CHAPTER 4

DATA COLLECTION AND ANALYSIS
FOR
COASTAL PROJECTS

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INTRODUCTION

Modern design concepts for coastal engineering works make increasingly heavy demands in respect of the number of variables to be investigated, of the accuracy of the field measurements and of subsequent methods of analysis. In general the larger the projects the greater the demand for accurate site data but frequently, whatever the field data requirement might be, environmental conditions impose severe limitations upon the quality and quantity of the obtainable information.

Before field measurements commenced on the two projects reported in this paper (see Figures 1 and 2) careful consideration was given to the relation between the probable status of the data, the level of statistical analysis to be applied and the constraints the results might impose upon research objectives or upon projected works. Such appraisal was specially relevant since the projects drew upon results from both physical and mathematical models and, in one case, involved assessments of extreme sea conditions related to nuclear safety. This approach provided sufficient flexibility to adjust the method or extent of data collection to take advantage of optimum conditions in the field and changing requirements for input to models and designs.

The time and energy expended in obtaining data of the correct order of confidence was justified by its direct applicability to alternative designs in the face of rapidly inflating construction costs. It was considered essential that the planning and control of data collection be co-ordinated by the design engineer for relating individual items to the project as a whole. It was found equally important that the hydrographic surveyors and oceanographers, familiar with the physical aspects involved, understood how their results were to be applied and hence appreciated the necessity of achieving appropriate tolerances for different parts of the work.

OUTLINE OF CASE STUDIES

The paper describes two data collection programmes which had significant analogies despite being devised for sites remote from each other and for quite different purposes. Both sites had gently shelving sandy shores and seabed and in each case the severity of the wave climate and degree of exposure determined the choice and operating methods of field equipment. These were

