material, perhaps supplemented by some mud carried in from offshore banks adjacent to the approach channel following periods of high wave activity.

With these considerations in mind, HR designed a study programme which included:

(a) continuous monitoring of flow and suspended sediment in river and existing harbour basin to determine the discharge of fluvial sediment under the range of river flows experienced throughout the year;

(b) laboratory experiments to investigate the erosional and depositional behaviour of the local mud under the action of currents;

(c) field measurements to establish the extent to which mud on the offshore banks flanking the approach channel was likely to be stirred by waves into suspension in the layers between the water surface and the lowest measuring point 0.15m above the seabed.

Analysis of these results produced some surprises. In the first place, continuous measurement of suspended silt in the river established that the annual contribution of sediment from this source to approach channel shoaling could account for only about 17% of the total quantity of material that has to be dredged to maintain existing channel depths.

Secondly, the measurements of suspended solids concentration made in the tidal basin demonstrated that throughout a tide, silt concentrations from the surface to 1m above the bed were much too low for basin siltation to be the result of sediment deposition from this part of the water column.

Thirdly, the laboratory studies on the effect of currents on local mud suggested that its critical shear for erosion was such that with the currents encountered in the sea channel, any material that had deposited on the bed during the slack water period would be picked up early on the following half-tide: they also showed that the fall velocity of discrete, fine particles fully suspended in the flow was too low anyway for settling to occur in the time available during slack water periods.

Finally, the field measurements of suspended sediment concentration under wave activity demonstrated that although concentrations 0.15m and higher above the bed did increase with increasing wave activity, it was only occasionally that values in excess of 1000mg/l were reached, and even then, these concentrations were not measured further above the bed than 0.3m.

The measurements provoked several questions. Should offshore silt concentrations be monitored nearer to the bed than 0.15m? Is there perhaps a turbid layer a few centimetres thick which is the result of wave-stirring produced by the light-to-moderate diurnal wind which blows with enough force to agitate the bed in the shallow waters over the mud banks? Was siltation in the tidal basin due to the near-bed inflow of such a highly concentrated turbid layer? Did the low value of shear needed to initiate particle entrainment in the flume experiments apply only to the very fine silt fraction and are current velocities higher than those actually reached in the tests needed to produce the formation of a highly concentrated fluid layer from relatively well-consolidated mud banks?

To pursue some of these questions further, exploratory wave flume experiments were carried out to examine the behaviour of local mud under wave action. They showed that in salt water of a given depth, waves of a certain period and height produced a highly concentrated turbid layer on the surface of the bed which oscillated to and fro and could be transported by a modest uni-directional current at approximately the speed of the current without any significant loss of material to the upper layers of water.

In fresh water, a similar result was achieved with a smaller wave height, the larger wave used in the salt water tests now increasing the vertical mixing of the sediment throughout the depth by virtue of the deflocculating effect of the fresh water which reduced particle bonding and enabled more sediment to be eroded from the bed.

When the results of the wave flume tests were considered in conjunction with those of the detailed analysis of field and model measurements and port records, an explanation of the pattern of siltation experienced in sea channel, river and harbour basin emerged.

The outputs from the sensors are taken by cable to an inboard readout unit. The depth measuring system can resolve to $\pm$ 1cm over the range 0-30m and the depth is read from a digital L.E.D. display. The inclinometer measures pitch and roll attitudes over the range $\pm$ 10° with a resolution of $\pm$ 1° and is read from twin analogue meters. The electro-magnetic current meter is calibrated in the range 0-1m/s and the calibration is unaffected by fluid densities up to 1.15 g/cm^3. 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 consists of two vertical stainless steel tubes connected by 130mm-long horizontal cross-bars forming an 'H'-shaped assembly. One vertical tube contains near its lower pointed end a 3-millicurie (1.1 x 10^8 Bq) Barium 133 radioactive source having 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 millimetres 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.

High voltage for the detectors and reading displays are provided by a Nuclear Enterprises PSR 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 10 seconds) the

A conceptual model was constructed on the basis of this siltation mechanism and calculations were made which yielded sufficiently close agreement with the siltation experienced in the existing port to justify extending them in an attempt to predict likely deposition associated with future port development proposals. Confirmation by field measurement of some of the necessary assumptions was, however, still lacking, and although existing equipment was used to measure the in-situ density of mud deposits, no instrumentation had yet been developed to record the movement of a near-bed turbid layer.

