SURVEY TECHNIQUES/PROCEDURES AND DATA PROCESSING FOR MONITORING NEARSHORE SEDIMENT TRANSPORT

by

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1. INTRODUCTION

The cost of many coastal projects is often increased by the expensive beach repair and maintenance required to remedy the destabilising effects of structures on the adjoining coastline. Physical and/or mathematical models have been developed for use in planning these projects in order to *predict* and *quantify* the effects of marine sediment transport on the coastal topography.

Such models need to be calibrated against prototype data and one method of gauging volumetric sediment movement is by successive bathymetric/ topographic *profiling surveys* which are performed seasonally and annually. Since large quantities of sediment are related to small changes in bed elevation it is clear that this profiling needs to be done with the utmost *precision.*

The areas most affected extend from the beach through the surf zone to water depths of about 25 metres. The surf zone in particular is a dynamic and hostile area which falls outside the traditional activities of both the hydrographic and land surveyors. Consequently innovative methods, deficient in sound survey principle and practice, have often been pursued in this area without any attempt being made to assess the tolerance on the data.

This paper attempts to show that it is possible to produce reliable and verifiable results to the required accuracy by using *conventional* survey equipment and techniques, also by taking the necessary precautions against the many possible sources of survey error. The procedures and techniques described have evolved from NRIO's involvement over the past decade in major projects at Richards Bay, Durban, Koeberg and in False Bay. The results of a recent verification investigation are fully reported in this paper.

2. METHODOLOGY

In principle the method is to survey a number of *parallel profiles* orthogonal to the coastline and extending across the beach, tidal and surf zones. Staff/polling methods are used from the beach to as far into the water as an operator can walk (or use a dinghy). A skiboat fitted with precision echosounder is used to work from behind the surf, and through the surf zone, towards the beach.

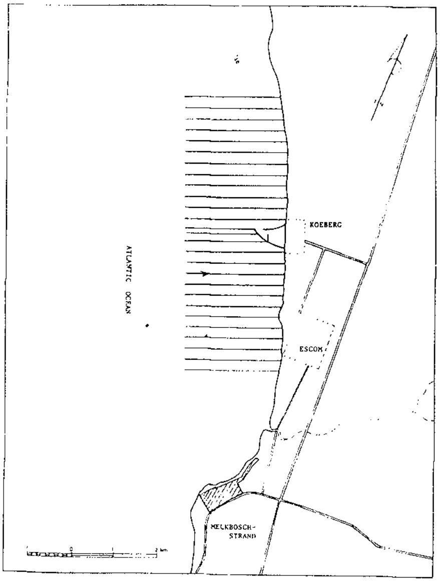

FIG. 1 KOEBERG SURVEY LOCATION

By regulating the work to span the low and high *spring tides*, a degree of overlap can be achieved between these two independent methods which permits verification of the data. By repeating certain profiles along the same lines (very exactly) further verification of the accuracy can be obtained.

The problem of precisely repeating the same echosounder footprint and the corrections required (for boat squat, wave profile, tides, etc) are dealt with in the following sections in which procedures are described for eliminating *random* errors and minimising *systematic* errors.

3. POSITION AND HEIGHTING

The profiling surveys are always preceded by a control survey to establish or replace substantial *reference beacons* erected along the coastline, based on the national trigonometrical co-ordinate and benchmark systems as datums for position and heighting. These beacons provide a reference for all measurements along a profile and for precise relocation of profiles during successive surveys. The location of the beacons should ensure unrestricted visibility, also security against erosion and wilful disturbance or removal.

3.1 Equipment

The use of electronic instrumentation is limited by the high initial cost, expensive maintenance (in the coastal environment) and the logistic requirements for recharging DC power supplies in the field. Optical/mechanical survey instrumentation is robust, portable, easily replaceable and is also required for the control survey. The close proximity of the survey area to the shore facilitates the use of conventional optical survey instrumentation with a resolution of 5 mm/km.

The basic instrumentation requirements are:

(a) Electronic distance measuring (EDM) equipment for control survey (and beacon replacement) measurements.

(b) Three precise (single-second) theodolites for accurate measurements over distances up to about 5 km.

(c) Two sounding poles consisting of aluminium tubing of 5 m length, 63 mm diameter, fitted with a flat base of 200 mm diameter and clearly marked in lengths of precisely 1 metre (painted white/black alternately).

(d) Four (plus back-up) radio transceivers (operating on VHF/HF frequencies) to synchronise observations and for general communication.

(e) Three measuring tapes to determine the elevations of theodolites above the beacons.

(f) One levelling staff.

(g) A lightweight dinghy (roof-top) powered by an outboard motor, for pole soundings in calm conditions (waves $\leq$ 0,5 m).

3.2 Procedure

The field party of *five* consists of three trained survey technicians, who undertake all optical measurements, and two others (boat/echo-sounder operators) who assist in the control survey and beach profiling (as pole carriers).

The reference beacons are linked by a closed traverse between two fixed survey stations (triangulated or Trig beacons) with orientation rays (full arc) being observed at each beacon. The levelling is connected to a benchmark at each end of the traverse, differences in elevation being determined from simultaneous reciprocal vertical observations (observed on both faces) between two theodolites and the measured heights of instruments above the beacons. The observers advance alternately (leap-frog) for successive measurements.

Position and heighting along a profile are both determined by indirect measurement from *synchronised* optical observations. Theodolite intersection techniques are used to determine accurately, relative to the survey beacons, the positions and corresponding elevations of targets (either stationary or moving) as they progress along the profile line at regularly incremented distances.

