

CHAPTER 232

HYDRODYNAMICS AND SEDIMENT CONCENTRATIONS AT WALKER BAY

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Abstract

A novel and cost-effective technique for measuring sediment concentrations in high energy surf zones, using a helicopter, was developed and applied at Walker Bay, South Africa. Using this technique, which involved an innovatively operated suspended sediment sampler (TASSS), 280 sediment samples and hours of continuous sediment concentration measurements (with a transmissometer) were acquired at several levels. Currents and waves were also measured at several positions along a cross-shore section. The helicopter was also used to successfully survey the nearshore area using a new method. Spectral analysis of wave and concentration data show responses of the sediment concentration to incident and infragravity waves beyond the surf zone, while suspension is seen to be more intermittent in the surf zone. The concentration profiles beyond the surf zone exhibited typical exponential distributions. Reasonable correlation between the TASSS and the transmissometer was found.

Introduction

Knowledge about sediment transport in the nearshore zone is of vital importance for the design of harbours and for the understanding of the processes causing beach erosion and the factors controlling the stability of estuaries. It is against this background that the CSIR undertakes field exercises as part of a research programme. The aims of these exercises (Schoonees, 1990) are to develop low-cost measuring techniques that are capable of measuring in high energy surf zones and to obtain accurate data under South African conditions against which to check the accuracy of predictive techniques.

During a previous exercise in November 1987 (Schoonees, 1990), field measurement techniques were developed to determine suspended sediment concentrations in the inner surf zone. From 12 to 15 and from 19 to 23 February 1990 a fourth field exercise (CAESAR 4) was held at Walker Bay on the Cape South Coast of South Africa (Figure 1) to measure sediment concentrations in the outer surf zone. One of the specific aims of this exercise was to test newly-developed equipment and its deployment procedures, thereby

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ensuring the capability of measuring sediment concentrations in the outer part of high energy surf zones.

Previous researchers tackled the problem of measuring in the outer surf zone by either deploying instruments from a permanent or temporary pier (e.g. Watts, 1953, Fairchild, 1977, Derks and Stive, 1984 and Antsyferov and Kos'yan, 1990), by using a helicopter (Kilner, 1976) or using a sampler attached to a rope between the shoreline and an offshore anchor (Kilner, 1976). At sites with large tidal variations like in the United Kingdom, it is also possible to deploy instruments in the dry during low tide and then to sample during high tide (Soulsby *et al.* 1990). In South Africa, however, the tidal variations are too small to do this.

It was decided to make use of a helicopter because a pier was not available and would be expensive to construct. In addition, a helicopter is very versatile for other applications during the exercise, (e.g. aerial photographs and survey work) and is useful at remote sites. The helicopter was also used to develop a new technique to measure nearshore profiles.

This paper describes the field exercise, with emphasis on the sediment concentration measurement. Environmental conditions, instrumentation, measuring techniques and finally some results are presented.

Site Description

Walker Bay, situated about 120 km south-east of Cape Town (Figure 1), is a large sandy bay of about 20 km length, which is completely exposed to the dominant incident southerly to south-westerly deep-sea waves (Schoonees, 1990). The 1 in 1 year and 1 in 100 years deep-sea significant wave heights are 7,6 m and 11,1 m respectively (Rossouw, 1989). Peak wave periods ranged between 5 s and 22 s with a median value of about 12 s. Surf zone widths of up to 500 m are not uncommon.

During the February 1990 exercise, the median grain size of the bed material was 0,30 mm. The slope of the beach face was about 1/16 while the nearshore slope was about 1/90.

Strong longshore currents (often 0,5 m/s) occur regularly. The mean spring tidal range is 1,44 m. The main wind directions are south to east in summer (December to February) and west to north-west in winter (De Decker, 1989).

The layout of the test site is shown in Figure 2. A temporary camp was established just behind the frontal dune where measuring equipment was stored, the helicopter refuelled, water/sediment samples were removed and data from the instrumentation transferred.

Instrumentation

General

Instruments were deployed on a line perpendicular to the shore (Figure 2), in order to measure the cross-shore variation of the wave height, longshore current velocity and the suspended sediment concentration in the

outer surf zone. Outside the surf zone in 20 m of water an Endeco directional wave buoy and a pressure transducer was anchored. A pressure transducer and an array of electro-magnetic current meters (Colbrook meters with discus heads) attached to an H-frame, were jetted into the sandy sea bed by divers at 5 m and 10 m depths .