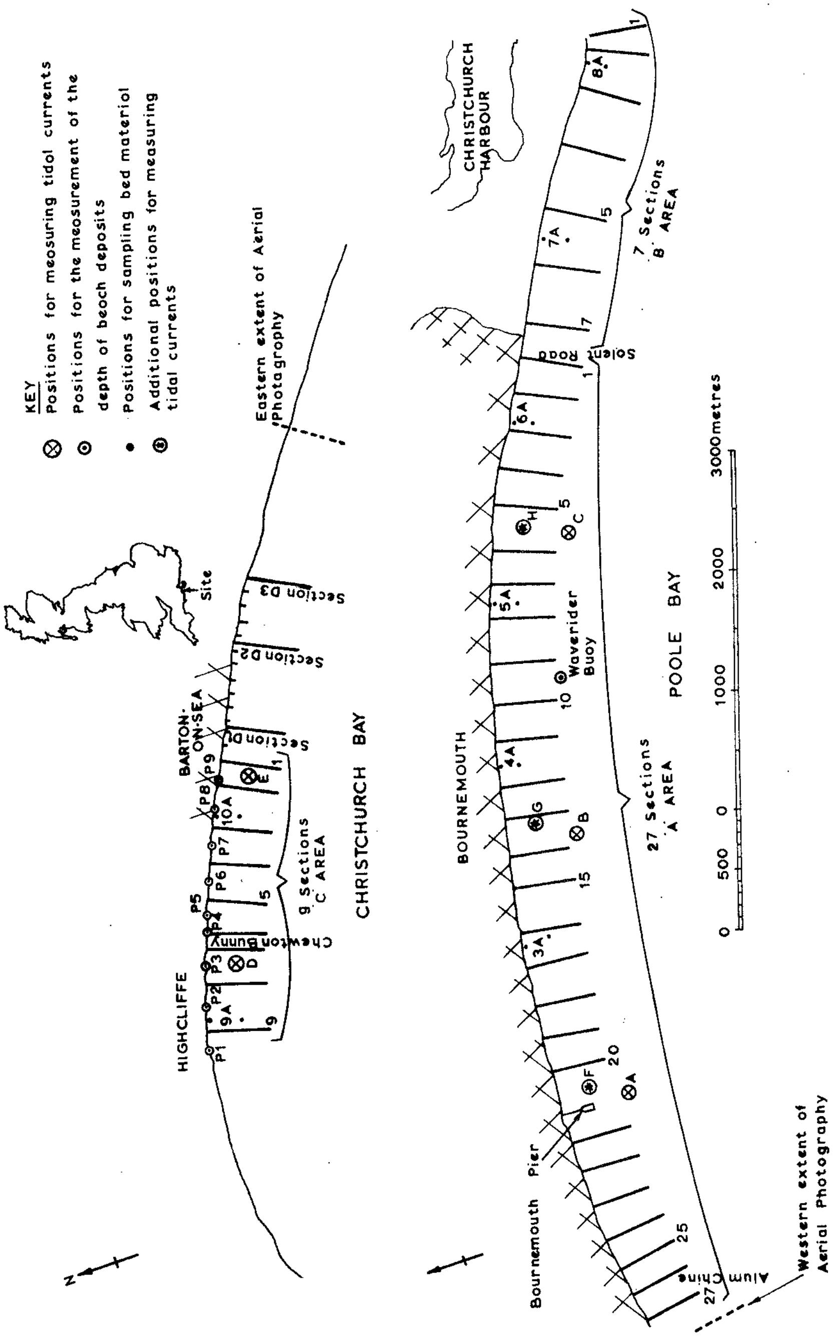


FIGURE 1. POOLE AND CHRISTCHURCH BAYS RESEARCH STUDY. POSITIONS FOR DATA RECORDING.

constraints that greatly affected the value of the data collected and established the tolerance standards for the data requirements.

Poole and Christchurch Bays Research Study

In the first project programme the primary study site was Poole Bay on the south coast of England, fronting the flourishing holiday resort of Bournemouth, where the beach was not only an amenity but provided protection to the promenade and cliffs. A secondary study site covered a short length of an adjoining bay where the beach was very small and had been insufficient to prevent rapid erosion of clay cliffs. As can be seen from Figure 1 both bays faced south, both had limited protection from the prevailing south-westerly storms, and both had fairly shallow shelving seabeds and beaches, the levels of which had been lowered during recent years.

Many of the problems at Poole Bay were analogous to those in other British coastal areas. Therefore the United Kingdom Department of the Environment agreed to sponsor a research project aimed at analysing the beach feeding parameters. The Authors were involved as Project Co-ordinators, being responsible for preparing Contract Documents and ensuring that the data was collected at the required time and was of an adequate standard for subsequent analysis by the Hydraulics Research Station, Wallingford. Colleotion of data from the two bays extends over a period of three years in association with the following schemes for coast protection:

a) In Poole Bay, renourishment of the beaches was undertaken by dredging about one million cubic metres of sand from an offshore bank and pumping this onto the beaches.

b) At the west end of the bay information on beach response was sought to the construction of two long semi-permeable groynes.

c) The headland between the two bays at the eastern end of 'B' area (see Figure 1) contained bands of ironstone which gave it a greater resistance to erosion than the surrounding material. Information was required on movement trends of mobile material past such a headland and its associated inshore shelf.

d) In Christchurch Bay, cliffs composed of overconsolidated clay were receding through a pattern of slumps, mud slides and mud flows. More information was required on the rate of recession related to the degree of beach protection at the toe and on the most suitable methods for beach development in this context.

(i) Hydrographic and Topographic Surveys

The surveys extended along 14 km of coastaline (see Figure 1) and consisted of 43 survey sections at approximately 400 m intervals. Each section profile began at the toe of the sea wall or cliff and terminated some 500m offshore or at the 9 m contour (5 fathom mark), whichever was the greater. These surveys were carried out immediately before and after the beach feeding and subsequently three times within the first year following completion of the sand replenishment. Further surveys were made at the end of the first year and then at six monthly intervals thereafter.

Each survey section was in fact a combination of topographic and hydrographic surveying carried out during a spring tide, the topographic survey at low water (LWST) and the hydrographic survey at high water (HWST). It was specified in the Contract that the topographic surveys wsre to be carried out within 1½ hours of LWST, and that the hydrographic survey was to be an extension of the topographic survey line carried out within 1½ hours of HWST. This method of operation ensured that there was a length of profile over which levels were repeated, this ovsrlap serving as a useful check on accuracy achieved, in particular that of the hydrographic work. It was also specified that the surveys had to be carried out within 24 hours of each other to ensure that recorded changes of beach levsls were kept to a minimum between the hydrographic and topographic surveys. In the hydrographic work horizontal and vertical tolerance limits were specified not to exceed ±1 m and ±80 mm respectively. For the topographic work it was obviously possible to obtain closer limits and the Specification required the points on a section to be within 1 in 5000 horizontally and ±20 mm vertically.

A recording tide gauge was installed at Bournemouth. This single installation was found to be insufficient to establish a datum for all the hydrographic surveying. The research area was under the influence of two amphidromic points and experienced flood peaks of varying height along its length. Consequently other temporary gauges had to be established along the frontage.

Current velocity measurements were taken every half hour at five stations and at four depths throughout a complete spring tide.