For beach profiling the traditional tachymetric survey method is discarded in favour of simultaneous observations by two (or three) theodolite observers to the *pole* which is held upright on the beach (at regular intervals) as the carrier progresses down the beach and as far as possible into the sea (to -2,00 MSL during 3 hours spanning low spring tide). The pole observations can be extended seaward to -6,00 MSL using the dinghy. The advantages of this method are:

(a) Economy of observations, three readings per pointing instead of five required for tachy, resulting in less pressure on the observer and more rapid progress. With good coordination a team of three observers and two carriers can complete nine beach profiles per hour.

(b) Greater length of beach profile can be covered since no fine staff graduations need be distinguished for the observation.

(c) Greater reliability and accuracy of the data (due to accurate distance, ± 5-10 cm) especially in the surf where the base of the staff is rapidly eroded during the observation.

For bathymetric profiling two theodolites are set up at suitable beacons, to fulfil the geometric requirements for accurate intersection, while the third instrument is set up at each intermediate beacon (in rotation) in order to position and continuously guide the boat by radio communication.

The boat traverses a fixed path (within two meters laterally), corresponding to the *exact bearing* of the profile sections, while theodolite observations are made at regular intervals of about 30 seconds. The boat operator assists in maintaining a straight track by visually aligning transit marks (topographic features) situated inland. For subsequent surveys the respective profiles are exactly relocated from the beacons.

The observations are made at regular intervals of about 30 seconds to a target mounted on the boat. These consist of *simultaneous* determinations of vertical and horizontal angle measurements, synchronised by the echosounder operator by radio, which are manually recorded, together with annotation of date, time, line and "fix" numbers.

3.3 Error Reductions

By maintaining a high degree of accuracy in the control survey (± 1 cm in elevation and position) it is possible to determine when beacons have been tampered with or replaced by unauthorised/unqualified persons. Affected or missing beacons are accurately replaced and verified by independent measurements from *both* the adjoining beacons.

Systematic errors in heighting, due to incorrect measurement of instrument elevation, are eliminated by *routinely* observing vertical angles to both the adjoining beacons (or instruments) prior to profiling. This also serves to verify the data of the control beacons which are used in further calculations.

Orientation errors in the intersection positions are eliminated by observing the known orientations to two distant beacons at the start and at the end of the observations for each profile.

The effects of random errors in observations of reciprocal vertical angles can be eliminated (and accuracy increased) by observing to both the instrument and the top of the beacon.

Instrumental error is eliminated by determining the corrections to be applied to the observations and by avoiding "creep" in the clamping/tracking mechanisms of the instrument. The index error (for correction to vertical observations) is determined by observations on both faces of the circle while the telescope is pointed at a distant object, correction = $\frac{1}{2}$ x index error (i.e. <360°>). The slow-motion tangent screws should always be turned against the spring to avoid creep.

Refraction and curvature corrections, to be applied to heighting over distances longer than 500 metres, can be verified by the index error observations if the distant object is a survey beacon.

Vertical accuracy in indirect heighting is increased by the accurate measurement of distance, from which the height is derived, or by reducing the elevation between the beacon and the target.

Observation and/or data processing errors are identified in the intersection method by comparison of the independently calculated elevations. A third observation enables an independent evaluation of accuracy to be made and allows the elimination of errors without loss of data. The conventional tachy method produces unchecked data.

The use of a theodolite for heighting, in preference to a level, enables the heighting error, due to the tilt of the staff, to be eliminated by sighting to a mark near to the base.

The accuracy of observations, when tracking a moving target, is dependent on the relative motion of the object. By maintaining a minimum distance of about 700-1000 metres from the boat, the movement can be followed accurately using the clamp and tangent screws of the theodolites.

The comparative accuracy attained in past surveys are 0,1 to 0,4 metres in position and 0,01 to 0,08 m in elevation for distances up to 3 km. Typical results for beach profiling are illustrated in Table 1. Similar pole soundings were previously made from a dinghy, to -3,0 MSL during neap tide, and a vertical accuracy of 2-3 cm (probable error) was obtained. It is estimated that a probable error of <0,10 m is possible for pole soundings at 5 m depths.

4. ECHO SOUNDING

The short period fluctuations in the elevation of the echosounder, resulting from waves or swells, are mirrored accurately in the continuous record of the depth profile provided that the sea bed is a flat sediment surface with regular changes of slope. For an irregular rocky

TABLE 1 - BEACH PROFILE DATA BY INTERSECTION METHODS

	Line OP.1		OP.1/ (MSL)	OP.2/
	Dist(a)	Dist (b)	Ht(a)	Ht(b)
1.	183,46	355,00	-0,93	-0,94
2.	160,60	354,40	-0,65	-0,70
3.	124,64	334,52	-0,19	-0,20
4.	85,03	318,48	+0,73	+0,68
5.	50,85	305,90	+1,64	+1,60
6.	27,39	300,24	+2,35	+2,30
7.	4,55	295,55	+3,10	+3,05
	Line OP.2		OP.2/	OP.1/
1.	5,43	294,68	+3,33	+3,26
2.	54,88	294,51	+1,36	+1,36
3.	87,04	296,48	+0,38	+0,37
4.	120,66	303,39	-0,33	-0,35
5.	143,61	310,72	-0,68	-0,66
6.	177,99	323,58	-1,19	-1,18
	Line OP.3		OP.3/	OP.2/
1.	184,97	282,03	-1,20	-1,21
2.	169,62	273,18	-0,92	-0,91
3.	139,34	259,44	-0,57	-0,56
4.	95,90	243,84	+0,23	+0,24
5.	64,11	236,78	+1,09	+1,11
6.	31,68	233,09	+2,10	+2,10
7.	8,44	234,03	+3,24	+3,22
	Line OP.4		OP.4/	OP.5/
1.	182,00	324,91	-1,28	-1,26
2.	152,12	303,02	-0,82	-0,82
3.	118,80	288,09	-0,35	-0,36
4.	79,01	270,26	+0,51	+0,52
5.	35,39	258,46	+1,88	+1,89
6.	5,54	254,57	+3,03	+3,04
OP.5	0,00	254,06	+0,05	+0,08(Instr/ Instr)
	Line OP.5		OP.5/	OP.4/
1.	7,32	253,58	+3,07	+3,12
2.	31,12	253,12	+1,88	+1,89
3.	81,16	259,62	+0,31	+0,34
4.	107,04	266,78	-0,28	-0,29
5.	129,93	276,07	-0,68	-0,64
6.	167,66	300,48	-1,39	-1,38

