Hydraulics Research
Wallingford

INSTRUMENTATION RESEARCH AND DEVELOPMENT

1982 to 1985

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Report No. SR 46
May 1985

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1 INTRODUCTION

Most organisations engaged on research into physical processes need to explore how technological advances may improve measuring procedures, and in some instances to pioneer instrument development in support of their specific research aims. In recognition of this need, and with the privatisation of the Hydraulics Research Station in April 1982, a three-year Instrumentation Project, attracting a total estimated budget of £300,000 was initiated, funded by The Department of Transport over the first two years and the Department of the Environment in its third year. The annual allocations from the two Departments declined from £104,000 for 1982/83 to £97,000 in 1984/85 and in practice inflation aggravated the diminution in real money terms.

In line with the Department's interests in the port sector the thrust of the programme commissioned by the Department of Transport was directed principally at wave monitoring, moored ship movements, and sedimentary processes in port approaches. The primary intention was to encourage the development of improved methods of taking measurements both in the field and on site-specific models in the laboratory. Advances in measuring methodology are necessary if Hydraulics Research is to offer the best advice to UK consultants and contractors on harbour design, especially to those operating in overseas markets. Additionally some of the chosen instrumentation topics were expected to command attention in the context of more general hydraulic and sedimentary studies undertaken by Hydraulics Research rather than be applicable solely to the port and harbour sphere. The programme also attempted to accommodate participation by UK manufacturers on certain developments with a view to the eventual commercial exploitation of any instruments that might show market promise.

The overall budget over the three-year term was divided over a number of topics. In general the topics can be grouped into three broad categories. These are:

(i) wave recording and moored ship movement;

(ii) sand transport measurements in nature;

(iii) measuring techniques for hydraulic models.

The individual topics are described in Annex 1 which is taken directly from schedule 1 of the original contract with the Department of Transport together with the contract amendment agreed with the Department of the Environment in July 1984.

The programme has been managed, and for the most part executed, by the Technical Services Department of Hydraulics Research. From about halfway through the contract term, corresponding to the time when staff had to choose between the public and private sectors, shortage of experienced technical personnel led to more of the programme being undertaken extra-murally than was originally intended. Thus the extra-mural component of the total sum of about £280K spent over the three years was 60 per cent higher than that originally estimated, while the HR staff element including overhead dropped from the anticipated 74 to 64 per cent of the total.

In spite of these staffing difficulties the principal objectives of the programme have been achieved. However, it is considered that progress made on the topic dealing with the measurement of wave directional spectra has been slowed by the scarcity of suitable in-house personnel. That topic together with another on the "in-situ" sensing of fine sand suspensions have always been regarded as the more speculative aspects of the programme and unlikely to come to fruition within the span of the present contract. In both cases provision has been made to carry over their development at HR beyond March 1985 within the ambit of other research contracts agreed with the Department of the Environment.

The shortfall in expenditure of about £20K is accounted for partly by the reduction in staff effort on the wave directional spectra topic and partly by the failure to progress an extra topic introduced at the time of the Department's contract amendment in July 1984. The new item lies outside the three development categories given earlier and concerned the evaluation of a novel electromagnetic current meter for field use. The reasons for lack of progress on this topic were outside the control of HR and will be explained later, following a summary of the results achieved on the three main themes. Full descriptions of the completed work can be obtained by reference to the various reports on the individual topics as listed in Annex 2.

This contract report does not describe all the R & D effort expended on instrumentation by the Technical Services Department of HR in the period 1982 to 85. Reference should be made to the completion reports of contracts PECD 7/7/049 and /050 for an account of progress on a few further items of field instrumentation.