In the inner surf zone a single current meter was manually installed on a fixed frame. In addition, a helicopter was used to place two frames at different places in the surf zone. One frame contained a pressure transducer and current meter while the second frame contained a "remote controlled" Time Averaged Suspended Sediment Sampler (TASSS), a sub-frame with an array of transmissometers (called Brutus) and a pressure transducer.

Although different sensors have been used to measure instantaneous concentrations (see e.g. Huntley, 1982, Brenninkmeyer, 1974 and Beach and Sternberg, 1988), a transmissometer was chosen for this purposes due to its availability. The Kilner suction sampler (Kilner, 1976) was not used to obtain time-averaged concentrations because it is bulky and as such will disturb the flow and limit the number of samples that could be taken per day.

Because of its reliability and simplicity, it was decided to modify the suction sampler of Nielsen (1984) for deployment with a helicopter.

Time-Averaged Suspended Sediment Sampler (TASSS)

The purpose of this sampler was to extract undisturbed water/sand samples at different elevations at a predetermined position so that time-averaged sediment concentrations can be obtained. The actual starting time of sampling was important to correlate the result with the transmissometer at a later stage. The principle of pressure difference between the suction inlet and the air outlet of the sample jars was used to suck in the samples (Nielsen, 1984). The intake velocities (about 1,5 m/s) were checked to give a well-defined relation between measured and real concentrations under field conditions (Bosman, 1982). The sampler was placed landwards of the transmissometer position at the side of the deployment frame in order to minimise the disturbance to the other instrumentation (Figures 3 and 4). In addition, a thin cantilever arm was used from which samples were sucked about a metre away from the main frame (Figure 4). Careful placing of the frame by the helicopter was therefore critical in order to avoid damage to the fragile cantilever arm.

A reliable triggering mechanism was required to initiate sampling as soon as the frame was properly placed on the sea bed and the disturbance to the sediment during placing had subsided. A system of pressurising the sample jars by means of compressed air which is released from a seven litre scuba tank on impact with the water surface was used. Figure 5 shows the pressurising principle in more detail. One common air outlet was used. The triggering mechanism consisted of a float which was attached to a valve on the scuba tank. A lock mechanism was attached to prevent opening and closing of the valve due to wave action after initial triggering. The delay in operation was in the order

of 2 to 3,5 minutes depending on initial pressure in the scuba tank. Considering the relevant settling velocities, this was deemed to be adequate for disturbed bottom sediment to re-settle. The delay in relation to the pressure in the scuba tank was calibrated in the laboratory in 1,3 to 1,5 m tanks and also in a 4,5 m deep pool.

The system was designed so that air bubbles do not disturb the flow regime near the intakes during pressurisation and so that the intake lines are cleared prior to sampling. Special care was also taken in the design to prevent overflowing and subsequent mixing of samples as well as to prevent loss of the samples when retrieving the frame by helicopter.

Transmissometer

The transmissometer is used to measure sediment concentration continuously, based on the principle of the attenuation of a light beam by suspended sediment. The seven beam transmitter/sensor pairs and the data logger are shown in Figures 3 and 4. These were manufactured at the CSIR. The transmitter housing consists of a PVC tube containing a lens and a light source with its driving circuit. The light shines through a glass window at one end. The receiver housing is similar but slightly longer than that of the transmitter, in order to prevent direct ambient light from reaching a phototransistor and causing erroneous readings. The instrument was operated at a frequency response of 2 Hz.

Since the instrument is sensitive to grain size, it is necessary to calibrate it with the sediment from the site of measurement. The calibration was carried out in a tank in which sand is suspended by the rapid oscillation of a grid. With the use of a pump, the sediment concentrations corresponding to transmissometer readings are obtained, yielding an exponential calibration curve.

The transmissometer is very sensitive to water turbidity due to fine particles. This "background" turbidity had to be removed from the measurements. In addition, the instrument is strongly sensitive to bubbles. Nevertheless, accuracy was sufficient to obtain some useful results.