	Line OP.6		OP.6/	OP.5/
1.	7,5	-tache-	+3,25	-
2.	29,97	264,30	+2,08	+2,06
3.	67,62	268,92	+0,82	+0,82
4.	92,79	275,07	+0,12	+0,14
5.	129,76	286,27	-0,55	-0,56
6.	162,06	295,18	-0,99	-0,99
	Line OP.8		OP.8/	OP.9/ Corrn+0,02
1.	167,77	306,10	-1,24	-1,25
2.	140,51	284,54	-0,85	-0,86
3.	128,35	279,14	-0,74*	-1,02*
4.	102,84	269,97	-0,14	-0,14
5.	73,15	259,59	+0,82	+0,81
6.	43,93	254,97	+2,04	+2,01
7.	13,0	-tache-	+3,46	-
	Line OP.9		OP.9/ Corrn+0,02	OP.8/
1.	11.50	-tache-	+3,30	-
2.	30,39	255,88	+2,16	+2,17
3.	53,74	260,53	+1,14	+1,18
4.	82,70	268,53	+0,18	+0,19
5.	108,77	278,40	-0,36	-0,32
6.	125,26	285,86	-0,83	-0,77
7.	135,98	291,75	-1,50	-1,44
OP.10	242,52		+7,29	- (T/Pipe)s/b
OP.10	242,52		+8,09	+8,10(T/Instr)s/b
	Line OP.10		OP.10/	OP.9/ Corrn+0,02
1.	4,28	242,63	+4,63	+4,62
2.	37,11	244,97	+2,39	+2,38
3.	57,44	249,25	+1,39	+1,39
4.	82,00	256,03	+0,44	+0,44
5.	108,00	266,99	-0,37	-0,39
6.	125,17	274,59	-1,29	-1,31

bottom along the profile, the effects of water level fluctuations and topographic undulations are combined to produce a confusing echo trace which cannot be resolved with sufficient accuracy.

4.1 Equipment

A 5,6 m skiboat, powered by twin outboard motors to ensure high manoeuvrability and safety in the surf zone, is used as a platform for the echosounder. A cabin houses the essential electronic instrumentation and provides protection and shelter to the crew. A spherical target (120 mm diameter) is fitted, for theodolite observation, to a mast projecting above the cabin.

The survey echosounder can operate on single/dual frequencies of 30 kHz and 210 kHz, the latter for greater accuracy in profiling and calibration, and has facilities for recording analog and/or digital depth data. The analog facility has an expandable depth scale producing a maximum resolution of 5 m/200 mm chart width, providing a resolution of about 1 cm, for accuracy in the calibration of the instrument and recording depths in calm sea conditions. Both transducers are mounted *inboard* in a well which is moulded onto the centre of the hull, and operate effectively through the hull with little loss of power provided that the well is filled with water (no splashing) and that *no air* is entrapped in the laminations of the hull.

A calibration bar is used to physically calibrate the echosounder during the survey. The bar consists of a 1,8 m length of open galvanised steel pipe, 125 mm in diameter, with a 14-metre length of light chain welded to each end. Tags are attached to the short links of both chains at predetermined distances from the pipe and exactly 1 metre apart.

An accurate tide gauge must be installed to record the sea level continuously throughout the survey. The resulting tide data are used to relate the recorded depth profiles to the vertical datum of the benchmarks (and beacons).

Radio communications are used to coordinate the operation of the echosounder with the theodolite observations.

4.2 Survey Procedure

The marine operation is performed by two operators (the crew) who can interchange their respective duties. The surveyors complete the manpower requirements for launching/recovering the boat from the beach when necessary.

The following relationships must be determined accurately for each survey boat:

1 The elevation of the transducer face relative to the reference target which is mounted on the mast.

2 The elevation of the transducer face relative to the gunwales, to

the deck and also relative to the sea level while the boat is stationary in the water.

3 The squat (settling in the water) of the boat while it is moving at various survey speeds ranging from 4 to 7 ms^{-1}.

These specifications are determined in a sheltered harbour under calm sea conditions with the aid of a theodolite, used as a level, and a levelling staff. The theodolite is set up at a slipway, near to the water level and aimed at the staff to measure the elevation of the various parameters. The respective rev-counter readings are noted at the various constant speeds.

Calibrations of the echosounder are performed *twice daily* in the work area. Instrument controls (for adjustment), which are initially set by the echosounder operator, include switches for the channel (frequency) selection, chart calibration settings and the attenuation of signal strength and stylus voltage in order to produce an optimum trace of the seabed at the maximum profile depth.

The boat is *anchored* and the calibration bar is then suspended below the boat by both chains so that the pipe hangs horizontally in a vertical plane through the transducers and directly below, the corresponding tags of each chain being held exactly on the edges of the gunwales while the top surface of the pipe is precisely 12 metres (or more) below the transducer faces. Further settings of the recorder controls are made for vertical scale expansion (set to maximum), the transducer depth below sea level (set accurately below zero line) and the "sound velocity" is finally adjusted to correct the recorded depth of the bar to the exact value. The depth of the bar is now decreased, in stages of 2 m (or 1 metre) throughout the depth range, while the measured depths are recorded and checked (should be exact). The bar is taken aboard. No further adjustments are necessary (or permissible) other than depth phasing, scale expansion and paper speed.