2 WAVE RECORDING AND SHIP MOVEMENTS

(a) Repeater buoy

Long-term wave records are often essential for the design of marine engineering works. For 20 years the Waverider accelerometer buoy has put the Dutch (Datawell Nv) in the leading position worldwide as the provider of a reliable device for monitoring wave height and period at frequencies of 0.05 to 0.5Hz. Until remote sensing of sea surface elevations from satellites is intensified dramatically, both in terms of world coverage and of scan repetition frequency, it seems likely that the Waverider and its more recent competitors, the British NBA (Controls) Ltd Wavecrest and the American Endeco Inc Wave-Track, will remain the favoured method for the recovery of short wave and swell data. In conventional operation all these accelerometer buoys telemeter their data to a shore station. Reliable signal reception is usually dependent on line-of-sight between buoy and receiver station. The telemetry range of the buoy transmitter is sufficient for most port and coastal engineering applications. However, it is sometimes difficult to establish the shore station in secure and accessible accommodation and at the same time satisfy the line-of-sight constraint.

In order to have greater freedom in siting of the shore station HR in conjunction with NBA (Controls) Ltd, Farnborough, Hants have developed under the present contract a repeater buoy to relay signals from Waverider and Wavecrest buoys. This makes possible the re-direction of signals around headlands and in some circumstances can avoid unduly long land paths for the radio transmission. The electronic design and construction of the prototype buoy was carried out by NBA (Controls) Ltd. The buoy electronics were quickly demonstrated as adequate on the first field deployment but when the buoy went adrift and was washed ashore in heavy seas the strength of the plastic buoy hull was found to compare ill-favourably with that of a conventional Waverider hull. HR subsequently re-housed a second electronics package in a modified Waverider hull and also substituted the battery pack used in Datawell's Waveriders in order to extend the operational life of the buoy.

The project has led to the production of a proven system for overcoming some of the radio transmission problems associated with existing wave buoys. The work is fully reported in Ref 1 and the main findings were presented at the 1984 Oceanology International Conference. NBA (Controls) Ltd report that there has been considerable interest displayed in the system particularly from U.S.A.

(b) Measurement of directional wave spectra

It is seen from the previous section that satisfactory sensors are commercially available and command widespread use for the measurement of wave height and period. The same cannot be said about devices for monitoring wave directional spectra for "ad hoc" engineering applications. Although pitch-roll sensors have frequently been used for research applications and within large oceanographic data buoys their deployment configuration or cost militate against their adoption for typical investigations of coastal hydraulics. A few smaller, more easily deployed devices that purport to measure wave direction are now available but firm evidence to support these claims is scarce. One such device is the Wave-Track Type 956 made by Endeco Inc of U.S.A. This buoy is unique among surface wave followers in measuring the direction of tilt of the buoy brought about not by water surface slope (i.e pitch-roll buoy) but by the surface velocity gradient acting on the buoy due to the wave orbital motions of the water particles. In view of the capital cost, circa £50,000, the loan of a system was arranged with Endeco to enable HR to carry out a field trial off the north coast of Cornwall. The opportunity to deploy Datawell's relatively small pitch-roll buoy, the Wavec, at the same time was unfortunately lost when Datawell withdrew their offer. The one-month deployment of the Endeco buoy, which proved to be both difficult and costly, failed to produce any meaningful directional data and the equipment was returned to the supplier. The exercise which is fully described in Ref 3, did have one valuable outcome, namely the performance of a makeshift bottom-mounted velocity/pressure gauge. In the absence of Datawell's Wavec buoy HR assembled a self-contained system from components remaining from an earlier "ad hoc" investigation to serve as a comparision for judging the results of the Endeco buoy. The consistency of the directional data derived from recording the horizontal oscillations of the water at the sea-bed in association with the simultaneous pressure fluctuations suggested that the velocity/pressure approach was worthy of closer examination. Although the form of the system was adequate for a one-month trial it was a temporary expedient and could not be considered as a practical proposition for long-term wave direction monitoring. Its greatest handicap was the vast quantity of raw velocity and pressure readings that had to be stored on the self-contained logger for subsequent processing on the mainframe computer at Wallingford. In order to achieve operation of several months duration between servicing the raw readings need to be processed in the sea-bed unit and only the directional spectra data committed to tape.