Some 200 bed samples were also taken, both onshore and offshore at regular intervals and their grain size distributions established. The depths of the deposits above the clay bed were also recorded at regular intervals at ths various sampling stations. These were repeated at the sams time as the surveys.

(ii) Wave Analyses

A waverider buoy was positioned in Poole Bay (see Figure 1). The buoy recorded for 20 minutes every 3 hours, producing information on parameters such as H_1, H_2, H_s, T_c, T_2 and E. The buoy had to be inspected once a month, taken out of the water, checked and cleaned, It was recalibrated every six months. The receiver was serviced every two weeks.

Wind data was also analysed from two recorders in the area and the wave data plotted in relation to the wind. Wave directions were observed visually from the cliff top once a day.

(iii) Aerial Survey

This provided stereographic coverage of some 20 km of coastline at a scale of 1 to 2500, the photographic coverage starting and finishing 1 km either side of the boundaries specified on Figure 1. The photography was to be carried out at LWST at six monthly intervals for a period of three years, with a cloud cover less than 10 per cent. Limiting tolerances with regard to crab and tilt were specified.

The aerial survey was later extended to cover the entrance to Poole Harbour to the west of the project area to assist in determining any tendancy for the beach feed sand to drift in a westerly direction.

(iv) Film

A film lasting some 20 minutes was commissioned in order to have a record of the research project. The various subjects to be recorded and the minimum duration of viewing time to be allocated to each item were specified. An allowance was made for additional footage of film.

Koeberg Nuclear Power Station

The site area, which lies some 27 km north of Cape Town on the west coast of South Africa (see Figure 2), consists of a zone of active dunes behind a gently sloping beach and sea bed. It is intended that a multi-stage development of nuclear power stations will be constructed at the site which together will generate some 6000 MW for the Electricity Supply Commission (ESCOM). The cooling water for the reactors is to be taken from a dredged basin, protected from wave activity by rubble mound breakwaters, and discharged as a low velocity jet south of the southern breakwater arm (see Figure 2). The site is exposed to the full force of the south Atlantic Ocean, the sea is rarely calm, and throughout most of the year there is a wide surf zone. During the summer, the site is affected by waves generated from the south and occasionally by storms travelling from this direction. In the winter, storm generation and waves from the north-west appear to predominate. Although the beach and offshore sea bed undergo seasonal changes there is no apparent net change from year to year (1).

On the west coast of South Africa the sea water temperatures are some 10°C below that of the ambient temperatures of freshwater lakes. According to Shannon (2) the main reason for this is that as the cold Benguela current, originating in the Antarctic, passes northward along the Continental shelf, upwelling is generated by the predominant southerly winds. However, this effect could be temporarily modified by north-westerly winds and therefore merited a detailed study as the upwelling of cold water has a direct bearing on the efficiency of the stations.

Mathematical models were used to predict siltation patterns in and around the intake basin (1), the susceptibility of the basin layout to seiche, resonance and recirculation patterns and temperatures for various discharge conditions. Physical models were used to establish the criteria for breakwater design and wave conditions within the intake basin.

Initially studies involving oceanographic measurements were carried out by the Institute of Oceanography of the University of Cape Town as early as 1968, as experience was gained using the data collected and, the project requirements were defined, it became apparent that a more intensive site investigation was required. A definitive data collection and processing programme was evolved by the Authors' firms with relation to the cooling water intake basin and discharge works. Data-gathering procedures were agreed and jointly developed with the National Research Institute for Oceanology (NRIO), together with the University of Cape Town who undertook this work.

(i) Hydrographic and Topographic Surveys

These surveys were undertaken on a quarterly basis for a period of 2 years using the survey markers shown on Figure 2. However, allowances were made for additional ad-hoc surveys after periods of extended calms or severe storms. It was intended that there should be an overlap between the beach and hydrographic surveys but, because of the almost continual occurrence of surf, this overlap was rarely achieved. In fact difficulties of surveying in the surf zone imposed severe restrictions on the data collection and on the accuracy of the survey. This problem was resolved during the course of the studies by the use of a ski boat fitted with a recording echo-sounder and a calibrated vertical pole fixed on it as a mast. When the ski boat indicated that it was making a fix on its echo-sounding trace a shore-based surveyor