On completion of the day's depth profiling, a second calibration is performed as before.

The bottom trace is recorded (at anchor) for three minutes, using the event marker, in order to measure the dominant wave period and wave height for determining the relationship between wave form and water depth.

The survey boat traverses the profile line continuously from a predetermined depth to a least depth of 1,5 metres, thereby obtaining bathymetric data (to about -0,70 MSL) during a period of 1½ hours spanning spring high tide, while position fixes are coordinated by the echosounder operator for the theodolite observations.

The boat speed is regulated so as to be overtaken by 5 to 6 swells per minute (confirmed by the echo trace), a requirement for accurately eliminating the wave action from the depth profile. A *constant* speed must be maintained between position fixes to permit interpolation of intermediate positions, speed changes should coincide with the fixes. The boat must also maintain its position between the breakers, hanging back while avoiding aeration in the water which will strongly attenuate the transducer signal. Repeated runs may have to be made in the surf in order to obtain the required profile coverage. The decision, to terminate the profile, rests with the skiboat operator who is advised by the echo-sounder operator on the clearance beneath the boat.

The observed position fixes coincide with the manually activated event marks which are on the analog depth trace. These marks must be fully and correctly annotated for time, date, line and fix numbers.

All profile lines are run *inshore* only. Previous attempts at running the lines in alternate directions produced a consistent difference of about 0,2 metres in the respective depths recorded (in/out), presumably due to the greater vertical acceleration resulting from a higher frequency of wave-crossings on the outward track.

Twelve profile lines (length 1,5 to 3 km) are normally surveyed in 3 hours each day and the survey may extend over several days because of delays resulting from poor sea conditions. Selected control profile lines (2 or 3) are therefore surveyed repeatedly, once each day, in order to verify the consistency of the data by comparison of the profile sections.

The recorded bathymetric depth data, measured from sea level, are related to the benchmark level datum by *accurate* tide data which are recorded continuously for the duration of the survey. The tide data are regularly

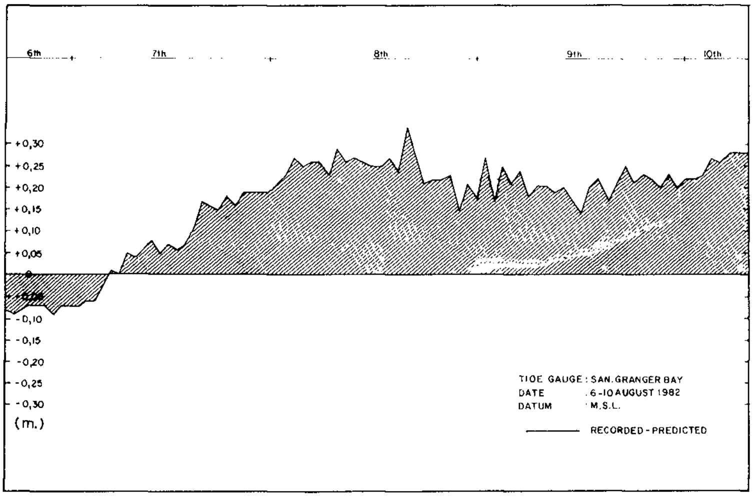

FIG.2 RECORDED VS. PREDICTED TIDE LEVELS

verified by direct observation and measurement, preferably with the aid of a stilling well or other sheltered and damped sea surface, or by comparison with similar data recorded independently nearby. The chart recordings must be meticulously *annotated* with reference to time, date and location.

Suitable tide-gauges, infrequently calibrated due to shortage of staff, are operated at various South African ports by the Hydrographer of the Navy and these data are freely available.

4.3 Error Reduction

Differences of about 300 mm (or more) often occur in elevation between recorded prototype tide data and predicted data, as prepared by the S A Navy and published in the TIDE PREDICTION TABLES, largely due to the effects of fluctuating meteorological parameters (see Figure 2) and therefore the *predicted data are totally unacceptable* for sediment profiling.

Inaccuracies in the time-scale of recorded tide data are a common cause of systematic error in the reduced bathymetric depth profile. By surveying only for a limited period spanning high tide, when the rate of change in elevation is small, the effects on individual profiles are reduced while the cumulative effect on the survey is eliminated.

Localised areas of rock outcrops along the profile *must* be identified and excluded from the comparisons. Large areas of rock may totally disqualify the location as being unsuitable for monitoring.

Temperature profiling should be carried out at random in the work area to ensure a consistent propagation (speed) of sound for all profiles.

The second calibration (each day) verifies the initial one and ensures that no "drift" in the electronics of the echosounder has taken place. The data are discarded and the profiles *resurveyed* if the calibrations differ.

When surveying in the vicinity of river estuaries during periods of flood or heavy run-off, the 30 kHz facility is used simultaneously with the 210 kHz as a precaution against the presence of dense layers of sediment (in the water column) which could mask the seabed and cause a false bottom to be recorded.

The boat speed is calculated between fixes to verify the squat correction (which is applied with the tide level correction). Squat varies in relation to the boat speed, from 10 - 11 cm at 4 ms^{-1} to 3 - 4 cm at 6 ms^{-1}. Care must also be taken to note changes in the buoyancy of the boat due to leakage of the hull and varying content of the 240 litre inboard fuel tanks.

The elevation of the boat is determined from theodolite observations to the target in order to verify the effects of wave set-down/set-up in shallow water. Observations beyond the breakers serve to further verify the tide data for gross errors.

The profile data is abstracted directly from the echo trace and tabulated together with the range distances for determining profile section and areas. The necessary precautions have been taken to ensure *direct profile comparisons* by the precise relocation of all profiles. In no circumstances need profile data be interpolated from contour plans.