The research contract was amended to include the development of a low-powered microprocessor capable of performing this data reduction task. A dedicated processor board using the Texas TMS 9995 microprocessor has now been produced and superficially bench-tested using a simulation method to prove the principal spectral analysis and wave direction extraction functions. The development is described in Ref 4 and the detailed software design, the microproessor subsystem and associated circuit diagrams are held by HR. Thus the first stage in the development of an overall recording system is complete. There remains the choice of suitable velocity and pressure sensors together with the design of low-powered driving circuits, data quality checks, general system control and recording of the processed data. It had been hoped to progress the evaluation of the individual transducers within the present contract term. However, staff commitments unfortunately precluded this. It is expected that the project will need to run for a further two years to reach the field prototype stage and provision has been made to continue the development under another research contract between DOE and HR. A successful system will find applications whenever data on wave directions have to be collected, provided that water depths are not too great to prevent the influence of surface waves penetrating to a measurable degree at the sea-bed. It will be particularly valuable for studies of bottom water processes governing sediment transport under waves.

(c) Ship movement recorder

A system has been developed by the Technical Services Department at HR for measuring wave-induced movements of ships moored alongside quays. It is primarily intended for use in harbours where long waves with periods of 20s or greater penetrate and cause excessive ship ranging. Measurement is made by logging readings of the angular and length variations of three tensioned wires attached to different points spaced along the moored ship from three independent tensator machines that are anchored to the quay apron. Digital data recorded on field magnetic tapes is subsequently processed on the mainframe computer at Wallingford to give heave, roll, pitch, surge, sway and yaw of the vessel. A laboratory simulation of ship movement has demonstrated that relative movements of the wire at its point of attachment to the ship some 30m from the quayside machine can be resolved to ±1cm, ±1cm and±10cm in terms of wire length, inclination, and azimuth respectively. A field trial at Dover Harbour, albeit under conditions of meagre ship movement, suggests that these resolutions should be achievable in practice. It is intended to undertake a second field trial to sample greater ship movements in 1985/86 under another research contract with DOE. Software developed under a separate research contract for extracting the six degrees of motion was fully tested with the data from the first field trial. The design and operation of the recording system is described in Ref 5, and a paper is being submitted to the BHRA-organised International Conference on Measuring Techniques of Hydraulics Phenomena in Offshore, Coastal and Inland Waters to be held in London in April 1986.

Although the complete system is of necessity heavy and the laying of a cable along a busy quayside is not without its problems, it is possible to manage a reasonably rapid and temporary installation at typical berths. The ship movement recorder with its operating staff and the backing computation services, is available on lease to port authorities interested in short-term deployments.

(d) Long wave recorder

The presence of long waves in excess of 20s period can be an important consideration in the location and design of new harbours because the ship ranging referred to in the previous section can possibly be excited by them. Harbours sited with exposure to waves over long oceanic fetches are particularly vulnerable to this phenomenon and in such cases it is prudent to confirm whether long waves are present or not at the port feasibility stage.

Most standard instruments for offshore detection at the low frequency end of the wave spectrum are self-contained, bottom-mounted pressure recorders programmed to sample water pressure fluctuations at 1 or 2 Hz every 3 or 6 hours. Sampling durations of 15 to 20 minutes suffice for short wave activity. However, in order to obtain good statistical averages, sampling durations of one or even two hours are necessary to establish the mean parameters of long wave activity. Sensing data for such long periods is extravagant on tape storage and leads to unduly frequent servicing of sea-bed instruments. HR, making use of the fact that long waves are normally correlated with high short wave activity, commissioned NBA (Controls) Ltd to adapt one of their standard pressure recorders with a view to overcoming this drawback. The proposal from HR was to adapt the DNW5m version from the NBA (Controls) range to sample the wave activity every 3 hours but only to take a full two-hour record when the short wave activity of a 5-minute sample exceeded a pre-selected significant wave height value. Trials carried out by HR off Port Talbot in the Bristol Channel of an instrument incorporating the "threshold record" circuitry clearly demonstrated the economies in tape storage that could be achieved by eliminating records of minimal wave activity. With the significant wave threshold set at 1m, less than 5 per cent of the regular 3-hourly interrogations were admitted for a 2-hour recording. The successful adaption and trial of the system were reported at the Oceanology International Conference in 1984 (Ref 2).