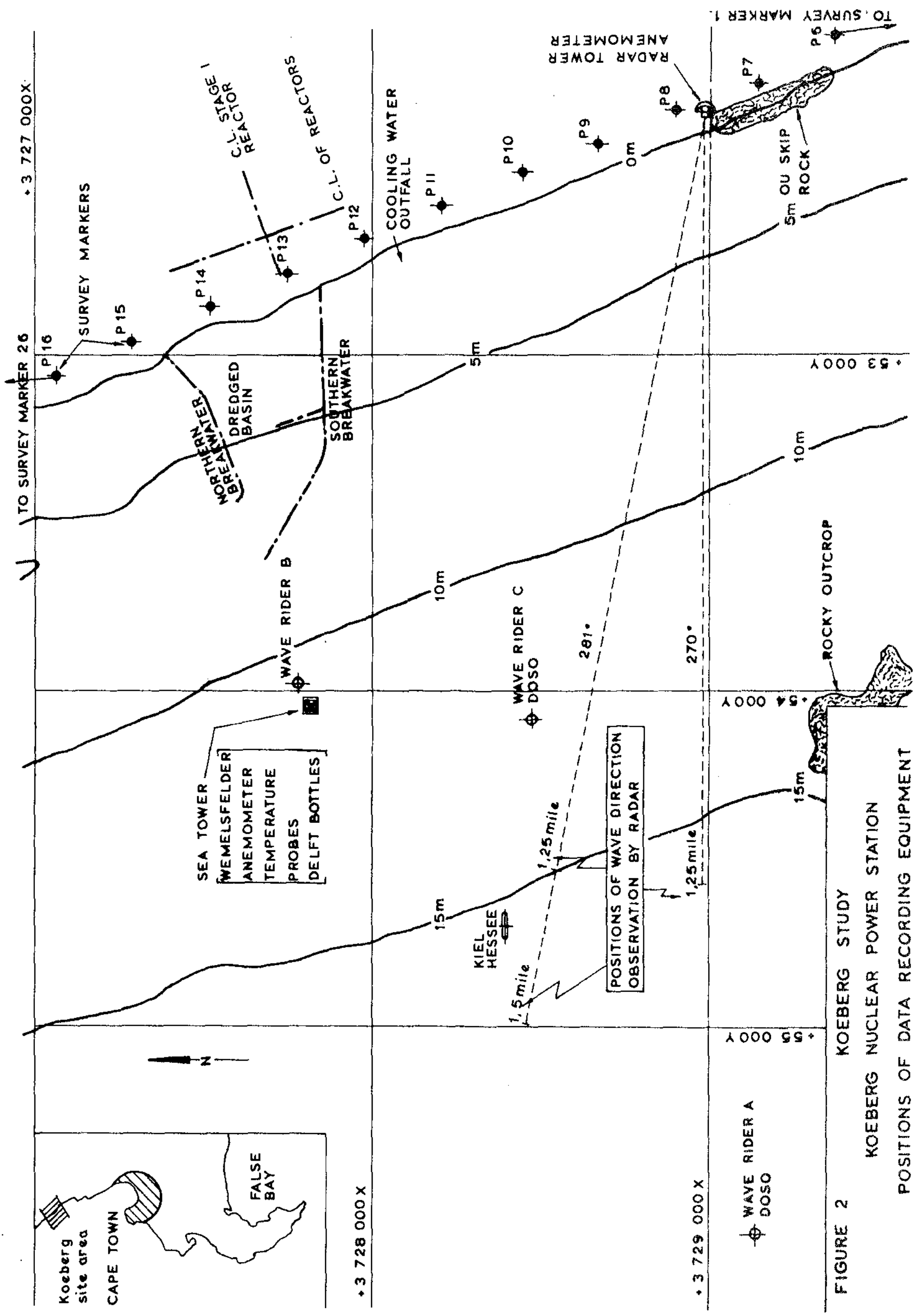


FIGURE 2 KOEBERG STUDY
KOEBERG NUCLEAR POWER STATION
POSITIONS OF DATA RECORDING EQUIPMENT

with a theodolite and camera attachment established the boat's position and elevation. This innovation ensured that the tolerances for the vertical accuracy of the echo survey were kept to an acceptable level.

In addition to the survey markers a series of beach poles was installed opposite the Sea Tower between low water and the dune area. Measurements of beach levels relative to the top of the poles were taken at weekly intervals and enabled a detailed picture of beach erosion and accretion to be established.

(ii) Wave Height and Period Data

Early in the data collection programme it was decided to install a Sea Tower in about 10 m of water (see Figure 2) and to operate it as a data collection centre. A Wemelsfelder float-operated wave height recorder, type W.R.67, which was installed on the Sea Tower in March 1972, provided basic wave data such as Hs, Hmax, H_{10}, Hrms and E.

Wave measurements were also taken using an NIO ship-bourne recorder on board the research vessel "Thomas B. Davie" during survey voyages, together with visual observations of wave direction. In general these records of the deep water wave spectra were discontinued once wave recorders were established at the site.