5 DATA PROCESSING (GENERAL)

The processing of survey data requires a special awareness of the potential survey inaccuracies and the need to personally scrutinise the many outputs of comparative data at different stages of the work.

Independent checks are systematically applied during each phase of processing the data which is first validated before being further applied. Sufficient observations are made to verify and correct any errors which had been made in the measurements.

Much of the data is processed manually and this also requires specialised experience and a knowledge of local conditions. To increase consistency in reducing the data of successive surveys, the manual reductions are always undertaken by the same persons (to reduce the effects of personal error) in successive surveys and scrutinised by a second party.

5.1 Equipment

Portable calculators are used in the field for processing the essential control survey data while an on-line mainframe computer is available for the processing of the resultant statistical data (profile section areas, etc) at headquarters. Printers are used (with the calculators) to reduce the probability of transcription errors being made in the data.

5.2 Procedure

The processing of all survey data is performed, both in the field and at headquarters, by the survey technicians of the field party.

All data relating to the control survey are processed manually and fully validated before the profiling survey is commenced. During periods of unfavourable weather or sea conditions, the available time is utilised by processing the other survey observations. All calibration data are immediately validated by inspection and comparison. Independent checks are systematically applied to all the survey data.

A graphical comparison is made of the recorded and predicted tide data, and with independently recorded data, in order to check for anomalies (such as errors in the time-scale).

The effects of swell and waves on the analog recording of the profile are reduced graphically, prior to applying the tide corrections, by applying an established theory to relate wave form to water depth (see Figure 3). The reduction graph is based on the VOCOIDAL WAVE THEORY (Swart 1977) defining the relationship (Nc) of the mean water level (WL) to the crest and trough of a design wave relative to water depth. The parameters of

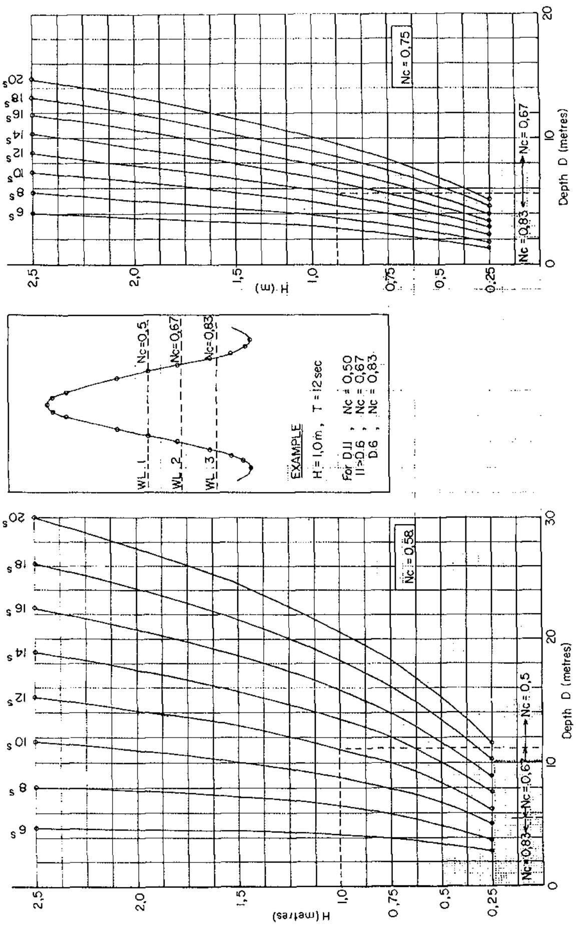

FIG.3 WAVE REDUCTION GRAPH

wave height and wave period are derived from the initial calibration record of each day and critical depth values for Nc = 0,5 and Nc = 0,67 (also Nc = 0,83) are determined from the graph.

The inverted wave crests on the echo trace are all joined by straight lines, as are the inverted troughs. The corrected WL image is then reconstructed in accordance with the Nc/depth relationship and smoothed. This is regarded as the true image of the sediment bed. All intermediate changes in slope are annotated and their proportional range distances are derived from the calculated "fix" positions. Tide (and squat, etc) corrections are then applied to all the recorded depths of both the "fix" and annotated positions and the data are then abstracted for the determination of the profile sections.

Graphical comparisons are made of the overlap of profile data derived independently from the beach and sonic profiling.

6 RESULTS OF A VERIFICATION EXPERIMENT

During a regular profiling survey at Koeberg in September 1982, a number of additional profile sections were surveyed in order to evalulate the probable error in the depth soundings for various sectors along the profile.

Line 10 was chosen as the control profile and ten runs were made over the profile in a consistently calm/moderate sea state with swell height of about 0,5 to 0,7 metres. There were four runs on 16 September and six runs on 17 September. No overlap was obtained with the beach profile, neither were vertical intersection angles observed in this exercise. The abstracted profile data are listed in Table 2.

6.1 Sounding Error

The following methods were used to determine the values for the probable error of the soundings:

1 The *average* depth was determined for each range position at intervals of 50 metres along the profile, these values were adopted as the *correct* values and the respective errors were determined for each of the range positions throughout the profile length from range distance 300 metres to range distance 2 050 metres. These error values are plotted against the range distance, from the reference survey beacon, to indicate the error distribution (see Figure 4). The standard deviation was likewise calculated and also plotted against the range distances (see Figure 4).

