THE FIELD MEASUREMENT OF
SUSPENDED SEDIMENT
IN THE SURF ZONE

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This dissertation is dedicated to the memory of a friend and colleague ;

John Dudley Woodward

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SYNOPSIS

Suspended sediment concentrations were measured in the nearshore environment at the site of the proposed breakwater of the Koeberg Nuclear Power Station. Reference concentrations are evaluated from the field data.

Two sampling systems to obtain these concentrations were designed and constructed. The Mark I sampler was used to collect the field data, whilst the Mark II sampler was extensively tested in the laboratory and the proposed operational system was tested in the field. Difficulties were experienced in the operation of the Mark II sampling system, and are described.

Recommendations for the improvement of the sampling systems are given, based on the experience gained using the sampling systems.

CHAPTER ONE

Introduction

This dissertation deals with the investigation of suspended sediment concentrations resulting from wave action in the nearshore coastal region using available techniques, and the design and development of new methods for determining these concentrations.

Two suspended sediment samplers are described, one involving the use of a helicopter, the other using a system entirely based on the shore except for an anchor point offshore. Both these samplers are time-averaging point samplers. The concentrations determined by one of these samplers will be compared with various other field results and existing theories developed by other sources.

On the request from various organisations dealing with the planning and design of major coastal engineering works, a project was initiated to develop means of measuring the suspended sediment concentrations, as no existing measuring techniques could be applied in the nearshore coastal region. This dissertation is a continuation of this project. During 1972, a research unit was formed by the Department of Civil Engineering, University of Cape Town, to investigate various coastal sedimentation problems encountered during diamond mining operations on the coast of southern South West Africa/Namibia. One of the problems encountered was related to the amount of sediment drawn into a sea water intake for one of the diamond recovery plants. A technique for measuring the suspended sediment concentrations in the surf and just beyond the surf was developed by this research team. This technique made use of an evacuated bottle and gave instantaneous point concentrations. In the later half of 1974, the same technique was used in similar applications at the site of the Koeberg Nuclear Power Station at Duynefontein, Western Cape Province. As these concentrations tended to be relatively small, the mass of sediment in the sample was too small for accurate analysis, and a new system was developed. All the field work undertaken during this project was at the site of the Koeberg Nuclear Power Station.

Existing techniques for sampling suspended sediment concentrations are all based on obtaining these concentrations in open channels and rivers where access to the sampling point is easy and sampling can be conducted safely. The emphasis in this type of sampling is to determine the sediment concentrations as accurately as possible and research has tended to concentrate on sampling at stream velocity to minimise disturbance to the actual flow. (1) However, similar sampling in the nearshore zone presents a completely different set of problems. Access to the sampling point is difficult due to the surf, and the natural fluctuation of sediment concentrations is greater than the order of accuracy of the sampler. Thus a fairly crude type of sampling system can be used, the main problem being the placement of the sampler at the desired sample point.

All previous suspended sediment sampling investigations in the coastal environment have either made use of a pier or a boat as access to the desired sampling point. Neither of these methods is very satisfactory; as a pier restricts sampling to one profile on the beach, and its effect on the suspended sediment concentrations is unknown; and a boat cannot remain within the surf zone for the time duration of sampling without being endangered, particularly under high surf conditions. A new approach to the problem of measuring suspended sediment concentrations within the nearshore zone is thus needed.

The region of interest in this dissertation is the nearshore coastal environment. This area is defined, for the purposes of this dissertation, as the area including the surf and breaker zones and the area immediately seaward of the breaker zone. As the wave energy per unit depth reaches a maximum value just outside the breaker zone, most of the sediment transport processes take place in this region due to the relatively high shear stress exerted on the sea bed by the wave action and the high degree of turbulence within the surf zone. The actual width of this nearshore zone is dependent on the wave climate impinging on to the particular beach, and the physical characteristics of that beach. At Duynefontein, for example, the nearshore zone, as defined above, could vary from 100 metres to 2000 metres in width under wave heights of approximately 0,5 metres and 10metres respectively. The suspended sediment concentration measuring system must thus be designed to operate effectively under the majority of wave conditions experienced.

CHAPTER TWO

Review of Published Work

A brief review of existing techniques for measuring suspended sediment concentrations in the nearshore region is made, together with other techniques used in related environments, as well as techniques and results from sediment concentration laboratory experiments.

In order to distinguish between the different types of samplers, a brief distinction between the various general types is given. Sediment samplers can either be of the instantaneous or time-integrating types. The instantaneous type of sampler obtains a concentration result at a particular point, at a given instant in time. The time-integrating type of sampler obtains a concentration result averaged over a period of time at a particular point. The two general types can each be further classified, by their mode of operation, into direct and indirect types of samplers. The direct type of sampler traps a quantity of sediment water mixture and the concentration can thus be measured directly. The indirect type of sampler measures some property of sediment-water mixture, for example, light attenuation or sonic velocity, and through calibration of the instrument, converts this reading into a sediment concentration. The direct type of sampler is more commonly used in the field where there is no control on the specific parameters that have to be known for calibration of the indirect type, namely grain size, particle density and particle shape factor. The indirect type of sampler has been almost exclusively used in the laboratory only, where the above mentioned parameters can be controlled and the scale of measurement is generally smaller than the direct type, and is thus more desirable. Recently, however, the indirect type of samplers have been used in the field by Wenzel (2) and Basinski and Lewandowski (3) with limited success.

Investigation of suspended sediment concentrations using direct type samplers can be categorised into three main types, depending on their mode of operation. Pump samplers, as used by Watts (4), Fairchild (5), and subsequently the type used in this dissertation, physically draw water from a desired point, and pump that through a filter or into a container. Syphon samplers operate on a similar principle of drawing water from the desired point into an evacuated bottle. The third type, defined here as trap type samplers, allows the water-sediment mixture to enter an enclosed space where the water velocity is reduced and the sediment settles out. This type of sampler was used in early investigation on suspended sediment movement in Japan by Fukushima and Kashiwamura (6) using bamboo traps, and also as a preliminary investigation at Duynefontein, Cape Province, by the Department of Oceanography at U.C.T. using Delft bottles (7). A disadvantage of this method is that the actual concentrations cannot be determined, only the relative masses of sediment trapped at each level and it is not possible to determine, with any confidence, the actual volume of water passing through these sand trap devices.

The indirect type of sampler has been developed more extensively than the direct type, possibly because of rigidly controlled conditions in the laboratory and the need for greater accuracy, and consequently more research has been developed in the instrumentation and calibration of the indirect type than in the direct type.

Five basic types of indirect samplers can be broadly categorised on their mode of operation, namely electro-optical or light attenuation type as used by Kennedy and Locher (8) and Hom-ma et al (9); underwater photography as used by Bijker (10), which uses the principle of light attenuation and is basically an extension of the above mentioned type; electronic particle counters as used by Hattori (11); ultrasonic adsorption apparatus as used by Wenzel (2) and gamma-ray adsorption as used by Basinski and Lewandowski (3). Four of the five types above use the principle of attenuation of some physical phenomenon when travelling through the sediment-water medium, namely visible light, sound waves and gamma-rays. The other method is closely related to the direct type of sampler in that it actually counts the number of particles passing the instrument but requires calibration and measurement of particle or water velocity in parallel to determine concentrations.

The first significant contribution made in the investigation of the measurement of suspended sediment concentrations was by Watts (4) between 1949 and 1951. Concentrations were obtained by using a pump type sampler from a pier on the western seaboard of the U.S.A., and a large number of results were obtained. In Japan, investigations using bamboo trap type samplers were first conducted by Fukushima and Kashiwamura (6) in 1957 and 1958 off the coast. Cumulative results were obtained and various types of concentration profiles were identified. The next significant contribution was made by Fairchild (5) in 1970 and 1971 on the eastern seaboard of the U.S.A. Various other authors have conducted work on suspended sediment concentrations apart from the above mentioned, but their application has either been deep sea, tidal or estuarine, or laboratory. From the literature available to date, the only significant results produced from suspended sediment concentrations in the nearshore zone have been Watts and Fairchild. The work of these two researchers will be discussed in detail and the work by other researchers in applications in associated fields, will be mentioned and discussed.

2.1 Pump Type Samplers

Watts (4) conducted the field investigations into suspended sediment concentrations at Pacific Beach near San Diego, California between 1949 and 1951, using an existing pier which extended approximately 300 metres seaward of the shore line. The wave spectrum during which the observations were made varied from wave heights of 0,3 metres up to 2 metres, and concentrations were measured both inside and outside the surf. The tidal range at the site varied between 1 and 2 metres. The pump-type sampler was lowered from a boom mounted on the pier into the sea at various intervals along the pier. The sampling points used were as far as possible from the structural members of the pier, and the sampler was positioned about 3 metres away from the pier by means of the boom, in order to minimise erroneous readings resulting from the disturbed flow patterns caused by the pier.

The unit was completely submersible and the main components were a pump, water meter and sediment filter. The sediment-water mixture was drawn in through a 12mm nozzle, positioned vertically downwards; pumped through a sediment filter in which the sediment was collected; through a water meter and the sediment-free water returned to the sea. The pump was powered by an electric motor, using an external power supply. A standard non-return valve was also included into the water circuit to prevent any reverse flows taking place before or after sampling. Sampling duration was approximately five minutes. The type of filter used was a filter paper, 10 ply and Z fold embossed, with a rating of retaining all solids greater than 25 microns.

When samples were taken within 0,3 to 1,3 metres of the sea bed, the intake nozzle was positioned by means of a round plate attached to the sampler and resting on the sea bed to prevent any lateral movement of the sampler during sampling. Watts does not give any indication of how the sampler was restrained against lateral movement for samples higher than 1,3 metres above the sea bed, and the author assumes, therefore, that the sampler was hung from the boom to the correct depth. This could give rise to a pendulum action of the sampler caused by the orbital motion of the water, and as the sampler was not stationary, the resulting readings could therefore be low as the sample was being continuously drawn off from the same region of water. The author believes, however, that this variation from the true reading will be small and other factors affecting the readings such as the effect of the fixed structure on the flow patterns, and the natural variation in wave height and wave length would result in variations in concentration readings far greater than that caused by a slight pendulum motion of the sampler.

Extensive laboratory calibrations were carried out by Watts (12) to determine the order of accuracy of the sampling procedure. As the unsteady motion of the water mass subject to wave motion cannot be accurately modelled in the laboratory and the resulting sediment concentrations in such a water mass are unknown, Watts decided to test the sampling procedure in a steady uniform flow where the sediment concentration is fairly uniform and initially measured concentrations using a reference nozzle sampling at stream velocity, directed into the direction of flow. The reference nozzle is then removed from the apparatus, and the test nozzle inserted and concentration determined using this nozzle. A circulatory system was set up to keep the sediment concentrations as uniform as possible. The velocity in the test section was varied to investigate the effect of the ratio of the velocity in the nozzle at the sample draw-off point, to the stream velocity. Watts used a high sediment concentration for the calibration, approximately 4% by volume (100 000 ppm by mass) which seems exceptionally high as the highest average concentrations determined in the field investigation was 3 500 ppm. Various sampling efficiencies were evaluated for different velocity ratios, nozzle sizes and orientations, and it was found that the highest sampling efficiency was obtained using a 12mm nozzle with as high a velocity ratio between the nozzle velocity and the flume velocity, as possible.

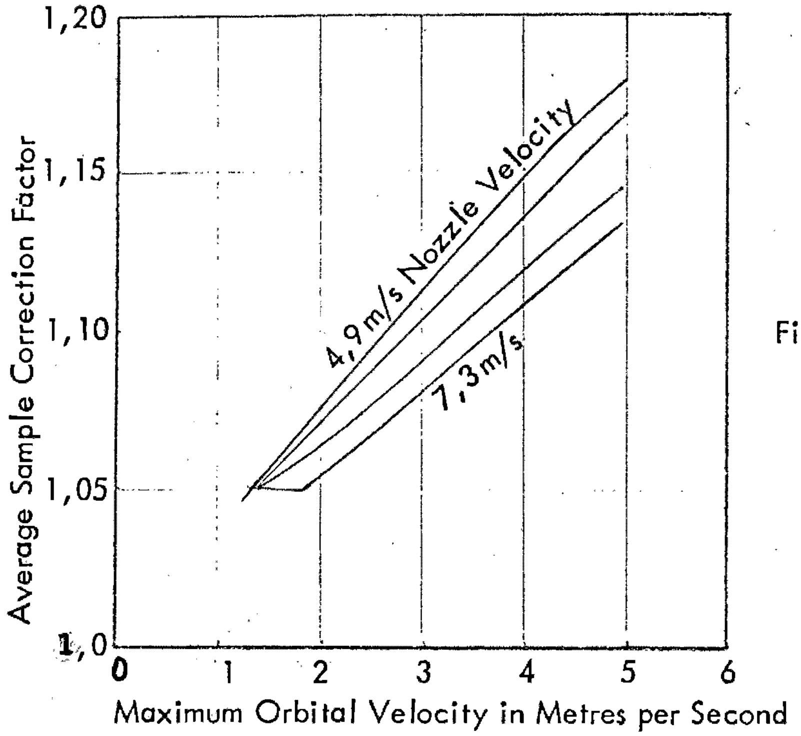


Figure 2.1 Correction Factor for Entire Wave in Breaker Zone.

From reference (12)

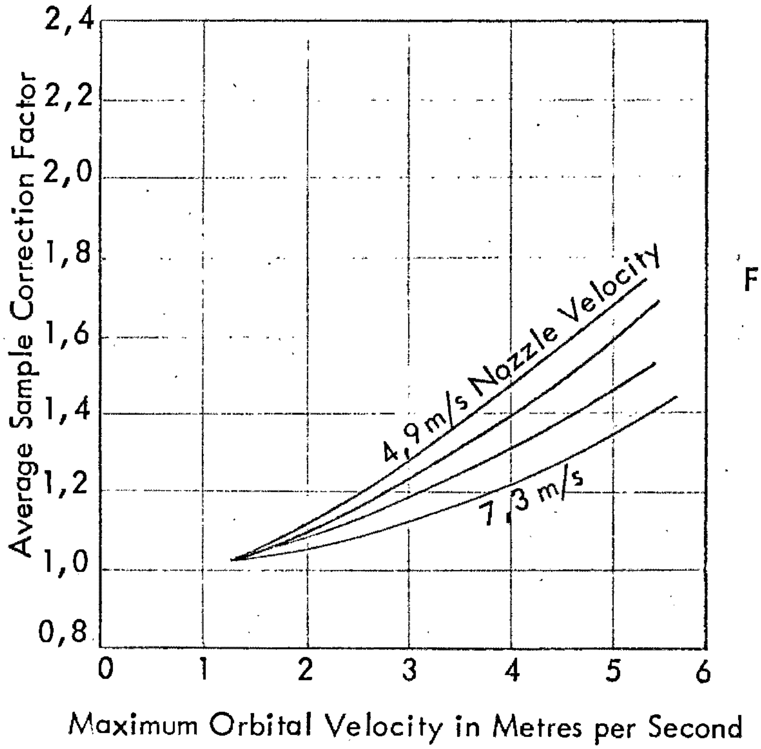


Figure 2.2 Correction Factor for Entire Wave Outside Breaker Zone.

The velocity ratios were evaluated both inside and outside the breaker zone in terms of the maximum orbital velocity and the nozzle velocity graphs of the sample correction factor versus maximum orbital velocity were plotted using the intake nozzle velocity as a parameter, and are given above in Fig 2.1 and Fig. 2.2.

Watts concluded the laboratory calibration with the evaluation of overall correction factors that could be applied to the field readings. These correction factors were based on the findings of the laboratory work and were evaluated knowing the nozzle velocity and the maximum orbital velocity. Watts tentatively concluded that samples could be obtained in the field to within approximately 15 percent of the true concentrations.

The laboratory calibration of Watts have indicated that the concentrations of the samples obtained can vary considerably from the true concentration. These results are however based on experiments carried out with very high concentrations which were not experienced in the field, and the author thus feels that the correction factors thus evaluated may be too high. If a lower concentration is used for calibration then there is less likelihood for the sediment to settle within the sampling system during sampling and consequently a higher sampling efficiency.

A total of 290 samples were taken at Pacific Beach, San Diego between January 1950 and May 1951, of which approximately one third were rejected on the grounds that the intake velocity was less than 4,6 m/s and it was concluded that the intake was blocked or restricted for these samples and hence considered unrepresentative. In total, 170 representative samples were taken landward of the breaker line and 22 representative samples taken seaward of the breaker zone. Each sample period was of 5 minutes duration, thus giving an average concentration over a time of 25 to 30 wave front passes, and the average size of sample was approximately 200 litres. The order of magnitude of the average concentrations varied between 89 ppm for 0,3 to 0,6 metres wave height class, to 1374ppm for 1,3 to 2,0 metre wave height class, with a maximum of 3470 ppm occurring under conditions of 1,0 to 1,3 metre wave height class. The median diameter of the samples was approximately 0,150 mm. The maximum concentration obtained in any one individual sample was 7 910 ppm under 1,0 to 1,3 metre wave height conditions, in 1,3 to 2,0 metre water depth, with sample elevation of 0,15 to 0,3 metres off the sea bed. The author believes that these high concentrations at very low nozzle elevations could result from possible entrainment of sediment from the sea bed. However, the water depth in which they are taken indicates that the sample position could have been at the breaker line, and high concentrations could exist directly under the plunge point of the breaker. This is also indicated by the wide variation in concentrations in this class, namely from 1 460 ppm to 7 910 ppm.

Watts concluded that there is evidence to suggest that the concentrations were fairly constant between 2/10 and 6/10 of the depth from the bottom. The correlation between grain size of each sample and the elevation of the sample was studied, but no definite trend in any relationship between these two parameters was found.

The investigations undertaken by Watts gave an initial insight into the order of magnitude and distribution of suspended sediment concentrations both inside and seaward of the surf zone. The method of sampling adopted was simple and practical, and the laboratory calibrations of the instrument provided an estimate of the order of accuracy of this type of sampler, even although prototype conditions were not attained in the laboratory. The main problem associated with this investigation is that the effect of the pier on the suspended sediment concentrations is unknown, and the results have thus to be accepted as being representative of the conditions prevailing if the pier were absent. The whole sampling system is dependant on the use of a pier as the base for the system, and sampling is thus restricted to one particular profile of the beach. The investigations conducted by Watts were carried out under a maximum wave height of 2 metres, which the author believes to be in the lower range of the total wave spectrum, and cannot thus be representative of the complete wave spectrum. Watts, therefore, provided a basic method for investigating the suspended sediment concentrations in the surf and is backed by an extensive laboratory calibration that shows the feasibility of using pump type samplers in this application.

Fairchild (5) conducted more than 800 suspended sediment tests between 1970 and 1972 from two fishing piers on the Atlantic sea board of the U.S.A. at City Pier, Ventnor, New Jersey and at Jennettes Pier, Nags Head, North Carolina. The samples were taken in waves of up to 1,3 metres in height, inside and outside the surf zone and in a maximum depth of 4 metres. The sampling unit used was a type of pump sampler, the pump and motor being mounted on a tractor which moved along the pier deck. A boom with the inlet pipe and nozzle was lowered onto the sea bed from the tractor on the pier deck, and the sample pumped from the desired sample point into a 150 litre drum. The sediment was allowed to settle, and the water was decanted from the drum to obtain a wet sediment sample suitable for handling. The sampling duration was approximately 3 minutes, and using a 12 mm nozzle, the average flow was 0,83 dm^3/s and intake velocity is 7,4 metres/sec, compared to an average flow and intake velocity of 0,67 dm^3/s and 5,3 metres/sec respectively, as used in the submersible pump sampler used by Watts (4).

Suspended sediment concentrations were sampled at points both inside and outside the surf zone alongside the pier, at elevations above the sea bed of between 75 mm and middepth. The sediment size distributions were found to be fairly constant, with a median diameter of approximately 0,150 mm at Ventnor and approximately 0,200 mm at Nags Head. Fairchild presented the results in the form of scatter plots of concentration versus nozzle elevation; height to depth ratio; and height squared. All the plots showed a relatively large scatter, but despite this, Fairchild was able to draw some important conclusions. On examination of the graphs of concentration versus nozzle elevation, Fairchild concluded that as the wave height increases, the distribution curve appears to become flatter, i.e. the rate of variation of concentration with elevation decreases, as shown in Fig. 2.3 and Fig. 2.4. This appears to be logical in that as the wave height increases, more energy is available in the form of turbulent shear stresses to lift sediment into suspension at higher elevations, but the bed load concentrations will remain fairly constant, and only increase in thickness with increasing wave height.

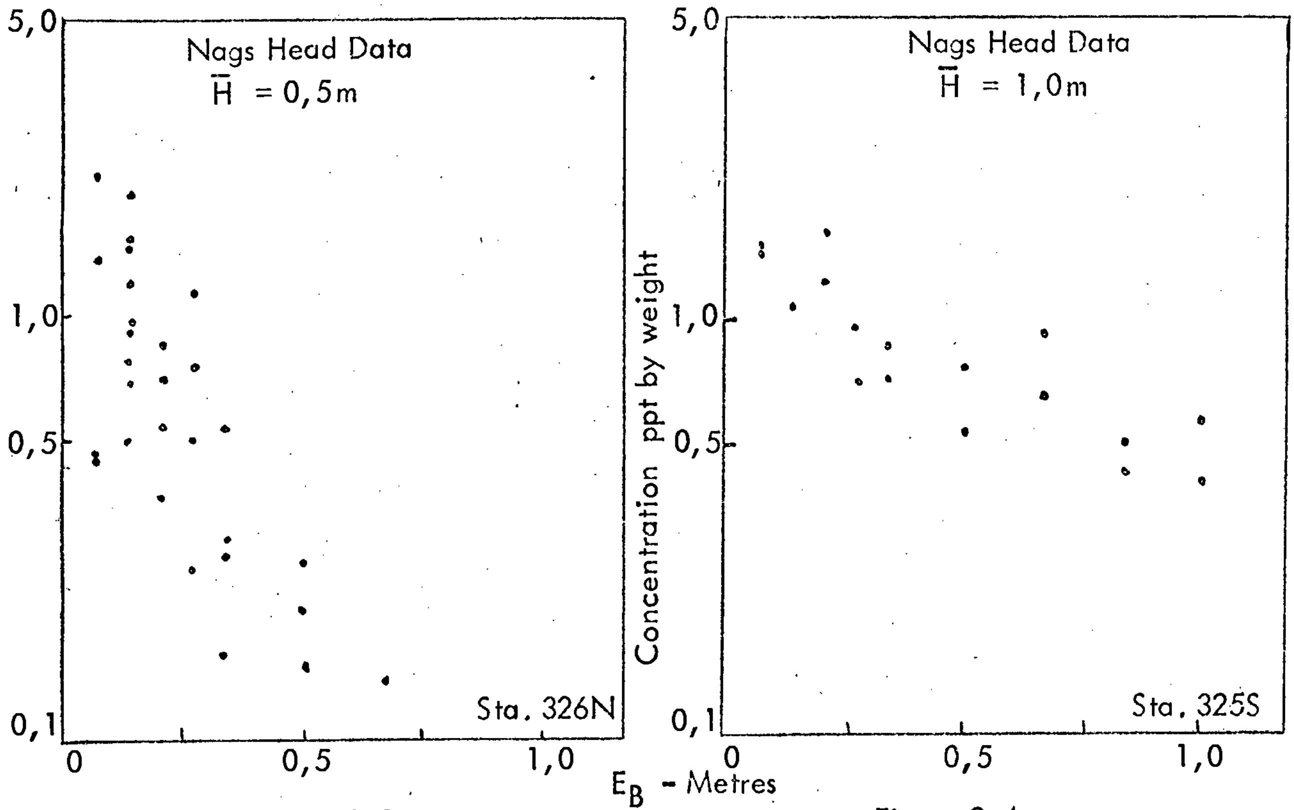


Figure 2.3

Figure 2.4

Vertical Distribution of Suspended Sediment Concentrations

From reference (5)

Fairchild also identified various types of distribution related to the type of breaker present, and found that the median diameter of the sediment remained relatively constant with nozzle elevation, but the coarser 5% fraction decreased with elevation.

The most significant observation by Fairchild was the sharp increase occurring in suspended concentrations just seaward of the breaker zone, reaching a maximum concentration at a point where the wave height to water depth ratio was approximately 0,78. The reason for this may be explained in energy terms. On a flat sandy beach, the energy dissipation due to bed shear stress is very small, thus most of the energy in a deep water progressive wave is still present in the wave when it begins to break. However, just before breaking, this energy is concentrated in the minimum depth of water encountered from deep water conditions to breaker point, and thus it can be expected that the bed shear stresses are a maximum, causing the greatest amount of sediment to be entrained and held in suspension due to the increase of turbulence. After breaking, the wave has lost much of its energy, hence the sediment concentration would be expected to decrease as the energy per unit depth has decreased.

Fairchild compared the results obtained in the field with those obtained in a wave tank, and concluded that the field results compare realistically with those obtained in the laboratory. In presenting the field data, however, no mention is made of the wave period. The author believes that the wave period is an important parameter in the determination of the distribution of suspended sediment, as it is the wave period alone that determines the deep water wave length, and consequently the shallow water wave length. Without a knowledge of the wave period, no estimate of the maximum orbital velocities at the bed can be made, and this parameter defines, to a large extent, the distribution of suspended sediment and the bed concentrations under oscillatory wave action. The field data thus presented by Fairchild with no reference to wave period, cannot be analysed further and the results can only be used to predict certain characteristics of the sediment distribution. With regard to the process of decanting the water from the 150 litre drum to obtain the sample, the author feels that this process can result in considerable errors when decanting in the field and in particular with such a large container with a relatively small sediment sample. A sand particle of 0,040 mm diameter would take approximately 14 minutes to settle. If the decanting process is done too quickly, the smaller size fraction of the sample will be lost. The author obtained some sediment samples at Stilbaai in the Cape Province, South Africa, during December 1976 using an instantaneous vacuum sampler, and due to a shortage of bottles, decanting had to be done in the field. This process proved to be very time consuming and the strict control needed for decanting in the field indicates that the filtration method, as used by Watts (4), is preferable.

The pump type samplers as developed by Watts and Fairchild have produced a large number of field results both inside and outside the breaker zone and have helped to define the expected order of magnitude of suspended sediment concentrations. However, the results obtained by these two investigators are only of value for comparatively low wave heights, up to a maximum of 2,0 metres. In addition, the system which requires a pier for access, gives rise to unknown effects on the concentration distribution caused by local flow disturbances. A pier is generally immovable, therefore sampling takes place on a fixed profile of the beach, and thus the day to day longshore variation of phenomena within the surf zone, such as rip currents, may alter their position with respect to the pier over a period of time, and the influence on the sediment transport characteristics near the pier will be significantly altered. Another problem encountered when using the pier as a platform for sediment tests, is the limited wave height conditions under which sampling can safely take place. This has resulted in relatively low wave height conditions under which Watts and Fairchild measured suspended sediment concentrations.

2.2 Time-averaging Trap Type Samplers

This type of sampler operates on the principle of allowing the water-sediment mixture to enter a container submerged in the water, in which the velocity of the dispersoid is reduced to the extent that the sediment will settle and collect in the container.

The water then flows out of the container via a small hole in the rear. This type of sampler has been used with success in the measurement of suspended sediment in undirectional flows, where together with a current meter, the absolute mass of sediment at a particular level passing a particular point in a known period of time is measured, and knowing the water velocity, the suspended sediment concentration can easily be calculated. Attempts have been made by several investigators to use this type of sampler in the nearshore environment.

Fukushima and Kashiwamura (6) used bamboo samplers off the coast of Tomakomai, Japan, to investigate the suspended sediment concentrations in various positions near a harbour. The bamboo sampler consisted of a length of bamboo, positioned vertically in the water with slots cut into opposite sides of each of the natural compartments that exist in a bamboo pole, such that each compartment acts as a settling chamber as described above. As the water flows through each compartment, the velocity is reduced and sediment settles out to collect within the compartment. Fukushima and Kashiwamura conducted the tests in wave heights varying between 0,3 metres and 1,0 metres and in water depths up to 7 metres. The tidal range experienced during the tests was small, namely 1 metre, and thus of little significance. From the mass of sediment trapped in the samplers at different levels, Fukushima and Kashiwamura identified four distinctly different types of sediment profiles and related these profiles to the positions of the samplers relative to the harbour. A double layer of sediment transport was also identified in which the sediment in the lower layer, namely within 1 metre of the sea bed, was of much higher concentration than that above it. The different types of profiles identified are given in Figure 2.5.

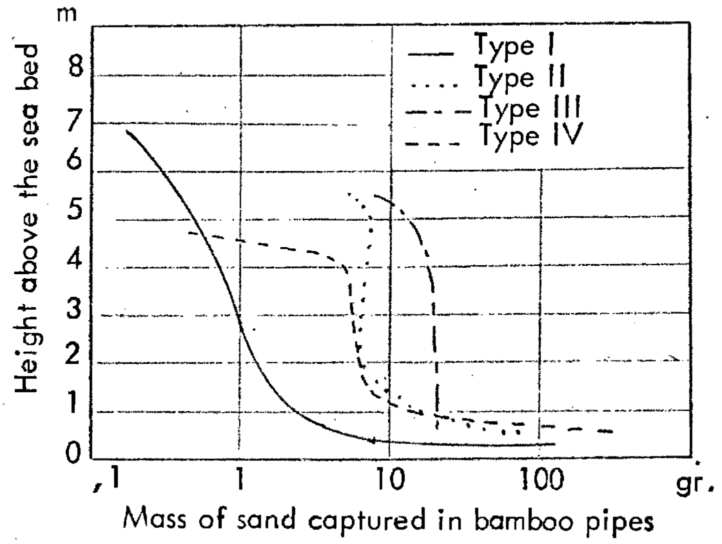


Figure 2.5

From Reference (6).

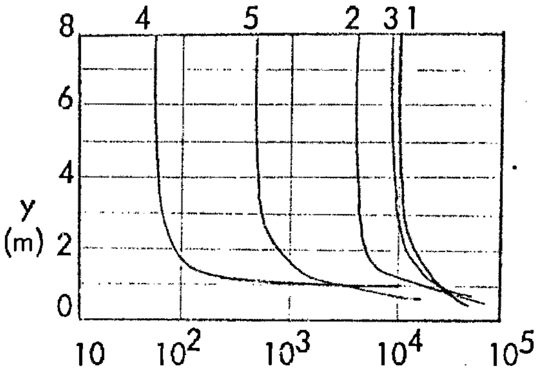
The type I distribution was found to occur on a natural sandy coast with little or no longshore obstructions. The type II distribution occurred at sample points alongside a breakwater, and the relatively larger masses of sediment trapped at the higher elevations from the sea bed can be explained by an increase in turbulence due to the interaction of the incoming progressive waves and the breakwater, coupled with the possibility that fine sediment could be injected into these levels by a river which entered the sea at that position. This type of distribution could thus be caused by the influence of the river sediment dispersing into the sea, rather from the result of increased wave action. The type III distribution is similar to the type II, but the higher mass retained at lower elevations are not present, possibly due to the fact that the sample positions relating to this distribution were at the head of the breakwater, and the influence of the sediment brought down by the river is not significant. The type IV distribution occurred in areas sheltered by the breakwater.

The mechanism by which sediment collects in the bamboo samplers was investigated in the laboratory by Fukushima and Kashiwamura (13). A study on the effect of the inclination of the slots relative to the water velocity was made, in order to determine the efficiency of sampling for various particle sizes. From the results obtained in this reference, it appears that the efficiency is rather low; the ratio of the mass of sediment captured in the tube to that flowing through the tube varied between 2% and 7% for different size particles.