HR has subsequently deployed three of these enhanced systems in support of various "ad hoc" engineering investigations in the UK.

3 SAND TRANSPORT MEASUREMENTS IN NATURE

The provision of reliable data on sediment transport is essential to any assessment of the effects of sediment mobility on port works, irrigation and drainage networks, water power development, submerged tunnel crossings and other such diverse projects. Notwithstanding the considerable research effort expended on the interaction of sediment movement with its carrier medium, no single sediment transport function has gained general acceptance and reliance continues to be placed on actual measurement of field data to underpin engineering predictions.

(a) Pump sampling of suspended sand

Traditionally the measurement of suspended sand transport in rivers and estuaries has relied on the recovery of representative sediment-water mixtures by sampling bottles and other containment devices. HR has pioneered over the last 15 years the use of pump sampling systems backed by on-line filtration of the suspension for observations of sand transport. Special support frames to allow precise positioning of the sampling intake and current meter at elevations close to the sea or river bed have been an integral part of the systems developed for this purpose. Accurate profiling in the near-bed flow layer is of course vital because it is there that sand concentration and velocity gradients are steepest. The basic concepts developed by HR have been followed by several UK research laboratories and replicas of the HR designs have been made by Valeport Developments Ltd (now Oceonics Ltd) for oceanographic and hydraulic laboratories overseas. With funding from the present contract HR has added another version to its range of pump sampling systems to make measurements possible in deep fast flows where the existing versions have previously proved difficult to operate.

When engaged on sand flux measurements in connection with the Severn Tidal Barrage pre-feasibility study, stream drag on the bulky umbilical joining the bed frame to the attendant moored boat brought about serious handling problems. The version developed under the present contract dispenses with the largest element of this umbilical, namely the pumping line, by transferring the pump and associated filters for extraction of the suspended sand, from the deck of the boat to the bed frame.

The new design incorporates three sampling intakes and current meters at different heights above the base of the frame which is lowered to rest on the sea-bed. Thus three points on the near-bed profile can be simultaneously sampled for sediment concentration and velocity for a single lowering of the frame before it has to be recovered for removal of the filters and retained sediment. The greater ease of handling makes this version attractive for use in deep fast flows and where rapid completion of the near-bed profile minimises the time the attendant boat must hold close-station over the bed frame. However, the disadvantage of having to retrieve the frame after each profile means that it will not supplant the earlier HR designs provided the flow environment is not too severe for their use. The performance of the prototype has been compared with results obtained with one of these standard versions and the findings are reported in Ref 6. Only one unit has been made and this is available for use by HR as occasion demands.

(b) "In-situ" sensing of suspended sand

The sampling approach to measuring sand transport on the lines outlined in the preceding section is cumbersome, labour intensive, and is not capable of being extended to unattended data collection. Normally information on sediment particle size is necessary to an analysis of the sand transport and entails tedious sieving of a very large number of samples. A submersible instrument capable of sensing sand concentration would bring about a substantial reduction in the cost of sediment flux measurements and would command wide application.

For fine sediment suspensions of clay and silt particles a direct approach already exists. The attentuation or scattering from a light or infrared emitter offers a means of sensing directly the concentration of very fine sediment in suspension provided adequate steps are taken to calibrate the turbidity response of the detector with natural suspensions taken from the actual sedimentary regime under study. Although the concentration of suspensions above muddy beds may change in response to varying flow conditions, broadly speaking the particle size composition of the fine-grained sediment for a given reach does not change. Unlike sand in transport, the size fractionation of muds in motion is weak. Thus a single but site-specific calibration curve normally suffices for a mud study.