The main information on the wave spectra was provided by Waverider buoys A and B, installed early in 1974, and Waverider buoy C which later replaced buoy B. The buoys recorded for 20 minutes every 6 hours and produced an almost continuous record of wave conditions on the site. The buoys were calibrated and maintained regularly and the records were analysed to give wave parameters, in the same way as on the Poole Bay Project.

(iii) Wave Direction

In 1974 a Decca radar system type RM 919, which is the smallest of the commercial shipping range, was established in a recording hut on Ou Skip rocks at the south end of the study area. This system was based on that developed by the Institute of Oceanographic Sciences (3), with the scanning dish on top of a tower some 33 m (100 feet) above mean sea level. The radar was operated for 10 minutes every 3 hours and recorded the wave patterns photographically, with an exposure time equal to the time of a complete sweep of the radar scanner. This unique method of recording enabled the whole wave front pattern to be recorded as far as 2 km ($1\frac{1}{2}$ miles) seaward of the site. In addition, by recording the photographs on successive frames of a cine film the resulting time-lapse photographs presented a two-dimensional picture of the wave fronts as they were refracted and diffracted. By timing the radar photographs to coincide with wave buoy recordings, wave direction was added to the other parameters obtained.

The radar system could not be arranged, economically, to record wave directions as far out as Waverider buoy A. Consequently, a Doso meter (4) was introduced in 1975 as an additional tool for measuring these directions in deep water beyond the range of the radar. This recorder, which is a simple bottom-mounted flow direction indicator, was positioned initially next to Waverider buoy C for two months and calibrated against the radar records. Once calibrated it was stationed next to Waverider buoy A.

Observations of wave height, period and direction were also taken from data recorded under the international system operated by Voluntary Observation Ships (VOS) (5). Records for a limited sea area of Marsden Square No.45 were obtained and analysed for use in conjunction with the data obtained on the site in order to improve confidence in the deep water wave spectra. Predictions regarding wave directions were also made by correlating the spectral energy plots obtained for the waves with the low pressure areas in the south Atlantic which generated the waves.

(iv) Wind

Measurements of wind speed, direction and duration were taken both at the Sea Tower and on the observation tower on Ou Skip rocks using Lambrecht recorders. These wind readings were compared with longer term records at nearby airports and at a refinery, as an independent check on the results and as a method of extending the 3 years of site measurements.

(v) Currents

The spring tidal range was 1.5 m (4.9 feet) on this stretch of the South African coast, but the co-tidal lines were almost parallel to the coast. Consequently the tidal currents were small, and not normally measurable on conventional current meters. A Bendix current meter was installed at the Sea Tower and a Keil Hassee current meter was installed on the sea bed near Waverider buoy A, but each meter only recorded current velocities outside instrumental error range during full flood of a spring tide or at times of strong onshore winds.

Most of the data on currents was collected by using free and fixed drogue systems. Measurements using the free drogue system were taken either on an ad-hoc basis or to examine in greater detail the pattern of currents resulting from a specific wind condition. Current data from fixed drogues was obtained by measuring the distances and angles between three drogues connected in series. This was done each morning and evening, and from the observations the current speeds and directions could be calculated. The results were analysed together with wind records and a relationship between winds and currents was established.

(iv) Bed Samples

A number of samples were taken and analysed during the programme. The bed material throughout the area was in general fine sand with a D_{50} of about 0.1 mm, but occasionally the bed material was coarser in areas where rip currents predominated.

(vii) Suspended Sediment

Samples were taken initially using Delft bottles, attached to the legs of the Sea Tower, at a number of levels. This sampling method was too crude for prediction of sediment in suspension, needed as essential input data to the sediment transport model that was being developed. However, Professor Kilner was developing a vacuum-operated sediment sampler at the University of Cape Town (6) and it was decided to use this, though at the time it was untried. Initially samples were collected instantaneously in a vacuum bottle, but as this was unsatisfactory as a record for long period storm waves, a later development of the equipment enabled a continuous sample to be taken during the passage of several waves. To operate in the breaker zone the sampler was suspended from a helicopter which, although an expensive method, enabled samples to be collected at a number of depths within the water column and for a variety of wave conditions, without too much difficulty. A more complete description of the method can be found in Professor Kilner's paper to this Conference.

(viii) Sea Water Temperatures

Initially measurements using thermometers were taken at monthly intervals on research vessels within the area. However, this was found not to provide a representative sample and later conductivity type temperature probes were installed at three depths at the Sea Tower. Also, additional measurements were taken regularly over a period of two years at a number of positions by wading into the surf zone. These measurements proved to be most interesting and a clear relationship was established between the sea water temperatures and the wind driving the upwelling current.