The probable error of a single depth sounding in the surf zone varies from ±0,06 m to ±0,10 m while offshore the probable error of a depth sounding varies from ±0,02 m to ±0,04 m where

$$P.E. = 0,6745 \sqrt{\frac{[dd]}{(n-1)}}$$

TABLE 2 - SOUNDINGS TAKEN AT LINE 10, KOEBERG

DEPTH IN METRES (MSL DATUM)

RUN NO (m) DIST	1	2	3	4	5	6	7	8	9	10	AVE		7/9
250	-2,11	-1,77	-1,90	-1,91	-2,09	-1,94	-1,97	-2,09	-2,35	-2,10	-2,023		-1,87
300	2,55	2,16	2,49	2,44	2,52	2,43	2,34	2,57	2,60	2,62	2,472		2,42
350	3,00	2,77	2,89	3,06	3,00	2,94	2,77	3,07	2,85	3,13	2,948	Surf Zone	3,02
400	3,55	3,49	3,45	3,64	3,55	3,57	3,70	3,66	3,65	3,80	3,606		3,70
450	4,38	4,37	4,27	4,46	4,70	4,50	4,72	4,76	4,71	4,60	4,547		4,34
500	5,14	4,88	4,86	5,23	5,03	4,91	4,95	5,11	4,82	5,30	5,023		5,07
550	4,88	4,80	4,90	4,74	4,93	5,06	4,81	4,80	4,91	5,00	4,883		4,47
600	5,15	4,87	4,94	4,96	5,30	5,16	5,07	5,08	5,08	4,92	5,053		5,12
650	5,67	5,59	5,60	5,66	5,76	5,67	5,60	5,74	5,53	5,63	5,645		5,98
700	6,27	6,40	6,36	6,34	6,35	6,37	6,42	6,41	6,23	6,34	6,349	Calibration Range	6,64
750	7,02	7,13	7,09	7,01	6,96	7,02	7,10	7,04	6,96	7,05	7,038		7,17
800	7,64	7,66	7,70	7,70	7,67	7,65	7,67	7,64	7,69	7,69	7,671		7,74
850	8,16	8,17	8,20	8,18	8,08	8,19	8,17	8,13	8,08	8,21	8,157		8,20
900	8,54	8,49	8,52	8,54	8,64	8,61	8,55	8,59	8,47	8,59	8,554		8,55
950	8,89	8,82	8,83	8,89	9,02	8,91	8,88	9,00	8,87	8,92	8,903		8,89
1000	9,24	9,14	9,16	9,19	9,31	9,19	9,21	9,30	9,24	9,24	9,222		9,15
1050	9,57	9,45	9,48	9,47	9,60	9,48	9,52	9,61	9,60	9,57	9,535		9,48
1100	9,87	9,76	9,76	9,78	9,88	9,79	9,80	9,91	9,88	9,85	9,828		9,77
1150	10,20	10,07	10,10	10,10	10,18	10,10	10,08	10,20	10,17	10,13	10,133		10,03
1200	10,52	10,39	10,42	10,44	10,48	10,41	10,38	10,50	10,47	10,43	10,444		10,33
1250	10,81	10,72	10,73	10,79	10,77	10,73	10,73	10,80	10,77	10,73	10,758		10,67
1300	11,13	11,04	11,11	11,14	11,10	11,06	11,08	11,10	11,06	11,10	11,092		11,03
1350	11,48	11,37	11,50	11,49	11,46	11,40	11,42	11,43	11,42	11,47	11,444		11,39
1400	11,84	11,70	11,88	11,82	11,82	11,74	11,75	11,76	11,78	11,83	11,792		11,72
1450	12,18	12,03	12,18	12,17	12,18	12,08	12,07	12,09	12,14	12,19	12,131		12,10
1500	12,51	12,36	12,47	12,51	12,51	12,42	12,40	12,44	12,47	12,54	12,463		12,36
1550	12,84	12,70	12,76	12,85	12,84	12,76	12,76	12,78	12,79	12,90	12,798		12,66
1600	13,20	13,02	13,10	13,16	13,17	13,10	13,11	13,13	13,10	13,24	13,133	Nearshore	13,00
1650	13,54	13,41	13,42	13,45	13,49	13,40	13,46	13,43	13,38	13,52	13,450		13,33
1700	13,89	13,74	13,76	13,74	13,81	13,71	13,70	13,72	13,64	13,77	13,748		13,70
1750	14,12	14,00	14,08	14,01	14,13	14,01	13,93	13,99	13,89	14,02	14,018		13,97
1800	14,32	14,27	14,28	14,30	14,34	14,26	14,16	14,28	14,17	14,26	14,264		14,22
1850	14,52	14,53	14,48	14,56	14,50	14,47	14,40	14,48	14,44	14,50	14,488		14,46
1900	14,71	14,68	14,63		14,67	14,61	14,62	14,68	14,63	14,71	14,660		14,63
1950	14,89	14,78	14,76		14,81	14,72	14,73	14,82	14,75	14,83	14,788		14,71
2000	15,00	14,86	14,86		14,92	14,82	14,87	14,94	14,84	14,89	14,889		14,84
2050	15,14	14,95	14,97		15,02	14,91	15,02	15,03	14,94	14,97	14,994		14,96
2100	15,30	15,15	15,15		15,14	15,06	15,18	15,17	15,11	15,18	15,160		15,08
2150	15,49	15,38	15,32		15,36	15,33	15,32	15,37	15,34	15,46	15,374		15,22
2200	15,69	15,64	15,62		15,60	15,60	15,50	15,58	15,58	15,73	15,616		15,46
2250	16,02	15,95	15,91		15,85	15,90	15,91	15,89	15,82	16,00	15,917		15,80
2300	-16,38	-16,26	-16,20		-16,16	-16,24	-16,29	-16,22	-16,16	-16,27	-16,242		-16,13
$[\frac{d}{u}]$	-0,050	+0,052	+0,028	-0,004	-0,034	+0,022	+0,027	-0,026	+0,021	-0,047	0,000		+0,044
Speed m/s	4,27	3,70	3,81	4,20	4,51	4,62	4,06	4,60	4,25	4,74	4,28		
Date	16/9/82				17/9/82								