2 TURBID-LAYER MONITOR

To bridge the gap in the range of existing mud monitoring equipment, the Field Services Section of HR has developed a field instrument array capable of measuring the thickness of the near-bed turbid layer, its density, and speed and direction of movement relative to the direction of movement of tidal flow in the water column directly above.

The underwater package 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 a nucleonic transmission probe is attached to lie on a horizontal plane. This is fitted with an electro-magnetic current meter to monitor fluid movements on the probe axis. At the upper end of the rod, and clear from 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 (Plates 1 and 2).

The underwater unit weighs approximately 50 kg which enables it to penetrate low-density material under its own weight.

incoming radiation pulses. The cumulative counts of elapsed time are displayed on a liquid crystal display. The bulk density equivalent of the count rate is then derived from a calibration curve.

The readout unit is powered by internal batteries, each set of batteries providing up to 120 hours of use.

The density probes are calibrated in the laboratory using a series of samples covering the density range 1.0 to 1.75 g cm^{-3}. Calibration tubs contain 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 $\pm$ 0.01 g cm^{-3} may be achieved.

In the field a calibration check is made using clear water.

Simple handling procedures are adopted which avoid any significant radiation dose to personnel. When not in use, the probes are housed in their shielded transport containers.

3 FIELD TRIALS

Field trials of the instrument package were carried out in Sea Mills Reach of the tidal River Avon near Bristol (Fig 1). This site was selected because earlier field measurements had established the existence of a layer of fluid mud at the bed which was particularly well formed during neap tides. The profile was deployed from the lifting tackle of HR survey vessel "Triton".

Measurements were made over a 2-day period but due to technical problems no measurements of fluid mud velocity were possible on the first day. In addition to monitoring the fluid mud layer, measurements were also made of the speed, direction of flow, salinity and temperature in the water column above. Readings were taken 0.5m and 1.0m above the bed and then at 1.0m-intervals up to the surface.

Although the bed density profiling and water quality measurements returned a good percentage of data, the surveyors expressed some concern about the accuracy of velocity measurements in the turbid layer. It was feared that the working platform was insufficiently stable, having a tendency to roll due to wind loading and the general movement of personnel on board. It was suggsted that this probably resulted in some horizontal and vertical movement of the probe and electro-magnetic current meter.

On the second day of the survey, observations began at 0930 hours (1.2 hours before low water) and finished at 1445 hours (4.1 hours after low water). They were carried out on a neap tide having a range of 6.45 metres on the flood. Winds were from the south-west having a strength of Force 3 on the Beaufort scale.

4 DISCUSSION OF RESULTS

The plotted field observations confirm surveyors' fears that boat movements gave rise to poor data. Whilst the sway and roll movements of the boat had little influence on water observations spaced in depth-increments of 1 metre, they certainly affected the observations within the turbid layer which were specified to be recorded at depth-intervals of 2cm.

The electro-magnetic current meter was attached to the instrument assembly with the Y-axis velocity component aligned with the direction of tidal flow and the X-axis velocity component normal to the flow. Both the sideways sway and, to a lesser extent, the roll movements of the vessel should therefore have had a greater effect on the X-axis velocity component than on the Y-axis component.

Of the nine sets of density/velocity measurements made within the near-bed turbid layer, the most representative, and probably the most reliable, was recorded just before low water. The results are shown on Fig 2.

The concentration of mud suspension is expressed in two alternative forms - as turbidity levels in mg/l and also as bulk density in t/m^3. Suspensions having concentrations up to about 100,000 mg/l may be regarded as comparable to the near-bed turbid layer likely to be generated by wave agitation. Suspensions of 200,000 mg/l to 400,000 mg/l are frequently referred to as fluid mud, and suspensions having a concentration exceeding 400,000 mg/l could be considered as representing the bed of the river. At the time of the observations on Fig 2, the tidal current strength 0.5m above the surface of the turbid layer was 0.66m/s and the water saliity was 32.05 g/l. From the surface of the turbid layer, the density increased progressively at an almost uniform rate. Movement of the layer reduced progressively with distance below the surface. The flow direction sketch below the graph shows that the upper part of the turbid layer moved in the direction of tidal flow while in the sub-surface layer it took the form of a very slow creep down the sloping side of the river section under the influence of gravity.

Another reasonably acceptable set of observations were recorded during the mid-flood, about 3½ hours after low water (Fig 3). Flow just above the turbid layer was 0.45m/s and water salinity was 36.25 g/l. The profile through the layer showed a degree of uniformity of both turbidity and rate of movement over a thickness of some 15cm. The direction of movement at the surface was influenced by tidal flow but further into the layer the movement was towards mid-channel under the influence of gravity.