PROBLEMS ENCOUNTERED

For major coastal engineering projects which merit extensive data collection programmes the problems encountered are numerous. The cost is high and, as Wright (7) has pointed out, the tender prices for the surveys can vary considerably depending on the engineer's specification and the contractor's assessment of the actual requirements. Any specification must not only allow for the logistics of collecting each set of data under a variety of sea and weather conditions, but also define the tolerances which can be applied in practice. In addition, it is generally necessary for the different types of data to be collected simultaneously. One set of data alone may be interesting, but to be of use it needs to be time-related to other different sets of measurements, e.g. hydrographic and topographic surveys require the continuous measurement of the wave climate and current patterns if the former are to be successfully analysed. For this it is essential not only to have back up equipment but also to adopt different methods of approach, so that any missing data may be filled in with some degree of confidence from alternative sources, or so that it can be used to correlate with other longer term records.

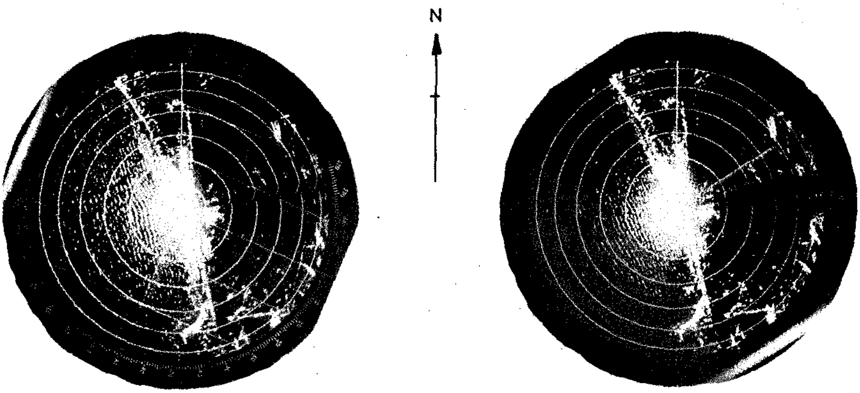
The limits of achievement of data collection from the two survey programmes of the projects described were dependent upon measurement of the wave-dominated environmental climate, the status of the project and the purpose intended for the use of individual observations.

At Koeberg, predictions of extreme events were required in relation to the safety of the nuclear plant. An intensive programme of investigations was called for in order to provide reliable input data for the complex physical and mathematical models. Even so the results obtained were limited by the severe marine environment.

At Bournemouth, the wave climate was far less severe and it was possible to use a much less intensive programme of investigations. However, on occasions important records could still not be obtained during the winter months.

Considering the problems that arise from the wave climate, some of the basic wave parameters can be relatively easy to collect. Waverider buoys were successfully employed on both projects and achieved a very high rate of useful collection. A buoy broke loose during the worst storm on both projects, resulting in a gap in the wave record while the buoy was reinstated. This also meant that the peak wave energy condition went unrecorded and consequently affected the predictions of wave and surge conditions which were dependent upon them. The Wemelsfelder recorder on the Koeberg Sea Tower also failed to provide a continuous record because, during major storms, waves broke over the tower and tended to force the instrument's float into the top of the well chamber.

The VOS observations were useful in that they provided relatively long-term records and gave an indication of the deep water climate.



DATE 27.MAY.74 TIME 09.00

Hmax = 3.8 m

Hs = 2.5 m

Tc = 7.5 secs

DATE 5.JUN.74 TIME 12.01

Hmax = 2.0 m

Hs = 1.3 m

Tc = 9.4 secs

FIGURE 3. WAVE FRONT PATTERNS RECORDED PHOTOGRAPHICALLY USING RADAR.

Establishing the direction of waves has always been a problem. Visual observation from cliff tops, such as at Bournemouth, proved satisfactory but only represented the near-shore, refracted, waves at one point along the 14 km coastal study area. Although this information could be used to back-track the wave rays in order to derive the deep water spectra, which could then be refracted in elsewhere along the coast, this process can pose many problems principally arising from the nature of the model grid. At Koeberg good results were obtained by combining radar records (see Figure 3), which also required a high vantage point, with Doso records. On their own the radar records were not entirely satisfactory as, even in the severe wave climate at Koeberg, only about 35% of the waves were recorded during a year, i.e. those waves which were sufficiently high and steep with, in general, 'fluffy' crests. However the radar faithfully recorded sufficient wave fronts over a fairly wide sea area and, by use of time-lapse photography, the refraction pattern of a wave as it shoaled could be checked against calculated values. Radar equipment had the further advantage that it was entirely land-based and could be easily serviced. This was not the case with the Doso meter, for which a diver was required to retrieve the records and to service the instrument. If subsequent analysis showed a fault in operation to have occurred, a section of the readings might have been omitted and lost. However, in general the Doso meter gave an excellent point recording of wave direction and proved to be a powerful tool when used in conjunction with radar recordings.