Further tests using bamboo samplers were carried out by Hom-ma and and Horikawa (14) of the coast of Tokai and Niigata in Japan during 1959 and 1960. Measurements were made in the field under wave conditions of 1,1 metres in height with a period of 6,2 seconds, and in water depths between 4,8 metres and 7,8 metres. Laboratory calibrations using a siphon sampler of 1,5 litre capacity were undertaken in order to determine the constants in the theoretical expressions developed by Hom-ma and Horikawa, so that the concentration distributions could be estimated under higher wave conditions. Hom-ma and Horikawa concluded that under high wave conditions, up to 5,5 metres in height with a period of 12 seconds, the suspended sediment concentration would decrease rapidly as elevation above the sea bed increased up to a height of approximately 2 metres, and would then remain relatively constant, as shown in Fig. 2.6.

These results are based purely on mathematical expressions and field observations in relatively low wave conditions with no verification under high wave conditions, and must be viewed accordingly. Hom-ma and Horikawa observed that the sand ripple dimensions have an important effect on the distribution of suspended sediment concentrations determined in the laboratory experiments. The effects of the sand ripple profile on suspended sediment concentrations in the field, are, however, unknown.

Figure 2.6



	H (m)	T (sec)
1	5,5	12
2	4,5	12
3	4,5	10
4	3,5	10
5	3,5	8

Analytical Vertical Distribution of Suspended Sediment Concentrations for Variable Wave Conditions.

From Reference (14)

Basinski and Lewandowski (3) used a time averaging trap type sampler made of perspex similar to the bamboo tube type of sampler as described above, to determine the relative concentrations of sediment at various levels above the sea bed at Lubiatowo in Poland off the coast of the Baltic Sea and off the coast of Libya during 1973. The sampler consisted of a perspex tube, 50 mm outer diameter and between 3 and 4 metres long with a compartment size of 20 mm, positioned vertically in water depths of between 2 metres and 5 metres. The tubes were kept in position for a period of 5 days, during the passage of a meteorological low pressure system which resulted in wave height of up to 1 metre. The tubes were positioned in a line offshore, approximately 100 metres apart, up to a maximum distance of 500 metres offshore. Basinski and Lewandowski evaluated the relative sediment transport both in the onshore - offshore direction and in the longshore direction at various distances along the profile relative to the underwater bars. However, no attempt was made to correlate the mass of sediment retained in the tubes at various levels with the prevailing wave conditions.

The bamboo type of sampler described above measures the accumulated mass of sediment at various levels above the sea bed. In order to determine the distribution of suspended sediment, the velocity profile at the sampling point must be known.

None of the investigators using the bamboo samplers took the velocity profile into account when analysing the data, but assumed that the curve resulting from the accumulated mass at various levels is similar in shape to the distribution of suspended sediment. The bamboo type sampler, however, determines a relative measurement of the total sediment transport in a particular direction at a particular elevation and position rather than the relative distribution of suspended sediment.

Investigations by Longuet-Higgins and others in reference (15) have shown that the velocity profiles are exceedingly complex in both the longshore direction, caused primarily by oblique wave attack, and in the onshore-offshore direction, caused by mass transport velocities due to the unsymmetrical wave profile. It is possible, under certain circumstances, for a reverse mass transport flow to occur at mid depth whilst the mass transport flow at the bed is in the opposite direction. Hence the determination of the distribution of suspended sediment concentrations from the measurement of the relative mass transport at various levels above the sea bed, as obtained by bamboo samplers, without knowing the velocity profile, can lead to large errors being made. The author, therefore, concluded that the bamboo type of sampler cannot be used with any accuracy to determine the relative distribution of suspended sediment concentrations existing in the field. The work carried out by investigators using this type of sampler has only been undertaken in very low wave height conditions and only seaward of the breaker zone. Although the bamboo samplers offer a simple and cheap method of obtaining results, the wave climate in which it can be used is very limited and thus is of little value when measurements are required off a beach experiencing high wave conditions.

Another type of time-averaging trap type sampler which has been used in the coastal environment is the Delft bottle commonly used in the measurement of suspended sediment concentrations in rivers and channels. Experiments were conducted by the Marine Effluent Research Unit of the Department of Oceanography, University of Cape Town (7) and (16), at Duynefontein, north of Cape Town during 1972 to 1974. The instrument was attached to the leg of a tower situated approximately 1200 metres offshore in a water depth of 11 metres. Measurements were taken over a period of approximately one to two months at a time, in water depths of 5 and 8 metres. Wave heights varied considerably during the sampling period, with heights of over 5 metres being recorded (7). Initially a Bendix current meter was installed with the Delft bottle to obtain current velocities and directions, but this had to be removed later because of corrosion problems and damage caused by wave action.

The data obtained from the Delft bottle experiments was thus unable to predict the suspended sediment concentrations, but the relative amount of sediment transported in various directions could be determined, together with the size of sediment present.

It was noted that 80% to 90% of the mass fraction of the sample was within 0,088 mm to 0,177 mm, but under more severe wave conditions, i.e. during winter storms, a significant proportion, between 10% and 15% of the mass fraction, was found to be between 0,177 mm and 0,250 mm in size. It was also noted that the mass of sediment trapped in the longshore direction was significantly larger than that trapped in the onshore-offshore direction, the ratio between these two masses varying between 1,5 and 10. The mass fraction of silt trapped, i.e. less than 0,060 mm in size, was very small in all cases.

Although this type of sampler was only used as a preliminary study of sediment transport, it does provide an indication of the relative transport of suspended sediment at various depths, and with further instrumentation providing velocity measurement, the distribution of suspended sediment concentrations can be obtained. However, as the sampler and accompanying velocity measuring equipment are not robust enough for measurements in the surf zone or outside the surf zone under high wave conditions, thus severe limitations restrict the use of this type of sampler to low wave height conditions, when the suspended sediment concentrations are small and contribute little to the overall sediment movement experienced on a beach.

2.3 Instantaneous Trap Type Samplers

The type of sampler used in this application of measuring suspended sediment concentrations in the surf is a portable siphon sampler, commonly consisting of an evacuated bottle of 1,5 litre capacity, connected to a quick release valve and intake nozzle. Hom-ma and Horikawa (14) mention the use of such a sampler in conjunction with bamboo samplers, but it proved to be "unfeasible due mainly to the difficulty of operation under rough sea conditions". No results using this type of sampler were mentioned by Hom-ma and Horikawa.

The Coastal Engineering Research Unit of the Department of Civil Engineering, University of Cape Town, used this type of sampler to determine sediment concentration in the surf zone off the coast of Oranjemund, South West Africa/Namibia, and at Duynefontein, north of Cape Town during 1973 and 1974 respectively (17). Measurements were made in wave conditions of up to 3 metres in height and to a depth of 10 metres. The samples from the surf and swash zones were taken by an operator carrying the sampler to the desired point in the surf zone and releasing the valve manually. Those samples in deeper water were taken using a modified sampler, enclosed in a P.V.C. drum with a float which triggered the sample valve by inflow of water into the float chamber. The modified sampler was placed into position using a Bell Jetranger helicopter when required in the breaker zone, and by a boat when required well seaward of the breaker zone.

The samples obtained were instantaneous measurement of the suspended sediment concentrations at a particular time in the wave cycle. In order to obtain the average concentration, several measurements had to be taken at various times in the wave cycle, at the same elevation above the sea bed. Some results obtained using this type of sampler are given in Fig. 2.7.

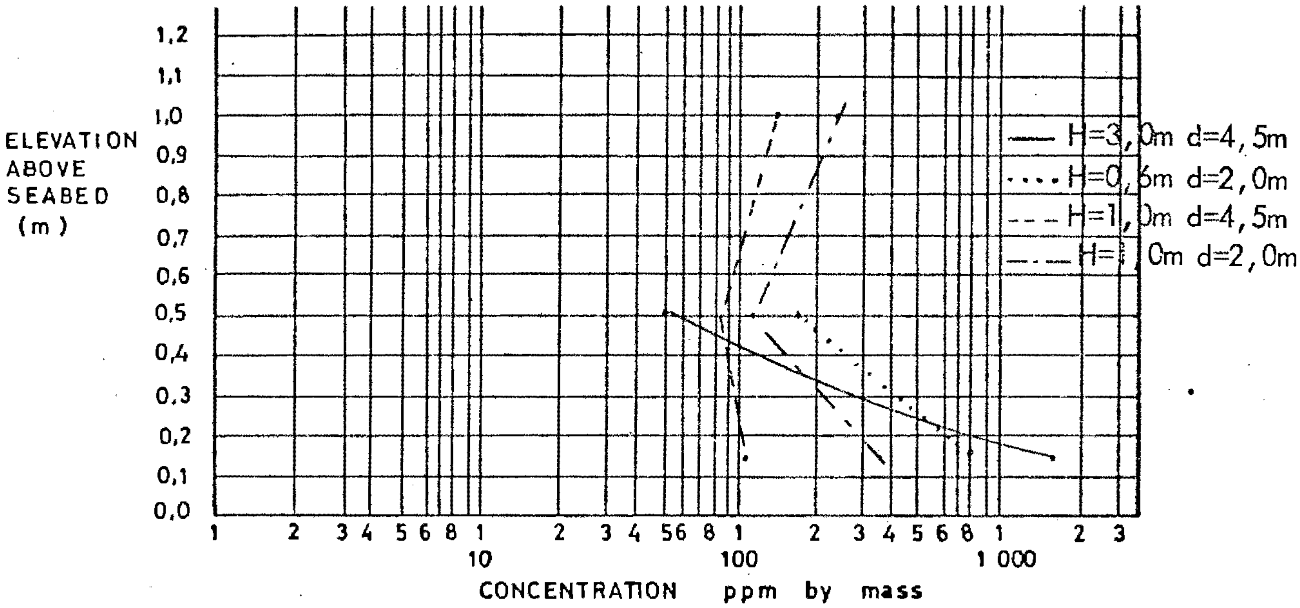


Figure 2.7 : Concentration results using siphon sampler.

From Reference (17)

The necessity to obtain several samples at one sample point to determine the average concentration is time consuming and costly if the operating costs are high, for example, use of a helicopter. In addition, the use of a boat seaward of the breaker zone sometimes proved to be hazardous if the beach profile was very flat. The main disadvantage of this type of sampler was the small quantity of sediment trapped. This can result in large variations in the concentrations as calculated as a small amount of residual sediment in the sampler will alter the total sediment mass trapped significantly, and with it, the concentration, whereas if the sample contained a larger mass of sediment, this small amount of residual sediment will have little or no effect on the concentration. In addition, the grading analysis of such a small sample is difficult to determine. However, this type of sampler is relatively inexpensive to manufacture and operate, and the results give a reasonable indication of the order of magnitude of suspended sediment concentrations which can be expected under prototype conditions. It can also be used in high wave conditions, obtaining samples from the breaker zone and just seaward of it, using a helicopter to place and retrieve the unit. None of the previous instruments discussed was able to be used under these conditions.

2.4 Indirect Type of Samplers used in the Field

Three types of indirect samplers will be considered, namely the ultrasonic method as described by Wenzel (2); the radiometric method as described by Basinski and Lewandowski (3); and by the electro-optical method as described by Brenninkmeyer (18).

Wenzel (2) developed an instrument to measure current velocity and sediment concentrations using the change in sonic properties of the water with increasing sediment concentrations. Electro-magnetic current meters were used, whereby a voltage is generated by water passing through an electromagnetic field. The actual construction of these current meters is not described by Wenzel. The sediment concentration can be measured by these acoustic phenomena; namely reflection, absorption and variation of sonic velocity. Wenzel postulated that the measurement of suspended sediment concentration can be made using two of these phenomena: absorption and variation in sonic velocity. Formulae for the sonic velocity in sediment-free and sediment-laden water are quoted by Wenzel. This results in a measuring system independent of water colour and turbidity, which handicap other indirect types of samplers in the field, but still needs extensive calibration.

The instrument consisted of a soundemitter and receiver placed vertically on a loop of approximately 600 mm in diameter. Water flowing through the loop resulted in a reduction in sonic velocity according to the concentration. The unit is to be mounted in a sturdy frame and placed on the sea bed during a calm period. An under-sea cable connects the instrument to the base on the shore providing power and data transmission link. This device, therefore, provides a continuous record of current velocities and sediment concentrations at a particular level above the sea bed, during a long period of time. It has been tested at Westerland on the Island of Sylt, North Germany, in the North Sea during 1972, but no results were mentioned by Wenzel, as the calibration was incomplete.

If the system as described by Wenzel is successful, it will provide a major advancement in the problem of measuring suspended sediment concentrations in the surf zone under high wave conditions. The unit is robust, lacks moving parts, and can remain in position for long durations. However, several problems still have to be solved, the main one being calibration. During operation, other problems may arise, such as the effect of marine growth on the instrument, giving rise to erroneous velocity measurement, and the possibility of the instrument being buried by seasonal changes in the beach profile. In addition, the instrument at present only measures the reduction of sonic velocity at one level, and if calibrated, the resulting sediment concentration, thus a number of these instruments with sensors at different levels would be required to determine the distribution of suspended sediment concentrations.

Notwithstanding these difficulties, this system could provide a good method of measuring sediment concentration in the future, if the calibration of the instrument is successful.

Basinski and Lewandowski (3) developed a system to measure suspended sediment concentration in the surf using the absorption of gamma radiation in sediment-laden water. Preliminary tests were conducted in the Baltic Sea off Lubiatowa in Poland during 1973 and 1974 but no concentration readings were published. Two aluminium tubes, 500 mm in diameter, one containing a radioactive source, the other containing the sensor, were placed 46 mm apart and fixed vertically to a platform resting on the sea bed. The probe and sensor moved simultaneously in each tube to the desired level, and a continuous reading of gamma ray absorption was obtained.

Laboratory calibration was carried out by inserting perspex sheets between the probe and sensor, and placing sand between these sheets. By adjusting the distance between the perspex sheets, different concentrations of sediment could be simulated. However, the variation of radiation as detected by the sensor can be caused by phenomena other than sediment concentration. The intensity of gamma radiation from the probe itself can vary, together with natural gamma radiation received from space. In addition the absorption of gamma radiation is also affected by the variation in salinity and chemical composition of the sea water and sediment respectively. The author believes that these factors render calibration as determined in the laboratory, not to be as accurate as found by Basinski and Lewandowski. If a very low emittance is used in the probe, then the level of natural radiation may affect the readings considerably, whereas if a probe of high emittance is used, radiation hazards may result to the detriment of the local marine environment.

During field tests, Basinski and Lewandowski mentioned several difficulties experienced, namely the electrochemical corrosion of the aluminium tubes in sea water causing the probe and sensor to jam in the tubes, and wave action on the tower caused leakages in the tube joints.

The system as developed by Basinski and Lewandowski has several major disadvantages, namely: the inflexibility of the system which relies on a fixed platform of sufficient structural rigidity to withstand wave attack, particularly if situated in the surf zone; the problems associated with calibration of the system as described above; the radioactive nature of the experiment may be hazardous to marine life and the consequences of failure of the probe casing could cause considerable damage; and the reliance on a high voltage system needed for the probe and sensor, requires an external power supply. Gibbs (26) concluded that the radiometric absorption method is not very sensitive in very low concentrations, and can only be used in the range of 5000 ppm to 100 000 ppm. The threshold limit of 5000 ppm occurs seldom in the coastal environment, and then only under conditions of high wave action.

As the Baltic Sea where Basinski and Lewandowski conducted the tests appears to experience a low wave climate, this system may be successful under these conditions. However, it is not feasible for this type of system to be employed in a region of high wave action as it is not sufficiently robust.

Brenninkmeyer (18) developed an electro-optical system to measure sediment concentrations in the swash zone. The system consisted of 64 photo-electric cells placed above each other in a tube, which was placed vertically in the upper region of the swash zone. A high intensity fluorescent lamp was placed next to the photo cells, and the light attenuation between the light source and sensor was measured. Tests were conducted at Point Mugu, California under wave conditions of up to 0,9 metres in height and 13 to 16 second wave period. Measurements were carried out under extremely low wave conditions and in the upper region of the foreshore only, thus results cannot be comparable to those obtained under high wave conditions.

The main disadvantage of this system is that it is not robust enough to conduct measurement under reasonably high wave conditions, i.e. up to 2 to 3 metres in height, and can only measure sediment concentrations in the upper foreshore where the concentrations are of little value in determining the overall movement of sediment. The electro-optical system is also susceptible to erroneous readings caused by turbidity, marine organisms and water colour.

2.5 Suspended Sediment Samplers used in Tidal, Estuarine and Deep Sea Applications

Numerous samplers have been developed for the measurement of suspended sediment in tidal and estuarine waters. A cross section of these types will be discussed briefly to illustrate the system used for sampling, and whether it can be developed for use in the nearshore environment.

Jensen and Sorensen (19) determined suspended sediment concentrations in a proposed dredged channel at the Port of Karachi in Pakistan during 1971. Sampling took place well outside the breaker zone, in 11 metres water depth, using a boat operated system. The sampler consisted of a frame in the form of a tripod with four nozzles mounted horizontally on to the frame, being 0,1 metre; 0,3 metre; 0,9 metre and 2,4 metres above the sea bed. The nozzles were connected by a flexible tube to the pumping system on the boat, anchored overhead, where two 1 litre samples were obtained every 45 minutes from each nozzle, the sampling duration being approximately 30 seconds. In addition, a sample was taken at middepth. The wave conditions during sampling varied between 1,4 metre and 2,7 metre, with a zero crossing period of between 7 to 9 seconds.

The tidal range was significant, being 3,5 metres, with a maximum velocity of 0,5 metres per second. Thus the sediment in suspension was the result of the combination of the wave action and the tidal current. Concentrations determined from the sampling system are given in Fig 2.8. The median diameter of the bottom sediments was found to be 0,080 mm. It was found that the concentrations at the 0,3 metre level and above agreed with the calculated values, but that the value for the 0,1 metre level varied considerably. This may possibly have been due to slight settlement of the tripod. Full scale laboratory tests were undertaken in an oscillatory water tunnel to determine the sediment concentrations at levels between the bed and 0,1 metre elevation.

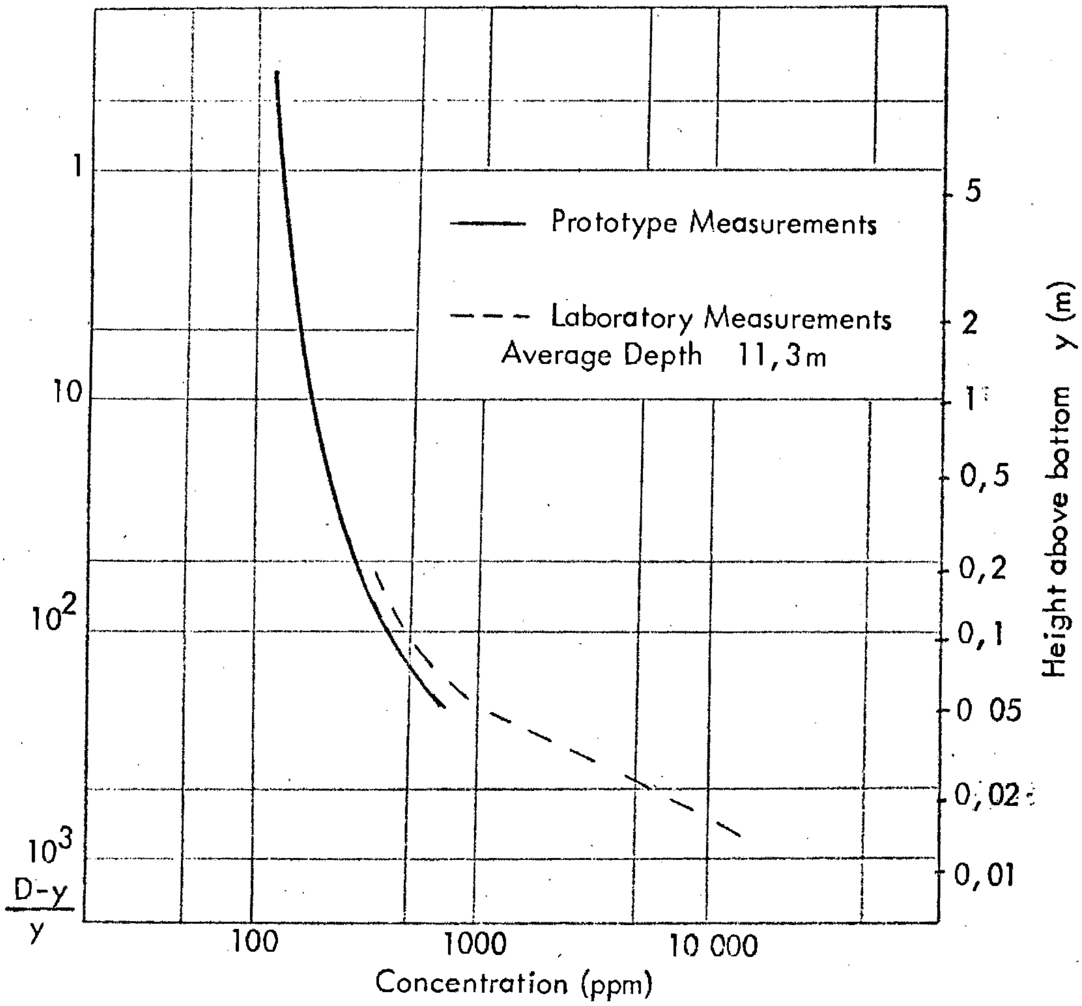


Figure 2.8 : Sediment Concentration Profiles

This system requires a boat as the support craft for sampling, and thus cannot sample near the breaker zone. In addition, the size of sample is rather small, namely 1 litre, which could affect the accuracy of the concentrations. It does, however, give the order of magnitude of sediment concentrations which can be expected under combined action of waves and currents.

Crickmore and Aked (20) describe four types of pump samplers used by the Hydraulics Research Station in the United Kingdom to determine velocity and sediment concentrations in estuarine and tidal water. Two of the units were point integrating samplers and the other two were depth integrating units as defined by the Draft ISO Standards (21) and (22). The point integrating units consisted of a bed frame type and a mast type, with intake nozzles and current meters fixed at various levels above the sea bed, the closest being 150 mm to the bed. The current meters were of the impellor type, measuring velocity by "make and break" principle caused by the rotation of the impellor blades. The electrical impulses were picked up by magnetic sensors and transmitted to the instrumentation on the boat by multi-way cables. The pump was mounted on the boat, connected to the nozzles by way of a single flexible hose, where the various nozzles were opened or closed using solenoid valves. One of the depth integrating samplers was operated from a boat, the frame being lowered to the sea bed on which a nozzle was mounted on a drive to enable it to move vertically. The other sampler was used on a fixed structure, where a wheeled trolley was mounted on to one of the vertical legs, thus enabling vertical movement of the nozzle. Fins were fixed to the frames to ensure correct orientation of the nozzle. The samples were filtered on board through terylene filters capable of retaining particles larger than 0,040 mm in diameter, and the throughput of water was measured by volumetric meter. The volume of sample was approximately 40 litres and pumped at between 10 to 15 litres per minute, giving an intake velocity of 1,5 metres per second for a 13 mm nozzle.

These units were designed specifically for calm water applications and can not be used in the surf without modification. They are very similar to the pump samplers used by Fairchild (5) and Jensen and Sorensen (19).

Crickmore and Aked (20) also investigated the effect of the relative intake and flow velocities and the orientation of the nozzle on the efficiency of sampling. Tests were carried out in a flume with water depth of 0,4 metres, and steady uniform flow of 0,62 metres per second, with a measured concentration of approximately 400 ppm at 0,1 metre above the bed. Concentrations at various velocity ratios were measured and are given in Fig 2.9.

It appears that for velocity ratios of 0,5 to 4,0 the concentrations determined show no large variations and thus the velocity ratio does not have a significant effect on the sample concentration. Tests were also carried out to determine the sampling efficiencies with different nozzle orientation with respect to the flow velocity. It was found that 13 mm and 15 mm nozzles showed a 6% concentration deficiency for a 90° orientation to the flow velocity, and an 18% deficiency for a 180° orientation.

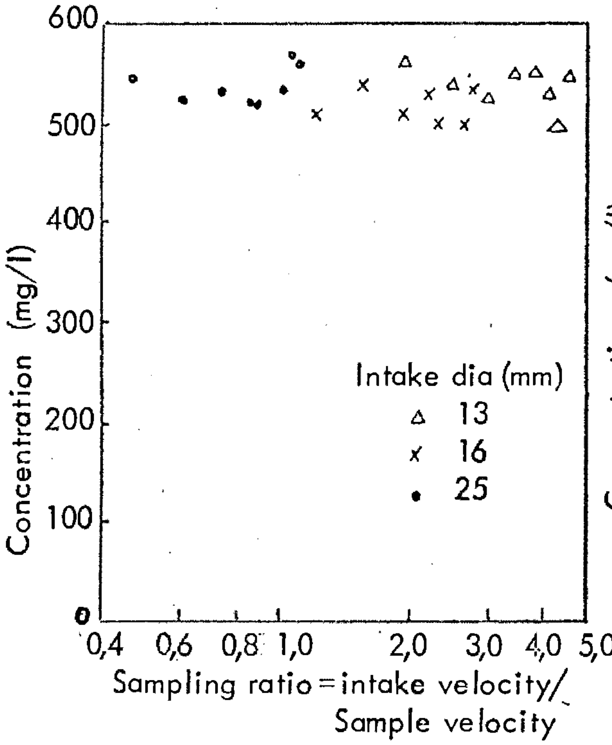


Figure 2.9 : Effect of Pumping Velocity on Sampling Efficiency

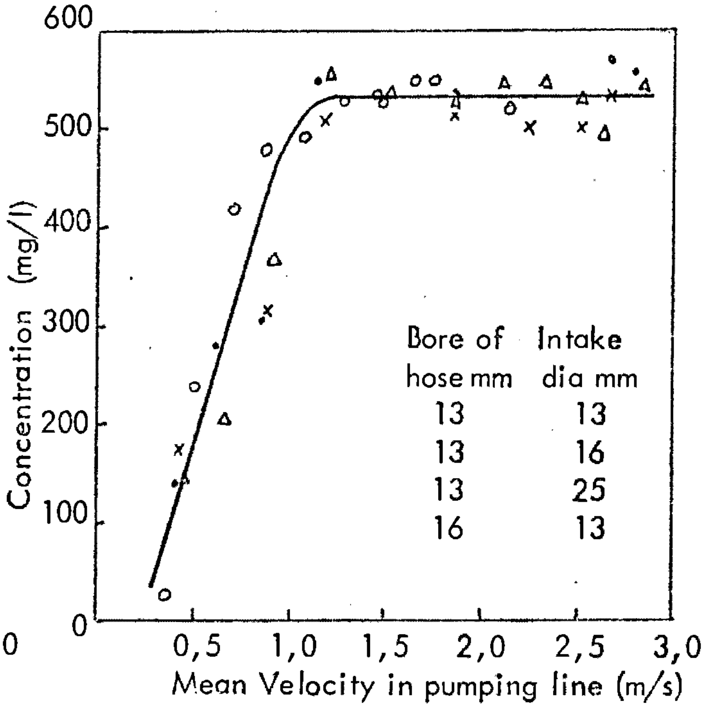


Figure 2.10 : Effect of Sampling Flow rate on Sediment Concentration

The duration of sampling has an effect on the coefficient of variation of the samples. Crickmore and Aked determined that the coefficient of variation for sampling periods of 12 and 240 seconds was 17 and 7 percent respectively. A minimum sampling time of 60 seconds was thus used to provide a coefficient of variation of less than 10 percent. In addition, they carried out tests to determine the minimum pumping velocities in the system needed to prevent fall-out of sediment within the pipes. Experimental values given in Fig 2.10, show that for velocities lower than 1,0 metres per second, sediment tends to accumulate in bends or horizontal lengths of the pipe. It is thus desirable to design the sampling system with pumping velocities above 1,0 metres per second.

Göhren and Laucht (23) developed a silt gauge to investigate the influence of wave action and drift currents on the suspended sediment load in tidal flats in the Elbe Estuary, West Germany. The instrument consisted of a conical settling tube, 1 metre in height, into which a 20 litre sample is pumped every hour. The sediment is allowed to settle into a measuring cylinder at the base of the tube, where the volume of sediment settled within one hour is recorded photographically, together with the time. The recorded volume therefore includes all sand sizes greater than 0,020 mm in diameter. A magnetic valve discharged the sediment back to the estuary, and a further sample is pumped into the settling tube by a submersible pump-motor unit. A continuous hourly record of sediment concentrations at a particular elevation above the bed can thus be made, and the whole system is self sufficient, relying on a wind generator for power supply. The instruments were mounted on a platform in the tidal flats, and can be operated up to 2 months when a change of film is required.

Collins (24) developed sampling towers used on the tidal flats of the Wash during 1971 and 1972, to determine suspended sediment concentrations at mid depth at various times during one tide cycle. The towers were constructed of light steel and aluminium frames, mounted on a concrete base cast in situ during low tide. The sampling system consisted of 0,5 litre polypropylene and polythene bottles connected to the surface and sampling point with flexible tubes. The sampling tube was clamped or bent in such a way that when the water level rose to a particular level such that the intake nozzle was at middepth, a release mechanism allowed the water to flow into the bottles, the air escaping to the surface via the exhaust tube. A variety of release mechanisms was used, namely a goose neck in the intake tube which would act as a siphon when the water level reached the desired height; a mechanism clamping the intake tube with a cistern float, released at the desired water level; and various mechanical releases involving time switches or magnetic reed switches and solenoids. These release mechanisms appear to work reasonably well in tidal areas according to Collins, but the size of sample, 0,5 litre, would make analysis of samples of small concentration difficult. This system of sampling would be unsuitable for sampling in the surf zone because of the light tower construction and the possibility of the release mechanisms failing due to vibrations caused by wave action.

Various authors have described sediment samplers used in deep water applications. Collins (25) used a transmissometer to determine suspended sediment transport routes and sources in the Outer Narragansett Bay adjoining Rhode Island, U.S.A. This instrument is based on the optical attenuation of light through a water-sediment mixture and can be used to determine low concentrations. Collins (25) determined concentrations of the order of 5 ppm with median particle diameter of the order of 0,015 mm to 0,020 mm. Gibbs (26) describes various samplers used in deep sea applications. As the concentrations are very low, pump type samplers are used with filters that must be capable of retaining particles of the size found by Collins, with a throughput of large volumes of water, up to 1000 litres.

Optical absorption devices as used by Collins (25), are unable to read low concentrations very accurately, in the order of 1 ppm. A new device is being developed for the determination of very low concentrations, namely the optical scattering method. The amount of light reflected from the particles is measured and with calibration, the concentrations can be determined. This system will only be accurate under very low concentrations because of the shielding and shadow effect at higher concentrations. As these low concentrations are unlikely to occur and are of little significance in the nearshore region, this method cannot be used in this environment.

2.6 Suspended Sediment Samplers used in Laboratory Applications

Measurement of suspended sediment concentration in the laboratory has mainly been determined by electro-optical techniques. Hom-ma and Horikawa (14) initially measured concentrations using a siphon sampler to obtain results which were compared with field data to estimate the concentrations under higher wave attack in the field. However, the siphon sampler has several disadvantages, namely the disturbance of the flow patterns in small scale models exaggerates concentration readings, and if a large number of samples is required, the resulting analysis of the samples is tedious. A new approach was sought, and two instruments using the same principle were developed.