Fig 4 is included as an example of poor observations, although in this particular case the cause cannot be attributed to large inaccuracies in X-axis velocity components since the flow was principally in the Y-axis direction. The increase in velocity with depth beneath the surface is unreasonable, and the suggestion that consolidated mud at 575,000 mg/l (bulk density 1.37 t/m^3) flowed at a velocity of 0.575m/s is unrealistic for the given transverse gradient of the estuary.

CONCLUSIONS

1. Although the working platform proved to be inadequate for the type of survey work being undertaken, the data recorded confirmed that the instrument package was capable of monitoring the movement of a near-bed turbid layer.

2. The results showed that the turbid layer was influenced by the movement of the water column immediately above, and the upper portion was transported in the direction of tidal flow.

REFERENCES:

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

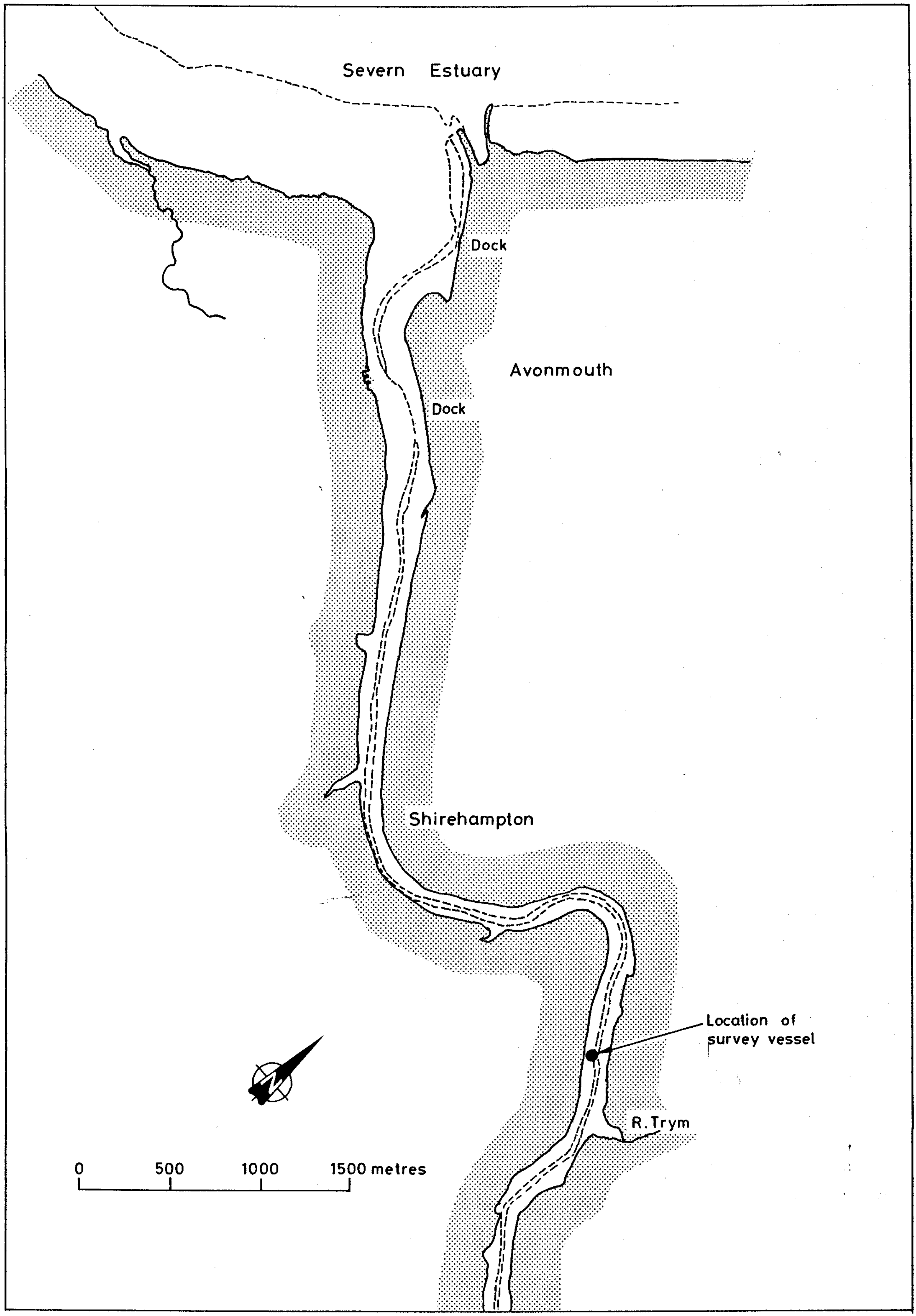


Fig 1 Survey location

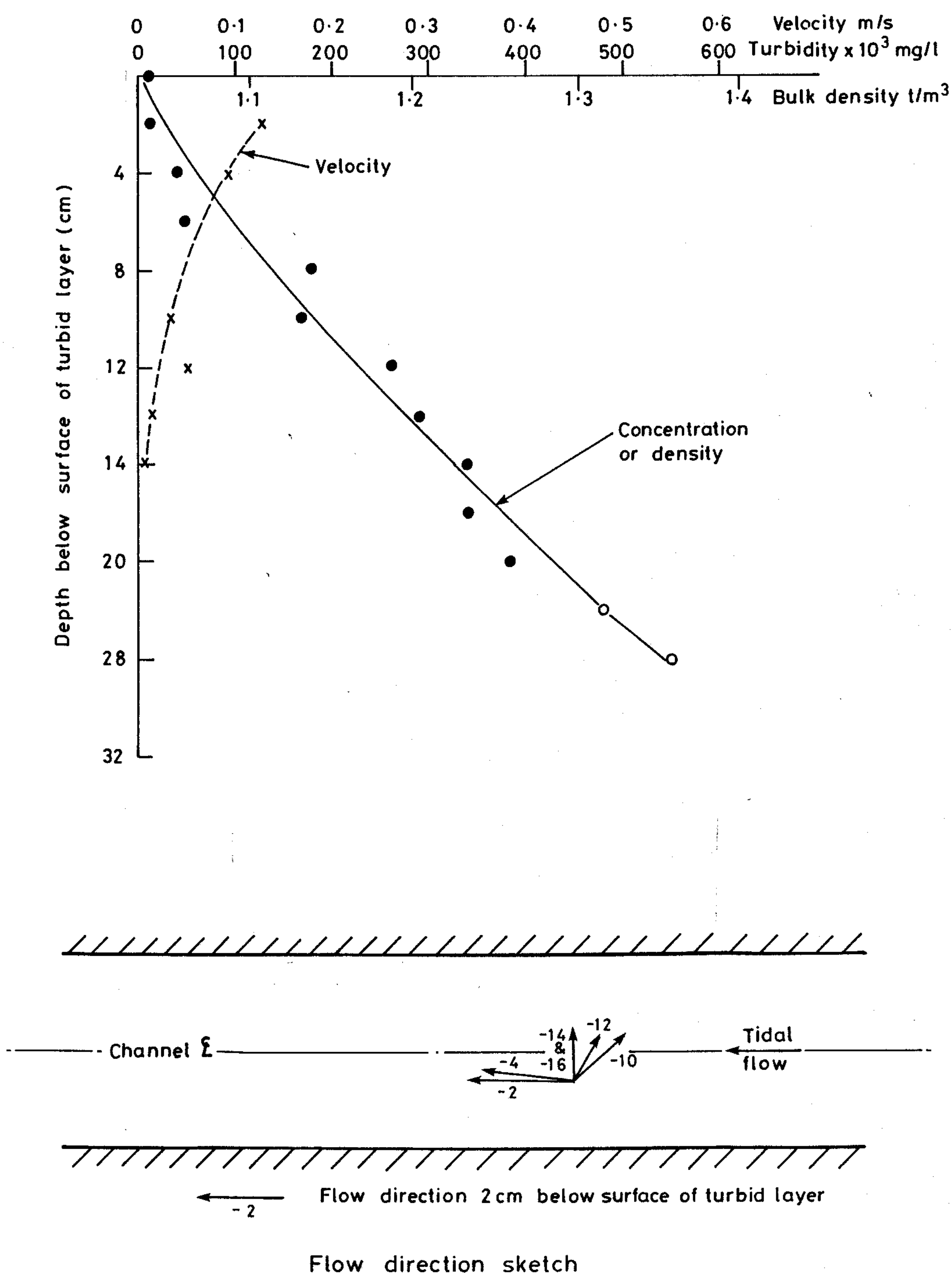


Fig 2 Variation in velocity and turbidity with depth (LW-0·33h)