At the time of the project study an alternative concept for determining wave direction was fortunately being developed by Dr Harris of the University of Cape Town and this was expanded in private correspondence.

In brief the deep water wave directions were established by comparing synoptic weather bulletins with contoured plots of spectral wave energy arrivals against wave frequency and the time of recording.

These contoured plots, normally covering a period of about one month, showed a series of high and low areas, representing times of peak energy arrival or of relatively quiescent periods respectively. The scales of the plot were calibrated so that a line drawn through the major axis of the peak area intersected the time abscissa at the date on which the generated storm waves had originated, and the included angles gave the distance to the storm centre in degrees of latitude. Examination of the weather bulletins showing the location of the isobars of the low and high pressure areas for the period preceding the arrival of the peak energy condition provided an essential check on the calibration.

This method was proved by comparing the results against those of the other methods of measuring wave direction and, once proved, was used to fill in missing data.

It was found that the hydrographic and topographic surveys were greatly influenced by wave activity. This was because wave energy not only alters the onshore and offshore topography and bathymetry but, as has been mentioned earlier, also affects the practical aspects of the survey itself. Cross (8) who discusses the many sources of error that can occur in inshore surveying also acknowledges the important influence of the wave climate. At Bournemouth the surveys were timed to coincide with spring tidal conditions to ensure that there was an adequate area of overlap between the topographic and hydrographic surveys.

On at least two occasions, rough seas led to a postponement of the surveys and only three out of eleven surveys were fully completed in the time specified. At Koeberg one of the surveys was abandoned altogether due to sea conditions. It was found that the zone of overlap on each line could be extended and thus the accuracy of the survey improved by using a survey pole with disc base for topographic surveying which could be taken into the water by a man in a wet suit. This technique was successfully employed at Poole Bay to extend the topographic survey by some 20 m, but at Koeberg the surf conditions rapidly halted progress outwards and overlap was rarely achieved. Even under ideal conditions, as can be seen from Figure 4, the overlap does not always give a good solution.

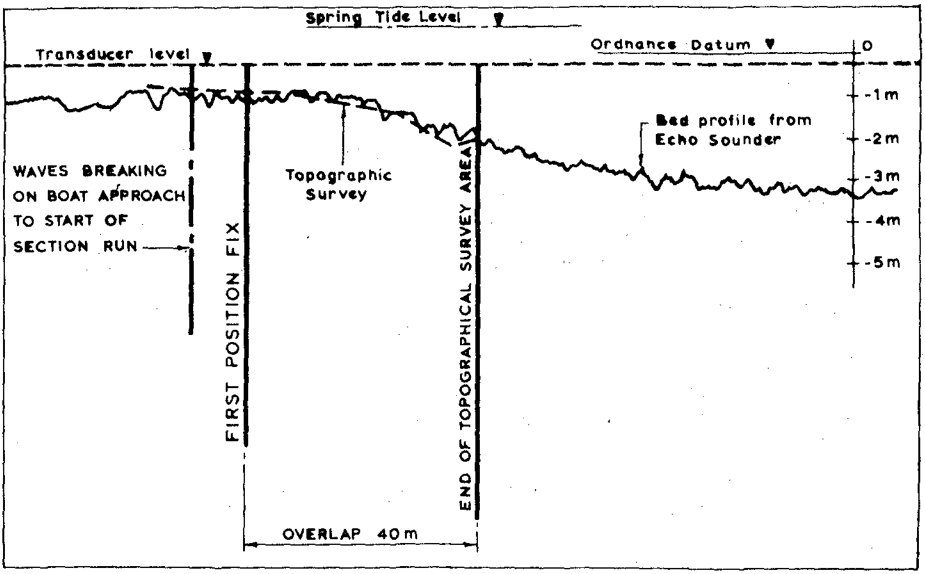


FIGURE 4. POOLE AND CHRISTCHURCH BAYS RESEARCH STUDY.
OVERLAP OF HYDROGRAPHIC AND TOPOGRAPHIC SURVEYS.