Hom-ma et al (9) and (27) developed a photo-transistor type of concentration meter, which measures the light attenuation across a glass sided flume. This instrument was developed further by Horikawa and Watanabe (28) who introduced an electrolytic turbulence transducer to measure the turbulent water velocities under wave action and investigated the effect of turbulence on suspended sediment concentrations. This instrument consisted of an electric probe immersed in the water, the turbulent velocities measured by the fluctuating voltage between the cathode and anode of the probe.

Bhattacharya, Glover and Kennedy (29) developed an electro-optical probe, the ISCP, containing diodes as light source and sensor each 1,6 mm in diameter. The emission spectrum of the light was in the visible and near infra-red regions. The source and sensor are coupled to amplifiers and filters and the output read on a voltmeter. Alternatively, the output can be read on an oscilloscope or plotted on a moving chart. The ISCP was calibrated for different sand size and a sand with median diameter of 0,21 mm was used in laboratory tests. This instrument was developed further by Bhattacharya and Kennedy (30) by coupling the output to an on-line computer for signal averaging and analysis of the mean and fluctuating components of sediment concentrations.

The ISCP probe of the Iowa Institute of Hydraulic Research has several advantages over that developed originally by Hom-ma and Horikawa (27). The small size of the probe when inserted into the flume produces little disturbance of flow patterns, and measures the concentration at a particular point.

The photo-transistor method as developed by Hom-ma and Horikawa is subject to the reflection and scatter through the glass sides of the flume, and measures the apparent concentration across the width of the flume. The opaqueness of the glass and the distortion of sediment concentrations caused by the wall effect, could give rise to slightly erroneous readings. In addition this system measures the average concentration over a finite width equal to the size of of the source and sensor, whereas the ICPS measures the concentration over a very small area. Nakato et al (31) investigated the effect of the passage of single sediment particles moving through the optical field of the probe, on the concentration reading, using ink dots on glass slides to simulate sediment particles.

Hattori (11) developed a probe which counted the number of sediment particles passing through a slit by the variation of electrical resistance between two electrodes in the probe. The relative distribution of suspended sediment concentration could be determined, but a knowledge of the water and particle velocities must be known to determine absolute concentrations. For the experimental results, Hattori introduced the concept of "delay distance", described by sediment particle moving at the same velocity as the fluid, but some distance behind it, caused by the inertial resistance of the particle.

Bijker (10) investigated the possibility of using photography in determining sediment concentrations. Although this method provides instantaneous measurements of concentrations over a large area at a given instant of time, the fluctuations of the concentrations cannot be determined. It does, however, provide useful information as regards the entrainment process and mechanics of sediment suspension.

An important aspect recognised in all the laboratory investigations is the effect of sand ripple profiles on the sediment suspension. Up to 5 peaks of fluctuating concentrations were measured at various positions above the sand ripple profile on the oscillatory wave motion near the bed. Many investigators have attempted to correlate the resulting sediment suspension with sand ripple profile in the laboratory models. However, the extent of sand ripples in the field at the sample positions is generally unknown, and thus the application of laboratory results in the field using the relationships between concentrations and ripples as determined in the laboratory, could be over-emphasising the role of the ripple profile in suspension of sediment in the field.

Some typical results obtained from laboratory experiments are given below in Fig 2.11 and 2.12, where the concentration is plotted against the parameters $(d - y)/y$ and y/d respectively, on a log-log plot.

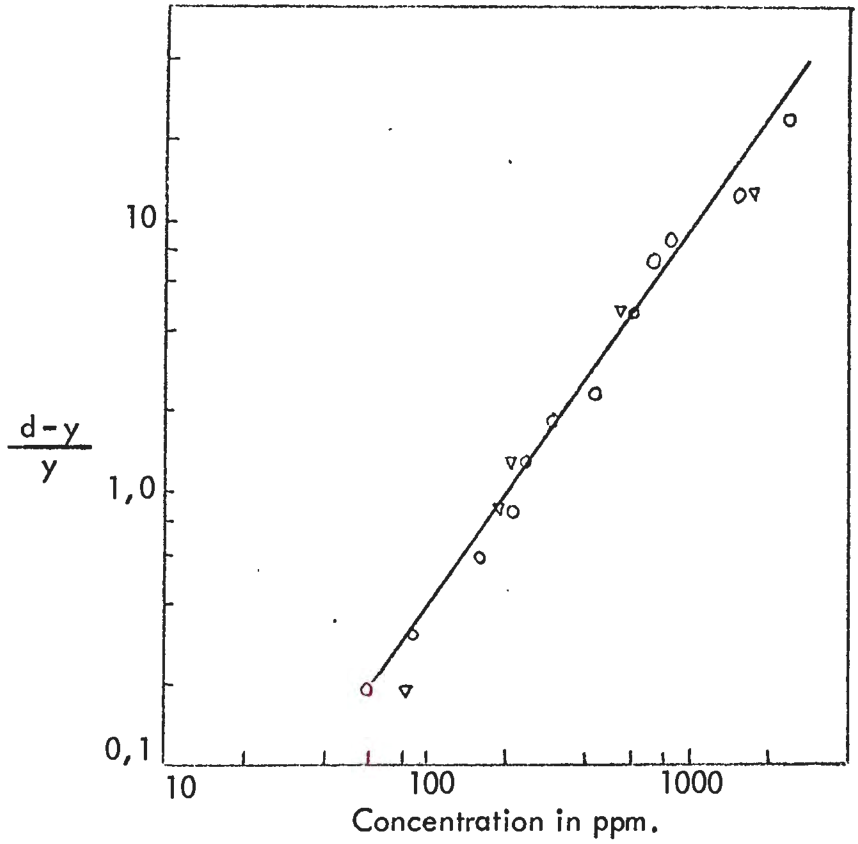


Figure 2.11

From Reference (29)

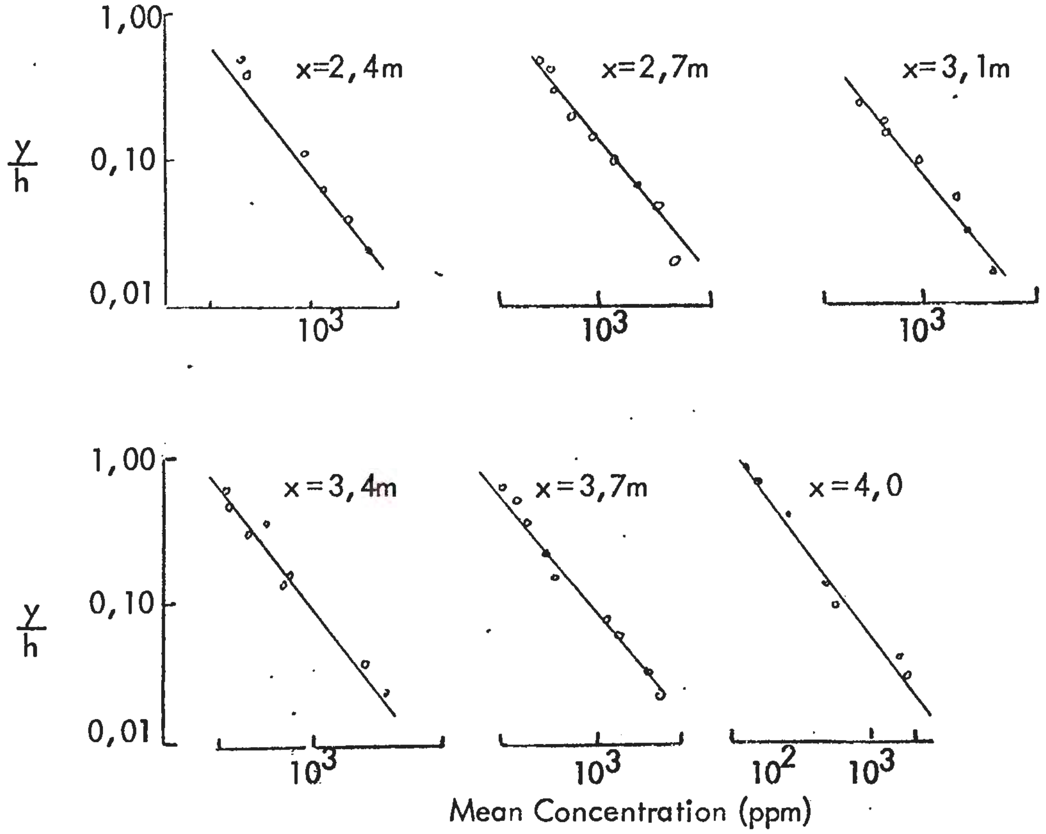


Figure 2.12 : Vertical Distributions of Mean Concentration, $\overline{C}$,

From Reference (8)

2.7 Conclusions

No satisfactory method has as yet been developed for the determination of the distribution of suspended sediment concentrations in the surf and nearshore zones. The direct type of pump sampler appears to be the most feasible sampler for adaption to this application because of the simplicity of the data acquisition and analysis. Indirect samplers have been tested in this application, but with little success, as the laboratory conditions under which the calibration is performed are not entirely representative of those existing in the field.

The use of instantaneous type trap samplers should be avoided because of the low concentrations and hence small size of sample obtained, and because of the difficulties of obtaining an average concentration reading from several instantaneous results. As concluded by Crickmore and Aked (20), the sampling duration should be at least 60 seconds for an acceptably low coefficient of variation of the results. Further, samplers which rely on fixed structures such as piers and towers, or boats, for operation should be avoided, as sampling from either the pier or boat is impossible within the breaker zone under moderate wave conditions.

The importance of sampling at stream velocity using pump samplers appears to have been overemphasised by research in sampling in unidirectional flows. Both Watts (12) and Crickmore and Aked (20) indicate that the orientation of the intake nozzle and the velocity ratio between the intake velocity and the oscillatory orbital velocity will result in concentrations being measured to within 15 percent of the true concentration.

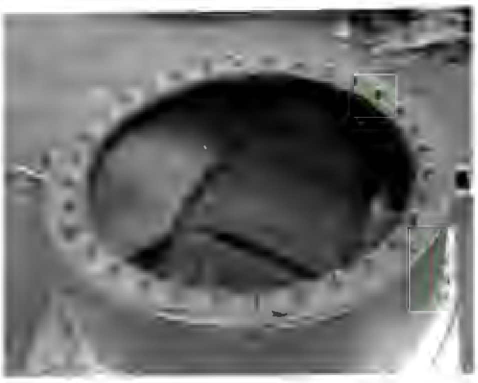


Plate 4.5 Ballast Tank Diaphragm

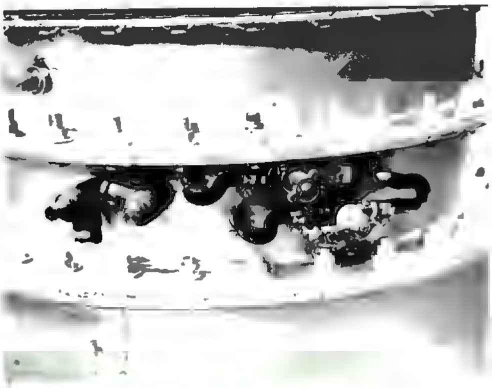


Plate 4.6 Relief Valves

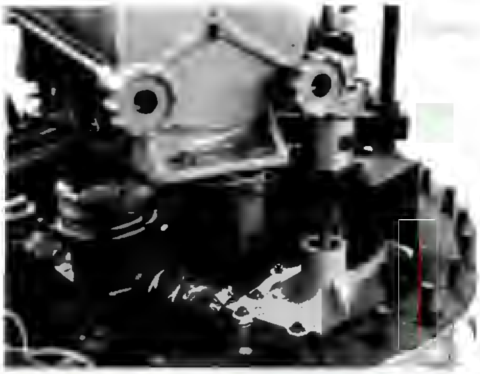


Plate 4.7 Pump Motor and Meter

Plate 4.8 Motor and Filter

CHAPTER THREE

Theoretical Considerations

In the practical application of bed, suspended and total sediment load transport formulae which have been derived theoretically, the transport rate is given as the product of the sediment concentration and velocity distributions integrated over the depth considered. Expressions for the velocity distribution have been derived by several authors, for example, Swart (32). Expressions for the suspended sediment distribution in both the upper and bed regions of flow have been derived, but are expressed in terms of the sediment concentration at a particular reference level. In order to evaluate the transport rate equations, this reference concentration must be determined empirically from data collected in the laboratory and field.

The choice of the reference level is arbitrary. However, it will be defined in this dissertation as the theoretical interface between the bed and upper layers of flow. The thickness of the bed layer is rather arbitrary in itself, as it is assumed to be the region in which the transported sediment transmits its weight directly to the unmoving bed, i.e. by sliding or rolling motion. The upper region is defined as that where the transported sediment transmits its weight entirely to the surrounding fluid. A transition layer of finite thickness exists between these two types of sediment motion, but for simplification of the mathematical model, it is assumed that the transition occurs at a definite level, this level being defined as the reference level. The concentration of suspended sediment at this reference level is thus common to both regions, and once determined, the sediment distributions in both regions can be evaluated.

In order to determine the position of this reference level, the form of the expressions for the distribution of suspended sediment concentrations must be theoretically determined. In the determination of these theoretical expressions, a study of the bed shear stresses that exist under oscillatory wave motion and the type of boundary layer encountered, must be made. No new theoretical expression will be developed below, but those developed by various investigators will be presented so that a procedure for the calculation of the reference concentration, can be established.

3.1 Bed Shear Stress Considerations

Expressions for the distribution of suspended sediment concentrations under oscillatory wave motion have not as yet been derived in terms of the parameters describing the oscillatory motion alone. However, expressions for this distribution derived for unidirectional steady-state flow in two dimensions have been adapted for use in oscillatory wave motion by determining the various constants empirically. Although these expressions have been found to describe the distribution reasonably well, the basic differences between oscillatory motion and unidirectional flow must not be forgotten.

The major differences between these two types of water motion with regard to sediment transport, are the shear stresses exerted by the fluid on a fixed boundary and the resulting boundary layer. Unidirectional steady state flow is kept in equilibrium by the existence of bed shear stresses and may be considered as a type of boundary layer flow in its entirety. The flow parameters can thus be defined entirely as functions of the bed shear stress and boundary roughness. Oscillatory motion, however, is defined as the motion resulting from an exchange of potential and kinetic energy in the water mass, and the flow parameters are defined in energy terms rather than equilibrium force terms. Bed shear stresses may exist under oscillatory wave motion in shallow water, but are caused by the introduction of a constraint on the motion, such as zero oscillatory wave velocity at a boundary. These bed shear stresses are thus determined by the thickness and type of boundary layer existing at a particular point and may vary considerably in relation to the depth in which the oscillatory flows take place. The description of the bed shear stresses and boundary layer is thus dependant on the form of the wave motion and cannot be used to define the water motion as is possible in unidirectional steady state flow.

The principal parameter used in describing any sediment motion in unidirectional steady state flow has been the bed shear stress, as this parameter is easy to evaluate by considering overall equilibrium of a body of water. As expressions using this parameter have been adapted for use under oscillatory wave motion, an expression for the bed shear stress under wave motion is sought. It is, however, difficult to evaluate as equilibrium equations as used in unidirectional flows cannot be applied with any success in evaluating this parameter. The shear stress can, however, be expressed in terms of the energy dissipation within the wave motion. This dissipation could be evaluated by measuring the difference in wave height between two sections. However, the order of magnitude of this energy dissipation is generally very small compared to that of the total wave height, and the difference in wave height is usually negligible. Expressions for the bed shear stress are therefore sought in terms of the velocity distribution near the bed. The shear stress in a fluid is defined in classical hydraulics as the sum of the viscous and turbulent shears, which in turn are described in terms of the velocity distribution :

$$\tau = \tau_v + \tau_t$$

$$= \frac{\mu\, du}{dy} + \rho l^2 \frac{du}{dy}^{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

With a knowledge of the velocity distribution and Prandtl's "mixing length", l, the shear stress would therefore be able to be evaluated. However, the actual velocity distribution at a mobile bed under wave action is exceedingly complex and is thus unknown as yet. Several investigators have developed expressions for the shear stress at the boundary under oscillatory wave motion. Two of these approaches will be studied and used in the evaluation of the reference concentration.

Yalin (33) defined the shear stress at the bed, τ_o, resulting from oscillatory wave motion as :

$$\tau_o = \alpha \rho U^2 + \beta \gamma \delta \bar{S} \qquad \text{...............(3.2)}$$

where δ = thickness of boundary layer
$\bar{S}$ = slope of the free surface
α and β are coefficients.

The above expression was simplified by putting

$$U_\delta = (U_\delta)\,\text{max} \qquad \text{and} \qquad \bar{S} = 0$$

For a rough turbulent boundary layer, Yalin determined a value for **o** resulting in the expression taking the form :

$$\frac{\bar{\tau}_o}{\rho (U_\delta)\text{max}^2} = \frac{1}{\left(2{,}5 \ln 30{,}1 \frac{\delta}{K_s}\right)^2} \qquad \text{.............(3.3)}$$

For laminar boundary layer conditions, the values of α and β are given as

$$\alpha_L = \frac{(\text{constant})_1}{\frac{U_\delta \delta}{\nu}} \qquad\qquad \beta = \text{const}_\beta$$

Thus with a knowledge of the thickness of the boundary layer, δ , and the sand roughness, K_s, the average bed shear stress can be evaluated.

Yalin determined an expression for the rough turbulent boundary layer thickness δ , in terms of the amplitude of the orbital motion at a distance δ above the bed, and the roughness :

$$\delta = \text{constant}\,(a_\delta)^{0{,}75}\, K_s^{0{,}25} \qquad \text{...............(3.4)}$$

An expression was also developed for the laminar boundary layer thickness :

$$\delta = (\text{constant})_1 \sqrt{T\nu} \qquad \text{...............(3.5)}$$

where T is the wave period. The constant was evaluated by Silvester (15) as $2/\sqrt{\pi}$. Laminary boundary layer conditions generally occur under long period waves such as tidal cycles, tsunamis and storm surges, and only occur in deeper water of the nearshore environment.

An alternative approach is proposed by Bijker (10). The bed shear stress under the combined wave and current action is evaluated in terms of the bed shear stress of the current alone :

$$\tau_{wc} = \left[1 + \frac{\left(\xi \, \frac{U\ max}{v} \right)^2}{2} \right] \tau_c \qquad \ldots\ldots\ldots\ldots\ (3.6)$$

where $(U\ max)$ = maximum orbital velocity at the bed
v = current velocity
ξ = coefficient given in terms of the Chezy roughness coefficient, C,
= $0{,}0575\,C$ ....(3.7)
τ_c = bed shear stress due to the current alone
= $\rho g v^2/C^2$ ....(3.8)

Swart (32) evaluates the Chezy roughness coefficient in terms of the depth of water and the hydraulic bed roughness, r :

$$C = 18 \log \left(\frac{12d}{r} \right) \qquad \ldots\ldots\ldots\ldots\ (3.9)$$

where $r = 25 \Delta r \left(\frac{\Delta r}{\lambda r} \right)$ ....(3.10)
Δr = ripple height
λr = ripple length

The evaluation of Δr and λr is complex and is given in reference (32) by Swart.

Alternatively, the Chezy roughness coefficient is given in terms of the Manning Coefficient, n , in classical hydraulics as :

$$C = \left(\frac{1}{n} \right) (d)^{1/6} \qquad \ldots\ldots\ldots\ldots\ (3.11)$$

assuming the hydraulic radius is equal to the depth for two-dimensional flow.

Bijker (10), however, simplified the expression for the hydraulic bed roughness, and assumed this to be 1,6 times the height of the ripples. The ripple dimensions are relatively easy to measure in the laboratory, together with the current velocity, but are under most circumstances difficult to measure in the field. If no current velocities have been measured, an estimate of the current at the bed can be made using the mass transport formula as given in references (15), (34) and (35) as :

$$U_B = \frac{5{,}0\ \pi^2 H^2}{4TL \sin h^2 \left(\frac{2 \pi d}{L} \right)} \qquad \ldots\ldots\ldots\ldots\ (3.12)$$

The accuracy of evaluating the shear stresses due to wave and currents using this method proposed by Bijker, is thus highly dependent on the accuracy of measurement of current velocities at the bed, which is difficult in prototype conditions.

Using formula (3.6) to evaluate the shear stresses, it can be seen that an under-estimation of the current velocity will produce large values of shear stress, which does not conform to that experienced in practice. In the limiting case, if the current velocity is zero, the expression becomes meaningless. Hence this expression can only be true between certain limits, but these are not evaluated by Bijker (10) or Swart (32). When calculating the shear stress using this formula, this lower limit must be kept in mind.

3.2 Boundary Layer

The type of boundary layer has been distinguished by using a critical Reynolds number. Einstein (36) conducted experiments using an oscillatory tray in still water to determine the form and values of this critical Reynolds number. For three dimensional roughness, the transition between laminar and turbulent boundary layer conditions was found to be given by :

$$Re = \frac{K_s\, a\, 2\pi}{T\nu} = 104 \quad \text{for } \frac{a}{K_s} < 1630 \qquad \ldots\ldots\ldots\ldots(3.13)$$

Silvester (15) quotes another form of Reynolds number to determine the transition between turbulent and laminar conditions. This value is given as :

$$Re = \left(\frac{U_{max}\,\delta}{\nu}\right) = 1000 \qquad \ldots\ldots\ldots\ldots(3.14)$$

It thus appears that two conflicting definitions of the critical Reynolds number exist. The form of the expression as developed by Einstein, involves parameters which are easily calculated from wave theory, whereas those quoted by Silvester, include the thickness of the boundary layer. This value cannot be calculated with any degree of confidence, and as the values obtained by Einstein are backed by extensive laboratory work, this form of the expression will be used to determine the type of boundary layer present.

3.3 The Distribution of Suspended Sediment Concentrations

Yalin (37) has identified the two basic approaches to the derivation of expressions for the distribution of suspended sediment concentrations, namely the diffusion and gravitational theories.

In the diffusion theory, the volumes of two fluid lumps, one moving upward and the other moving downward through a particular level, each a distance, l , apart, are equated. The distance, l , is equal to the mixing length as defined by Prandtl. The volumes are then expressed in terms of weights of solids contained within the fluid lumps, and subsequently expressed in terms of concentrations. The differential equation for the distribution of suspended sediment is thus determined :

$$\frac{dc}{dy} + a_* c = 0 \qquad \ldots\ldots\ldots\ldots\ldots (3.15)$$

where $$a_* = \frac{2w}{/v^1/} \qquad \ldots\ldots\ldots\ldots\ldots (3.16)$$

where $/v^1/$ is the vertical velocity of the turbulent eddy diameter, This expression can be integrated if the shear stress and velocity distributions are known. If the shear stress distribution is assumed linear and the velocity distribution assumed logarithmic, and the eddy diffusion to vary quadratically with elevation above the bed, then :

$$\frac{c}{c_o} = \left[\frac{y_o\,(d - y)}{y\,(d - y_o)}\right]^{e_1} \qquad \ldots\ldots\ldots\ldots\ldots (3.17)$$

where $$e_1 = \frac{w}{K\ v_*} \qquad \ldots\ldots\ldots\ldots\ldots (3.18)$$

If the eddy diffusion is assumed to vary linearly with elevation above the bed then the differential equation resolves to :

$$\frac{c}{c_o} = \left[\frac{y}{y_o}\right]^{-b_1} \qquad \ldots\ldots\ldots\ldots\ldots (3.19)$$

where $$b_1 = \frac{w y_o}{\varepsilon\, y_o} \qquad \ldots\ldots\ldots\ldots\ldots (3.20)$$

Laboratory results by Kennedy and Locher (8) are given in Chapter 2 and are seen to conform to both solutions. Kennedy and Locher concluded that virtually any estimate of the eddy diffusion could be used and a workable theory would be obtained. Neither of these theories could therefore be rejected by the lack of conformity to experimental results. A discontinuity was noted when $\eta = 0,05$, and this value could be an estimate of the upper boundary of the bed layer. Yalin (37) also observed this discontinuity at the same relative depth in unidirectional steady state flows.

Swart (32) compared these expressions with field and laboratory results and concluded that equation (3.19) fitted the experimental data best. A value for b_1 was determined empirically :

$$b_1 = 1{,}05\, e_1^{\,0{,}96} \left(\frac{r}{d}\right)^{0{,}013\, e_1} \qquad \ldots\ldots\ldots\ldots\ldots (3.21)$$

Fleming and Hunt (38) and (39) derived an expression for the suspended sediment distribution above the bed layer as :

$$\left(\frac{c}{1-c}\right)\left(\frac{1-c_o}{c_o}\right) = \left[\left(\frac{1-\eta}{1-\eta_o}\right)^{\frac{1}{2}}\left(\frac{B-(1-\eta_o)^{\frac{1}{2}}}{B-(1-\eta)}\right)\right]^{e_2} \quad \ldots\ldots\ldots (3.22)$$

$$\text{where} \quad \eta = \frac{y}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.23)$$

$$e_2 = \frac{e_1}{B} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.24)$$

B is the multiple of the von Karman coefficient, K, to take into account the reduction in value of this coefficient when sediment is present. The suspended sediment distribution in the bed load was also determined:

$$c = c_m \left(\frac{c_o}{c_m}\right)^{\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.25)$$

Where c_m = 0,52, i.e. the maximum concentration possible assuming the sand particles as spheres.

The gravitational theory was derived by Velikanov and is described by Yalin (37). It uses the energetical structure of the liquid-solid mixture to determine the distribution of suspended sediment. The average value of the work done by the sediment particles moving downwards under the action of gravity is equated to the loss in energy of the flow if the suspended sediment concentrations at a particular level remain constant. Using this principle, a differential equation is formulated similar to that of (3.15). Assuming a linear shear stress distribution and a logarithmic velocity distribution, the relative concentration is given by :

$$\frac{c}{c_o} = \exp\left[-\frac{w}{v_*}\;\frac{K\,Y_s\,d}{\tau_o}\int_{\eta_o}^{\eta}\frac{d\eta}{(1-\eta)\ln(\eta/a)}\right] \quad \ldots\ldots\ldots (3.26)$$

The evaluation of the integral is complex and the diffusion theory seems to present a simpler solution that has been shown to correlate well with field and laboratory data.

3.4 Wave Theories

In order to calculate the orbital velocities and diameters of the water particles subject to oscillatory wave action, the first order wave theory will be used. This theory is the simplest to evaluate and as the data measurements such as wave height and period are not known very accurately, the advantage of using higher and more accurate wave theories is lost.

In the surf zone, where the first order wave theory is strictly no longer applicable, it is assumed that the wave height decreases linearly from the breaker point to the foreshore.

First order wave theory will be used to calculate velocities and orbit diameters, but in order to take into account the unsymmetrical profile of the waves, the values will be multiplied by a correction factor of $2a_c/H$, where a_c is the amplitude under the crest at the breaker point as determined by cnoidal wave theory. A graph is given tabulating a_c/H, in Fig 3.1, and is obtained from reference (15). Value of the functions used in first order wave theory are obtained using tables given in reference (40).

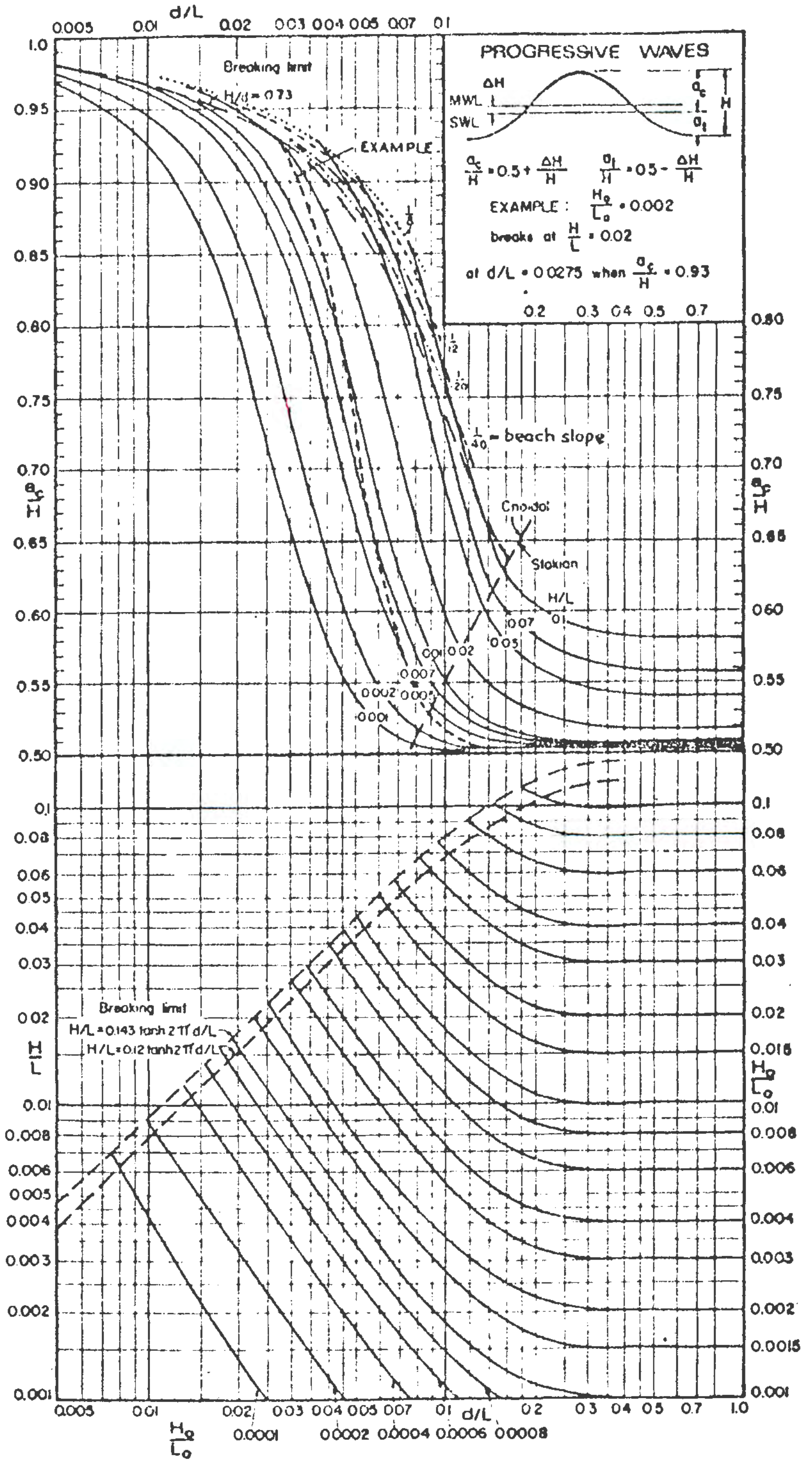


Figure 3.1 : Graph of a_c/H versus $\frac{H_o}{L_o}$

CHAPTER FOUR

Design and Construction of Sampling Equipment

4.1 Design Criteria

Two main design criteria must be fulfilled when considering the design of the sampling system. The first is that the type of instrumentation to be used must obtain a representative sample at a given point. The second is that the operation of placing the instrument at the desired position must not risk the safety of personnel and must be as economical as possible.

Pump type samplers were chosen to be used in this application so that a direct reading of sediment concentration was obtained. Initial investigations by the CERU, Department of Civil Engineering, University of Cape Town (17) showed the shortfall of obtaining small sample volumes. A larger sample volume, of the order of 100 litres, was chosen. If the concentration sampled was 100 ppm, then the resulting sediment mass would be 10 grammes, which is sufficiently large enough for sieve and settling-tube grading analyses. In order to reduce the physical size of the sampler, filtration is necessary to separate the sediment from the water, the water being returned to the sea via a volumetric meter. The sampling period must be longer than 60 seconds, as shown by Crickmore and Aked (20), to obtain a sample with an acceptable coefficient of variation. The system used obtained a sample over a period of 15 to 30 wave passes, i.e. of 3 to 5 minutes duration, which is deemed sufficiently long enough to obtain the average concentration.