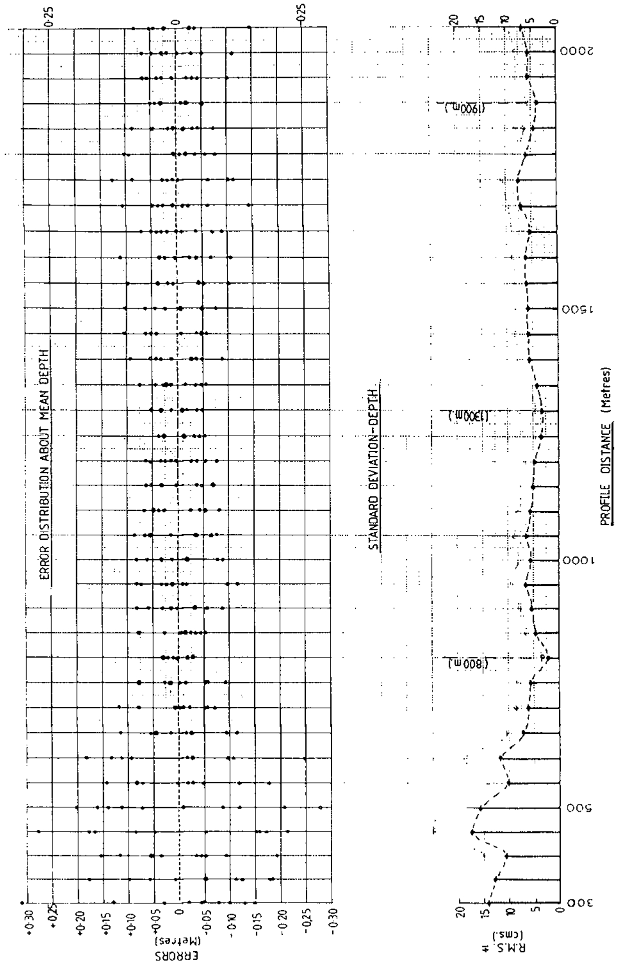

FIG. 4 EVALUATION OF ERRORS IN SONIC PROFILING

The error limits within the *95% confidence band* were found to be ±0,20 - 0,33 m in the surf zone and ±0,07 - 0,13 m offshore (for 9 degrees of freedom).

In comparing the *average* elevations of each run with the mean elevation (of all 10 runs), the differences are found to have a standard deviation of ±0,04 m.

Of special interest in Figure 4 are the apparent node points in the error distribution which recurs at regular intervals of 500-600 m apart and is apparent again at a range distance of about 2 500 m (for only three runs). These nodes indicate some tide level phenomenon, similar to a "standing wave" situation, which accounts for 50% of the probable sounding error beyond the surf zone.

The profile data listed in Table 2, under column 7/9, were recorded on 7 September during an earlier survey which was aborted because of deteriorating weather and sea conditions. A comparison of these data, with those which were acquired on 16-17 September, indicates the consistency of the profile data obtained during routine surveys.

2 No *correct* value is assumed for this analysis and the errors are derived on the basis of direct comparison between *any pair* of measurements taken, in all there are 45 possible combinations (from 10 measurements). Calculation of the probable errors of a depth sounding (as in the first method) yields values which are consistently 40% higher than previously. Within the 95% confidence limit, the errors are ±0,27 - 0,42 m in the surf zone and ±0,09 - 0,18 m in the offshore area.

Profile section *areas* were calculated for each of the 10 profile runs and the error values were determined from the mean values, a distinction being made between the surf zone, offshore and for the overall section. These results are shown in Figure 5 together with the probable error, indicated above (n = 10). For the 95% confidence band the magnitude of error value is increased by a factor of 3,35.

A second analysis was done of the section areas, as for the sounding error, and the probable errors are also indicated in Figure 5 (as n = 45) except for the overall chart where n = 36. For the 95% confidence band the magnitude of error is increased by a factor of 3.

6.2 Spacing Error

The effect of spacing error, due to the insufficient density in the profile spacing, was investigated by surveying an extra four profiles (marked A-D) which were fairly evenly spaced between the regular profiling lines 10 and 11. The section areas of profiles A-D were calculated and these values are tabulated in Table 4 and indicated graphically in Figure 6 (where comparative elevations are shown for volummetric calculations).