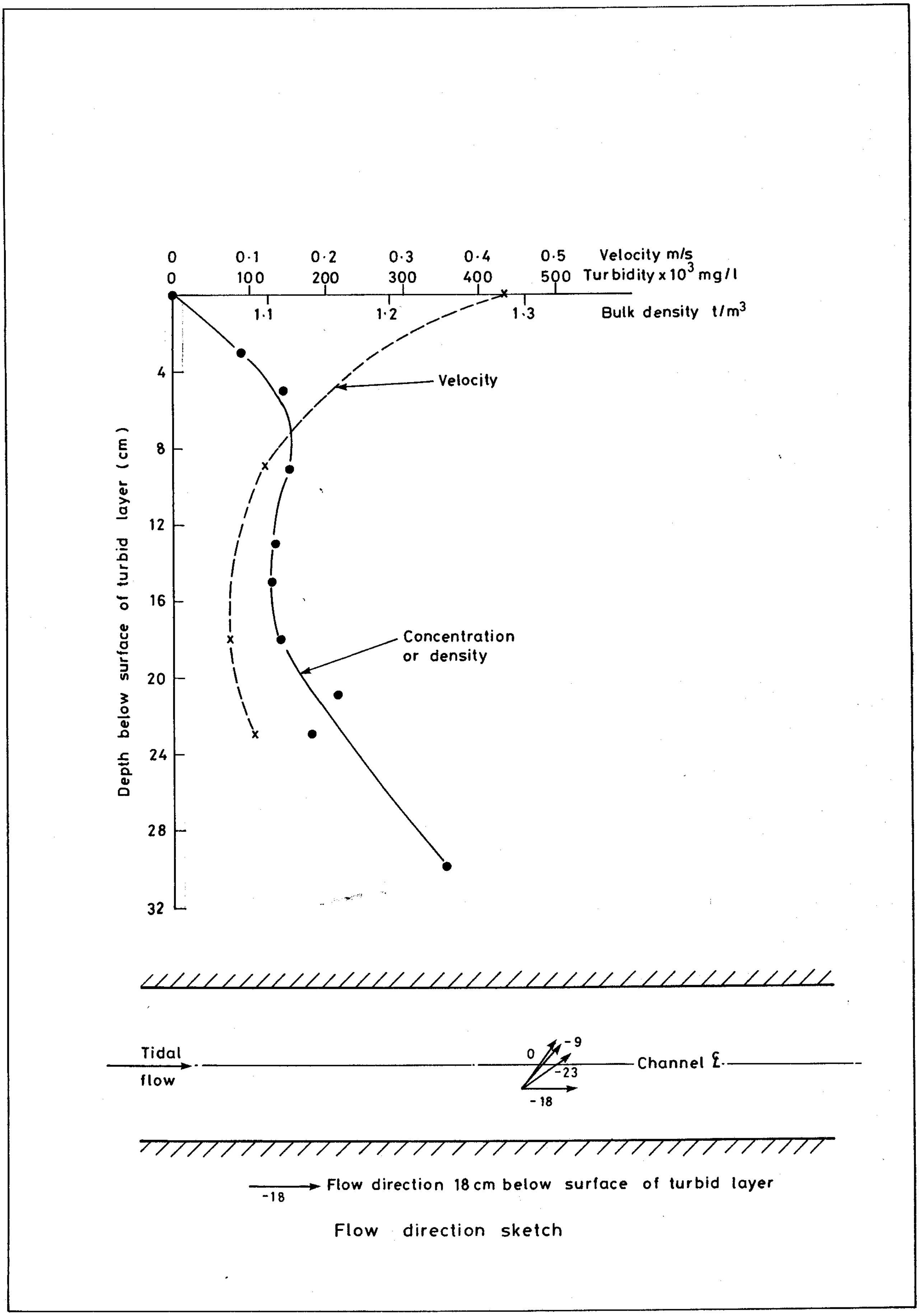


Fig 3 Variation in velocity and turbidity with depth (LW + 3·5 h)