As the units used were relatively small compared with the overall depth of water, the disturbance of flow patterns is assumed not to affect the readings. The author's observations from helicopters of horizontal eddies occurring in the surf zone, indicate that this turbulence is far greater than that caused by the influence of the sampler.

The indirect type of sampler was rejected as the sediment characteristics and water quality are unknown parameters. These parameters must be known for successful calibration of the indirect samplers. The author observed red tide, a type of plankton, on several occasions in the sampling area whilst diving at the sea tower. This red tide would affect the readings of an indirect type of sampler considerably and it cannot be assumed that marine organisms such as red tide are not present at lower levels if they are not visible at the surface. In addition the indirect type of sampler is unable to determine the type and grading of the sediment present.

The sampling unit must be able to operate and be placed under high wave conditions in the surf zone. Also the system must be flexible, in that sampling can take place along various profiles of the beach. These criteria rule out the use of a fixed pier or boat.

Two systems are proposed, one making use of a helicopter to place and retrieve the sampler, the other using a more complicated sampler, which is floated into position, sunk and refloated after sampling. The samplers used in both these systems must therefore be self-contained and sufficiently robust to withstand large dynamic forces caused by the oscillatory water motion.

A portable power source is thus needed to be contained within the sampler for pumping water through the filter. A choice between pneumatic and electrical power sources is available. Pneumatic power was chosen because of the susceptibility of electrical power being shorted out in damp conditions existing inside the sampler during sampling. In addition, the electrical power source is normally a lead-acid accumulator, which could be damaged in the rough conditions under which it must operate and is susceptible to spillage if the sampler is inverted. Alternative non-spill rechargeable accumulators with the same storage capacity as the lead-acid accumulator are expensive and difficult to obtain, as the author discovered when investigating the purchase of an electrical power source for the control system of the Mark II sampler. The pneumatic power source used was a 7 litre compressed air bottle with a working pressure of 20 MPa, commonly used for underwater breathing apparatus.

4.2 Design of the Mark I Sampler

This unit was designed as a prototype to be used in conjunction with a helicopter. The unit is attached to the aircraft by means of a cable, and lowered onto the sea bed. It must therefore be self-triggering and stable during sampling. Fig 4.1 shows an elevation of the instrument. The unit is designed for a rapid replenishment of filters and air cylinders to reduce the sampling cycle period to a minimum.

The water circuit consisted of brass intake pipes of 15 mm diameter which could be interchanged so that the sample could be drawn off at different elevations above the sea bed. The intake nozzles are positioned at 0,3 metres, 0,6 metres, 1,0 metres and 1,5 metres above the sea bed, projecting 0,5 metres from the body of the sampler. The sample is pumped by a fibreglass pump, Marino type FP-2, through a Kent water meter able to read to the nearest litre. The sample then passes through a non-return valve and into the filter, a Thomas Tube type with a terylene filter cloth held in position by means of a jet tube and rubber bungs. This filter is commonly used in the filtration of water for drinking purposes and the minimum size of solids retained on the filter was found to be approximately 0,030 to 0,040 mm in diameter. It is easily interchangeable without any loss of sediment. The water is then discharged back to the sea via the outlet of the filter.

The average flow through the instrument was measured to be 0,56 dm^3/s with an intake velocity of 2,4 metres per second.

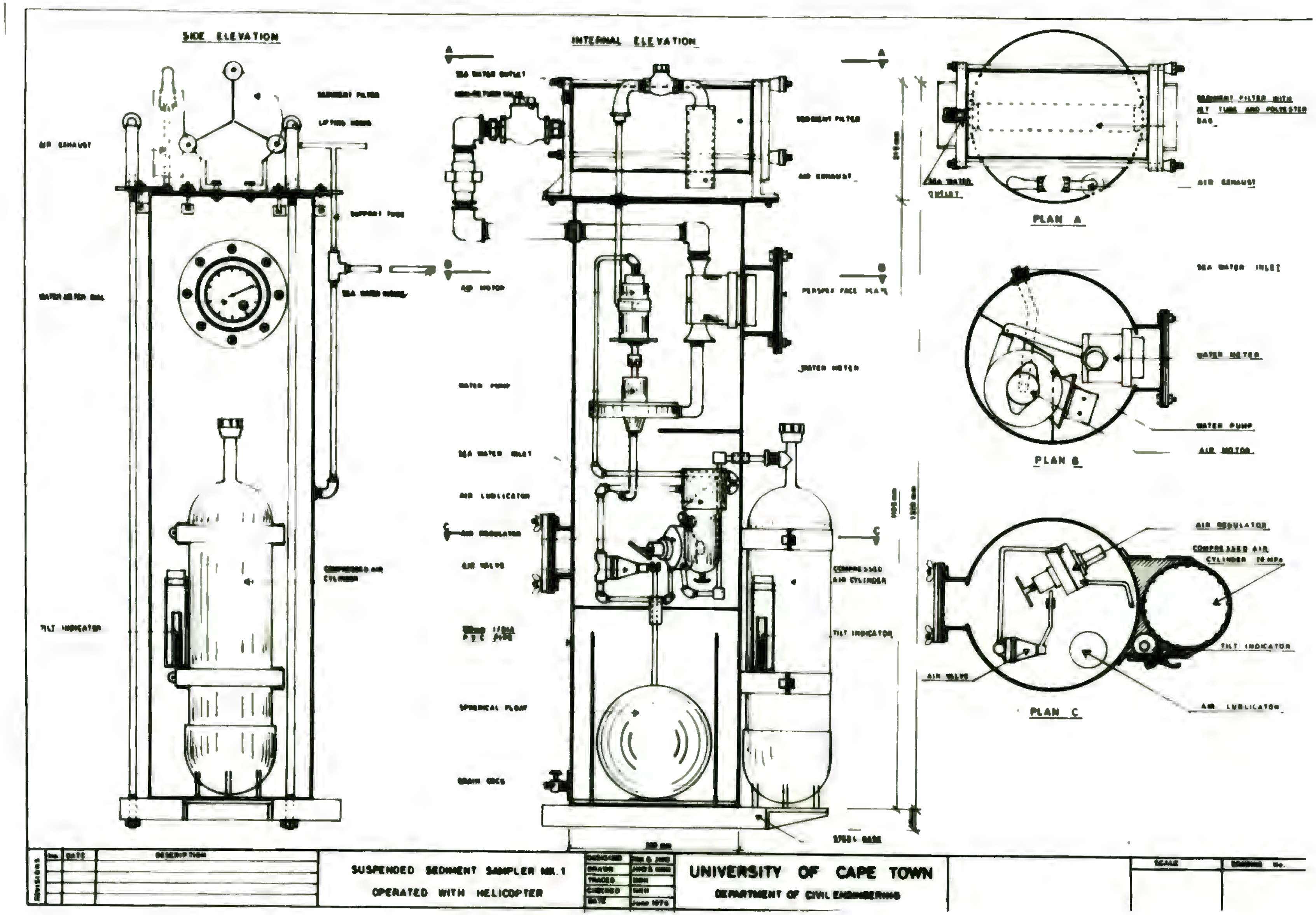


Figure 4.1 : Mark I Suspended Sediment Sampler

The largest piping used in the instrument is 25 mm in diameter, giving an internal pumping velocity of 1,1 metres per second. This velocity is greater than the minimum velocity required to prevent settlement of sediment in the instruments, as determined by Crickmore and Aked (20).

The pump is coupled on a common shaft to an air motor, a Desoutter type SRM 3000, of maximum output 350 watts. The motor is powered by compressed air from the 7 litre, 20 MPa air cylinder. The air passes through an air regulator to reduce the pressure to 700 kPa, then through a Parker Hannifin oil drip to introduce a small amount of oil into the air to provide lubrication of the fins in the air motor, and to prevent corrosion. The air is expelled into the sea via a non-return valve on the opposite side of the sampler to the water intake.

The sampling cycle is triggered by a float rising in the lower compartment with the inflow of water through holes in the compartment. This float activates a quick release Saunders type A valve in the airline and operates the motor.

The components are housed in a modified PVC pipe of 300 mm diameter with two ports covered with perspex as face plates. One port is opposite the water meter, so that this instrument can be read without opening the sampler, the other port gives access to reset the air valve and air regulator. The float chamber in the bottom compartment is drained by a drain cock. The overall height of the instrument is approximately 1,4 metres.

A weighted base of 40 mm thick steel is attached by long, threaded bolts to the unit. Lifting hooks are provided at the top of these bolts. Horizontal stabilizing legs are screwed into the base to prevent overturning during sampling.

The dry weight of the assembled sampler on the beach ready for lift-off is 185 kg. The submerged weight is 77 kg, with a maximum lift-out weight of 250 kg if filled completely with water. The lifting system must therefore be designed for this maximum weight. The maximum operating depth is estimated to be 20 metres of water. Plate 4.1 shows the unit fully assembled on the beach ready for lift-off.

A simple tilt indication was developed to determine whether the sampler had been overturned during sampling. This consisted of two perspex tubes, the smaller one placed inside the larger. The larger was closed with a rubber stopper to prevent any water entering the tube, and the smaller was partially filled with a red liquid. If tilting occurred, the liquid in the inner tube would flow out and collect in the outer tube. This could easily be identified when changing the filters on the beach. The tube could be drained and refilled for immediate re-use. The tilt indicator is shown in Plate 4.2.

Plate 4.1: Mark I Sampler

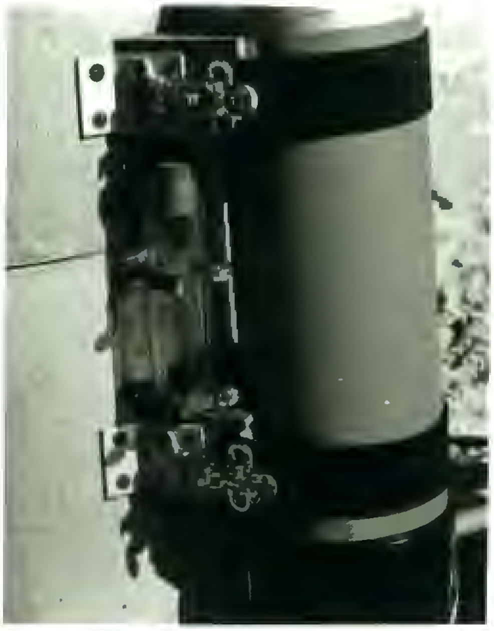


Plate 4.2: Tilt Indicator

Plate 4.3

Plate 4.4

Mark II Sampler

Landon (41) conducted performance tests on various components of the sampling unit under supervision of the author. The head-discharge curves obtained for the marine pump are given in Fig 4.2 together with the manufacturer's head-discharge curves. The speed of the motor and pump was found to be approximately 2000 rpm under working conditions. A pumping efficiency of approximately 53% was determined, which is fairly low, but as the pump was one for the few fibreglass models available, it was used with a slight sacrifice in efficiency. A shape factor of 0,23 was determined for the pump. The manufacturer's torque and power curves for the Desoutter air motor are given in Fig 4.3.

Tests to determine the head loss in the filter and water meter were also conducted by Landon. The head loss in each of these components are expressed in terms of the value of K, and are given below :

$$h = KQ^2$$

For the filter, $K = 0{,}47 \times 10^3 \ s^2 \ m^{-5}$

and For the water meter $K = 3{,}14 \times 10^3 \ s^2 \ m^{-5}$

The graphs for head loss versus flow through the filter and meter are given in Fig 4.4 and 4.5. The water meter was found to be over read by 2%.

The Mark I sampler described above was basically an experimental prototype. The components within the sampler were matched together on manufacturer's specification rather than designed. Design weaknesses became apparent during the field operations, and the sampler was modified slightly to overcome these weaknesses. The sealing of the top cover of the PVC body proved to be difficult because of the distortion of the cover by the clamps. As the components were not affected by slight leakage, no attempt was made to seal this cover completely. The components did suffer from corrosion problems, however, and the bearings in both the pump and motor had to be renewed. The air regulator suffered from corrosion and also had to be renewed after failure during a sampling operation. In addition, the sampler was overturned in high wave conditions and an extra weight was fitted onto the base as well as additional stabilizing legs. This subsequently appeared to work satisfactorily except under extremely high wave conditions in the breaker zone. When the instrument was overturned, the complete system was completely clogged with sand as the pump continued to run, requiring a complete overhaul to unblock the pipes. Modifications to prevent the pump from running when overturned, were adopted into the design of the Mark II sampler.

4.3 Design of the Mark II Sampler

The sampler was designed to float out from the beach on an endless rope system, sink at the desired position, refloat after sampling and be pulled back to the beach by the rope.

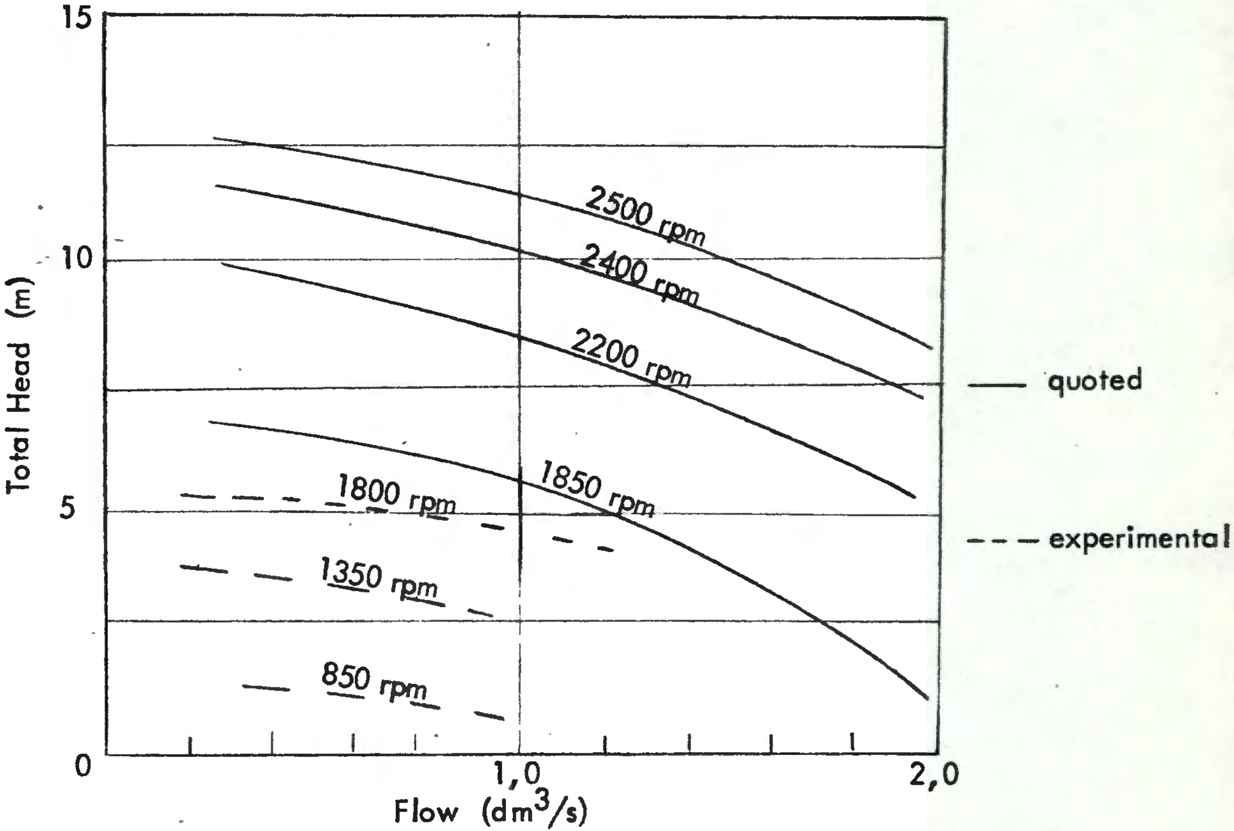


Figure 4.2 : Head Discharge curves for Marino Pump

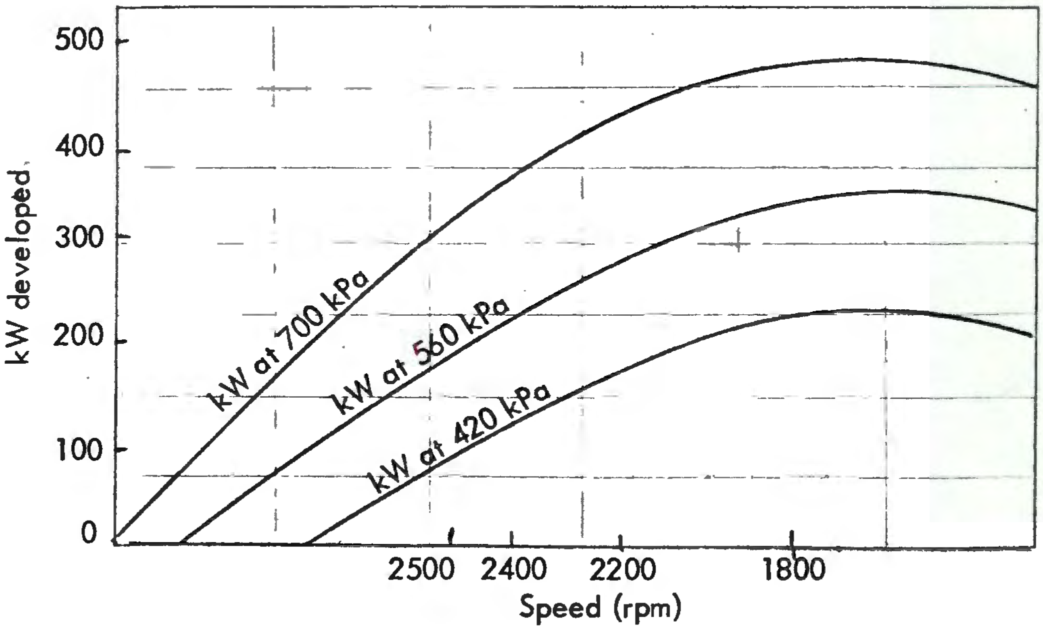


Figure 4.3 : Power Curves for Desoutter air motor

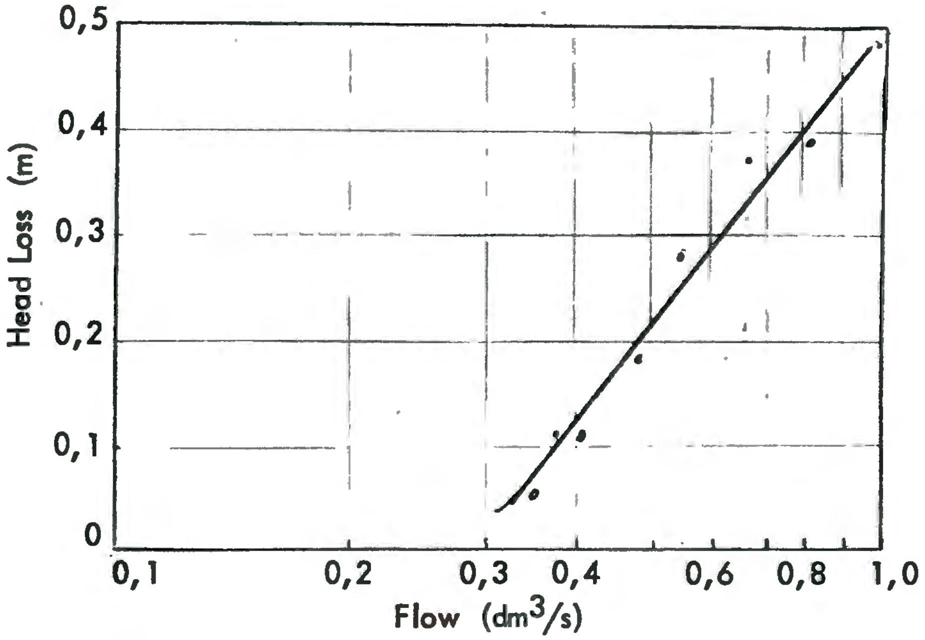


Figure 4.4 : Head Loss versus Flow through Filter

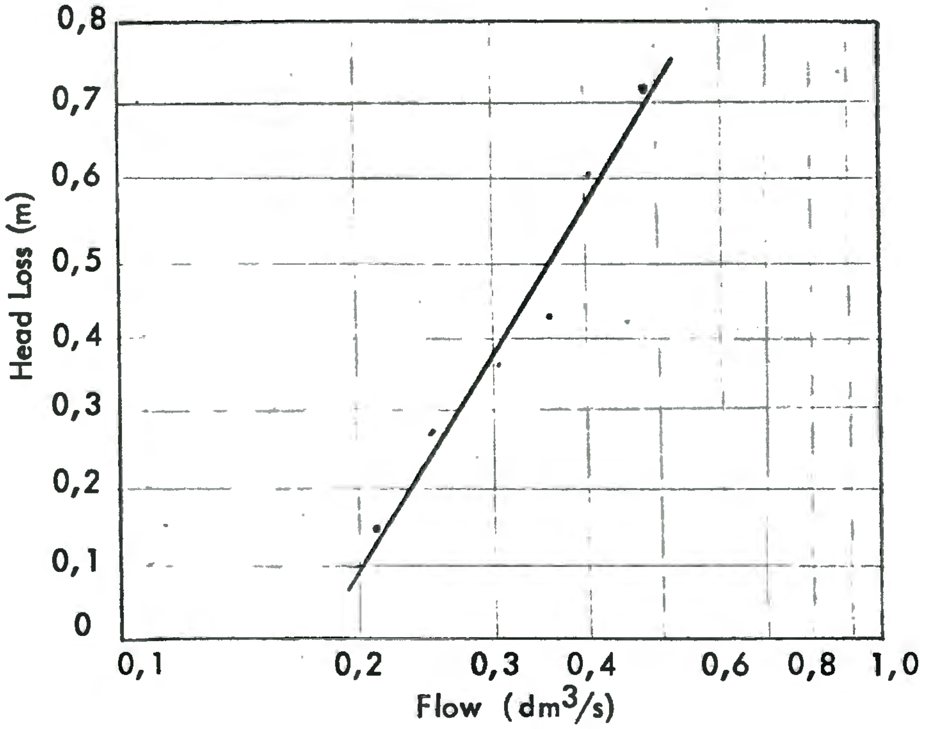


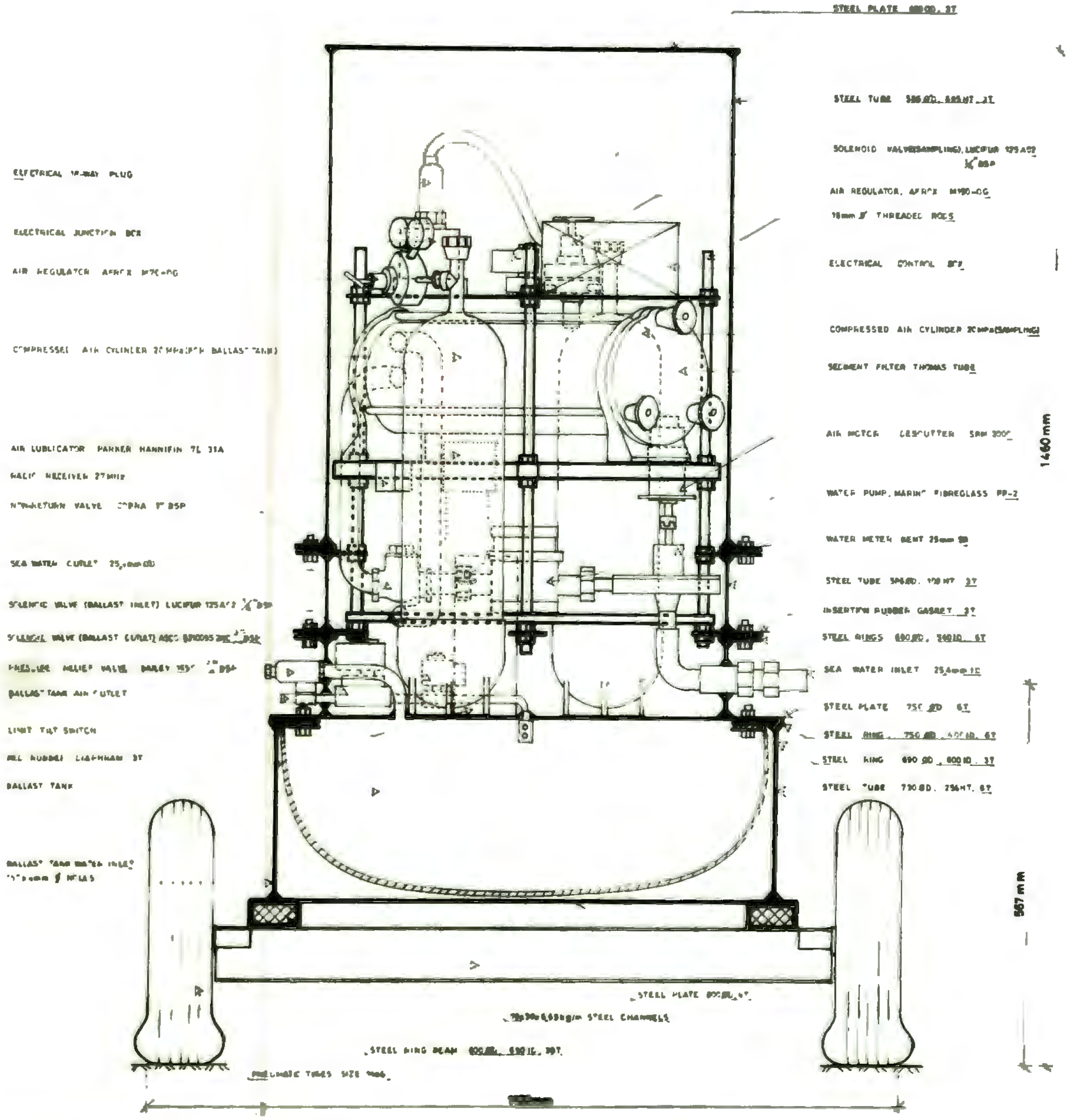
Figure 4.5 : Head Loss versus Flow through water meter

The design requirements called for a robust, water-tight unit, capable of sinking and refloating using an internal control system, and fitted with some form of traction unit to enable the sampler to be pulled up or down the foreshore into the water.

A steel casing was chosen in place of the PVC type as used in sampler Mark I. Steel has the advantage that joints and pipes passing through the casing can be welded to obtain water-tightness, and a circular steel cylinder is robust because of its shape. Flanges and "O" rings are used to seal joints not welded. The corrosion of steel in the sea water was not viewed as a serious problem, as the casing could be inspected and and repaired after each field trip. One of the difficulties experienced with the Mark I sampler was the inaccessibility of the components when assembled in the PVC pipe. Access was only available from the top, and fitting and overhauling components was difficult. Consequently the concept used in the Mark II sampler was that of the cop cover fitting over all the components which are mounted on platforms supported by three threaded rods welded to the lower plate of the instrument chamber. Fig 4.6 and plates 4.3 and 4.4 show an elevation of the Mark II sampler. All pipes entering and leaving the instrument chamber did so below the top cover so that this cover could be lifted off in order to gain easy access to components.

A ballast tank was fitted on to the bottom of the instrument chamber. The inlet and outlet valves were situated in the instrument chamber and were connected to the ballast chamber via the common steel plate. During sampling, the sampler may be toppled on its side. Using a conventional ballast tank, similar to the saddle tanks of submarines which are open at the bottom and have control valves at the top, the air blown into the tank to expell the water would escape through the bottom, and thus the sampler would not refloat. Various configurations of valves were tried to eliminate this problem, but all were unsuccessful. A rubber diaphragm, made of 3mm thick red rubber was eventually used. When inflated in any orientation, the diaphragm would expand and expell the water from the tank, and assume the shape of the tank when fully inflated. A separate 7 litre 20 mPa compressed air cylinder was used for inflating the diaphragm. The pressure was reduced to 150 kPa using an Afrox M70-OG regulator. A safety valve was fitted to the tank to prevent over-inflation. Similarly, as the instrument compartment contained high pressure compressed air cylinders, a safety valve was fitted to prevent rupture if the internal pressure rose too high, caused by a leak in the air hose. Plate 4.5 shows the diaphragm in the ballast tank before assembly of the sampler.

As the control system was electrically controlled and thus subject to shorting by moisture and failure, external control valves were fitted to the side of the sampler, so that in the case of complete electrical failure during sampling, the sampler could be refloated by manual operation of the valves by a diver.



NOTE – ALL MINOR COMPONENTS, MOUNTING BRACKETS, ELECTRICAL WIRES AND AIR HOSES (9,5 mm BORE) HAVE BEEN OMITTED FOR CLARITY

ABBREVIATIONS

OD = OUTER DIAMETER (mm)
ID = INNER DIAMETER (mm)
HT = HEIGHT (mm)
T = THICKNESS (mm)

EXPOSED ELEVATION SUSPENDED SEDIMENT SAMPLER MK 2	DESIGNED DRAWN TRACED CHECKED DATE	[illegible] [illegible] [illegible] [illegible] [illegible] 1976	UNIVERSITY OF CAPE TOWN DEPARTMENT OF CIVIL ENGINEERING	SCALE DRAWING No

Figure 4.6 : Elevation of Mark II Suspended Sediment Sampler

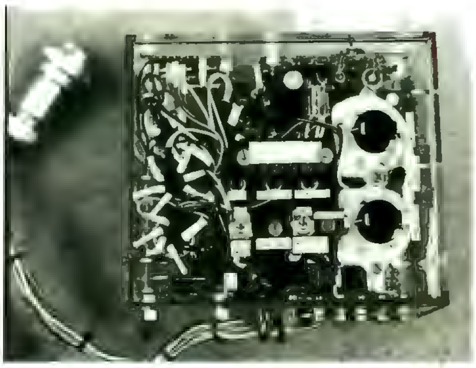


Plate 4.9 Control Box

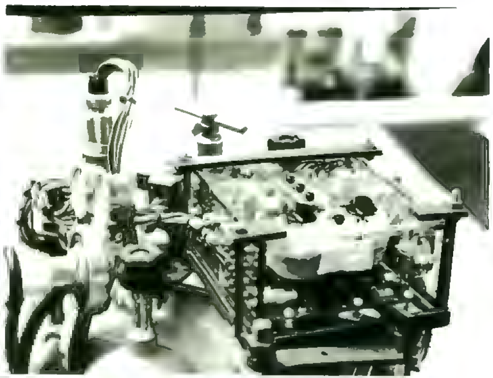


Plate 4.10 Control Box and Air Regulators

Plate 4.11 Junction Box and Solenoid Valve

Plate 4.12 Buoy and Sea Anchor

These valves were fitted with an easily removable cover to prevent damage. Plate 4.6 shows the arrangement of these valves and the safety valves.

A tracked unit consisting of steel tubes covered with a continuous rubber belt was originally used as the traction unit. However, after field tests on this crawler, it was found to bury itself into the sand by the sand piling up in front of the unit. An alternative traction unit was designed using inflatable tyres and was tested with reasonable success on the beach.

The components used for the basic pump sampler unit are identical to those used in the Mark I sampler. As no basic modification was needed on the design of the sampling system after field tests, it was decided to use the same components so that they could be interchangeable between units, and components such as air cylinders and filters were common to both units. Slight modifications in the design were however undertaken.