Field Procedure

In the inner surf zone a combined pressure transducer and electromagnetic current meter was installed on the sea bed at low tide. Two frames were designed for helicopter deployment. The frames were manufactured from galvanised steel tubing and had overall dimensions of 5 m x 2 m. One frame contained an electromagnetic current meter while the other frame contained the TASSS, transmissometer and a pressure transducer (Figures 3 and 4). Problems that had to be overcome using deployment by helicopter (a small Jet Ranger with a maximum lifting capacity of 450 kg) were:

Placing the frame in a predetermined position

A series of prisms was connected to the skid of the helicopter and by means of a theodolite and electronic distance meter (EDM) and radio contact

between surveyor and pilot, the pilot could be guided to the correct position. The frame was attached to the quick release hook of the helicopter by means of a rope and swivel connectors. The frame was therefore rotating continuously. The rope was connected to an off-centre arm on the frames (Figures 3 and 4) causing the frame to hang slightly forward (Figures 6 and 7). Before the frame was lowered it was allowed to rotate to the correct position. Thereafter it was dropped on its "back legs" and pushed forward by the waves and the helicopter (Figure 7). Although at this stage the frame was more or less in its correct position, it could still be adjusted by the helicopter. The hoist rope was left in the water with a buoy. This was retrieved with a grip (hook) attached to a thin line by which the rope attached to the frame was pulled up and then reconnected to the helicopter.

Stability and strength

In order to withstand wave impact the frame was given the dimension (in plan) of 5 m x 2 m (5 m perpendicular to the wave crests). The length of five metres was chosen because when lowering the frame in five metres of water (about the maximum placing depth) it was still visible when its "back legs" touched the sea bed. At that stage it could be observed whether the frame was in the correct position and if it would possibly overturn. The 2 m width was chosen as a practical width for stability and for overland transport purposes. The layout of the frame is shown in Figures 3 and 4. To prevent the frame from sinking too deeply into the sand, galvanised steel tubing was used, because this has a relatively large surface area. This also provided the necessary structural strength and caused the least local turbulence. Flat bars were welded on underneath the tubing (Figure 3) to limit the sliding of the frame during deployment. Diving inspections revealed that the frame sank into the sand up to the centre of the bottom tubing.

Weep holes of about 20 mm diameter, were made near the ends of the tubing of the frame. These were covered with permeable cloth preventing sand from entering the tubing but allowing air to escape, thereby improving the stability of the frame. At the same time, these holes allowed the water to run out again when the frame was retrieved so that it was not necessary for the helicopter to have to pick up the added mass of the water.

Five to six deployments were performed over the turn (3 h) of each tide (during which the water level stayed virtually constant). The electromagnetic current meter was first deployed and remained at the same position during the measuring cycle of three hours. The sampler frame was first deployed beyond the surf zone and then subsequently at different positions in the surf zone. Measurements were taken for 20 minutes each time after which the frame was retrieved and sample jars were replaced. The turn around time was about 30 min. Measurements were taken on seven days and 56 helicopter deployments were undertaken in total.

Beach surveys were performed before and after each series of tests. The beach sections were taken by theodolite, EDM and staff with prism. For the nearshore measurements use was made of a 6 m high stand on which three

prisms were attached at the top. This stand was placed in the surf zone by helicopter (Figure 8). Communication between surveyor and pilot was maintained by means of radios. Very accurate surveys were obtained in this way.

Results

Hydrodynamics

Figure 9 illustrates the prediction of wave height with distance offshore, using the wave transformation model of Battjes and Janssen (1978) and Battjes and Stive (1985) (called the Battjes model hereafter). As can be seen, the model provides a good prediction of the measured values. Furthermore, accurate predictions of wave height and direction, using the refraction model RCPWAVE (Ebersole *et al.*, 1986), were found to compare very well with measurements obtained from the pressure sensors at the 20 m, 10 m and 5 m depths.

TASSS

In total, 280 samples were successfully collected during the 56 deployments. All samples were accurately weighed (to determine the volume) and sediment was separated from the samples. The concentrations were calculated and adapted using the results from calibration tests as presented by Bosman (1982), whereby the measured concentrations were multiplied by a factor of 1,37. The concentrations were subsequently plotted and some typical results are shown in Figure 10.

It can be seen that an exponential distribution exists over the first metre above the sea bed. The samples collected at the highest intake showed relatively high concentrations for that particular day. The reason for this is that the top intakes were sampling only when large waves were passing by, while during lower waves the inlet was exposed to the air. It was often found that the sample jar connected to the top intake was only partly filled.