The overlap between the two surveys cannot be relied upon to provide a datum line for the hydrographic survey. The reference level must be related to datum using the tidal level at the time of the survey, especially at the seaward end of the section. This presented few problems at Koeberg which has a small and reasonably regular tide. The Bournemouth coast, however, under the influence of two amphidromic points (see Figure 5), caused tidal differences in the two bays which were not only notable from tide to tide but also varied during a tide. A careful check had to be made of the tidal level variation along the coast by the installation of additional tide boards.

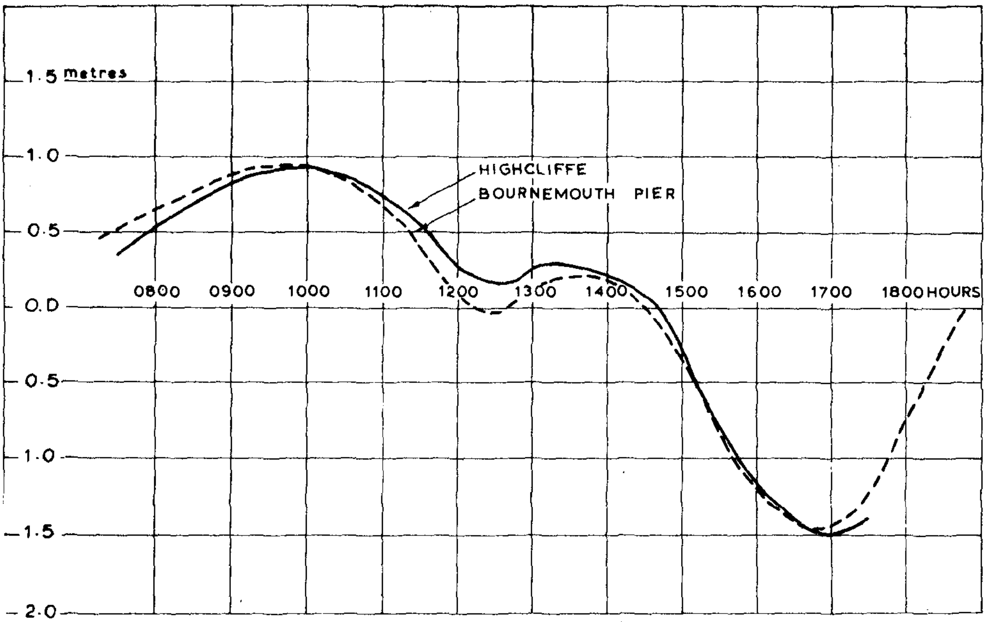


FIGURE 5. POOLE AND CHRISTCHURCH BAYS RESEARCH STUDY. SPRING TIDAL OBSERVATIONS FOR 17 FEBRUARY 1976

It was realised that the mathematical model for sediment transport, developed specially for the Koeberg project, would rely heavily upon site data records, especially on suspended sediments in relation to wave height. When the studies commenced, no reliable method was known for obtaining suspended sediment samples in the surf zone. Fortunately the 'Kilner' sampler was developed, providing suspended samples in waves up to 6 m high which showed good correlation with those developed from theory (1).

In areas where tidal current predominated conventional current meters were adequate and, if used during spring and neap tidal cycles, the tidal current pattern could be easily established. Where the tidal currents were low or non-existent the current pattern had to be established using drogues. This required at least one year's data, preferably taken on a daily basis, which was possible using a fixed drogue system. A relationship had then to be established between the currents and the wind driving them. This proved possible at Koeberg and the relationship was used together with the continuous records of wind to predict flow patterns.

CONCLUSION

It can be said with confidence that a data collection programme can be accurately planned only when the parameters to be measured are known. Clearly this is an unrealistic situation and consequently latitude must be allowed in the collection programme for lack of knowledge by, if possible, providing for more than one method of measuring the data. This requires thought, planning, finance and an assessment of what the answers will be. A complete set of data taken at the same time is essential to any project, especially if models are employed. No matter how sophisticated the theory or advanced the modelling technique that is adopted, the quality of the answer will directly reflect the quality of the data fed in.

It is also essential that, when planning data collection, the engineer understands the technique to be used and the practical difficulties involved. He must not demand a level of accuracy that is impossible or, unless he makes provision for it, extremely expensive to achieve. On the other hand the hydrographer or University Department must realise how the data which they collect is to be used and what influence it has on the project as a whole. The engineer must not be afraid to experiment but should not rely entirely on new untried equipment which tends to produce results later than expected.

In general the cost of taking measurements of the coastal environment are high but their true value is not always apparent at the beginning. The Authors have found that because of this high cost many institutions are willing to undertake analyses of data on a shared use basis. Co-operation of this kind between research personnel and practising engineers can be very beneficial to a project as a whole.

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