In order to keep the head loss to a minimum, but still maintain the required minimum pumping velocity in the pipes, 25 mm copper pipes were used throughout the system. Copper was used, as corrosion was found to occur in the galvanised steel pipes of the Mark I sampler. The pump motor unit and meter unit were mounted as low as possible to prime the pump, and the filter was placed inside the instrument chamber instead of outside as in the Mark I sampler, to prevent damage. Plates 4.7 and 4.8 show the positioning of these components in the instrument compartment.

The centres of gravity and buoyancy were calculated in order to establish the stability of the sampler before manufacture. To achieve the condition where toppling was minimised, the centre of gravity was kept as low as possible, such that it was below the centre of buoyancy, thus always resulting in a positive righting moment. The calculated and measured weights and centres of gravity and buoyancy for both the tracked and wheeled units are given in Table 4.1

Table 4.1

Weights and Centres of Gravity for sampler Mark II

	Dry Wt. (Kg)	Submerged Wt. (Kg)	Floating Reserve Wt.(Kg)	c.g.(mm)		c.b. (mm)	
				Floating	Sunk	Floating	Sunk
Trolley Unit:							
Calculated	364	71	40	345	311	460	535
Measured	387	72	22	-	-	-	-
Wheeled Unit:							
Calculated	372	40	56	491	460	600	700
Measured	390	72	22	410	-	-	-

The c.g. and c.b. are measured from the bottom of the sampler.

Landon (41) calculated the overall friction head losses in the pipes and components in the Mark II sampler, under supervision of the author. The head loss is expressed in value of K in the formula

$$h = KQ^2$$

and is given in Table 4.2

Table 4.2

Friction Head Losses calculated in Mark II Sampler

Component	K $(s^2\ m^{-5})$
Pipes	$0,62 \times 10^6$
Inlet	$1,59 \times 10^6$
Outlet	$0,20 \times 10^6$
Bends	$1,10 \times 10^6$
Water Meter	$3,14 \times 10^3$
Filter	$0,52 \times 10^3$
TOTAL	$3,51 \times 10^6$

These values are plotted in Fig 4.7 and superimposing the head discharge curves on this graph, an expected flow of 0,9 dm^3/s is obtained for a pump speed of 2000 rpm, which was measured in the laboratory. Flume tests revealed a sampling flow of 0,85 dm^3/s.

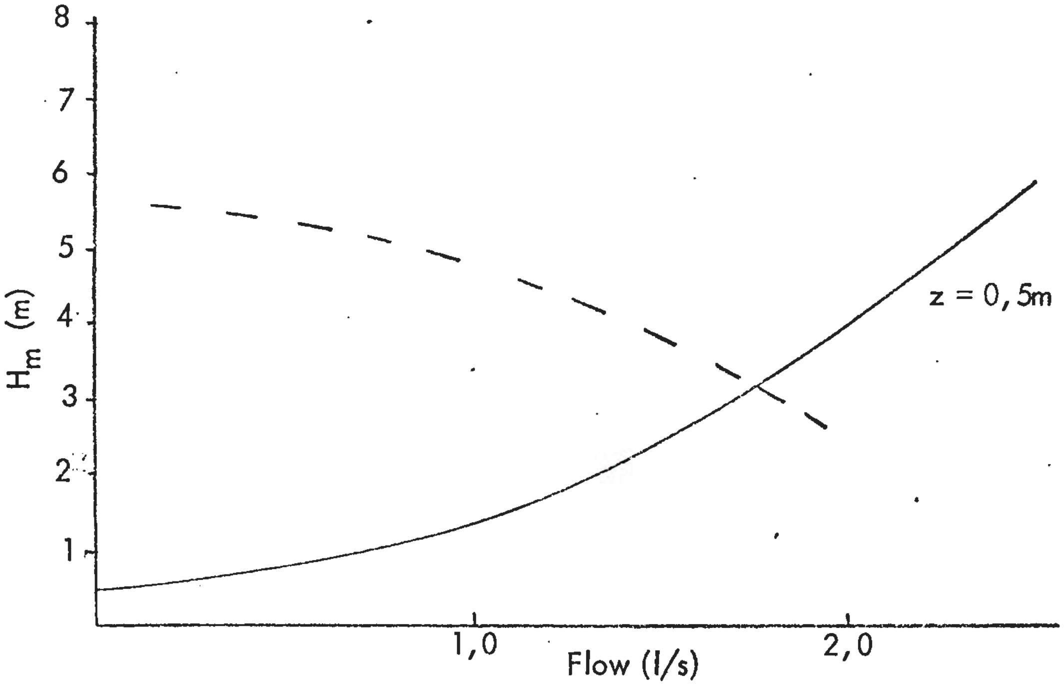


Figure 4.7

External water pressure acts on the sampler when it is at the sampling point. An estimate of the critical external buckling pressure must therefore be obtained for the structural design of the sampler. Formulae by Timoshenko and Gere (42) and Baker et al (43) are used to estimate this buckling force. The values obtained using Timoshenko and Gere was 802 kPa, and using Baker et al, was 600 kPa. The stiffening of the flanges was not taken into account. If a factor of safety of 4 is used, then the maximum operating depth of the sampler is 15 metres, which is satisfactory as this is the outer limit of the nearshore zone.

4.4 Control Equipment for Mark II Sampler

The sampler is required to sink at the desired position, sample, and refloat by remote control. It was thus necessary to develop a control system to carry out the various operations. These basic operations are given in a block diagram in Fig. 4.8

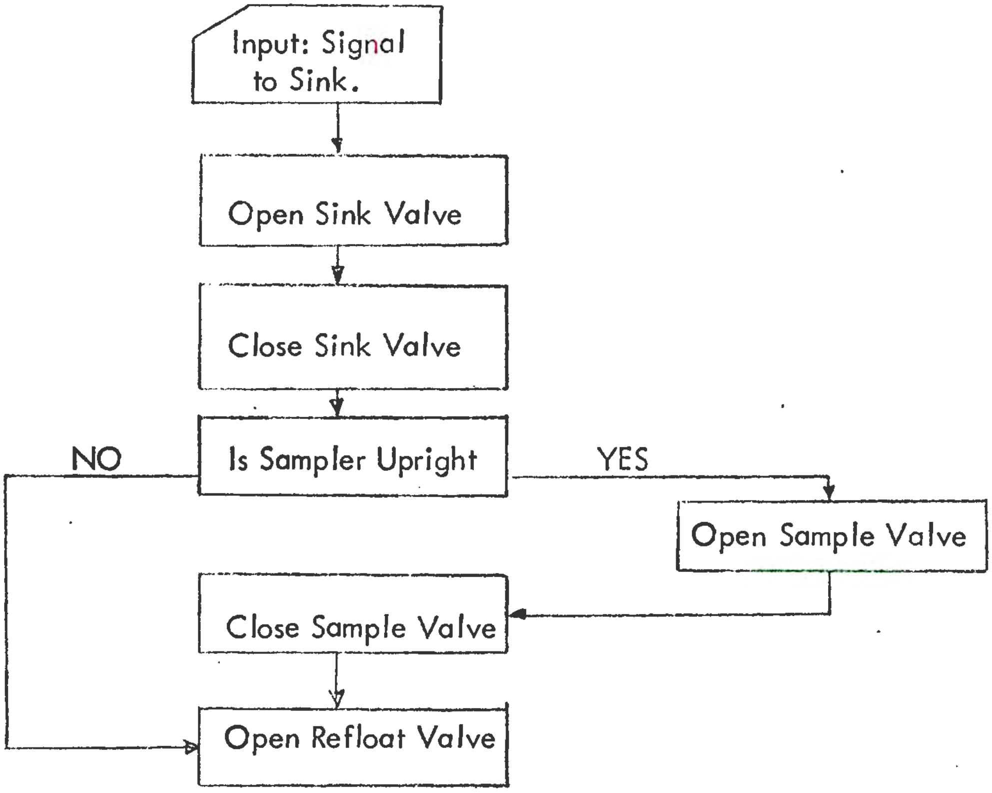


Fig 4.8 Diagram Showing Operations of Sampling

Solenoid valves are used as the basic control for sinking, sampling and refloating. These valves are opened and closed by relays in the control box. The initial signal to sink is given by a radio transmitter on the shore. This signal is received by a receiver in the control box and opens a solenoid valve to float the ballast tank.

This valve is a 19 mm ASCO normally closed valve. The sinking cycle is determined by a timer that is started the same time the valve opens. Sufficient time is allowed for the sinking cycle, and was determined in the laboratory to be 3 minutes. After this cycle is complete, the sinking valve closes, and a limit switch determines whether the sampler is upright or not. If upright, the solenoid valve in the sampling airline is opened, and sampling commences. In addition, a timer is started, which is calibrated to a sampling time of 4 minutes. If at any stage during sampling, the sampler is tilted so that the limit switch closes, then the sampling valve is closed and the refloating valve is opened. The refloating valve is also linked to a timer, and is closed after a period of 5 minutes. The limit switch is positioned vertically with a brass weight attached to the pendulum at the base of the switch. Inclination of the switch in any direction will cause the brass weight to move the pendulum and thus close the switch.

The sampling solenoid valve is a Lucifer 6 mm impulse control valve. The radio receiver is super regent, and thus able to pick up any signal on the 27 MHz band. However, a delay timer is operated in the control box, to cut the receiver out until a certain time has elapsed and the sampler should be in position. After sampling, a relay switches the receiver off so that the sampler cannot be accidentally sunk again.

All the relays and controls are situated in the control box. Fig 4.9 gives the circuit diagram for the control system. The abbreviations used are as follows :

B - Battery
SV - Solenoid Valve
RL - Relay
T - Timer
RX - Radio Receiver
L.S.- Limit Switch

Three batteries are used, namely a 3 volt battery for the radio receiver, a 12 volt battery to power the solenoid valves and a 24 volt battery for the control system. It was decided to operate the solenoid valves and the control system on different batteries as sudden steps in voltage are caused by opening and closing of the valves. Initially, thyristers were used in place of relays in the control circuit to control the time cycles, but it was found that the thyristers were susceptible to sudden current and voltage changes caused by the solenoid valves. Light emitting diodes are placed in parallel with certain time cycles so that a check can be made whether these time cycles are operating.

A simple clockwork switch, MT2, is used as a back-up in case the control sequence fails. If sampling has not taken place within a certain time, it will automatically open the refloat valve. This switch was normally set to 60 minutes. Double wiring from the battery packs and solenoid valves to the control box also assisted in preventing control breakdown.

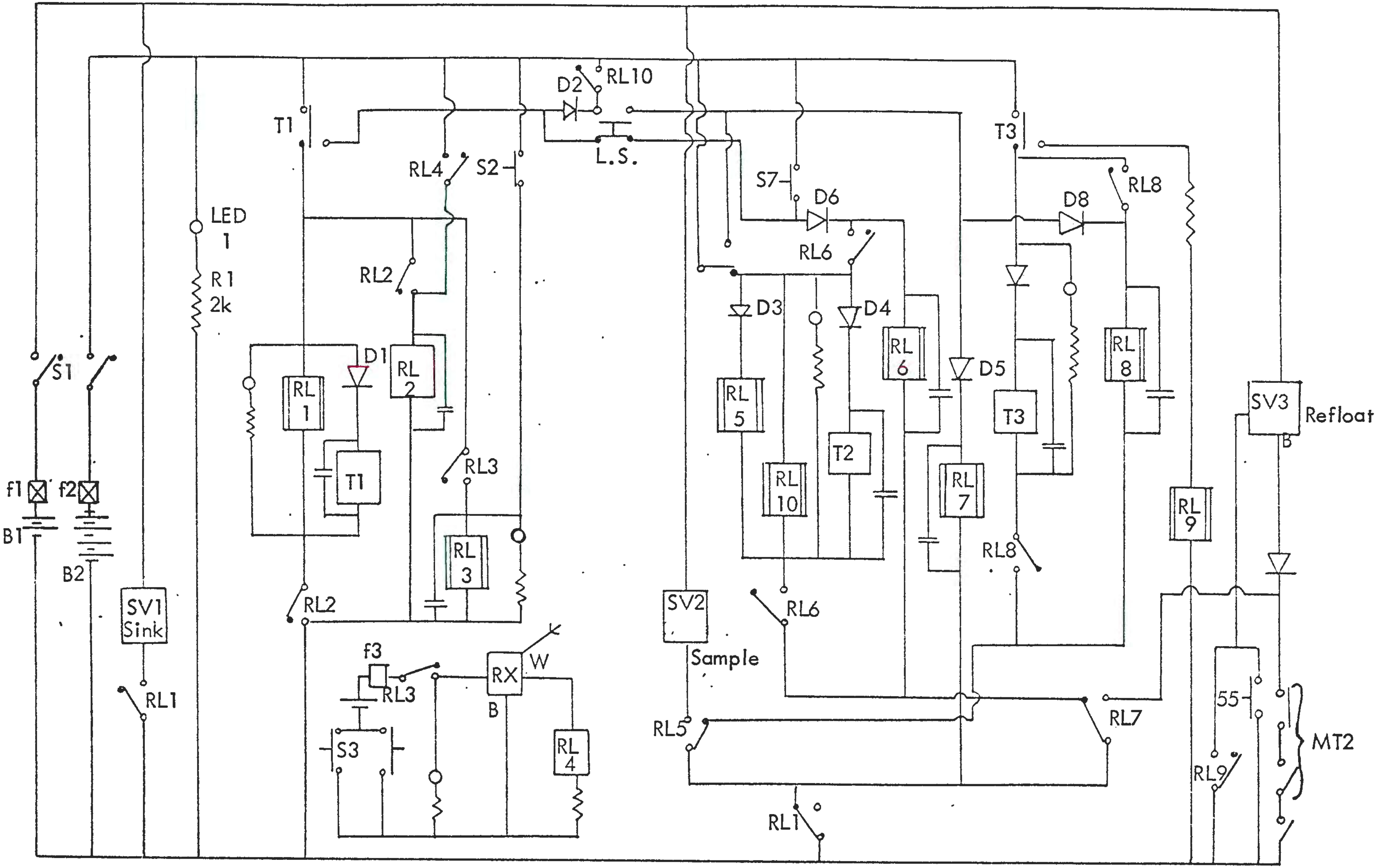


Figure 4.9 : Control Circuit Diagram

To assist easy removal of the control box from the sampler, a multi-way plug was installed. This connects the control box to a junction box in which the fuses for all three battery systems are located.

Plates 4.9 and 4.10 and 4.11 show the control box, junction box and solenoid valves in the top of the instrument chamber.

4.5 Evaluation of the Forces due to Wave Action on Mark II Sampler

The Mark II sampler is designed to be pulled into position using a sea-anchor and endless rope powered by a winch on the beach. Fig 4.10 shows the proposed layout of the system. In order to design the buoy, anchor, rope and winch, an estimate of the total forces which can be expected on the sampler must be calculated.

Design wave height conditions were assumed to be a deep water height of 4 metres and a wave period of 12 seconds. This is assumed to be the maximum wave height under which this sampler is to be used. For sampling in higher wave heights, it was proposed that the Mark I sampler is to be used. In order to evaluate the total forces on the sampler, the following assumptions are made :-

(a) The maximum forces on the sampler will occur in the breaker zone and just outside the breaker zone.

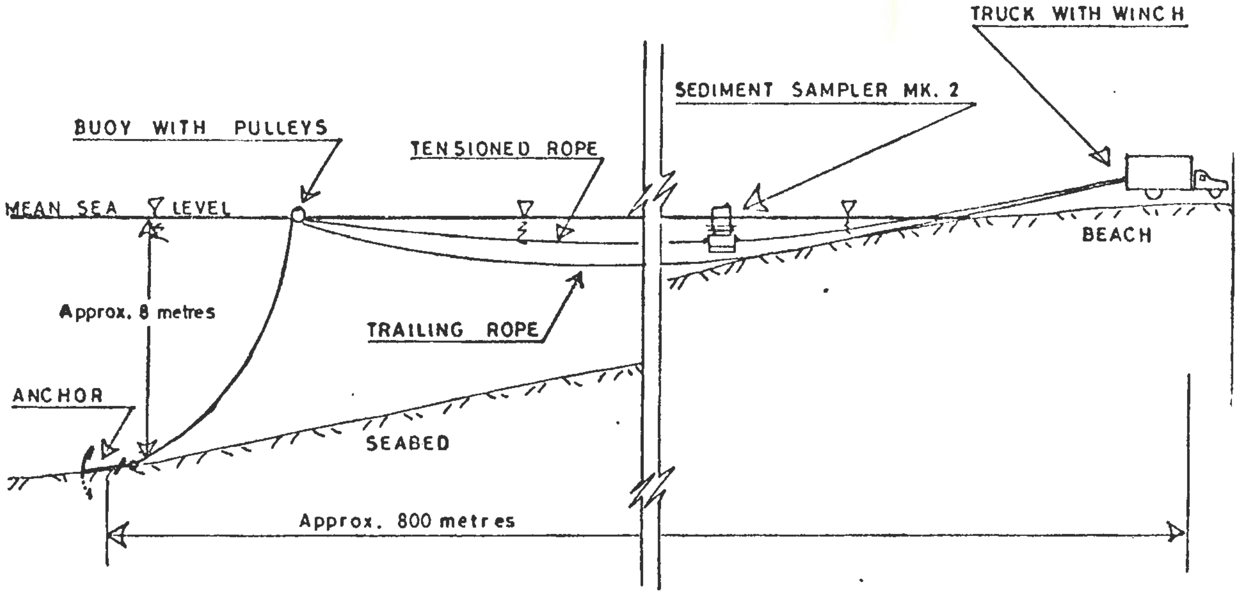
(b) The forces on the sampler will be evaluated assuming the sampler to be stationary. This would occur if the sampler was being pulled out such that when the crest passed the unit, it was held stationary by the rope, and moved seaward with the orbital motion occurring in the trough of the wave.

(c) 1st order wave theory is used. In the surf zone, however, the velocity of the breakers is greater than that of the orbital motion theoretically calculated. This can be clearly indicated at the breaker point where the water in the crest of the breaker is accelerated to the wave celerity, and hence the breaking process occurs. In order to evaluate some relative velocity between the breakers and the sampler, this velocity is assumed to be equal to three quarters of the wave celerity at breaking point. The acceleration is estimated as the average rate of change of velocity from zero to maximum in a period of one second.

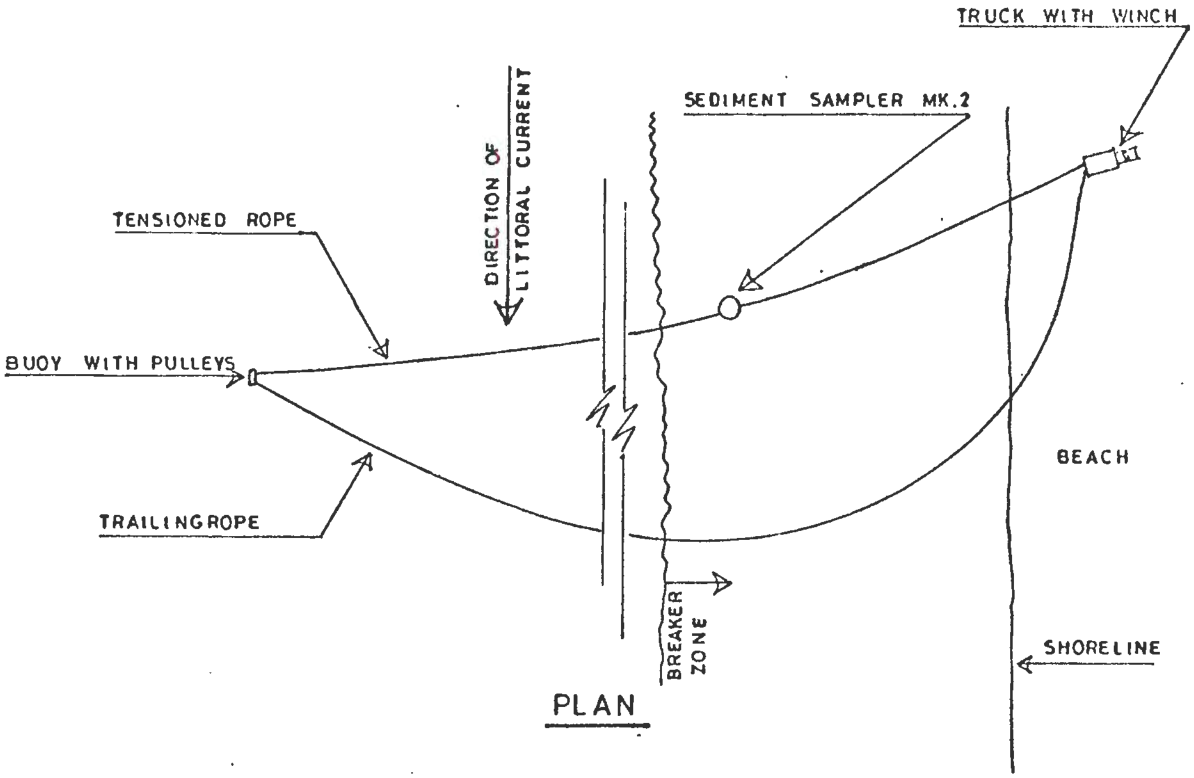
(d) The total drag force on the sampler is the sum of the velocity drag, Dv, and the acceleration drag, Da, as given by :

$$Dv = (\tfrac{1}{2}\rho v^2)\, C_d \times \text{(frontal area)}$$

$$Da = Cm\, M\, v$$



ELEVATION



PLAN

Figure 4.10 : Proposed Operational System of Mark II Sampler

The values for the coefficients Cd and Cm are assumed to be :

$Cd = 1,2$
and $Cm = 2,0$

(e) A beach slope of 1:100 is assumed.

The relevant properties of the flow at the positions considered in the design are summarised below :

Deep water wave length, $L_o = 225\,\text{m}$
Breaker height $H_b = 4,9\,\text{m}$
Breaker depth $d_b = 7,2\,\text{m}$
Wave celerity at breaker point $C_b = 7,8\,\text{m/s}$
Wave length at breaker point $L_b = 103\,\text{m}$

	Outside Surf	In Breaker Zone
Orbital velocity Umax	3,4 m/s	0,75 x 7,8 = 5,8 m/s
Orbital acceleration Umax	$1,8\,\text{m/s}^2$	$5,8\,\text{m/s}^2$
Dv	4,0 kN	11,6 kN
Da	1,1 kN	3,6 kN

The velocity and acceleration drag forces are added vectorially and are plotted in Fig 4.11. The drag forces in the breaker zone occur simultaneously and may thus be added. These forces, however, are of very short duration, as they are assumed only to occur under the plunge point of the breaker.

The design forces acting on the sampler are thus :

Outside breaker zone : Dt = 4 kN
Under plunge point : Dt = 15 kN

4.6 Design of the Sea Anchor and Buoy

The design and construction of the sea anchor and buoy was carried out by Anderson (44) under the supervision of the author.

The Mark II sampler is designed to operate in conditions of 2 to 3 metre wave height, with a maximum of 4 metres. Under these normal conditions, the outer limit of the nearshore region in which the suspension of sediment is of interest, is approximately 800 metres offshore. It was thus decided to position the buoy and sea anchor at this distance from the beach. The water depth at this position was estimated to be 9 metres.

The buoy was designed to withstand a force exerted on it by the sampler of 5 kN, together with drag forces to the wind and wave action on the buoy itself. Anderson (44) evaluated these forces under design conditions as :

Drag force due to wind = 0,3 kN
Drag force due to wave action = 9,5 kN

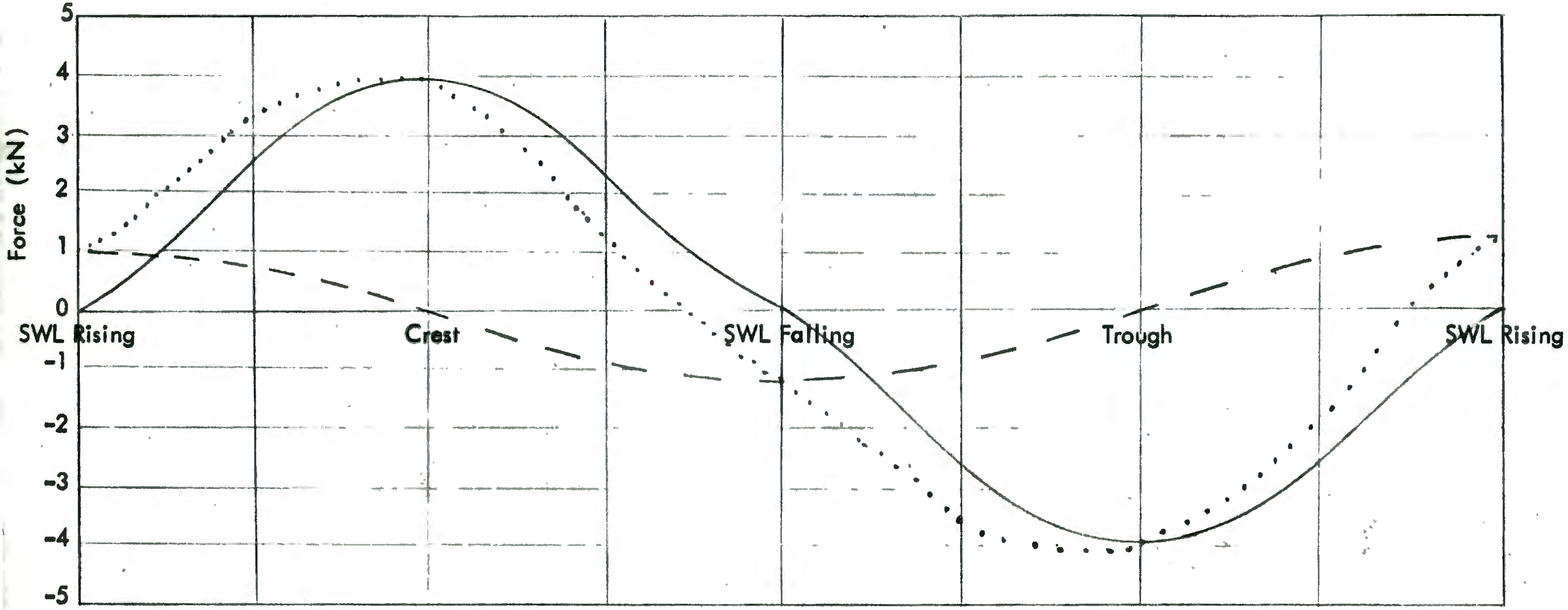


Figure 4.11 : Design Drag Forces on Mark II Sampler

The buoy and anchor are thus designed for a resistant force of 15kN.

The buoy was constructed using a 120 litre drum filled with a polyurethane foam to prevent sinking if damaged. A frame was clamped to the drum and connected to the sea anchor by way of a 32 mm polypropelene rope with breaking strength of approximately 90kN. Two rollers were fixed to the frame to form the pullies for the rope. The layout of the buoy and anchor is given in Plate 4.12 as it was being assembled on the beach prior to placement. A view of the roller used is given in Plate 4.13. The roller was the type generally used on boat trailers, and was tested in a compression machine to determine the maximum rope load it could carry. It was found that it could safely carry 10kN without deformation, and thus was deemed satisfactory as the maximum rope force was evaluated to be 5kN.

Two design philosophies were considered. If the buoy was to remain on the surface of the sea under the pull of 15kN, then a nett buoyancy of approximately 280 kg is needed, for a 20 metre length of anchor rope. This would require a buoy of total volume of approximately 600 litres and drag forces would be considerably increased. However, if the buoy were allowed to submerge under the 15kN pull, the proposed 120 litre buoy could be used, and the design force on the anchor is reduced considerably. The weight of the buoy as constructed was 55 kg, with a nett buoyancy of 65 kg.

The anchor system was designed to withstand a force of 15kN. Myers et al (45), give holding powers for various types of anchor . The types of anchor that has proved to be most reliable, and has a holding power of approximately four times its own weight, is the kedge anchor. Anchor chain and clump anchors have a holding power of approximately their own weight. A 220 kg scrap kedge anchor was acquired from a salvage yard, and together with chain weighing 150 kg and a clump anchor made of scrap steel reinforcing bars of 230 kg, give a holding power of 14,8kN. This matches the required holding with sufficient accuracy.

4.7 Design of the Main Rope and Winch System for the Mark II Sampler

A rope with a working load of 5kN and total length of 1600 metres was required. After investigating the different types of rope available, a nylon rope, 6 mm in diameter, and 16 strand braided twine construction with a central core was decided to be adequate. The quoted breaking strength of this rope was 9kN. The rope had to be joined, however, and splicing proved to be difficult with a braided rope, therefore knots were used. The author carried out laboratory tests on the rope, and found that the breaking strength in the knot was reduced to 5kN. Other types of rope were considered, but the 6mm nylon was chosen on the grounds that nylon is the strongest synthetic fibre available, and also the most economical.

The quoted breaking strength of other types of rope are given below :

Terylene : diameter 8mm - 6kN
Polypropelene : diameter 6mm - 5,5kN
Nylon : diameter 4mm - 4,5kN
Nylon : diameter 5mm - 6,6kN

This nylon rope chosen also had an approximate strain at breaking of 25 percent, and this helps to reduce the magnitude of the impact forces in the rope which may occur under high wave conditions.

A winch was constructed using a 1,1kW electric motor. driving a capstan through a reduction box and a variable speed drive. It was mounted on to the back of the four wheel drive vehicle used to transport the sampler and equipment to the beach, and powered by a portable 220 volt single phase AC generator. The capstan speed varied between 180 r.p.m. and 45 r.p.m. The maximum calculated tensions in the rope for these speeds are 1,1kN and 4,4kN with linear rope speeds of 41 metres per minute and 10 metres per minute respectively.

This winch was constructed as a preliminary operational unit using existing components in the laboratory. The 1,1kW single phase motor is the largest single phase motor commercially available, and the power supply was limited to the portable generator. Preliminary investigations into the possible use of a hydraulic motor system were carried out, but shelved as capital was limited. Details of the winch as constructed are given in Fig 4.12 and the mounting arrangement on the vehicle is shown in Plate 4.14. A protective wooden box was constructed to cover the winch during operation for protection from the belt drives.

4.8 Ancillary Equipment

A four wheel drive vehicle was used to transport the equipment to the beach. A gantry and crawl beam was constructed on the vehicle to enable off- and on- loading of the 390 kg sampler. This gantry is shown in Plate 4.15, offloading the Mark II sampler.

A portable Bauer compressor was used to charge the compressed air cylinders to 20MPa. It was powered by a 2,2 kW petrol motor, and normally took 25 minutes to charge one 7 litre bottle.

A settling tube was constructed to analyse the grading of the sediment samples obtained. It consisted of a 2 metre length of perspex tube, 150 mm in diameter, with a perspex plate near the bottom hung from three nylon strands from a cross-piece resting on a Mettler balance.

The sample was released from a perspex tube by way of a trapdoor, and the mass accumulation read on the Mettler balance. After no further mass was accumulated on the plate, the tube was drained and the plate removed from the tube to recover the sediment.