Sand suspensions are not so amenable to simple calibration: not only concentration but also particle size composition varies with height above the bed as well as with flow intensity. Successful in-situ measurement of sand suspensions requires that turbidity effects attributable to concentration must be discriminated in some way from those due to particle size. This requirement still holds if only the concentration is sought. The development of a sensor with this two-fold capability is the key to measuring suspended sand transport.

With this long-term objective in mind HR had let in August 1981 an extra-mural research contract with the Cranfield Institute of Technology to develop a battery-operated system for the "in-situ" determination of concentration of fine sand suspensions with particle diameters between 60 and 300 microns over the range 0 to 5000 mgl^{-1}. At inception the extra-mural contract was expected to run for three years and its funding from April 1982 came under the wing of the present contract. The study was carried out in the Fluid Engineering Unit of Cranfield and was throughout managed by the Technical Services Department of HR. Following a literature review (Ref 7) it was decided to examine the use of ultrasonics as offering the best prospects of a working method. The Cranfield Institute of Technology in conjunction with HR proceeded to explore the feasibility of deriving concentration and particle size by simultaneously measuring attentuated and scattered sound intensity brought about by fine sand suspensions settling in a calibration chamber. Experimental difficulties and problems with the detection system resulted in progress being slower than expected. At the time of terminating the contract with Cranfield in March 1984 the general principles had been demonstrated using a laboratory mains-operated detection system and showed sufficient promise (Refs 8 and 9) to encourage HR to initiate the design of a one-off field prototype by Bell Electronics Ltd, Aldershot, Hants; a company with considerable experience in the development and manufacture of marine ultrasonic systems. Following the findings from the demonstration laboratory rig at Cranfield Institute of Technology the field transducer array is so configured to measure direct attentuation, backscattered and forward scattered sound intensity from a 6.5 MHz acoustic source. The principle of measuring scatter by the intensity of the doppler-shifted signal is also retained from the earlier contract. However, the chosen electronics are considerably refined from that used previously and the output signals are compatible for processing on a BBC microcomputer. The construction of the d.c. powered transducer array, the housing of the underwater electronics and cabling are all consistent with the requirement for operating to an immersed depth of 30m. The product of the design contract with Bell Electronics Ltd (Ref 10) will be subjected to performance tests by HR in 1985/86 under a new research contract with DOE. The intention is to undertake a full laboratory evaluation in a sediment settling chamber before passing to field trials.

4 MEASURING TECHNIQUES FOR HYDRAULIC MODELS

The need to measure velocity is common to virtually the whole spectrum of modelling work undertaken at Wallingford. The standard model instrument for this purpose is a simple mechanical device, the miniature propellor current meter which was designed by Hydraulics Research some 30 years ago. The meter is satisfactory when operating in reasonably clean water and for slowly changing flows. However, it has obvious shortcomings for measurements in turbid water and where instantaneous velocities, and particularly instantaneous flow directions, are to be recorded such as in studies of turbulence or oscillatory flow under waves. Various solid-state sensors having no moving parts are possible candidates for these more demanding laboratory applications. Small electromagnetic current meters have provided a satisfactory solution in certain applications but in others flow disturbance created by the immersed head or their resolution has not been acceptable. The prospects of employing two other commercially available instruments, one using ultrasonics and the other lasers, have been investigated under the present contract for these more difficult model applications.

(a) Miniature acoustic current meter

The Gytre "Minilab" acoustic current meter from Sensordata of Norway is a miniature version of the ultrasonic devices designed for field use at the Chr. Michelsen Institute in Bergen. It measures the travel times of short acoustic pulses over the same water path but in opposite directions. The difference between the travel times is an indication of the "convection" of the pulses with the flow. Depending on the number of transceiver pairs the instrument purports to measure flow velocity on one axis, or on two or even three orthogonal axes. The multi-axis versions utilise an acoustic mirror and thereby an indirect path between the horizontal transceiver pairs to avoid the wake shed by leading parts of the transducer frame. The makers claim high sensitivity, detecting velocities down to 1 mms^{-1} and a bandwidth of 0 to 30Hz. The velocity is averaged over a 30mm path length therefore the size of the measuring volume is no smaller than that of a model electromagnetic current meter. However, the sensor design offers much less obstruction to the flow.