Transmissometer

Figure 11 illustrates a typical concentration record from the transmissometer in the shoaling region, together with the wave record. Truncation of the concentration record of the lower sensor can be seen; this occurred at high concentrations and in the presence of bubbles. Careful observation shows that the peaks in the sediment concentration record correspond to peaks and troughs in the wave record, indicating a response to wave orbital motion. In addition, an increase in the mean concentration in response to wave groups is evident.

Figure 12a illustrates wave energy spectra and spectra of the sediment concentration in the shoaling region (outside the surf zone) and in the surf zone (measured less than one hour later). In the shoaling region (Figure 12a) a clear peak is evident in the wave energy spectrum at about 0,08 Hz. A second peak can be seen at 0,017 Hz, apparently representing the group-bound infragravity

wave energy. Corresponding to these, clear peaks are evident in the sediment concentration spectrum.

A different situation is, however, evident in the surf zone (Figure 12b). Although an energy peak in the sediment concentration spectrum is evident in response to the incident wave frequency (although somewhat shifted), no clear response occurs at the infragravity wave energy. Rather, an increase in the spectral energy of the concentration with decreasing frequency in the infragravity region towards 0,0 Hz can be seen. Experimentation showed that this type of spectral shape is indicative of intermittent (i.e. non-periodic) sand suspension events.

It is worthwhile to point out that linear spectral analysis of sediment concentrations does have limitations, since the non-linear "spiky" nature of sediment concentration records can cause erroneous energies in the spectrum. This is recognized in the above analysis, which is taken in the context of comparative results between the shoaling region and the surf zone.

Figure 13 illustrates the simultaneously sampled results of the transmissometer and TASSS, averaged over five deployments in the shoaling region under similar wave conditions (depth about 3 m and a significant wave height of about 1 m). The lowest transmissometer result is eliminated from this analysis due to frequent truncation of the record at higher concentrations. As can be seen (excluding the sensor at 1,046 m elevation, which was found to be erratic) the exponential distribution is found from the transmissometer results as is expected beyond the breakers (Nielson, 1984). In the case of the TASSS, an exponential distribution with a similar slope and of the same order of magnitude is found.

Figure 14 illustrates the results of comparisons between concentrations obtained from the TASSS with concentrations measured with the transmissometer. The comparison is limited to cases where the transmissometer record was not truncated due to bubbles or high concentrations. A tendency of the transmissometer to give relatively lower readings at high concentrations is apparent. Over 75 % of the concentrations agree within a factor of four. This type of result is to be expected since the two instruments are approximately 2 m apart, and the timing of their sampling is not perfectly correlated. Huntley (1982) confirms this; he considered that a 50 % agreement between an *in situ* calibration and a laboratory calibration would be a "good match". In a similar comparison, sand flux measured with a streamer trap sampler is compared with measurements from an optical backscatter sensor, OBS (with flow measured with a current meter). Agreement is found within a factor of 3,5 with 68% certainty (Rosati *et al.*, 1991).

Beach and nearshore surveys

During the exercise seven beach and nearshore surveys were undertaken. The results are shown in Figure 15. It is shown that the largest variation occurred at -0,5 m mean sea level (MSL) to -2 m MSL. A maximum vertical variation of 0,75 m occurred within the seven days. Also clearly shown are the

two offshore bars. These were situated at -3 m MSL and at -1 m MSL. The outer bar was fairly stable while the nearshore bar was highly dynamic.

Reasonable to good correlation was obtained between the helicopter survey and the conventional theodolite and staff method in the regions where the profiles overlapped (Figure 15). It has to be taken into account that the measurements were not done simultaneously nor at exactly the same positions.

Conclusions

Techniques for measuring in high energy surf zones have been successfully developed. Particularly successful was the use of the helicopter, allowing extreme flexibility and accurate positioning of instrumentation and proving to be cost-effective. In addition, a time-averaged suspended sediment sampler, operating on simple and reliable principles, allowed a large number of samples to be collected in a short time.