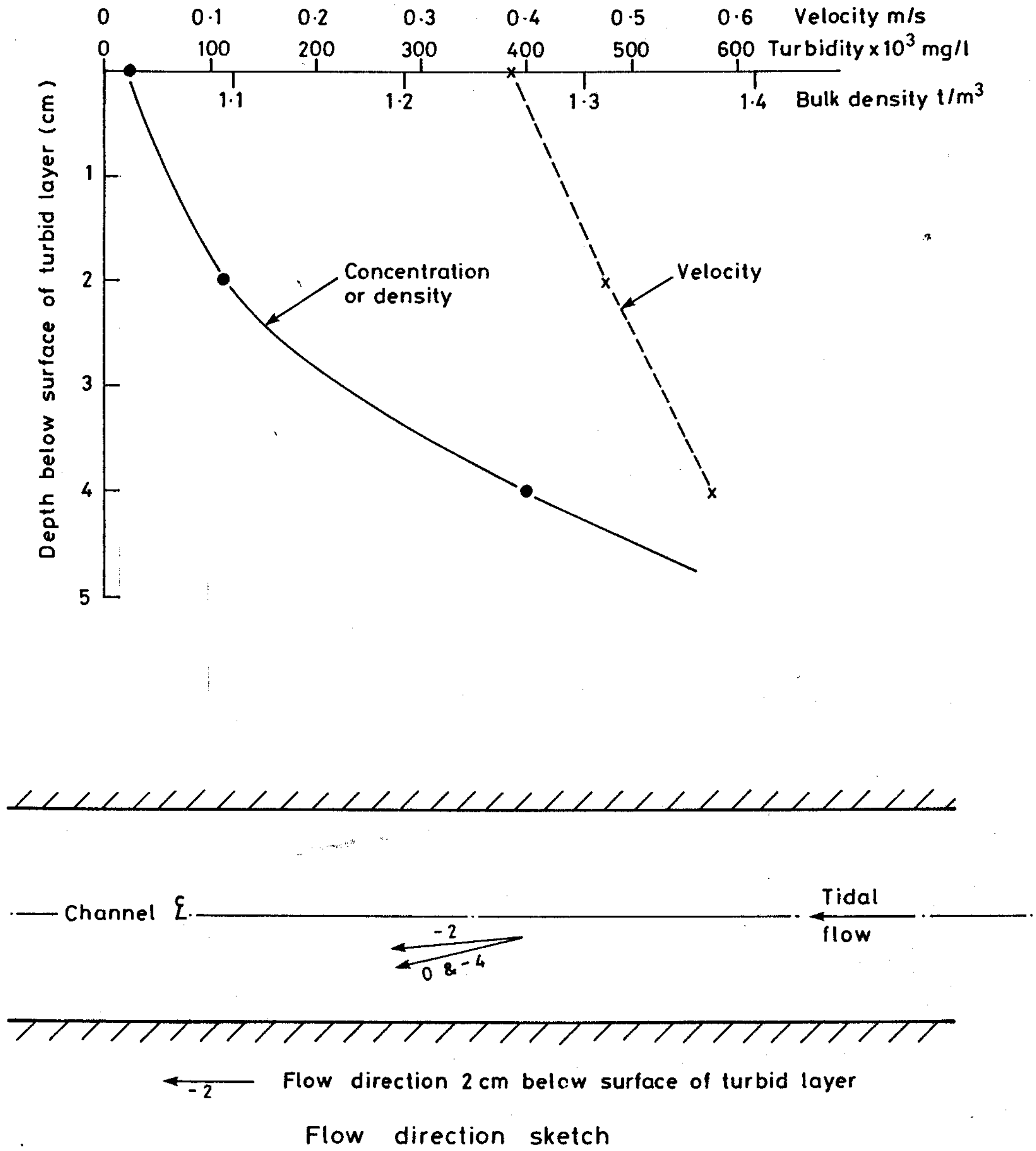
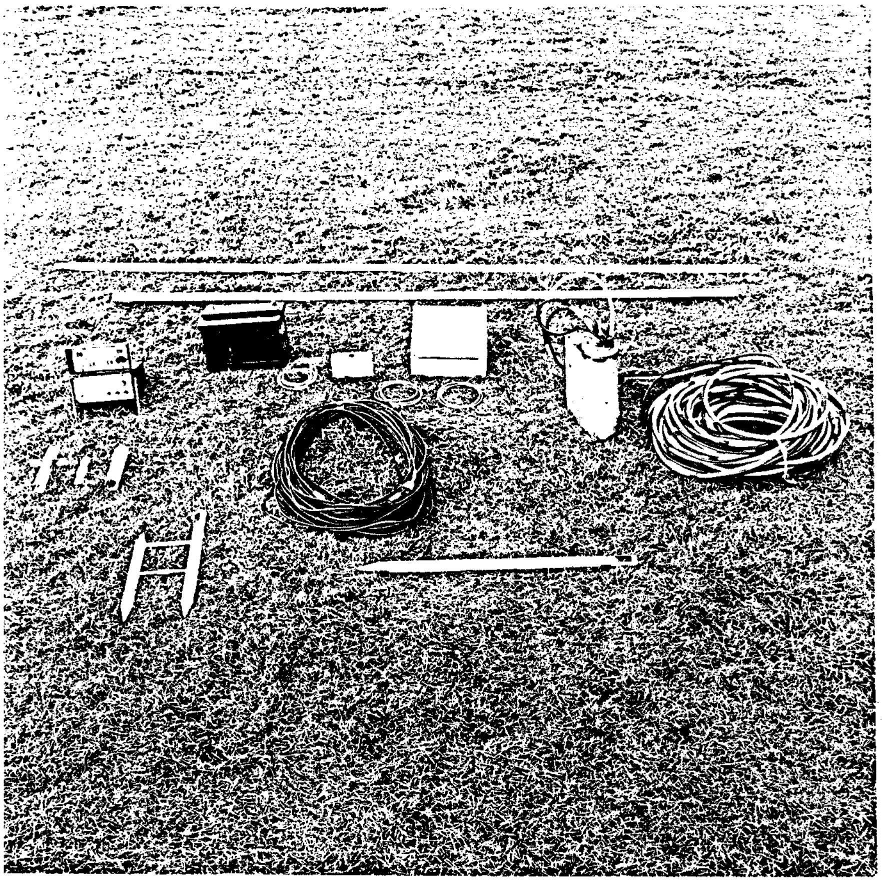