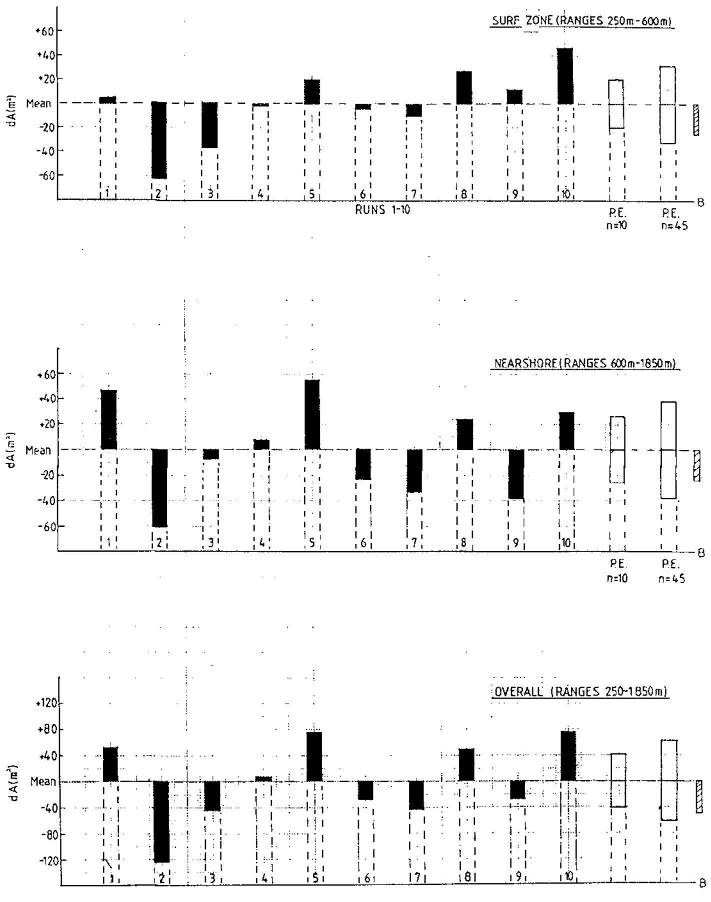

FIG. 5 ERROR DISTRIBUTION FOR PROFILE SECTION AREAS

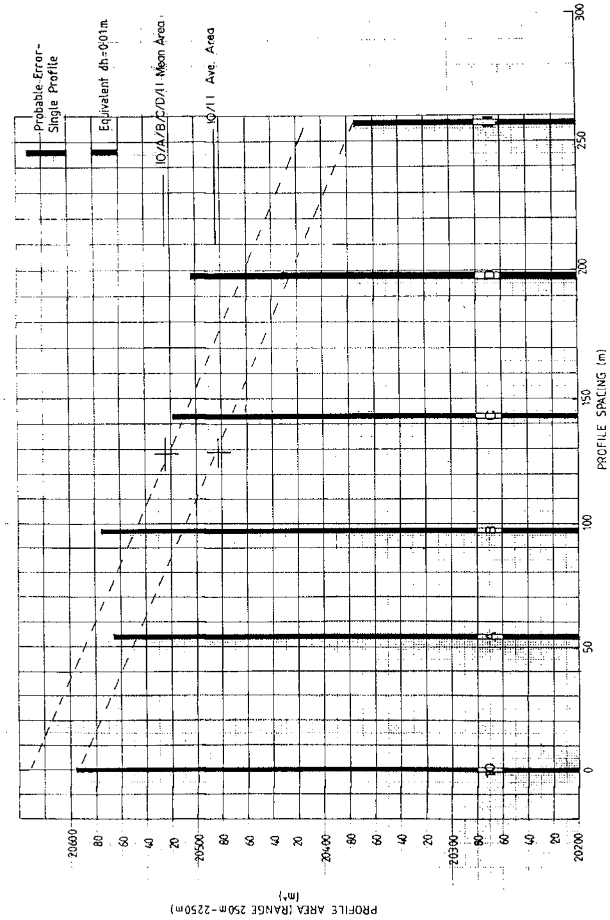

FIG. 6 SPACING ERROR FOR PROFILE DENSITY

TABLE 3 - COMPARISON OF SECTION AREAS WITH AVERAGE PROFILE

RANGE DISTANCE (m)	RUN										
	1	2	3	4	5	6	7	8	9	10	Average 1-10
250-600 Δa_1	1356 +5	1289 -62	1314 -37	1350 -1	1371 +20	1347 -4	1341 -10	1378 +27	1363 +12	1398 +47	1351 RMS ±31
600-1850 Δa_2	13164 +47	13056 -61	13110 -7	13125 +8	13172 +55	13094 -23	13084 -33	13140 +23	13078 -39	13146 +29	13117 RMS ±39
600-2250 Δa_3	19239 +89	19090 -60	19135 -15		19207 +57	19104 -46	19103 -47	19178 +28	19094 -56	19197 +47	19150 RMS ±56
250-1850 Δa_4	14520 +52	14345 -123	14424 -44	14475 +7	14543 +75	14441 -27	14425 -43	14518 +50	14441 -27	14544 +76	14468 RMS ±64
250-2250 Δa_5	20595 +95	20379 -121	20449 -51		20578 +78	20451 -49	20444 -56	20556 +56	20457 -43	20595 +95	20500 RMS ±81

Δa = Deviation from the average area (Profile OP.10)
RMS(250-600) = $\pm 9m^2/100m$; RMS (600-2300) = $\pm 3m^2/100m$; RMS (250-2300) = $\pm 4m^2/100m$

TABLE 4 - COMPARISON OF INTERMEDIATE SECTION AREAS WITH PROPORTIONAL AREAS

PROFILE SECTION	10	A	B	C	D	11
Calculated area (m^2)	20595	20566	20574	20518	20504	20374
Proportional area (m^2)		20539	20504	20467	20422	
Δarea = (m^2)		+27	+70	+51	+82	

Profile spacing (m)	10–A	A–B	B–C	C–D	D–11
	53,96	42,71	46,21	55,27	58,72
	256,87				

The apparent result of spacing error in the volume, as calculated from the end section areas, is 10 143 m^2 which is equivalent to an average error in elevation of 0,02 m (which is well within the accuracy indicated for the probable error). From a visual comparison of the intermediate areas, A to D in Figure 6, with their assumed profile areas (indicated by the broken line from profile 10 to profile 11), it is obvious that here the disagreement is also within the limits of the sounding error.

The spacing of about 250 m between profile lines 10 and 11 is adequate for this particular section of the sea bed. Since the bathymetry of the area is very regular and the coastline is straight (see Figure 1), the profile intervals are assumed to be acceptable although further sampling of the spacing is required.

7 CONCLUSION

The results of the experiment indicate clearly that the required accuracy of measurement can be achieved under normal conditions by standard survey procedure and that the effects of systematic errors are significantly reduced. The spacing of profiles, about 250 m, is apparently acceptable in the case study.

The field operation is cost efficient in terms of capital outlay, reliability of instrumentation and optimum productivity of personnel. The required technical expertise is easily acquired without specialised training.

The survey procedure is highly efficient in the identification/elimination of random errors and the evaluation and reduction of systematic errors thereby increasing the degree of accuracy which is attained.

The precise relocation of profiles in successive surveys, together with the verification of the data, serves to confirm the validity of the resulting quantitative assessment of sediment transport.