Plate 4.13 Buoy Roller

Plate 4.14 Winch

Plate 4.15 Offloading Mark II Sampler

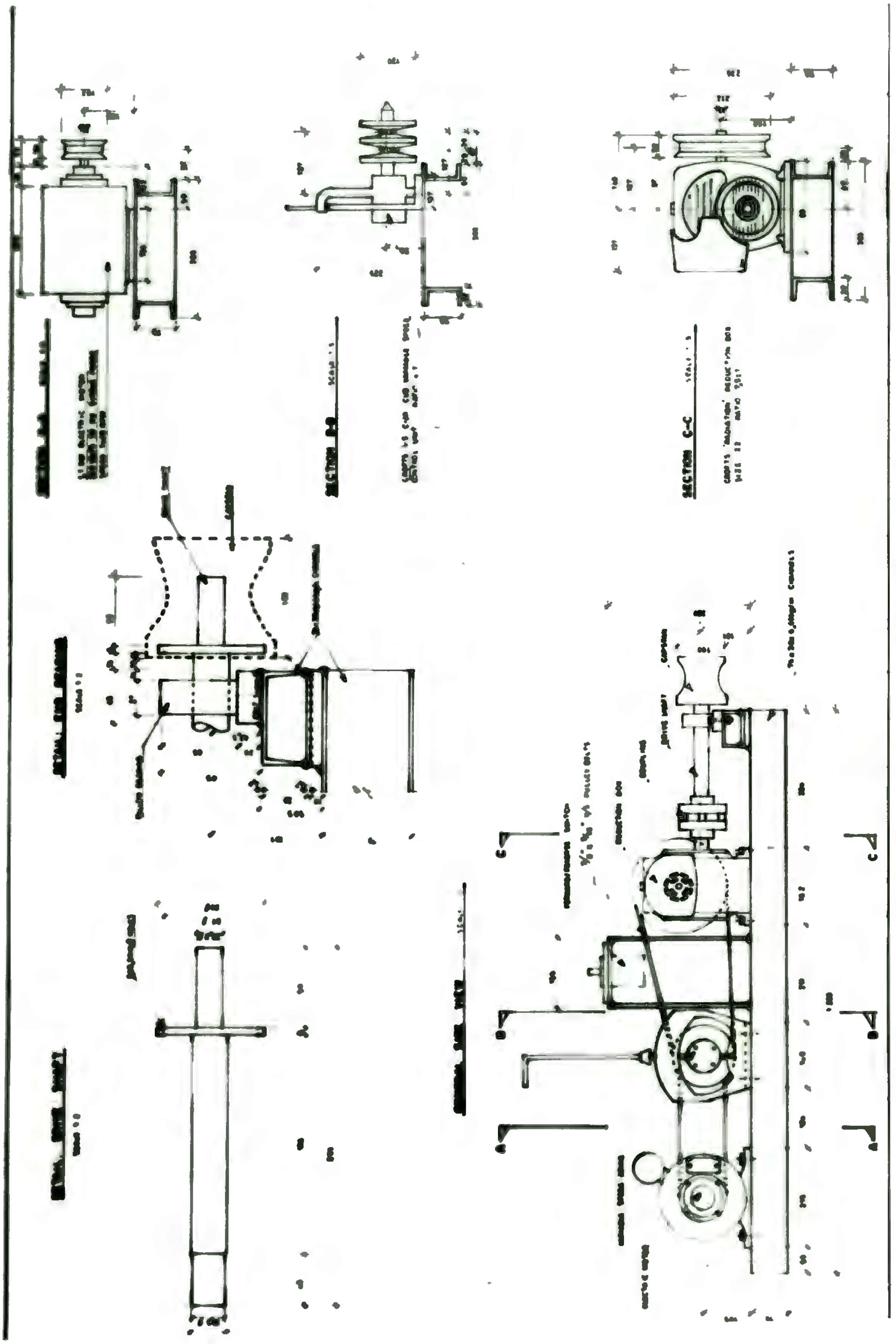


Figure 4.12 : Winch for Mark II Sampling System

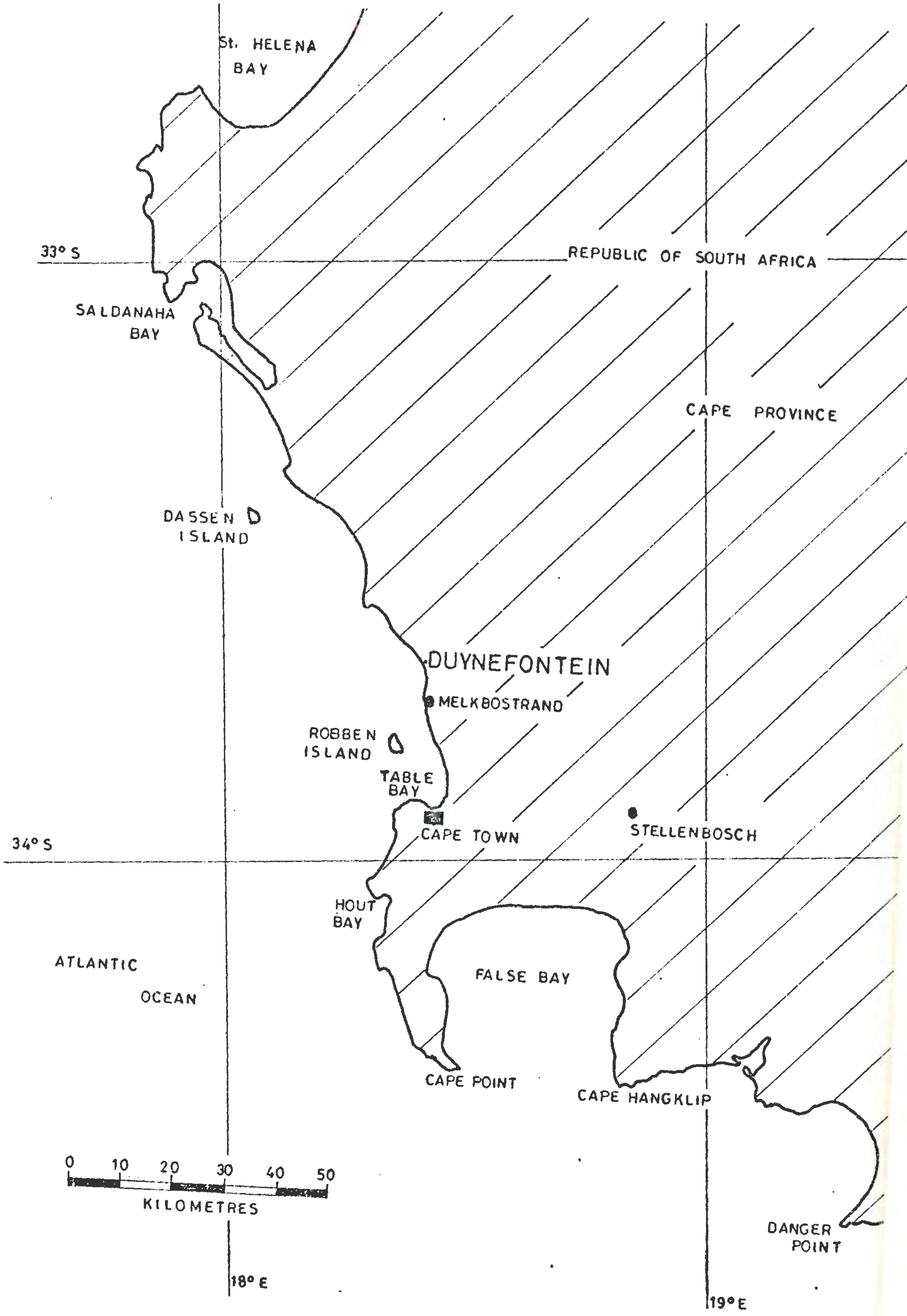


Figure 5.1 : Locality Map

CHAPTER FIVE

Sampling Operations

Sampling operations were carried out in the field using the Mark I sampler, and attempts were made to put the proposed system for sampling using the Mark II sampler into practise, but were hampered by difficulties encountered. All field sampling was conducted at the site of the proposed Koeberg Power Station on the farm Duynefontein, north of Cape Town.

Suspended sediment sampling was also carried out to a minor extent in the laboratory by Crosswell (46) under the supervision of the author. A simple electro-optical indirect type of sampler was constructed and relative sediment concentrations determined under wave action with a mobile bed in a glass sided flume. Calibration of the instrument was attempted, but was not successful.

5.1 Helicopters used with the Mark I Sampler

The operation of the Mark I sampling system required the use of a helicopter to place and retrieve the sampler in the surf zone. Use was made of commercial helicopters hired from a local company. Four types of helicopter were used on various occasions.

In the initial field testing of the Mark I sampler, during December 1974, at which the author was not present, use was made of a Bell Jetranger 206. This aircraft is powered by a single 250 kW gas turbine engine and has a maximum lifting capacity of 500 kg on the external cargo hook. As the aircraft has no winch, a long length of rope had to be attached between the sampler and the helicopter. The typical lifting arrangement is given in Fig 5.2. When the Jetranger attempted to transport the sampler to the desired position, it was found that the pendulum action of the sampler resulting from take off, could not be counteracted by the aircraft. The Jetranger was therefore not powerful enough to be used in sampling operations.

The next size of helicopter locally available was a Sikorsky S62A. This aircraft is powered by a single 925 kW gas turbine engine and has a maximum lift capacity of 1300 kg on the external cargo hook. In addition, it is equipped with a rescue hoist of 270 kg capacity. This helicopter was proved to be the most compatible for sampling as it is comparatively light and easy to manoeuvre when compared with the larger helicopters used. The flying time, however, was limited to approximately one and a half hours at site, including twenty minutes flying time to and from base. Unfortunately, this aircraft was out of commission towards the end of 1975, and use had to be made of larger and more expensive aircraft.

Plate 5.1 Sikorsky S 62 A

Plate 5.2 Sikorsky S 58 T

Plate 5.3 Sikorsky S 61 N

Plate 5.4 Mark I Sampler entering Water

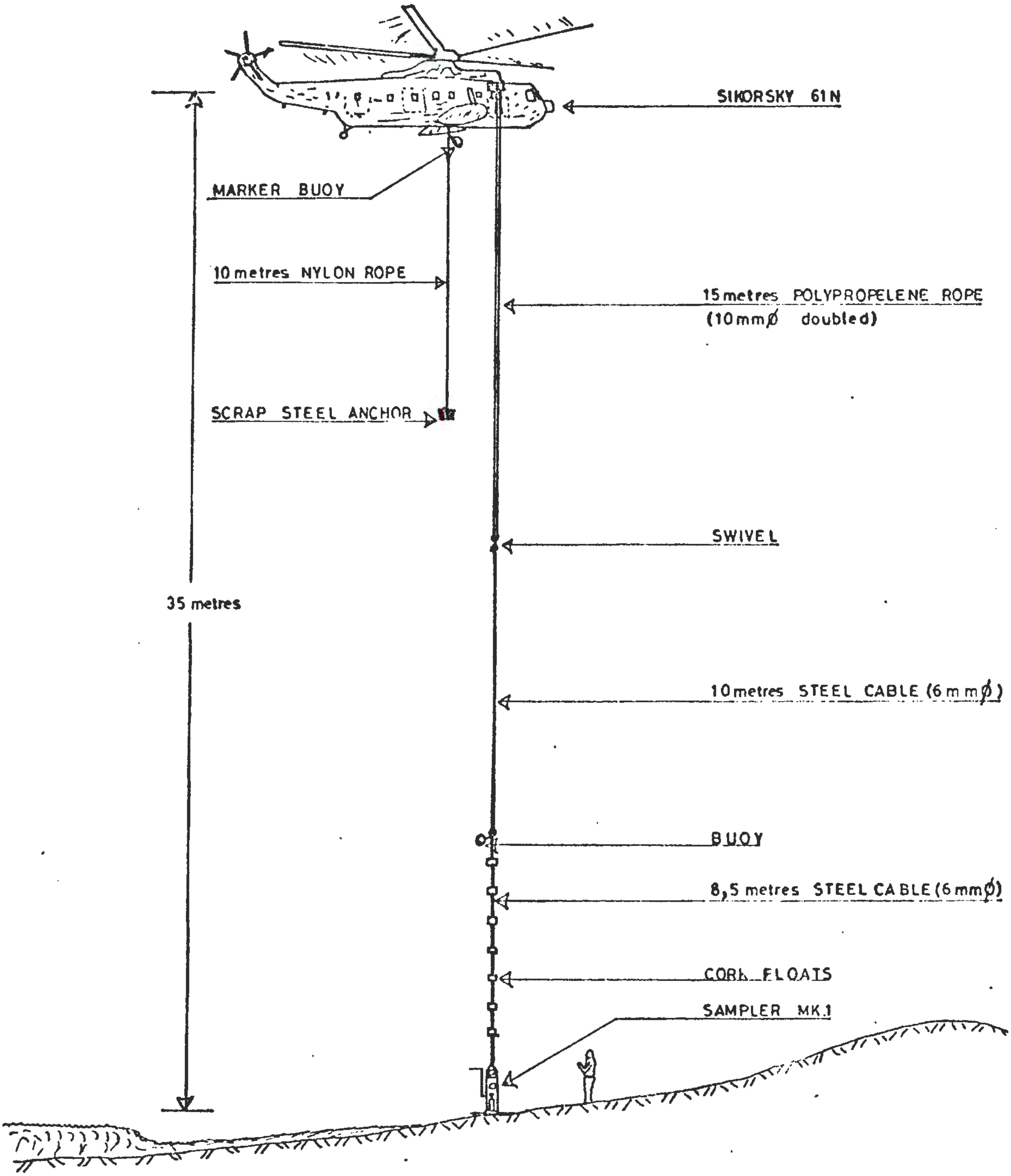


Figure 5.2 : Lifting Arrangement for Mark I Sampler

When the Sikorsky S62A was not available, a Sikorsky S58T was used. It is powered by two 960 kW gas turbine engines and has a maximum lift capacity of 1800 kg on the external cargo hook. Occasions arose when this helicopter was on contract elsewhere and the largest helicopter, a Sikorsky S61N was used. This aircraft is powered by two 1100 kW gas turbine engines and the maximum lift capacity on the external cargo sling is 3000 kg. It is also equipped with a rescue hoist. The flying endurance at site of the two larger helicopters is limited to two hours.

5.2 Sampling Procedures for the Mark I Sampler

A description of the typical procedures used when obtaining samples with the Mark I sampler is given.

The sampler and ancillary equipment were transported to site by truck and prepared at beacon P13 on the beach, near the proposed breakwater at Duynefontein. The helicopter would fly out from base and immediately begin sampling. The sampler was hooked up to the cargo hook or winch, depending on the type of aircraft used, and placed in position at the desired sampling point. The placement of the first sample was done by judgement of the author and pilot as to where the sample was to be taken i.e. in the surf or outside the breaker zone. A long length of rope was used to allow manoeuverability of the hovering helicopter during sampling. Cork floats were attached at half metre intervals to the rope to prevent the lower cable from snagging the instrument. A buoy was placed on the cable, 8,5 metres above the sampler to indicate the position of the sampler to the pilot when hovering. The author also found these cork floats useful to determine the depth of water at the sampling point. Fig 5.3 shows the sampler on the sea bed.

After the first sample was completed, and as the sampler was being lifted out of the water, a marker buoy was released from the aircraft to indicate the sampling point. This buoy was made up of a plastic bottle filled with polyurethane foam and painted fluorescent red, attached to an anchor of scrap metal. Once the sampling spot was marked, the sampler could be positioned to within 15 metres of the original sample point for samples at different elevations above the sea bed. Plate 5.4 shows the sampler being lifted out of the breaker zone by the helicopter after sampling.

It was usual to commence sampling with the highest elevation nozzle fitted as there is less likelihood of the intake being clogged by slight tipping of the sampler, and resulting in having to abort the sampling operation.

After a sample was completed, the sampler was returned to the beach for changing of filters and air cylinders. Plates 5.5, 5.6 and 5.7 show these operations.

Plate 5.5

Plate 5.6

Replacement of Air Cylinder and Filter during Sampling

Plate 5.7

Plate 5.8 Mark I Sampler being Landed on the Beach

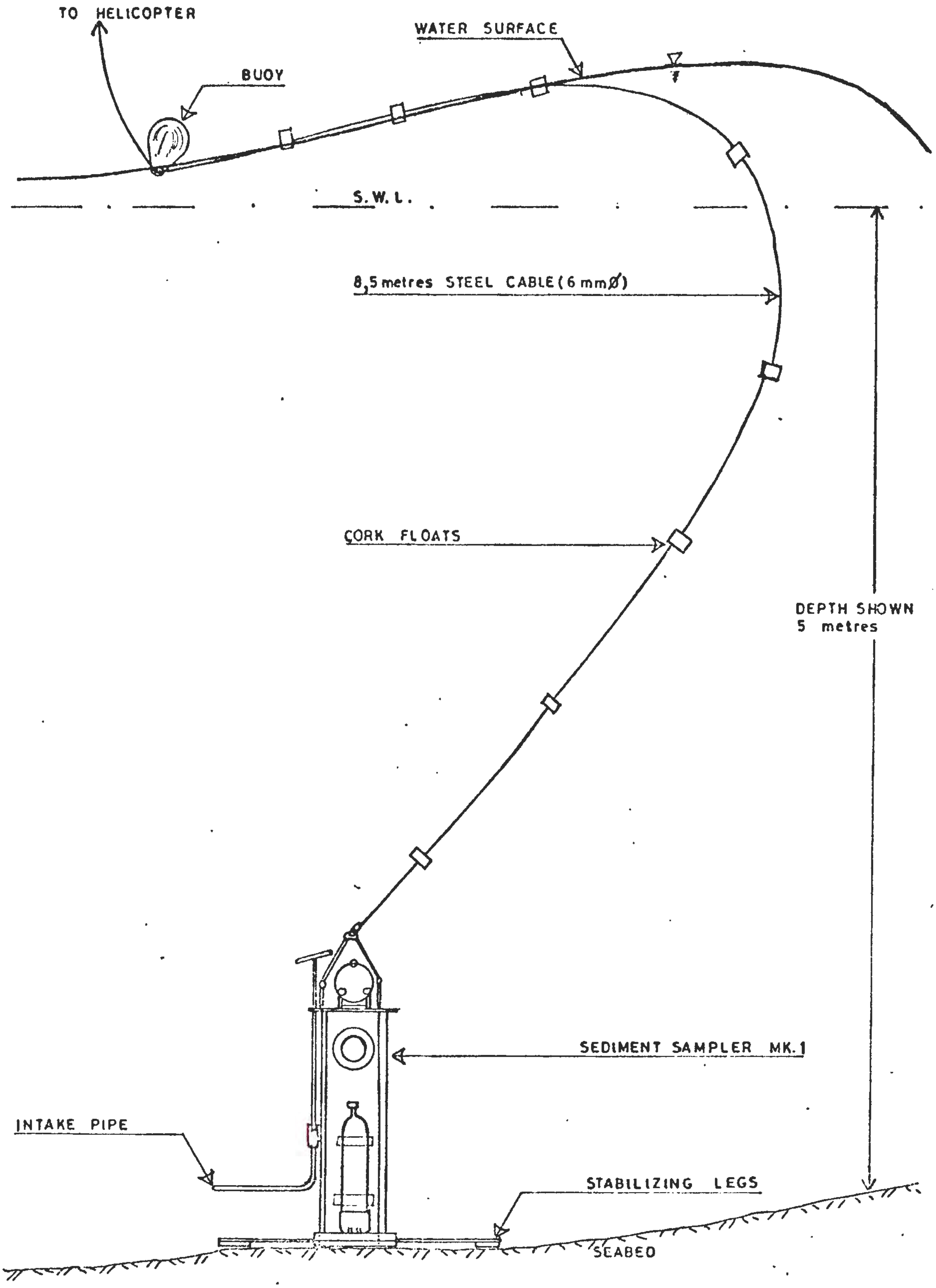


Figure 5.3 : Diagram showing Mark I Sampler on Sea Bed

Attempts were made to place greased discs on the base of the sampler to obtain a sample of the bed material. Difficulties arose with the method when the sampler was returned to the beach after sampling. Due to the long suspension, it was difficult for the pilot to place the sampler next to the personnel on the beach so that the greased discs could be removed before contact was made with the beach sand. Plate 5.8 is a view from the helicopter looking down on the sampler as it is placed back onto the beach to illustrate this problem.

The used filters were placed in perspex containers immediately after sampling and sealed so that no foreign material could enter. Once removed to the laboratory, the sediment was washed to remove all traces of salt water, and carefully removed from the filters into perspex containers by a fine water jet. The samples were allowed to stand for six hours and then carefully decanted to remove excess water. The wet sample was then transferred to a porcelain dish where it was dried and subsequently weighed. Sieve and settling tube analyses were then conducted to determine the size fractions of the sediment.

5.3 Determination of Sample Position

During the first sampling operation in June 1975, the positioning of the helicopter was attempted by using two intersecting lines of sight established by two sets of marker boards on the beach. This method is used with success to position boats. However, it was found to be impractical with a helicopter, as the aircraft normally flew out at a height of 200 to 300 metres above sea level and the boards appeared to be above and below each other rather than horizontally in line. In addition, the boards were not sufficiently large enough to be seen adequately from 1000 metres offshore. It was thus decided to use the marker buoy system as described above to determine sample positions.

Two theodolites were initially used to determine the actual sampling position, by recording angles between the sampler as it was lowered to the sea bed, and the base line between the instruments. Two pegs were co-ordinated and Plate 5.9 shows the theodolites set up on these pegs.

An alternative method was used for positioning by measuring two angles between three known points on the shore from the helicopter using a sextant. Resection circles were plotted for these angles, and the position of the helicopter could be immediately determined. This method proved to be the most useful as it dispensed with the use of theodolites and minimised the number of trained personnel needed. In addition, the sand clouds generated by the downdraught of the helicopter rotors when landing, damaged the theodolites and on one occasion blew a theodolite over. An example of the resection circles is given in Fig 5.4 along the reactor centreline.

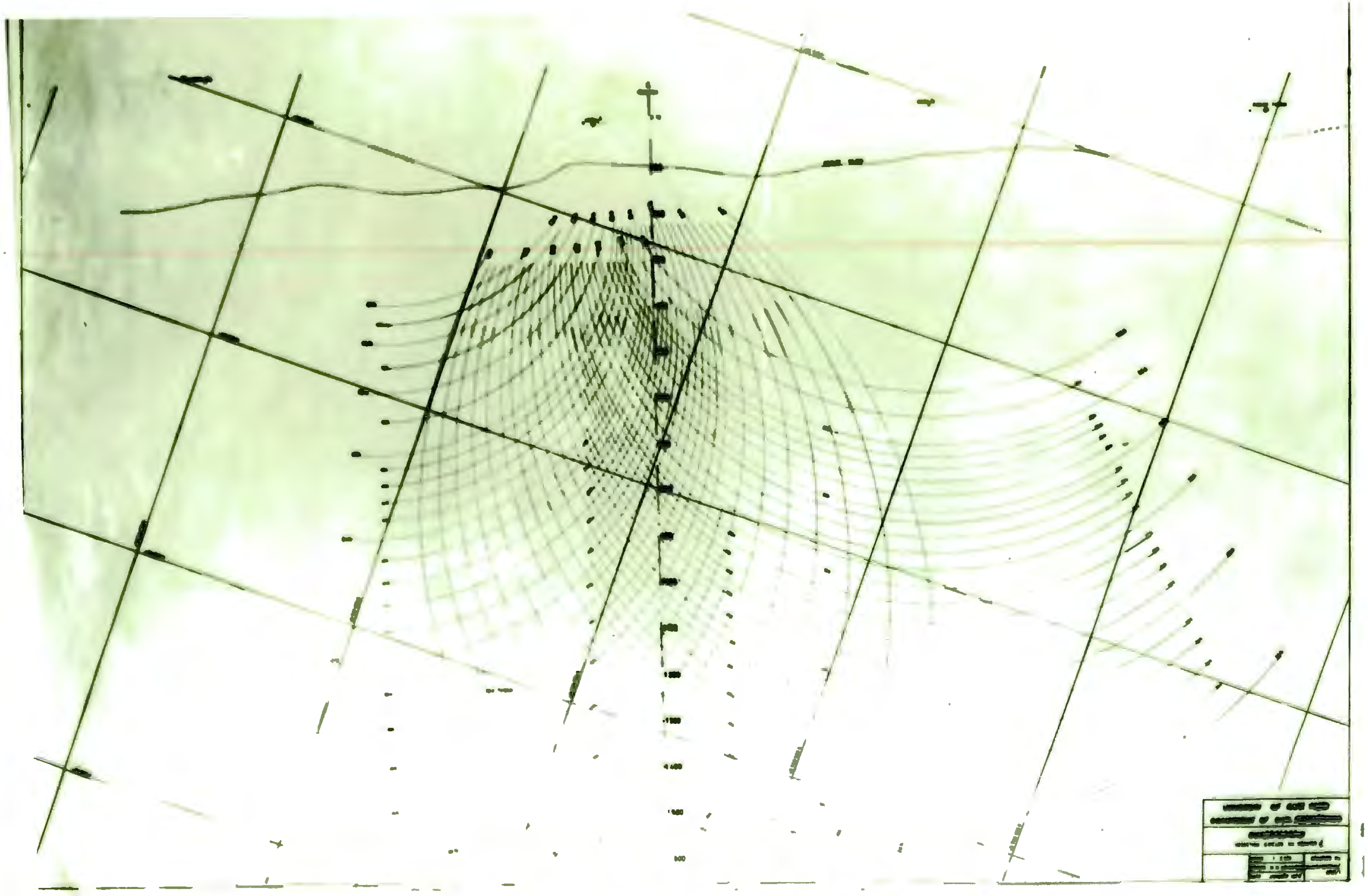


Figure 3.4 : Survey Resection Circles along Reactor Centre Line

The three fixed points subtending these angles were the shelter, housing the experimental switchgear, Peg CERU/3; Peg CERU/1, where the vehicle was parked; and the Radar Tower. All these three points were easily identifiable from the helicopter. A co-ordinate list of the sea and radar towers and survey points is given in Table 5.1.

Table 5.1 : Co-ordinate List

	Y (m)	X (m)
Sea Tower	54 041	3 727 814
Radar Tower	52 287,6	3 728 979,7
P 13	52 753,7	3 727 747,9
CERU/1	52 796	3 727 634
CERU/2	52 522	3 728 295
CERU/3	52 995	3 726 762
SSBI	53 240	3 728 624

5.4 Mark I Sampler Summary

Various minor modifications had to be made to the Mark I sampler after faults developed during operation, and are mentioned under section 4.2. Despite the need for minor changes and problems experienced, the sampler performance was reasonable considering that it was built basically as a prototype. Table 5.2 gives a summary of the number of samples taken, and number of hours flown.

On average, one sample was taken per half hour of flying time. It should be remembered that each sample operation involves 20 minutes flying time to and from base. If this time is subtracted from the overall time, the average time for each sample is 24 minutes. Out of a total of 11 operations, five had to be aborted. This method of obtaining samples from the surf zone under moderate wave conditions is thus expensive as the hire charges for helicopters used are very high. A cheaper alternative was sought, using basically the same pump sampler unit but avoiding the use of a helicopter. In addition, some element of danger is present when flying the helicopter at such low altitudes, and a system was sought which was entirely shore based to minimise the occasions when personnel were actively working in or above the surf.

The sampler, however, was able to sample under exceptionally high wave conditions just outside the breaker zone. On the operation of 8th June 1976, the average wave height was 6 metres and the breaker zone approximately 1400 metres offshore.

Plate 5.9 Survey Points at P13

Plate 5.10 Sea Tower under High Wave Conditions

Plate 5.11 Sea Tower under High Wave Conditions

Plate 5.12 Sea Tower

Plates 5.10 and 5.11 show the extent of the waves breaking seaward and over the sea tower on that day. These photographs were taken with a very long focal length lens and are consequently fore-shortened. Plate 5.12 shows the tower in calm weather as a comparison.

Table 5.2 Summary of Operations of the Mark I Sampler.

Date	Helicopter	Flying Time	No. of Samples	Remarks
2-12-74	Jetranger	1 hr	0	Aircraft not powerful enough
2-12-74	S 62 A	50 min	0	Cable snagged
6-12-74	S 62 A	1 hr 25 min	4	
12-6-75	S 62 A	3 hr 15 min	8	Helicopter returned to base to refuel
3-10-75	S 58 T	1 hr 10 min	0	Regulator failed
15-10-75	S 58 T	1 hr 20 min	4	
6-11-75	S 58 T	30 min	0	Aborted - pipes blocked
1-12-75	S 62 A	1 hr 45 min	4	
8-12-75	S 62 A	1 hr 10 min	3	
12-3-76	S 61 N	2 hrs	6	Interrupted - helicopter low on fuel
8-6-76	S 61 N	1 hr 35 min	2	Aborted - pipes blocked
TOTAL		16 Hours	31	

5.5 Field Operations using the Mark II Sampler

The basic system of operation proposed used an endless rope as the mode of transporting the Mark II sampler to the desired sampling point. This fulfilled the requirement of a more economical method of obtaining samples and increasing the personal safety of the operators as the point of control, namely the winch, was situated on the beach. A certain degree of danger was involved, however, in the establishment of the rope system from the shore to the buoy offshore.

The initial proposal was to establish the endless rope from shore to buoy and back to shore using a light nylon rope. This would then be used to pull the heavy rope into position. The sea anchor and buoy were placed using a Sikorsky S 58 T helicopter during sampling operations involving the Mark I sampler in November 1975.

In order to position this buoy accurately 800 metres offshore, a marker buoy was previously placed using a boat positioned by theodolite from pegs CERU/1 and CERU/2. The buoy broke loose after a storm in March 1976, and was cleaned of marine growth and repositioned in April 1976. Plate 5.13 shows the condition of the buoy after 4 months at sea. The anchor was located by the use of two theodolites set up at CERU/1 and CERU/2, set on fixed angles. A boat was positioned by these theodolites and a diver was used to locate the anchor, and reshackle the buoy to it. Use was made of resection circles shown in Fig 5.5, to obtain approximate positions of the boat.

The buoy subsequently broke loose again in July 1976 and was replaced by the same method in October 1976. The anchor rope was shortened to approximately 12 metres to try to prevent abrasion at the rope-chain junction. This was found to be the weak point which eventually parted during heavy seas when the buoy was in the breaker zone.

Several attempts to establish the rope link between the buoy and the shore were made. In very low wave conditions, a light line was established using swimmers and surfboards and a Zodiac inflatable dinghy was used to pull the heavy rope to the buoy. This operation could only be carried out in very low surf conditions. For higher surf conditions, the use of line throwing equipment commercially available was considered, but after the author witnessed the use of such equipment at Oranjemund, the range of this equipment being only 200 metres and insufficient for use at Duynefontein, the idea was rejected. The conditions under which the Zodiac dinghy would be used were in wave heights of up to 1,5 metres, under which circumstances it would not be able to approach closer than 400 meters to the shore with safety.

The endless rope was installed in July 1976, and attempts were made to pull the sampler out into the surf. Difficulties were encountered due to the large tensions developed in the rope caused by the drag of the rope in the surf, and the catenary action of the rope caused by longshore current. The winch system used was found to be underpowered. The rope was left in overnight, the ends anchored to concrete blocks buried on the beach approximately 300 metres apart. The following morning the rope was found to be extensively tangled at the buoy end, and was cut loose to retrieve it. Plate 5.14 shows the Mark II sampler and equipment on the beach in attempts to establish the rope system.

Operations using the Mark II sampler were attempted again during October and November 1976, but the same problems were experienced as in July 1976. The author therefore concluded that for this system to work satisfactorily, a more powerful operational system was needed. If a powerful boat was available, the system could be modified to eliminate the return end of the rope and decrease the probability of tangling at the buoy. This however involves personnel on the sea, and could not operate under wave conditions of more than 2,5 metre wave height.