Measured wave heights compared favourably with predictions using the Battjes model. Despite some serious limitations, due primarily to truncation of the record and the influence of bubbles, useful recordings were obtained with a transmissometer array, especially with regard to almost instantaneous concentration phenomena. In the shoaling region, sediment suspension due to wave orbital motion and due to wave groups was evident. However, although suspension does occur at the incident wave frequency in the surf zone, it mostly occurs in the form of intermittent events. A further result was the occurrence of exponential distributions of sediment concentrations beyond the breakers. Comparisons of the transmissometer with the TASSS showed that over 75% of the concentrations agree within a factor of four. This type of result is typical of previous, similar studies. Finally a simple yet accurate method was devised to measure the nearshore bathymetry (up to 6 m depth) by means of a helicopter.

Acknowledgement

The field exercise was a team effort. We would like to thank Messrs J P Möller, F van Dulm, L van der Merwe, A K Theron, C Roux, E Mabile, J de V Serdyn, W Daniels, H J A Davids, Miss J B Crowley and Dr J W Gonsalves for their contribution. A special word of thanks is due to the pilot Mr K Wittle and the flight engineer Mr S Harbottle for excellent flying.

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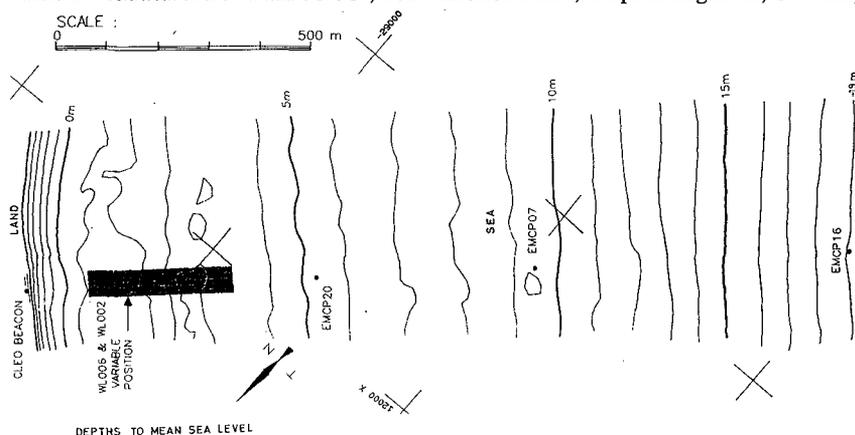