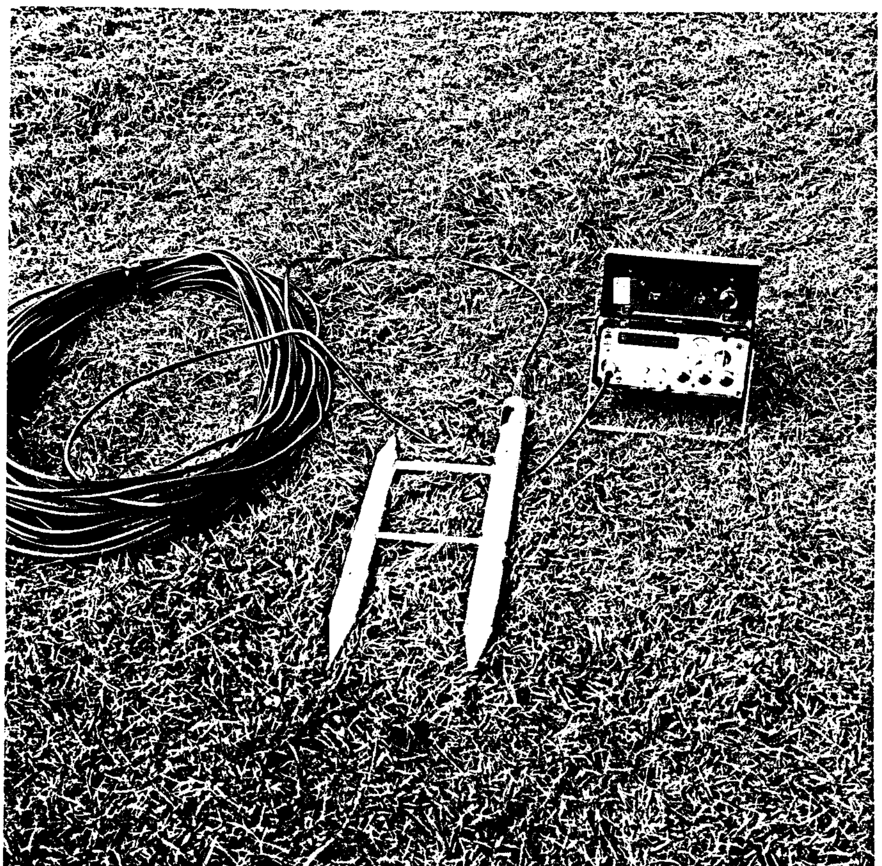