Because the meter seemed to offer distinct advantages over the minature current meter with respect to linearity and sensitivity HR evaluated the steady-state and dynamic performance of a three-axis probe. The findings of the tests were reported in 1982 (Ref 11) and concluded that while the instrument showed promise its performance was seriously degraded by zero shifts with temperature and its reliability left much to be desired. Since then and following correspondence with the designer, other models of the probe, ostensibly better engineered, have been tested at Wallingford. Unfortunately the conclusion remains the same and at its present state of development the "Minilab" requires so much operator care that it would be unrealistic to expect its regular utilisation on hydraulic models.

(b) Laser velocity meter

Lasers provide a means of non-intrusive sensing of structural vibrations and of flow measurements. They are normally only appropriate to model flow applications where access to the cross-section is possible through side windows. The measuring volume is small compared with most other velocity sensors and thus they open the way to detailed profiling including measurements close to the flow boundaries.

A DISA (now Dantec Electronics Ltd) laser interferometer, originally purchased for measuring flow-induced vibrations of a scale model gate valve, has been enhanced to permit examination of its range of application on flow studies. Considerable success has been achieved under the present contract in the utilisation of lasers on diverse research projects. The experimentation in these cases is carried out in flow or wave channels of regular cross-section having windows in their side-walls that provide convenient entry for the laser beam or beams. Normally the backscatter mode of operation has not been feasible and on some applications where optical access has only been practical from one side of the flow a mirror has been used to reflect the forward scattered light. This and other techniques devised for measuring single axis velocities have been reported in Ref 12.

In the last year for a relatively modest expenditure the equipment has been further enhanced to make it capable of two component velocity measurement. The separation of the two velocity components is achieved by producing two orthogonal sets of crossing laser beams intersecting at a single measuring point, and then polarising each set differently. The technique is described in Ref 13 which gives the results of measurements of orbital velocities under waves, indicating that for some applications performance equals that of more expensive two-colour laser systems.

5 EVALUATION OF A FIELD CURRENT METER

The appearance of a new American electromagnetic current meter, InterOcean Systems model S4, at the 1984 Oceanology International Exhibition prompted the suggestion that the meter should be evaluated within the scope of the present contract. DOE accordingly amended the contract in August 1984 to include a laboratory inspection and field evaluation of the new instrument but keeping within the original budgetary provision.

The InterOcean model S4 offers the same benefits as several commercially available recording current meters that rely on the principle of measuring flow with two-component solid-state sensors. The common merits of many of these devices are the programming versatility given by self-contained microprocessors for setting the instruments for various recording modes including vector-averaging and burst sampling at fast repetition rates; long deployable life; solid-state recording; and no need to open the device in the field either to input its operational duty or to recover its data. In addition to these shared attributes the model S4 is particularly attractive because its simple shape and size should make it easy to deploy. The entire sensing and recording package is housed in a low-weight sphere only 260mm in diameter, and is particularly suited to in-line mooring. The maker claims excellent horizontal and vertical cosine response and a resolution much better than $10mms^{-1}$.

The major objectives of the planned evaluation exercise were to ascertain from laboratory calibrations whether the maker's claims are justified and to test the meter's performance in a nearshore location off the Dorset coast. Interest centred on examining whether the spherical shape of the immersed body is likely to make it vulnerable to eddy shedding and thereby bring about unwanted self-induced oscillations of the meter. On the field trial the meter was to be moored for one month alongside other recording meters of a simple mechanical type e.g. Aanderaa and Plessey. The contemporaneous wave conditions were to be recorded by locating a Waverider in the trial area in order to judge the extent to which waves contaminated the tidal current recordings of the individual meters.