Figure 2. Field experiment layout

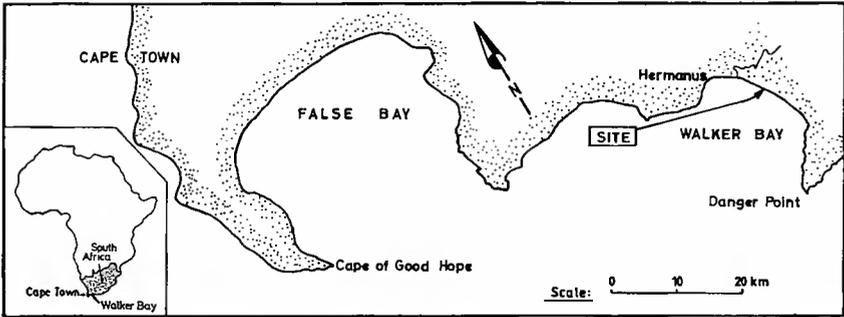


Figure 1. Locality map

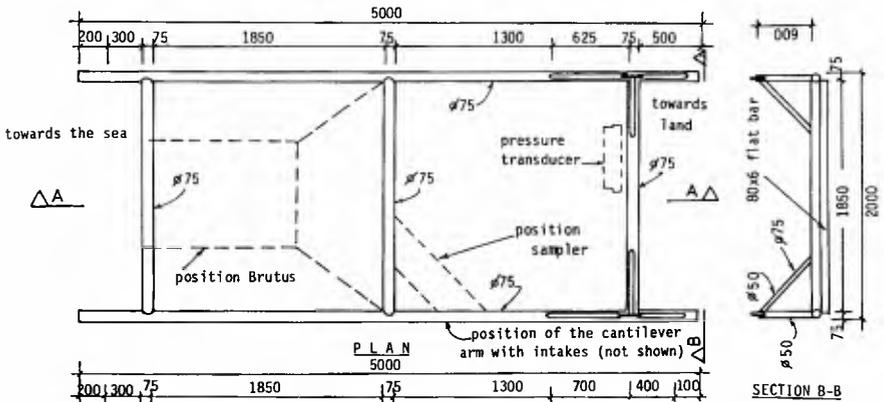


Figure 3. Details of the deployment frame

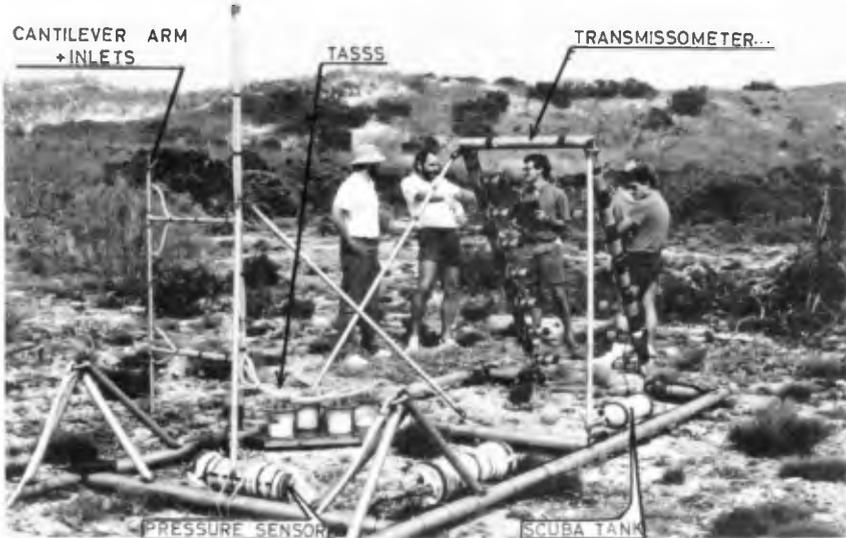
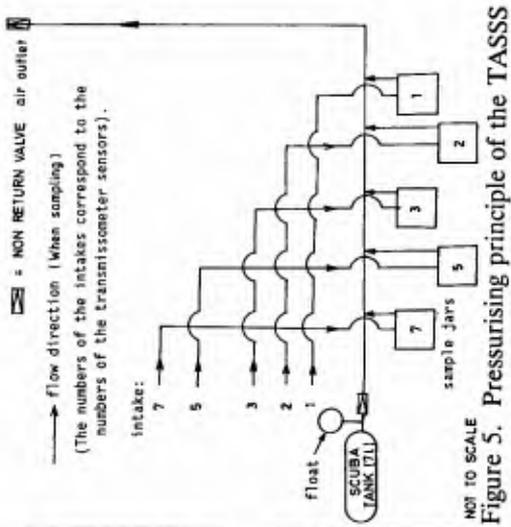