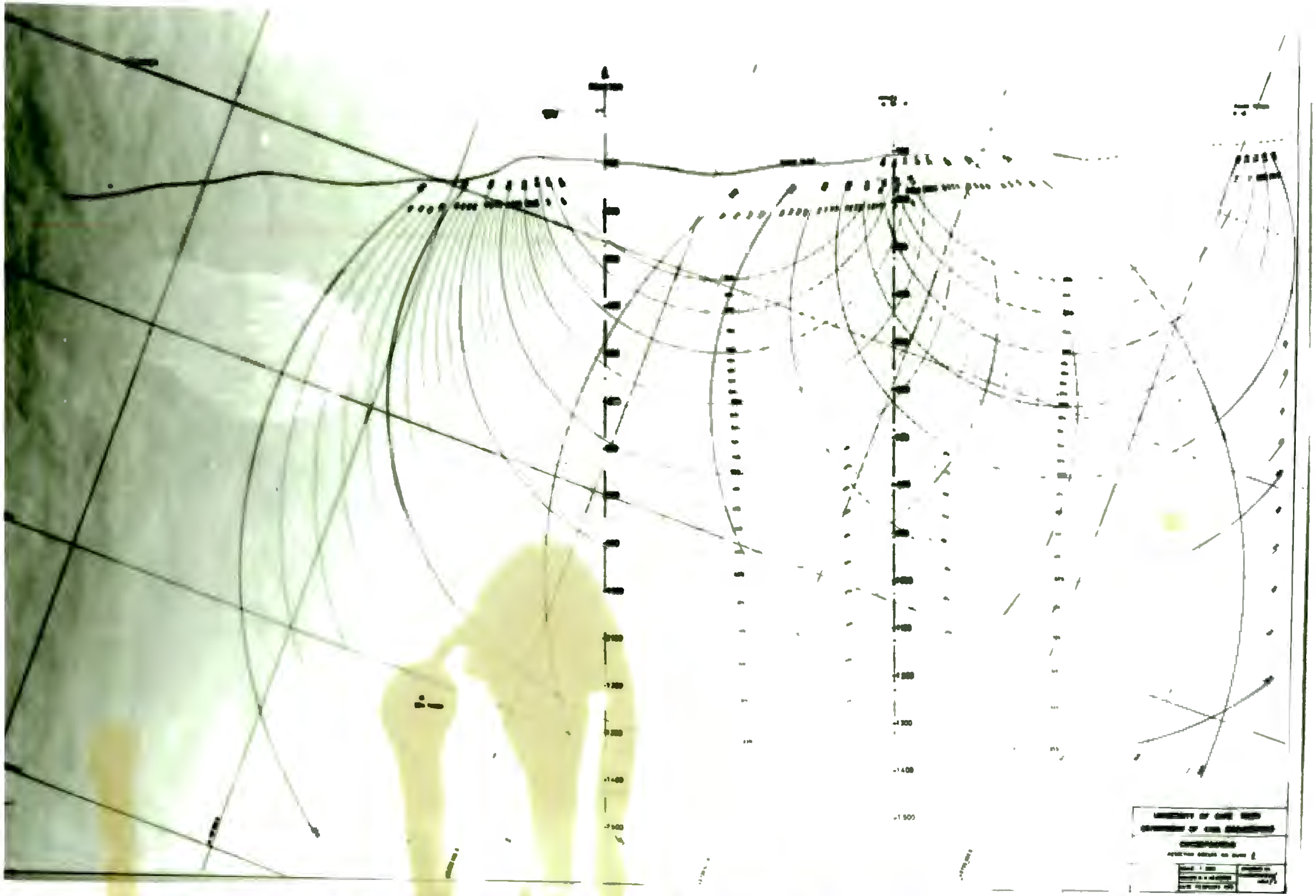


Figure 5.5 : Survey Resection Circles on Buoy SS81 Centre Line

Plate 5.13 Marine Growth on Buoy after Four Months in the Sea

Plate 5.14 Mark II Field Operations; Attempts to Install Main Rope

The Mark II sampler was tested extensively in the laboratory and the sampling cycle of sinking, sampling and refloating worked thoroughly. The sampler was also tested in the swash zone of the beach and the wheeled motive system was found to work with a reasonable degree of success. No samples were obtained using this sampler because of the problems encountered with the operational system as described above.

5.6 Laboratory Experiments

Crosswell (46) undertook preliminary laboratory investigations into the suspension of sediment under the supervision of the author in October 1975. A wave flume 20 metres long and 0,6 metres wide was used, capable of producing waves of up to 0,32 metres in height and of wave period of between 1,0 and 4,5 seconds. A mobile bed was used with an average slope of 1:15. Two types of sampler were used, a siphon sampler consisting of a 1,5 litre evacuated bottle and an electro-optical indirect type of sampler. The output from this sampler was initially read on a voltmeter, but subsequently plotted on a pen recorder. Calibration of the electro-optical system was attempted by allowing a known mass of sand to settle in a container and compared with voltage drop readings recorded by the electro-optical sampler measuring across this suspension. Difficulties were encountered in establishing a constant flow of sand through the sieves to provide a constant suspension, and the calibration results were not conclusive. The results using the siphon sampler were found to be subject to large variations because of the small mass of sediment obtained.

The relative concentrations of suspended sediment at a particular point were able to be determined, and instantaneous readings were plotted by the pen recorder. An example of the output is given in Fig 5.6. It is seen that several bursts of sediment occur with high peaks during a wave cycle and are caused by the vortices generated by the sand ripples on the bed passing the optical beam. If the drop in voltage is assumed to vary linearly with the concentration, then these peaks are of the order of 3 to 4 times the magnitude of the average concentration.

In conclusion, the following points were observed in the experiments :

(a) The amount of sediment in suspension for a given wave height and period appears to be greatest just outside the breaker zone. This phenomenon was also observed by Kennedy and Locher (8)

(b) Suspension of sediment did not occur in any significant amounts until sand ripple formations occurred on the bed. These ripples varied between 50 and 180 mm in length and 5 to 30 mm in height. Under low wave conditions, the ripples appeared to be well formed, but as the intensity of wave attack increased, the ripples tended to become flatter and less pronounced.

(c) The principle mechanism of the suspension of sediment is the vortex formation caused by turbulent flow over the ripple bed.

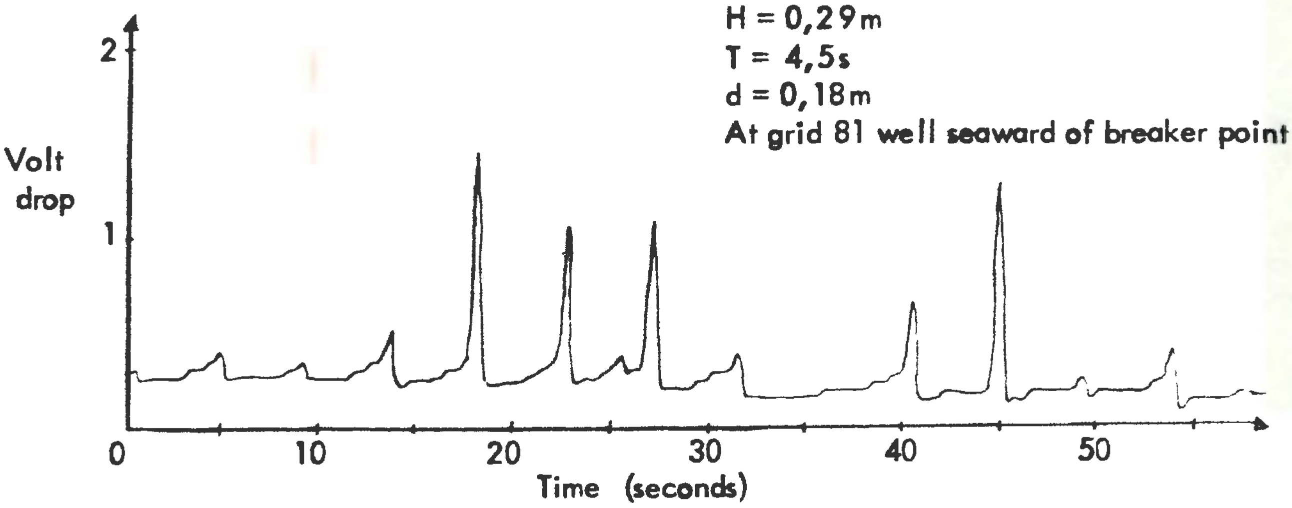
Several peaks in the instantaneous measurement of suspended sediment were identified, caused by turbulent vortices laden with sediment forming on the landward side of the ripple and being carried over the crest of the ripple in a seaward direction by the oscillatory motion of the flow. The number and intensity of these peaks was found to vary with the wave period, wave height and position relative to the ripple.

(d) Calibration of the indirect type of samplers is difficult and can result in erroneous readings particularly if organic turbidity is present.

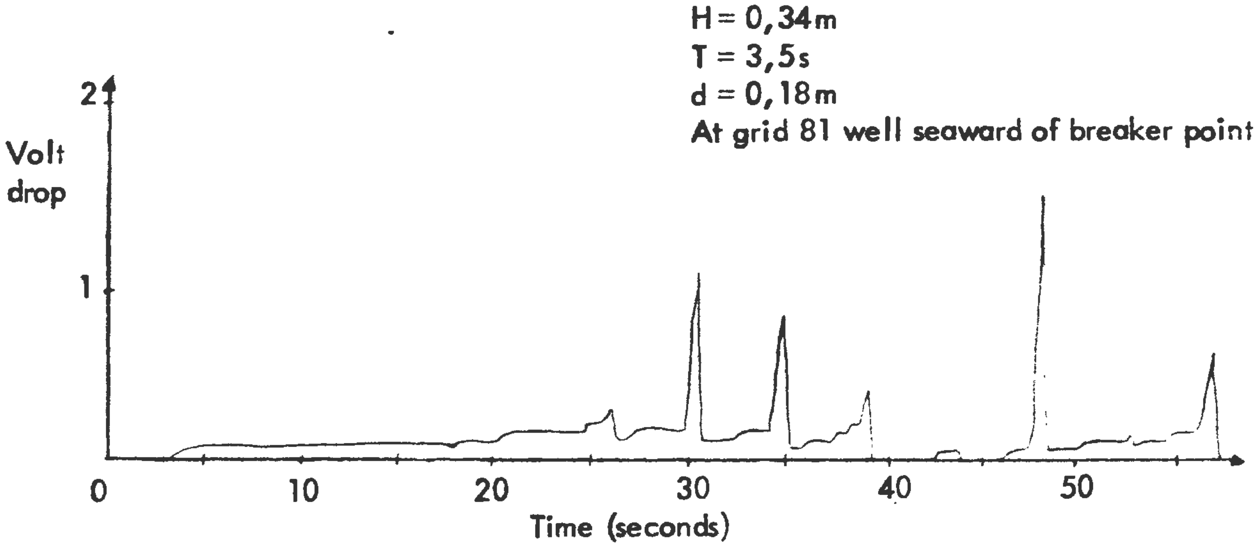
(e) Readings taken by electro-optical instruments in the surf zone are unreliable because of the presence of entrained air bubbles.

The author concludes that the sand ripple formations occurring in laboratory experiments were found to have a significant effect on the suspension of sediment. Observations made by the author whilst diving in the sea at the area under investigation, indicated that the scale of the sand ripples was more dependant on the current occurring at the sea bed rather than that resulting from wave motion. Sand ripples of approximately 100 mm in length and 10 mm in height were observed at a point 800 metres offshore under 2 metre wave height conditions. The orientation of these ripples was normal to the direction of the current, rather than parallel to the wave crests. The ripple formation was, however, reasonably symmetrical.

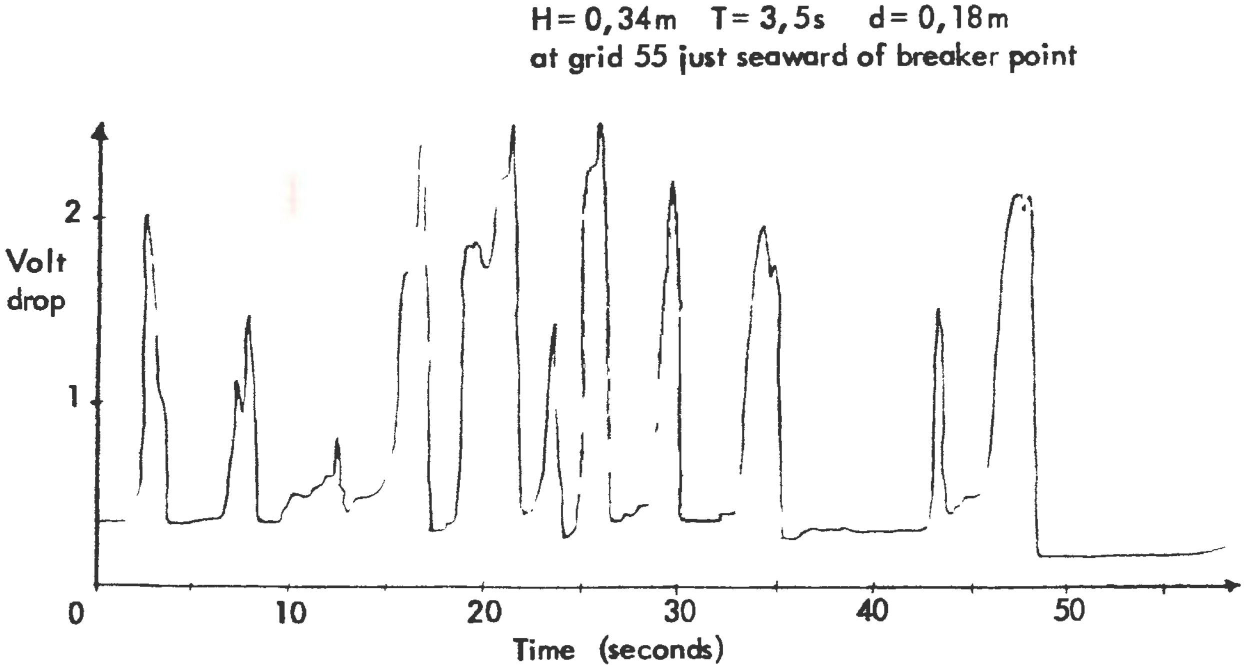
A comparison between the ripple dimensions occurring in the laboratory experiments and in the prototype, compared to their related depths, indicated that the ripple formation in the prototype does not assume such a significant role in the suspension of sediment as assumed under laboratory conditions.



H = 0,29m
T = 4,5s
d = 0,18m
At grid 81 well seaward of breaker point



H = 0,34m
T = 3,5s
d = 0,18m
At grid 81 well seaward of breaker point



H = 0,34m T = 3,5s d = 0,18m
at grid 55 just seaward of breaker point

Figure 5.6 : Output from Electro-optical Sediment Sampler

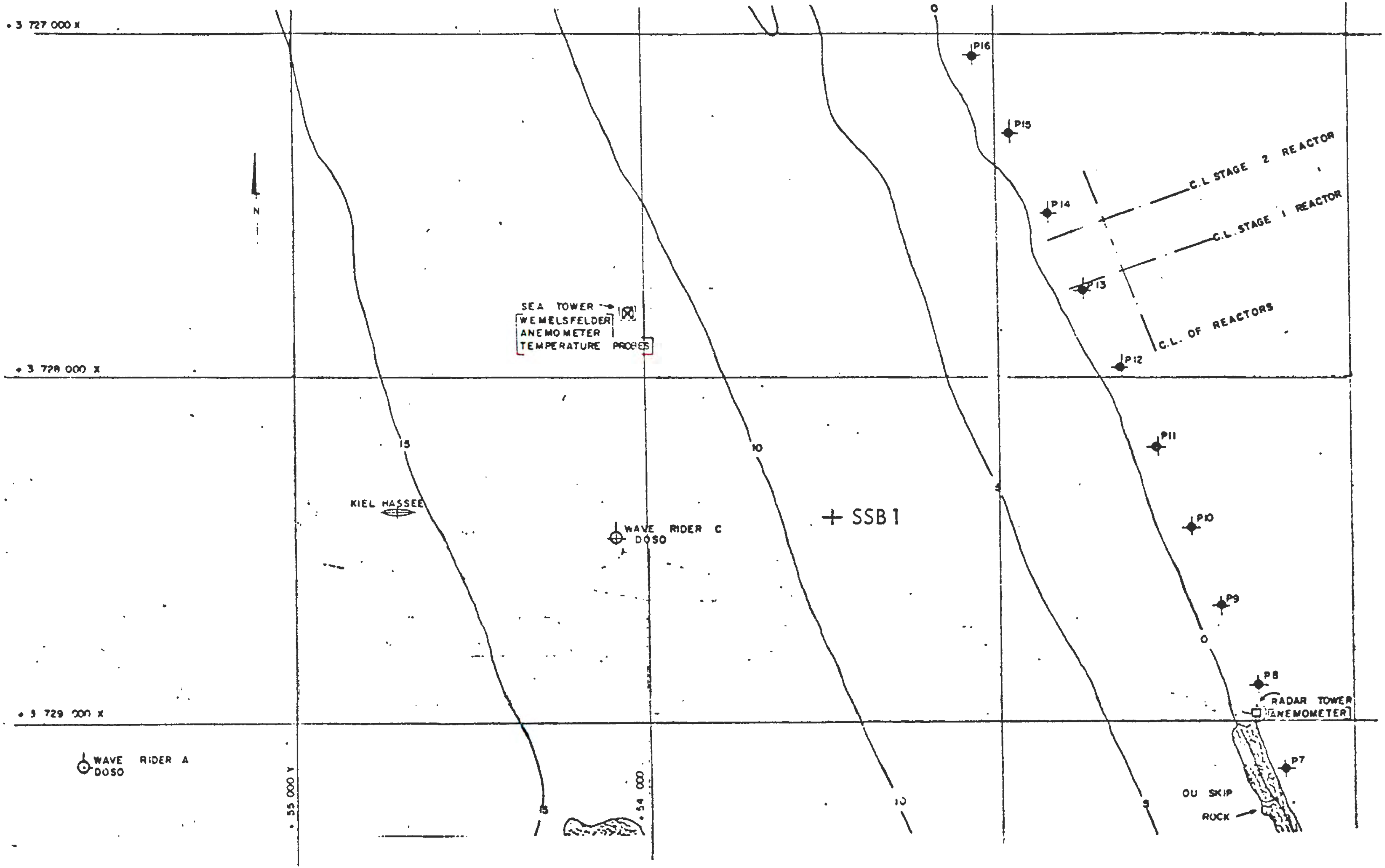


Fig 6.1 : General Plan of Duynefontein Coast.

SSB1 - position of buoy and anchor for Mk II sampler.

CHAPTER SIX

Field Results and Analysis

6.1 Beach Topography and Wave Climate

The approximate depth contours of the beach and positions of the data recording equipment are shown in Fig 6.1. The approximate beach slope was 1 : 100 and found to be fairly constant throughout the season, as shown by Bosman (48). The position of the breaker zone as observed by the author is given in Table 6.1 and it is noted that the surf zone is unusually wide.

Table 6.1 : Observed Width of Surf Zone.

H Average (m)	Surf Zone Width (m)
0,5	50 to 100
1	200
2	300 to 400
3	up to 600
4	800 to 1000
5	1000 to 1200
6	1200 to 1400

Larger sets of waves occurred and would break well seaward of the normal breaker position for the specified average wave climate.

The tidal range at the area under investigation was assumed to be the same as that for Table Bay. Tide tables (47) give the following values for Table Bay :

HAT = 2,02 m
LAT = -0,01 m
MHWS = 1,69 m
MLWS = 0,27 m
MHWN = 1,26 m
MLWN = 0,71 m

The above levels are given relative to the local datum.

Bosman (48) showed that the offshore contours were well spaced and regular, with no reef or sudden local changes in depth. The average deep sea swell direction was found to be WSW (247°). The beach orientation was 335° so that the incoming waves are approximately parallel to the beach when entering the nearshore region.

Wave heights and periods during sampling were measured by a Wemelsfelder wave recorder situated on the sea tower, and by a Wave Rider buoy situated 1500 metres offshore.

Wave direction was measured by radar from a tower on the beach. Wave data used in the analysis of the suspended sediment results was obtained from reference (7).

The following assumptions are made in the analysis of the results :-

(a) The density of the sea water and sand is assumed to be 1025 kg/m^3 and 2650 kg/m^3 respectively. In the determination of the sediment size fraction by settling tube analysis, it is assumed that the sediment behaves as spherical sand particles. Thus the larger sized shell particles are assumed to be smaller sized sand particles with the same hydraulic properties.

(b) The wave heights given were recorded at the sea tower in 11 metres water depth. As the wave heights are not known to any great degree of accuracy, the wave height at the sample point well seaward of the breaker zone is assumed to be equal to that at the sea tower. For sample points in the surf, the breaking wave height is found and used in the calculations. The wave heights recorded are given as $H_{1/10}$, and as the significant wave height is to be used in the calculation of orbital velocities, the following conversion is used, as given in reference (40) :

$$H_s = 0{,}79\ H_{1/10}$$

(c) The wave fronts are assumed parallel with the shore line, and no refraction will be considered. This was found to be true in most cases by Bosman (48).

(d) The kinematic viscosity of the water is given by the equation quoted in Swart (32) :

$$\nu = 1{,}792 \times 10^{-6}\ \exp(-0{,}042\ t^{0{,}87})\ m^2/s.$$

where t is in degrees Celsius. The value for von Karman coefficient is assumed to be 0,38.

(e) The settling analysis of the sediment was determined using the Stokes', Transitional and Allen's Laws as given by Lazarus (49) and is plotted in Fig 6.2 for water at 20° C. The fall velocity of the particles used in the calculations is assumed to be equal to that for a sand particle of size D_{50}, determined from the grading analyses.

6.2 Results

The sediment concentrations and grading analyses for the samples obtained by the Mark I sampler are given in Fig 6.3. to Fig 6.11. The maximum sizes of particles were determined in the grading analysis by observing the time of first arrival on the scale, and are given in Table 6.1.

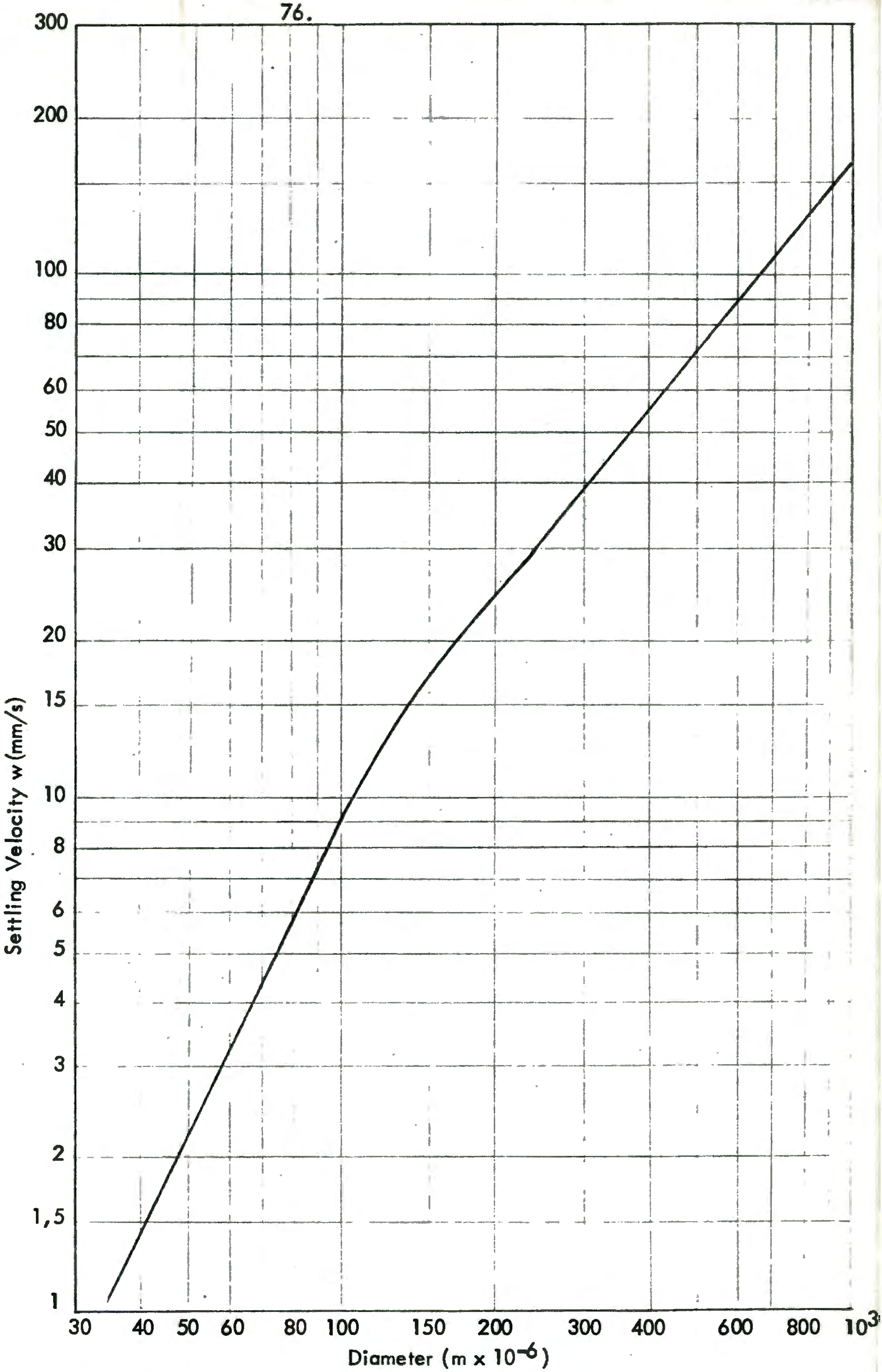
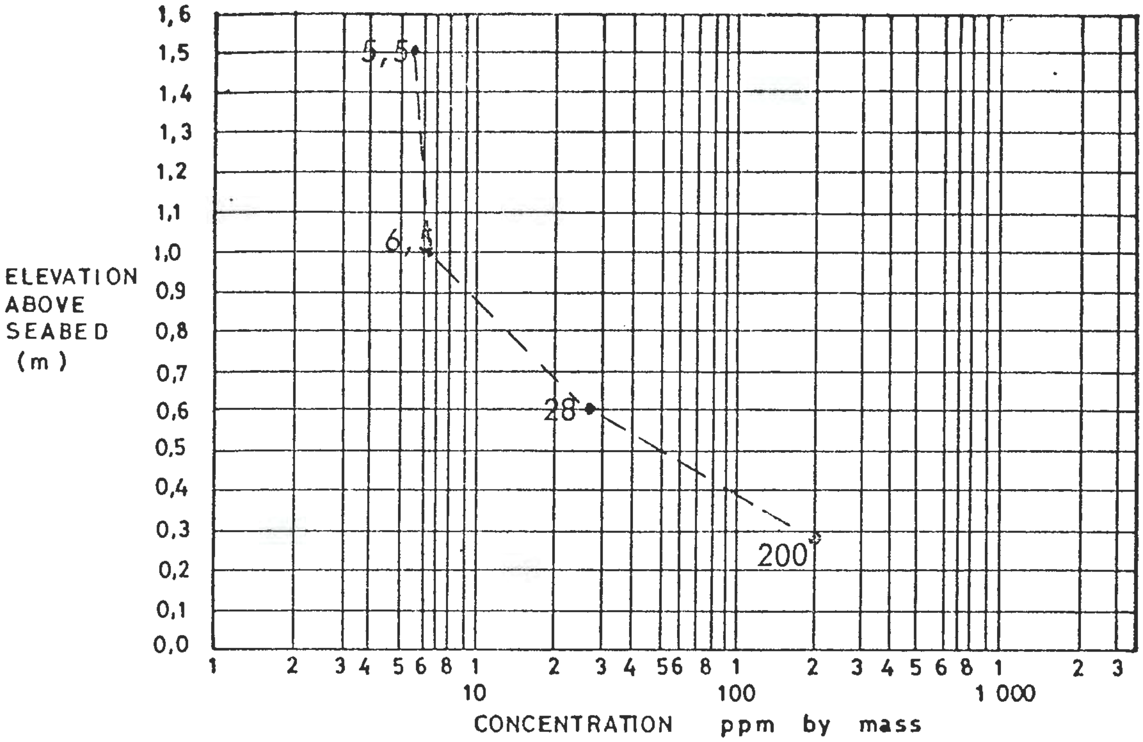


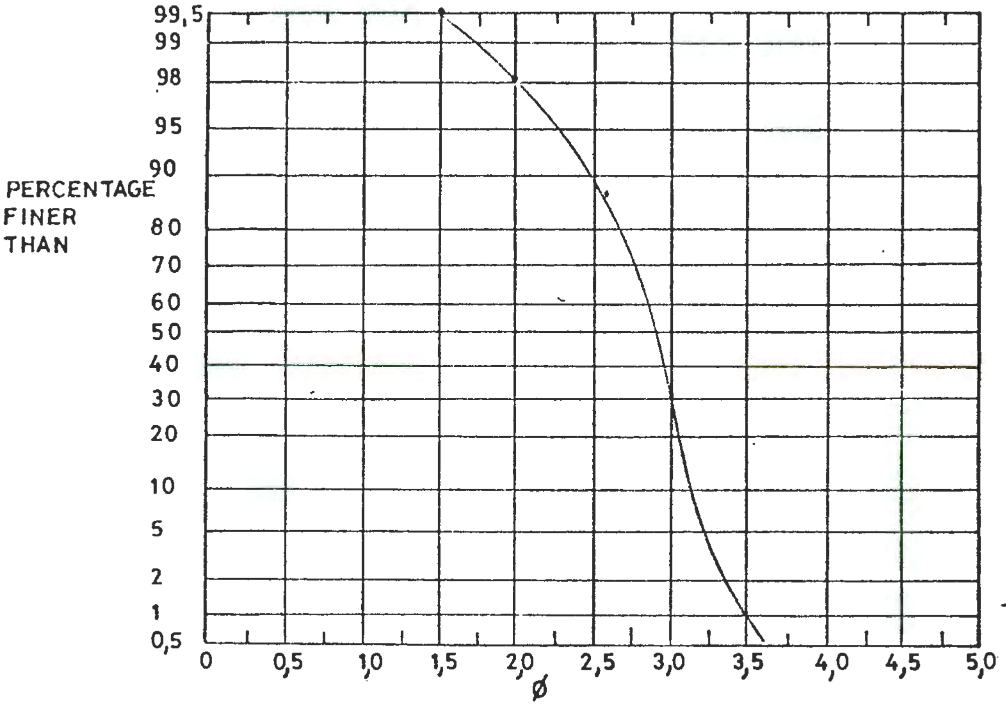
Figure 6.2 : Settling Velocity of Sand in Water at 20° C

Figure 6.3 : Profile No. 1.