Progress on meeting the above objectives has been very disappointing. A model S4 meter has been purchased using HR's funds, the intention being to employ an existing hand-held microcomputer, the Husky Hunter, made by DVW Microelectronics Ltd to communicate with the self-contained electronics of the meter sphere. On delivery of the meter in December 1984 an unexpected problem in making the RS232 interconnection between the two units necessitated the ordering of a separate interface from U.S.A. When the system was finally complete in late January it was found that the meter's integral real-time clock was no longer functioning and precluded setting the instrument to a programmed recording cycle. The meter was subsequently air-freighted back to the makers for repair but delays in clearing U.S. Customs led to the returned meter not being available until towards the end of March, too late for deployment in the present contract term.

Thus apart from some software developed for listing the meter's stored data on the Husky Hunter there is little material progress to show for the expenditure of considerable staff effort. The software converts the stored eastings and northings which are in the form of hexadecimal numbers into decimal, calculates and lists flow velocity and direction against time.

Talks with other users reveal that although no field comparisons as comprehensive as that intended by HR have been carried out, at least one U.K. hydrographic survey company have ordered a substantial number of the meters following the outcome of a trial deployment. The future position on HR's own proposed evaluation, namely whether it is to be included in any on-going research contract with DOE, remains undecided.

ANNEX 1

Schedule 1 of DGR/465/32 Contract

INSTRUMENTATION

Objectives

The development of instrumentation in support of research programmes relating to water movements and sedimentary processes in port approaches and to forces on moored ships. This is a continuing programme which will lead to improved modelling and field techniques benefiting UK consultants and contractors involved with harbour design, especially in overseas markets. Where there are potential commercial possibilities in the development of specialised instrumentation industrial manufacturers are involved as soon as feasible.

Programme

1. Completion and field trials of a ship movement recorder designed to measure the wave-induced movements and mooring forces of ships alongside a quay. The project is of particular significance to harbours susceptible to excessive ship movement arising from long wave excitation.

2. The adaptation, in conjunction with NBA (Controls) Limited, of their commercial self-contained, bed mounted pressure recorder for long wave recording and subsequent field trials. Records have to be lengthy in order to obtain a representative number of long waves and this creates data storage problems. The modification aims at improving the efficiency of collection of site data on the spectral properties of long waves and their relationships to wave grouping.

3. The development and field trials of a repeater buoy to increase flexibility in the siting of shore stations for receiving transmissions from Waverider buoys, the standard equipment for measuring wave height and period at offshore locations. The repeater buoy will relay transmitted wave data so that line-of-sight positioning between Waverider and receiver station is no longer obligatory. The development will be in conjunction with NBA (Controls) Limited.

4. Commence the evaluation of commercially available pitch-roll buoys for measuring wave directional spectra. The requirement is for a relatively small system to serve for routine monitoring the same way that the Waverider is used for wave height and period. A satisfactory system will command much use for studies of harbour and breakwater design and in littoral drift assessment.

5. Continuing development to extend the range of application of HRS' pump sampling systems for sand transport measurement, in particular to facilitate handling of the equipment in deep fast estuarial flows. Continuation of an extra-mural contract with Cranfield Institute of Technology (begun in August 1981) aimed at the development of a battery operated system for the in-situ determination of the concentration and grain size distribution of the sand fraction in sand-silt suspensions. Both developments are required to inprove the capability of obtaining essential field data for evaluating the sediment regime of port approaches. Previous pump sampling systems developed by HRS have been marketed by Valeport Developments Limited.

6. Further work on commercial devices to measure flow velocity and direction in physical models for those applications where simple mechanical current meters are unsuitable. An acoustic current meter will be assessed for tidal model applications where velocities are very low. In addition, the range of practical utilisation of a laser velocity meter and interferometer will be explored to quantify the effects of water condition and boundary proximity and to determine range in backscatter mode of operation. The small measuring volume inherent with this device should open the way to instantaneous velocity readings under short-crested random waves in wave flumes and to detailed profiling of velocity in various laboratory sediment studies such as mud scour and deposition.