Fig 4 Variation in velocity and turbidity with depth (LW-1·0h)



(a)

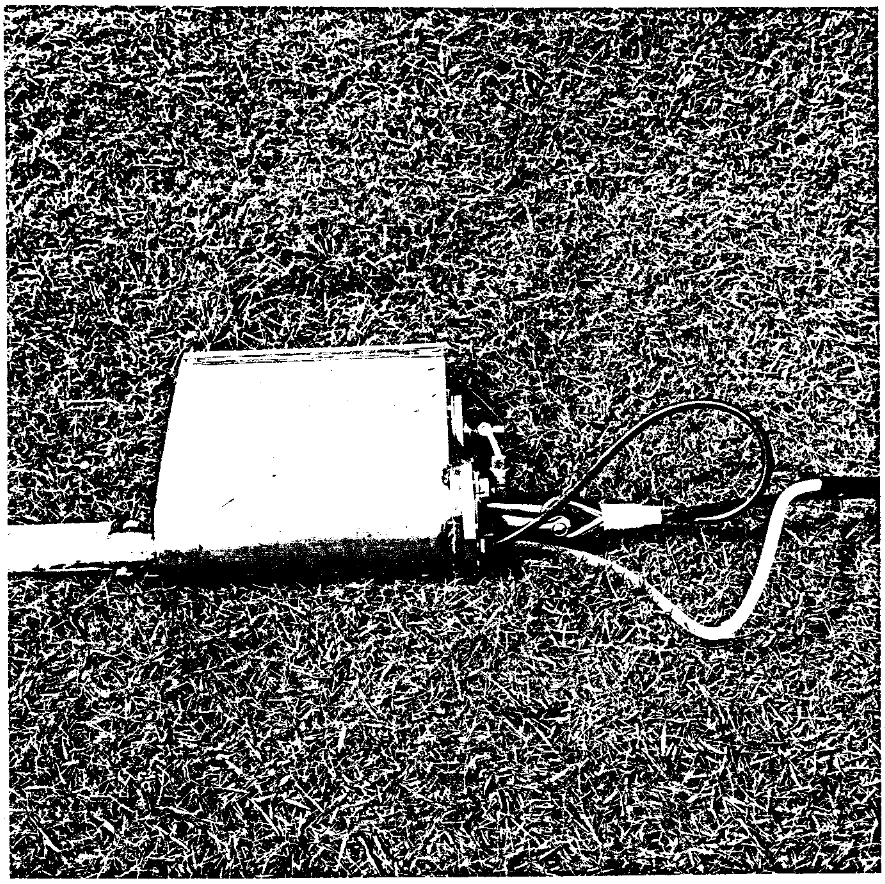
Main elements of transmission probe assembly excluding EM current meter



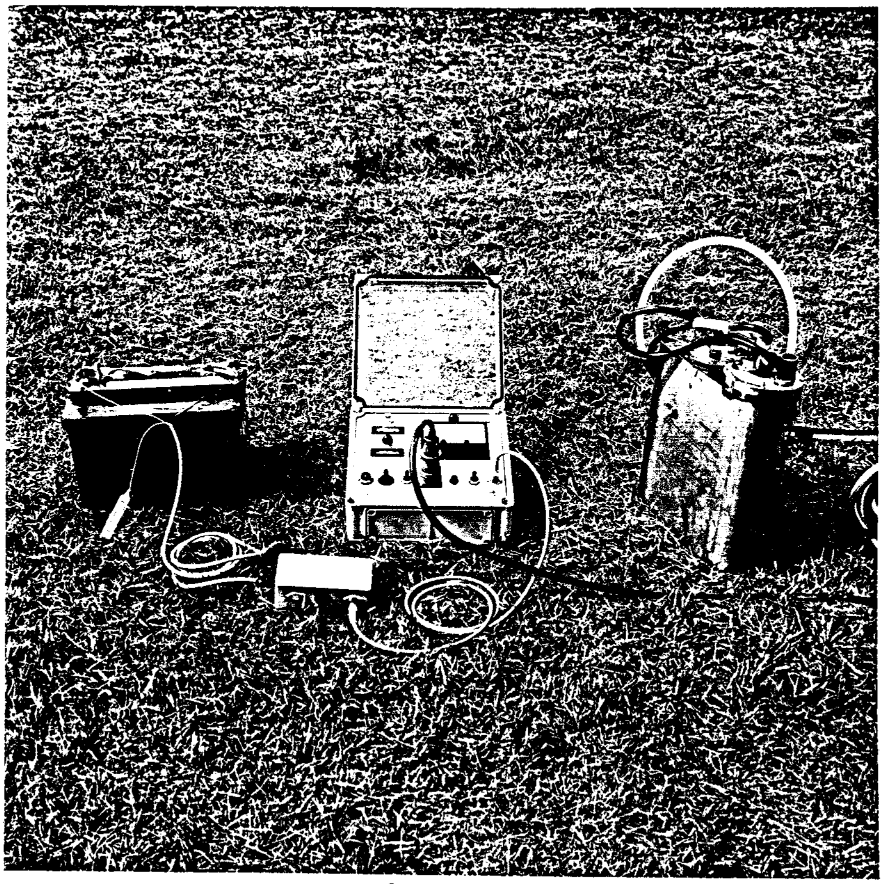
(b)

Transmission probe

PLATE 1



(a)
Depth transducer, inclinometer and compass assembly attached to suspension rod and lifting cable



(b)
Depth transducer, inclinometer and compass housing with ship-borne readout unit

PLATE 2