Figure 4. Deployment frame and instrumentation



NOT TO SCALE

Figure 5. Pressurising principle of the TASS



Figure 7. Placing of the deployment frame



Figure 8. Survey stand deployment

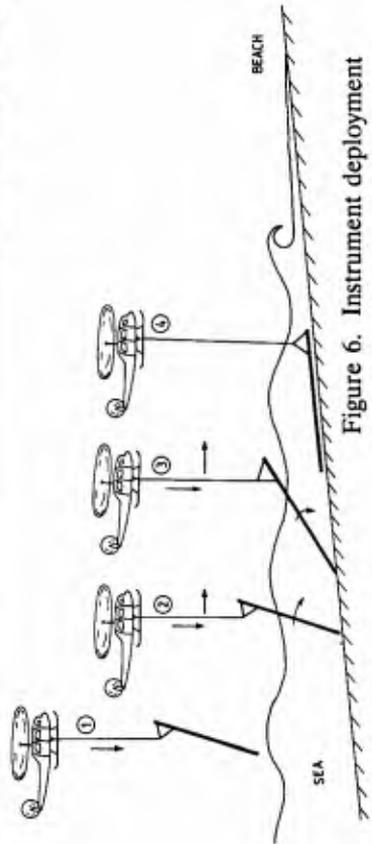


Figure 6. Instrument deployment

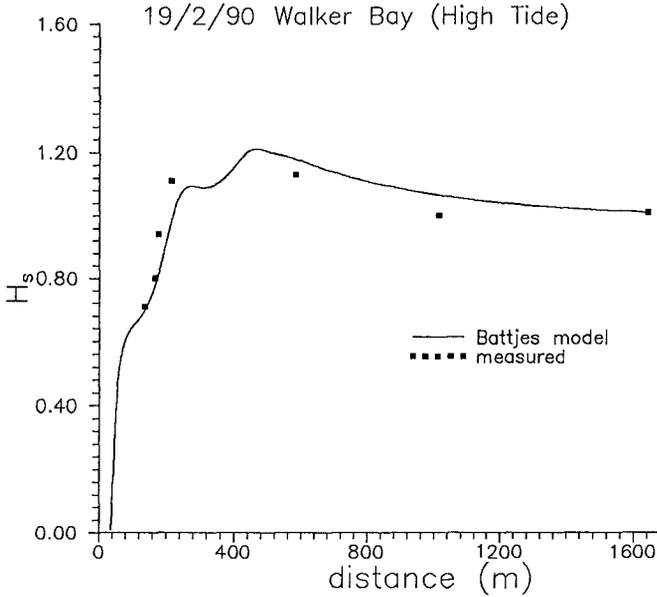


Figure 9. Nearshore wave transformation.

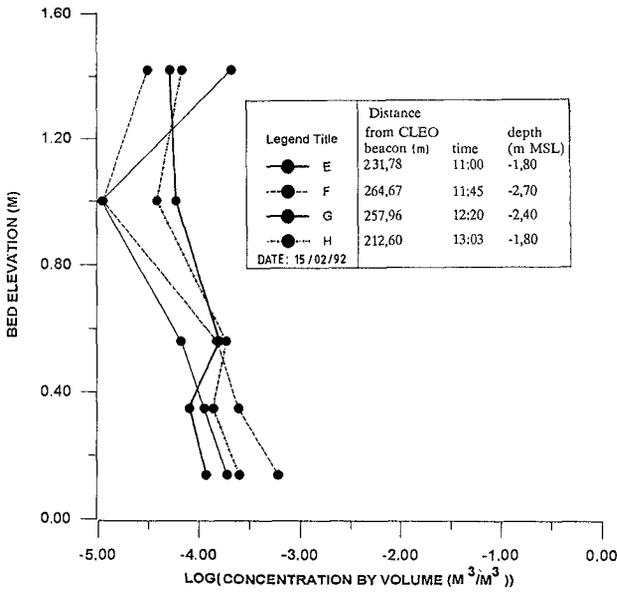


Figure 10. TASSS results

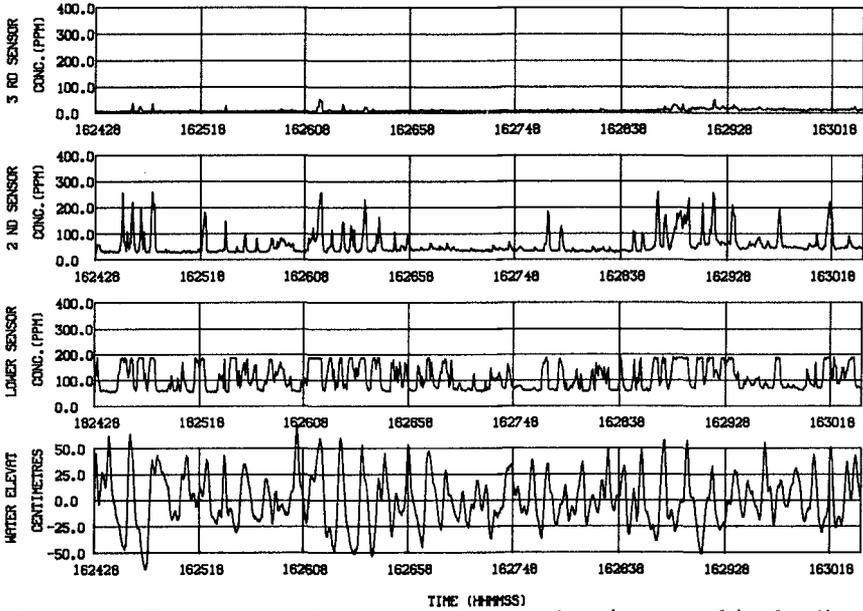


Figure 11. Typical transmissometer and water elevation record in shoaling region (depth = 2,8 m, H_{mo} 1,11 m)