Programme variations agreed 30 August 1984

(a) Add

"4A. Having completed an appraisal of surface sensors for measuring wave directional spectra an alternative sub-surface system will be developed using a bottom-mounted velocity/pressure sensor and associated self-contained data reduction and logging system in accordance with Appendix C of Hydraulics Research Report IT 256. This constitutes a long-term development that will not be finished by March 1985. The objectives in the present contract term are limited to:

a completion of the design and laboratory testing of a central microprocessor capable of substantial data reduction before logging the significant spectral parameters:

b evaluation and decisions on the individual transducers particularly with reference to a solid-state velocity sensor having low power consumption and the design of driving circuits for the selected transducers".

(b) Clause 5, first sentence. Insert after "estuarial flows" the following: "and for measurements over sand beds which are subject to significant horizontal oscillatory flows under waves."

(c) Add

"5A. Assuming that the final report from the extra mural contract with Cranfield Insititute of Technology will confirm the practicability of using ultrasonics for measuring in-situ the concentrations and particle size of sand in a sand-silt suspension, further development is requird to progress from the existing laboratory analogue on which the principle has been demonstrated, to an instrument that is capable of operating in a field environment. It will be necessary for the development to continue beyond March 1985. In the current contract term the objectives are to manufacture a multiple acoustic transducer head; to design the circuits of low current drain to drive the transducers; and to achieve some preliminary signal conditioning. Further signal processing together with display and recording circuits; the underwater housing for the entire system; laboratory testing; and final field trials are not included in this contract.

(d) Clause 6. Add at end

"In 1984/85 the work will be restricted to exploring the application of the existing laser interferometry system to the measurement of turbulence in laboratory flow channels."

(e) Add a new Clause 7

"7. Purchase and evaluate a novel recording electromagnetic current meter that has recently been introduced onto the market. The instrument, the InterOcean S4, shares the merit of other solid state field current meters in not being as prone to fouling and damage as conventional mechanical meters but it also is so configured that it promises significant advantages in ease of handling and low drag compared with other electromagnetic and acoustic current meters. The instruments performance is to be evaluated in the laboratory and a follow-up field trial."

ANNEX 2

REPORTS AND PUBLICATIONS

Reference

1. The development of a repeater buoy for use with Waverider and similar wave-measuring buoys, C B Waters, Hydraulics Research Report No. SR17, 1985

2. Recent instrument developments enhance the capabilities of certain wave recording systems, C B Waters and T H A Sloane, Oceanology International Conference, Brighton, 1984.

3. Evaluation of a wave orbital buoy for measuring directional spectra at sea. M J Crickmore and R W P May, Hydraulics Research Report NO. IT 256, 1983.

4. Measurements of wave directional spectra at sea - a wave direction processor, M Towers, Hydraulics Research Report No. SR 16, 1985.

5. Ship movement recorder, I E Shepherd, Hydraulics Research Report No. SR 4, 1985.

6. A new pump sampling array for measuring the flux of fine sand suspensions. C B Waters and M J Crickmore, Hydraulics Research. Report No. SR 50, 1985.

7. The in-situ measurement of suspended solids, a review of the literature, C P Lenn, Fluid Engineering Unit Report, Cranfield Institute of Technology, 1982.

8. The feasibility of ultrasonic methods for measuring fine sand suspensions, C P Lenn, Fluid Engineering Unit Report TR/18423/7, Cranfield Institute of Technology, 1982.

9. The feasibility of ultrasonic methods for measuring fine sand suspensions, C P Lenn, Final Report TR 18423/19, Cranfield Institute of Technology, 1984.

10. Ultrasonic sensor for monitoring fine sand suspensions. Final Report, W/O 694. Bell Electronics Ltd., Aldershot, Hampshire, 1985.

11. Some tests on the Gytre "Minilab" ultrasonic current meter, Hydraulics Research, Technical Note 1/82, 1982.

12. Practical applications of laser interferometers, D K Fryer. Hydraulics Research Technical Memorandum 2/1983, 1983.

13. Two-component laser velocity meter. L J Smith, Hydraulics Research Report No. SR 40, 1985.