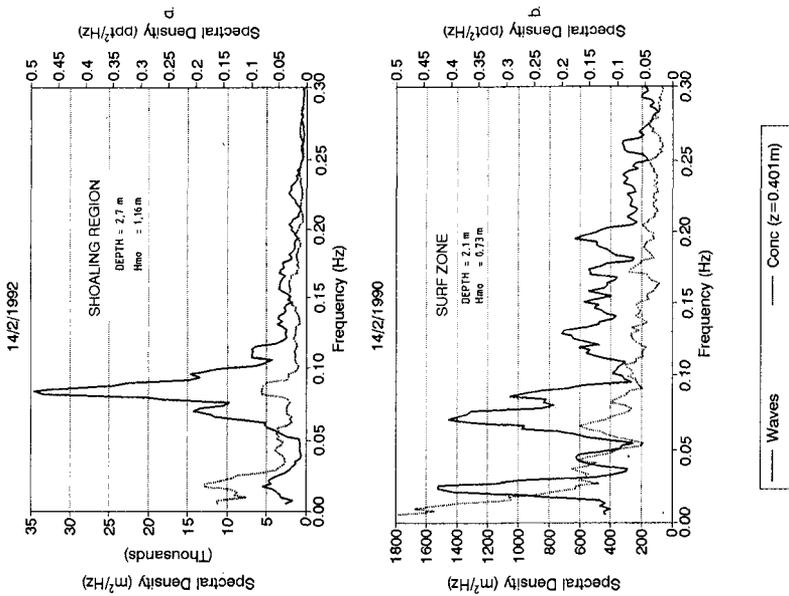


Figure 12. Energy spectra of the wave record and the sediment concentration ($Z = 0,40$ m)

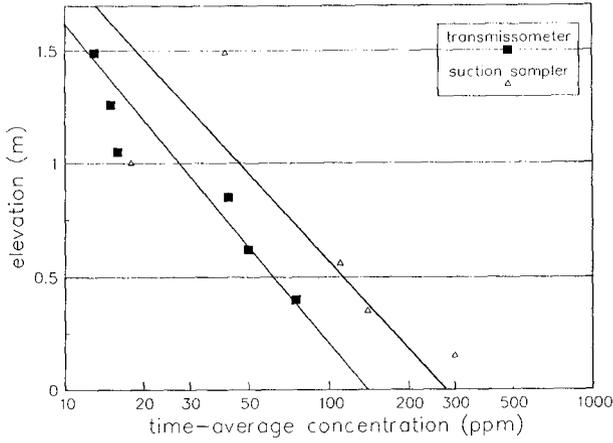


Figure 13. Averaged results of TASSS and transmissometer

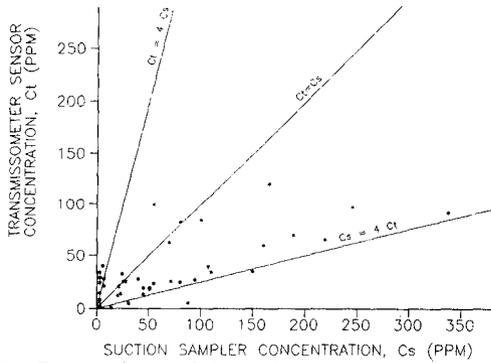


Figure 14. Comparison of TASSS and transmissometer results

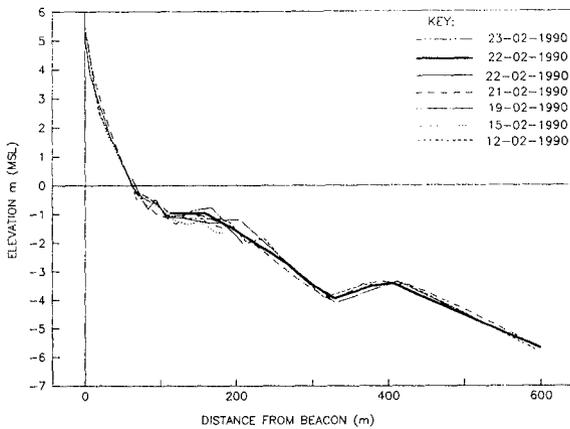


Figure 15. Beach and nearshore survey results