CONCENTRATION CURVE



GRADING ANALYSIS



ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

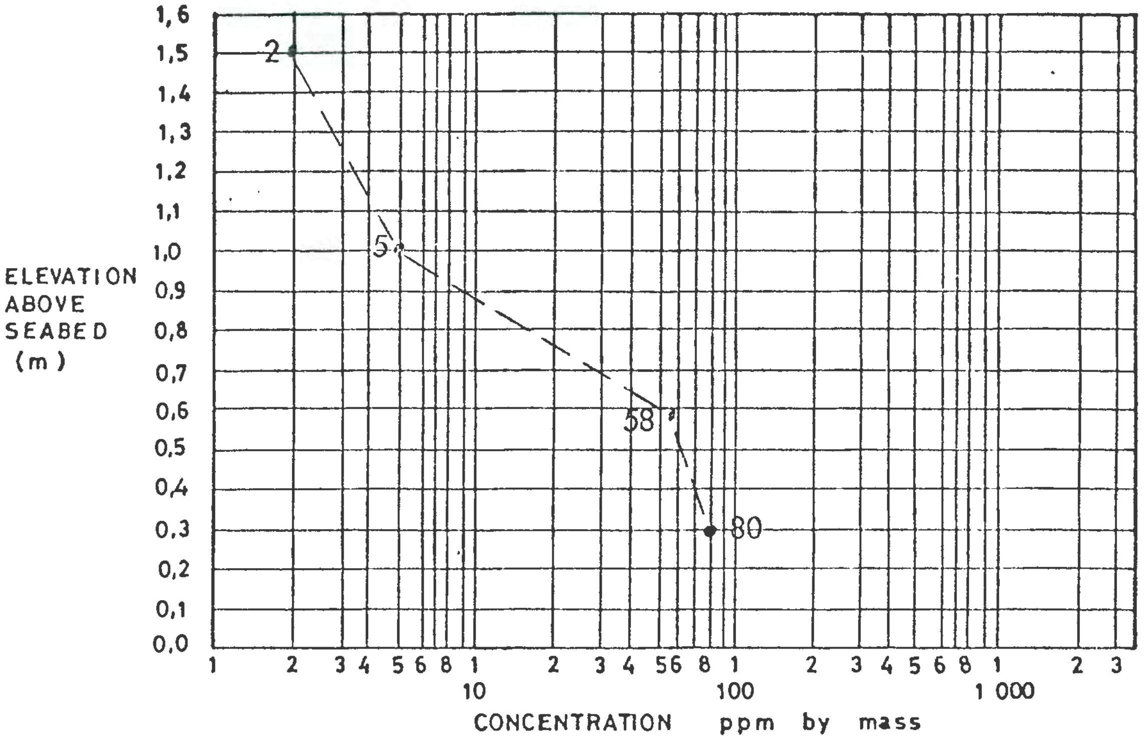
y

280 mm

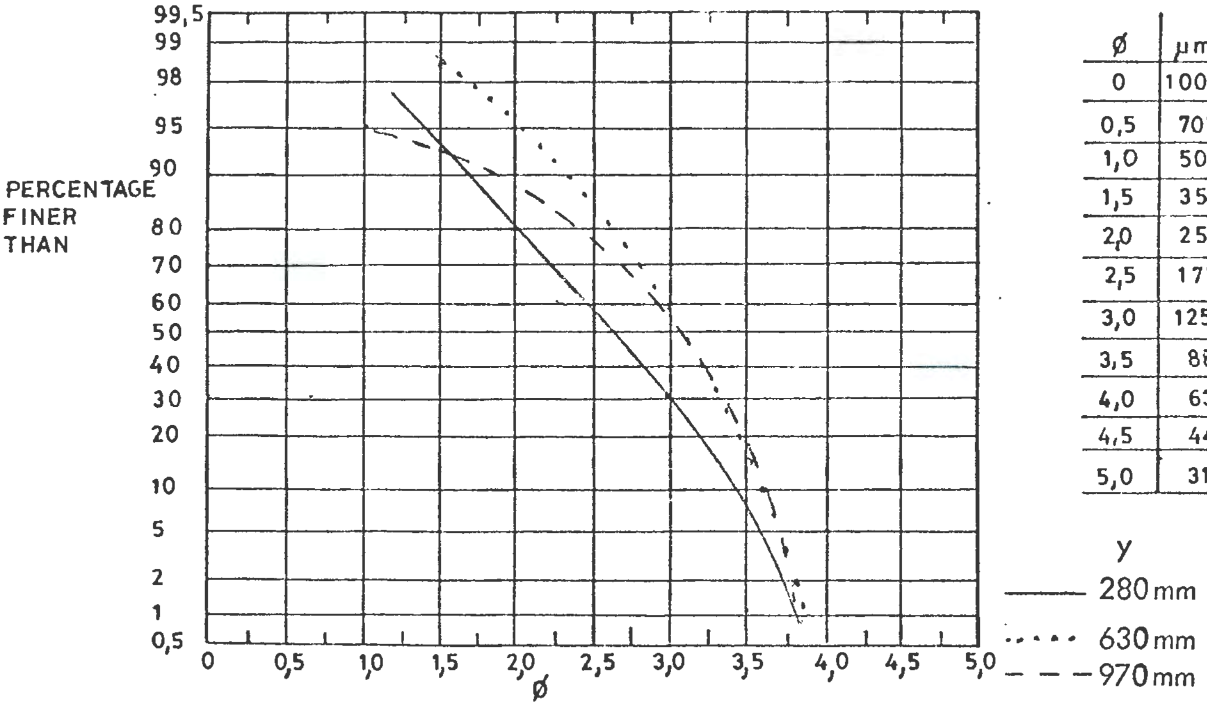
SAMPLING DATE AND TIME:- 6-12-1974; 11h00 to 12h00
SAMPLE POSITION :- 450 m from P13
WATER DEPTH :- 5 m
WAVE HEIGHT:- Hmax - Hs 1 m $H_{1/10}$ -
WAVE PERIOD:- 9,5 seconds
WAVE DIRECTION:- -
BREAKER POSITION :- 200 m from P 13
WATER TEMPERATURE :- -
CURRENT VELOCITY:- -

Figure 6.4 : Profile No. 2.

CONCENTRATION CURVE



GRADING ANALYSIS



ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

SAMPLING DATE AND TIME :- 12-6-1975; 13h00 to 13h40

SAMPLE POSITION :- 1300 m from P13

WATER DEPTH :- 12 m

WAVE HEIGHT :- Hmax 2,8m Hs - $H_{1/10}$ 2,0m

WAVE PERIOD :- 12 seconds

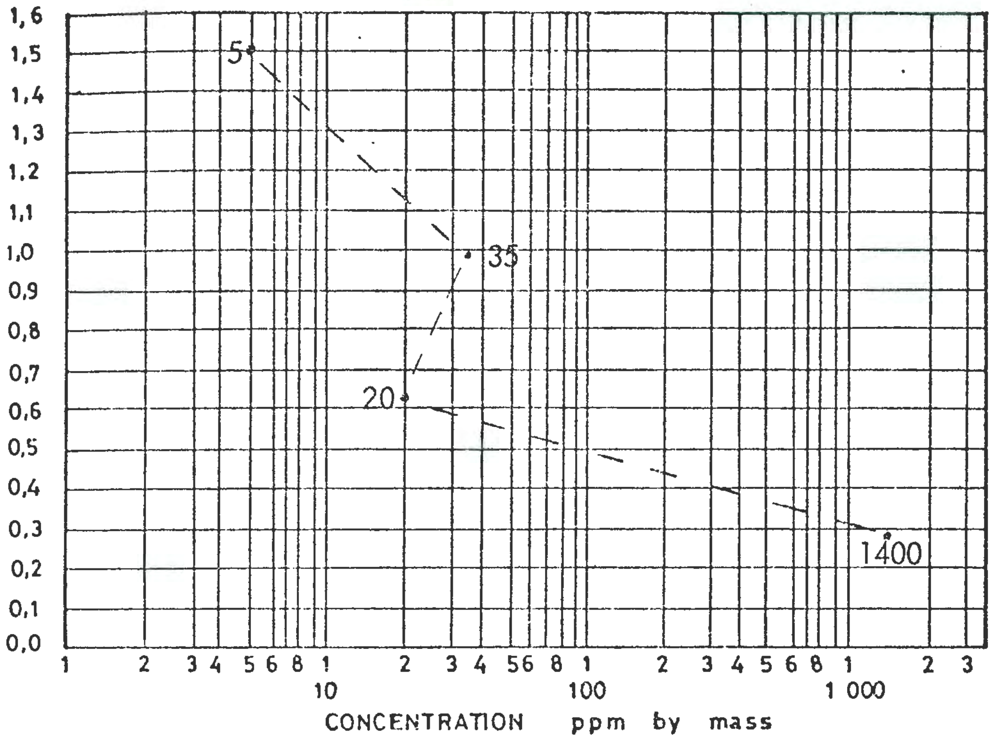
WAVE DIRECTION :- -

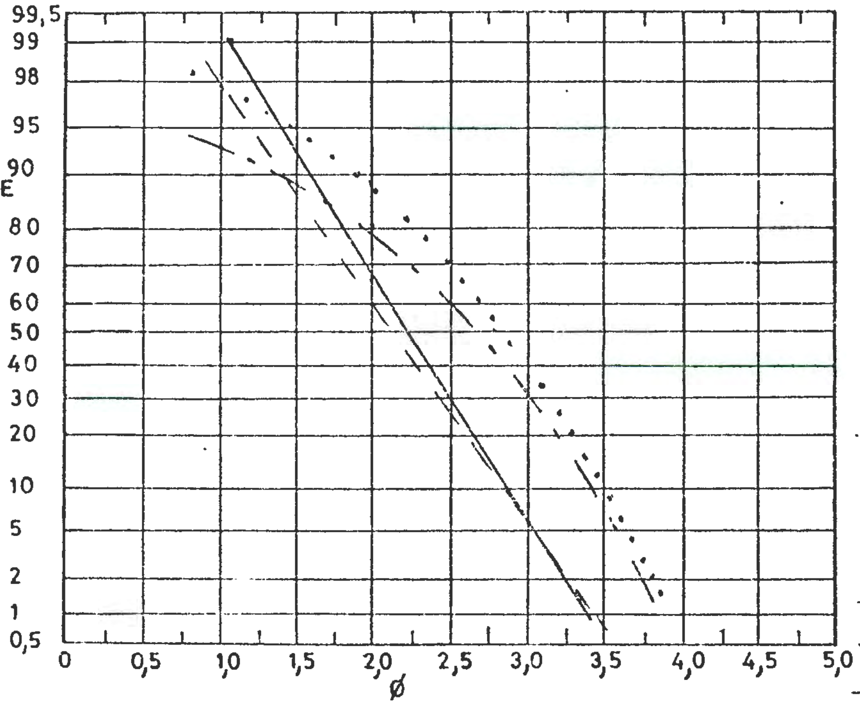
BREAKER POSITION :- 400m from P13

WATER TEMPERATURE :- 15°C

CURRENT VELOCITY :- -

Figure 6.5 : Profile No. 3


CONCENTRATION CURVE


GRADING ANALYSIS

ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

SAMPLING DATE AND TIME:- 12-6-197 15h30 to 16h20

SAMPLE POSITION :- 700m from P13

WATER DEPTH :- 8m

WAVE HEIGHT:- Hmax 2,8m Hs - $H_{1/10}$ 2,0m

WAVE PERIOD:- 12 seconds

WAVE DIRECTION:- -

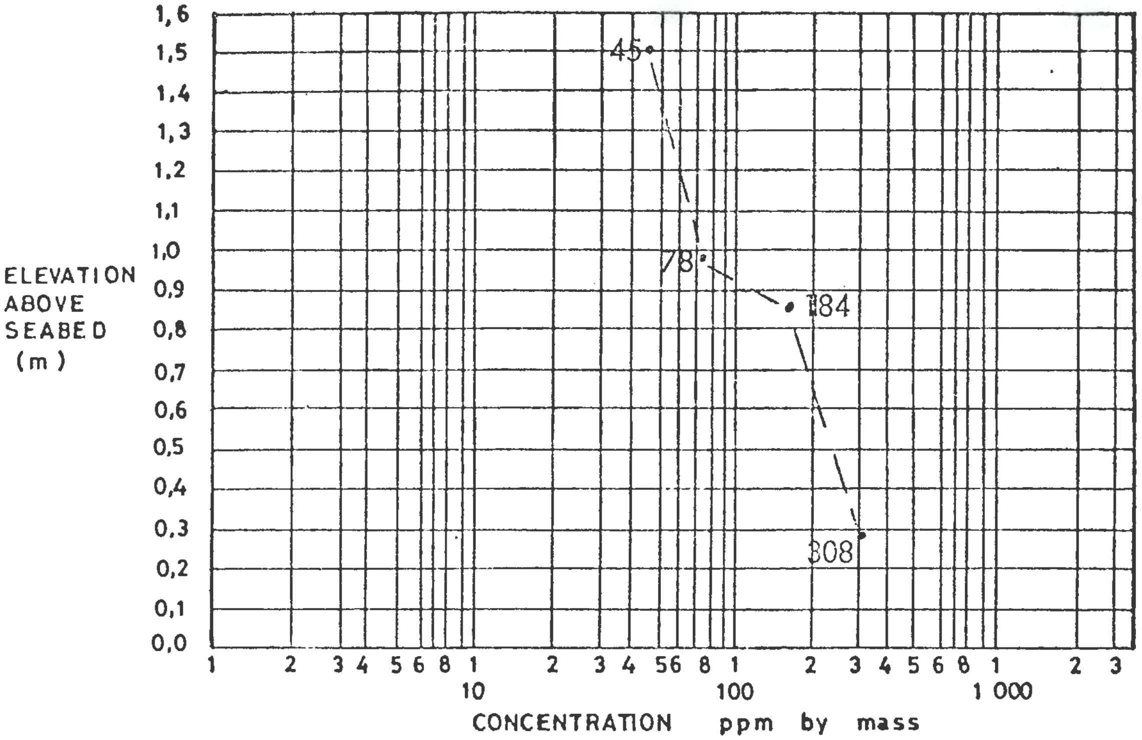
BREAKER POSITION :- 400m from P13

WATER TEMPERATURE :- 15°C

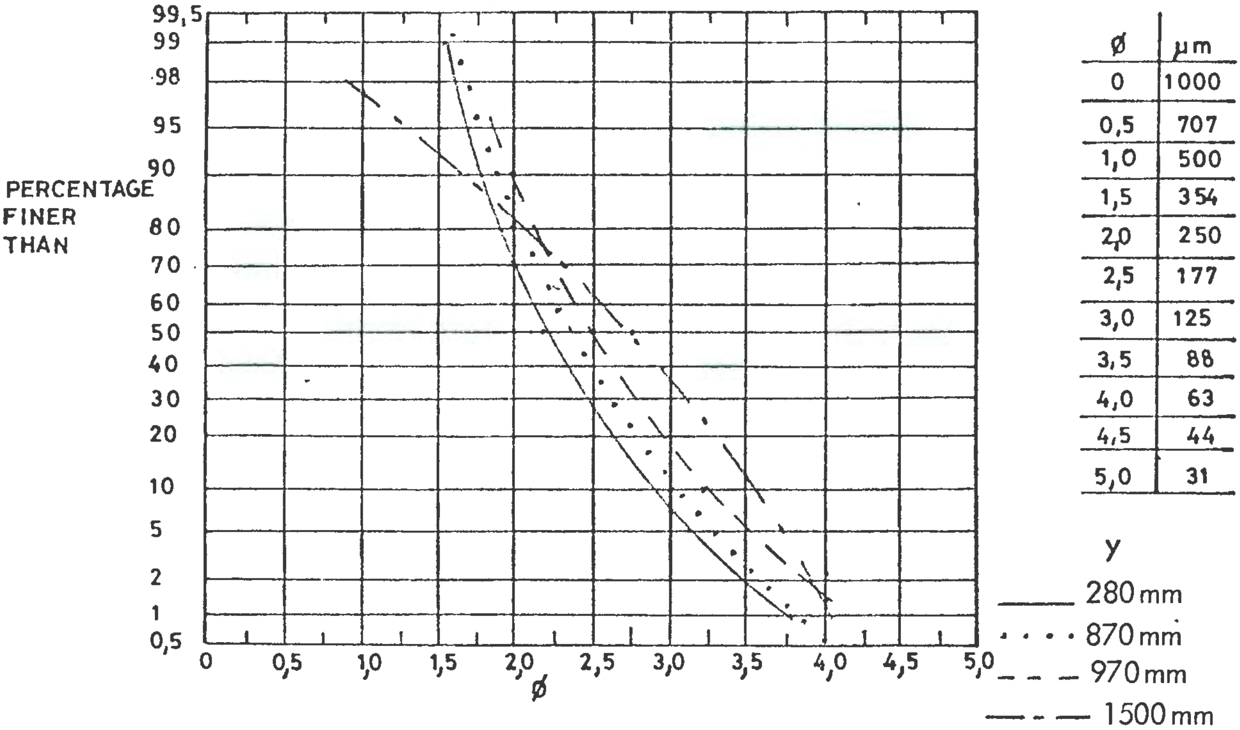
CURRENT VELOCITY:- -

Figure 6.6 : Profile No. 4.

CONCENTRATION CURVE



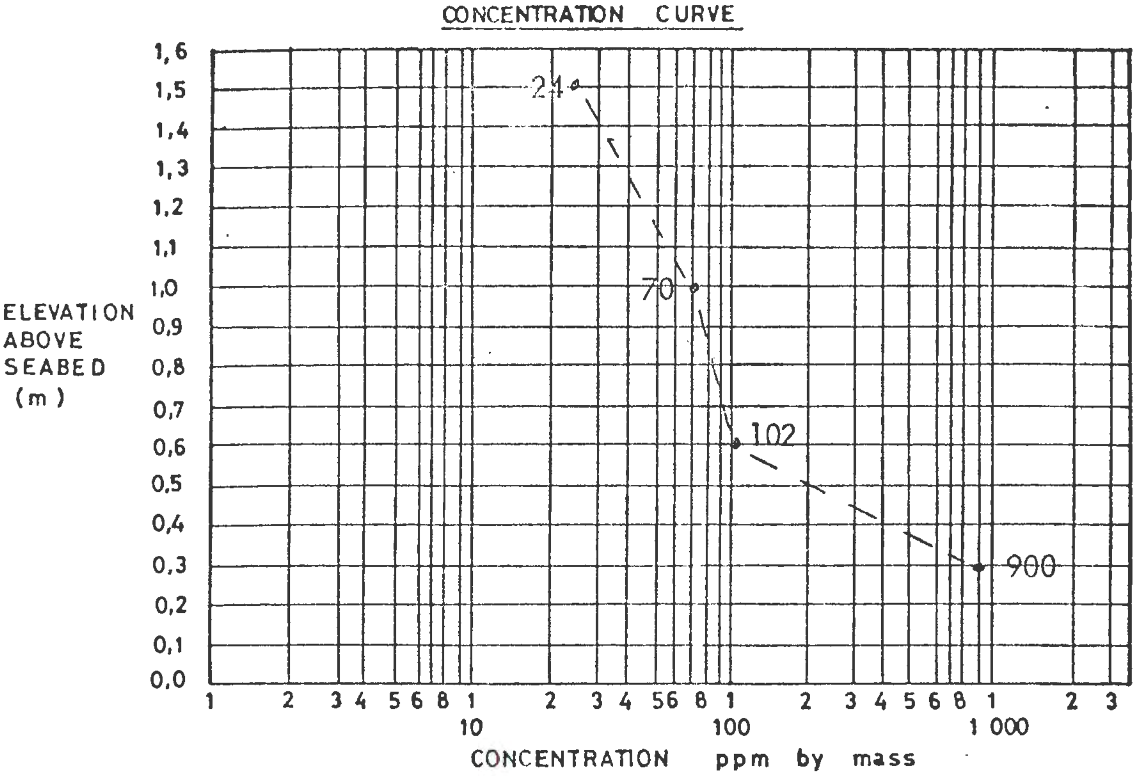
GRADING ANALYSIS

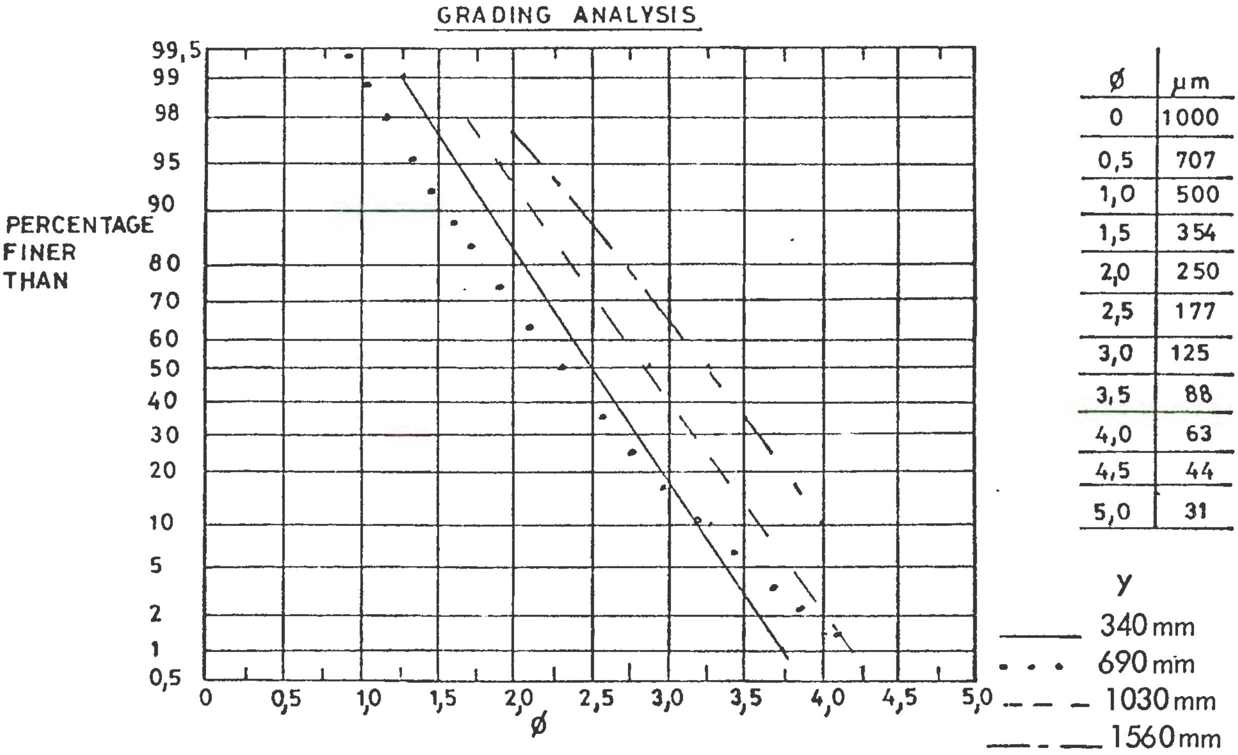


ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

SAMPLING DATE AND TIME :- 15-10-74 15h45 to 16h30
SAMPLE POSITION :- 550 m from P13 in surf zone
WATER DEPTH :- 4 m
WAVE HEIGHT :- Hmax 3,7 m Hs - $H_{1/10}$ -2,7 m
WAVE PERIOD :- 10 seconds
WAVE DIRECTION :- 253°
BREAKER POSITION :- 600 m from P13
WATER TEMPERATURE :- 13,5 °C
CURRENT VELOCITY :- -

Figure 6.7 : Profile No. 5



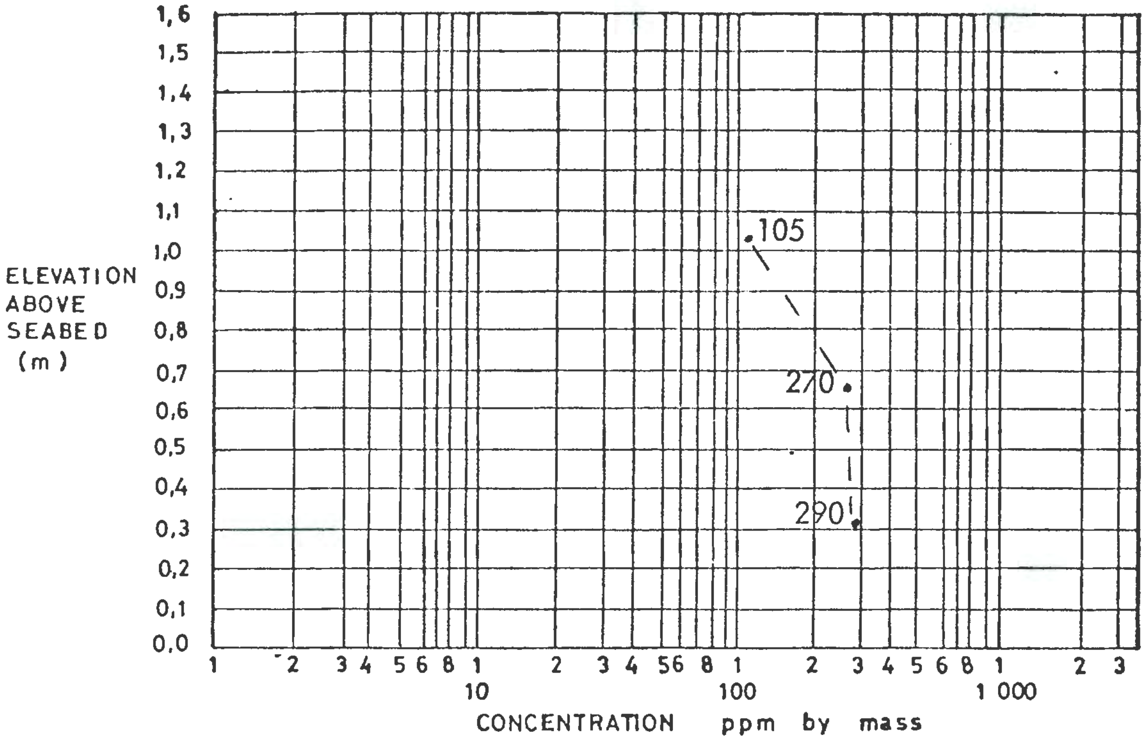


ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

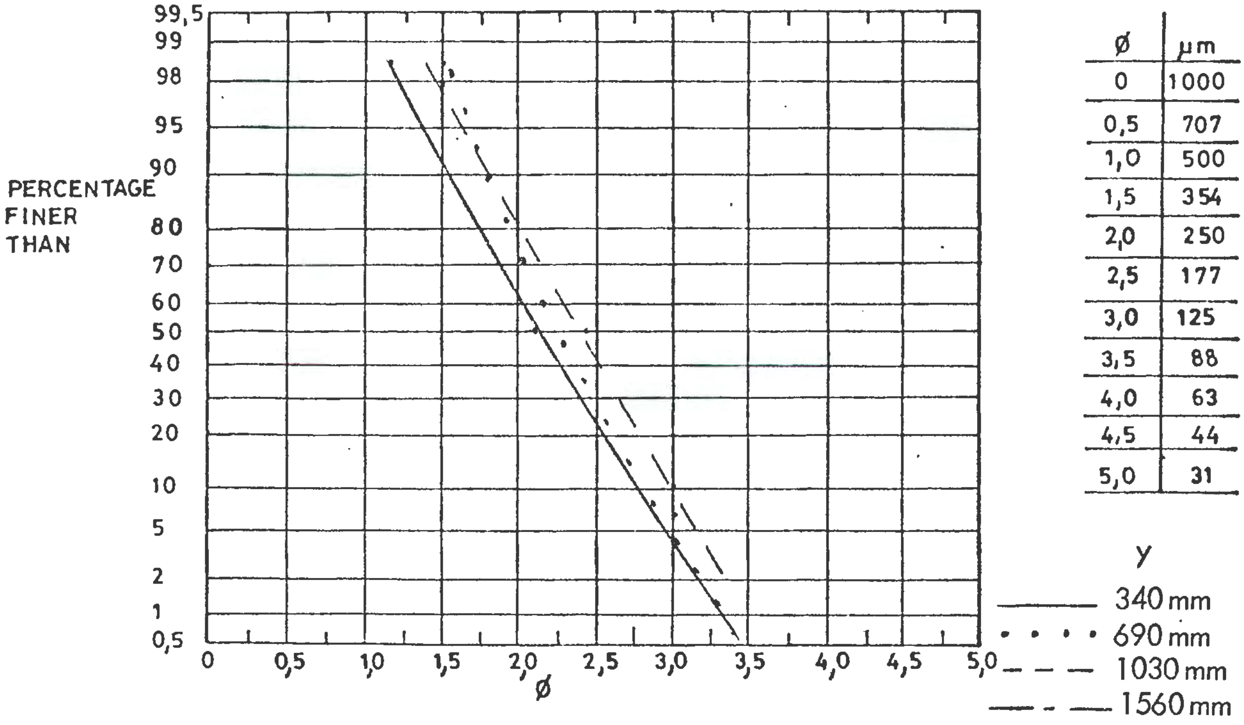
SAMPLING DATE AND TIME:-	1-12-1975 15h25 to 16h30
SAMPLE POSITION :-	600m from P13
WATER DEPTH :-	6,5m
WAVE HEIGHT:- Hmax -	Hs 2m $H_{1/10}$ -
WAVE PERIOD :-	9,0 seconds
WAVE DIRECTION :-	233.°
BREAKER POSITION :-	400m from P13
WATER TEMPERATURE :-	13°C
CURRENT VELOCITY:-	

Figure 6.8 : Profile No. 6

CONCENTRATION CURVE



GRADING ANALYSIS

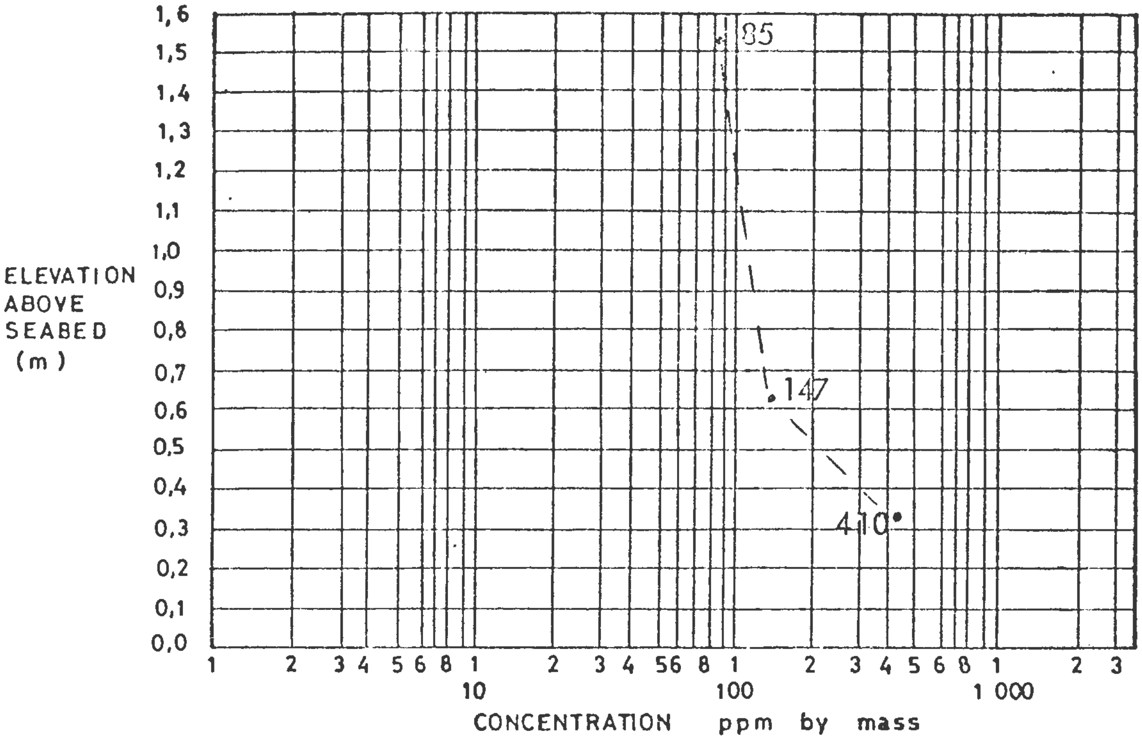


ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

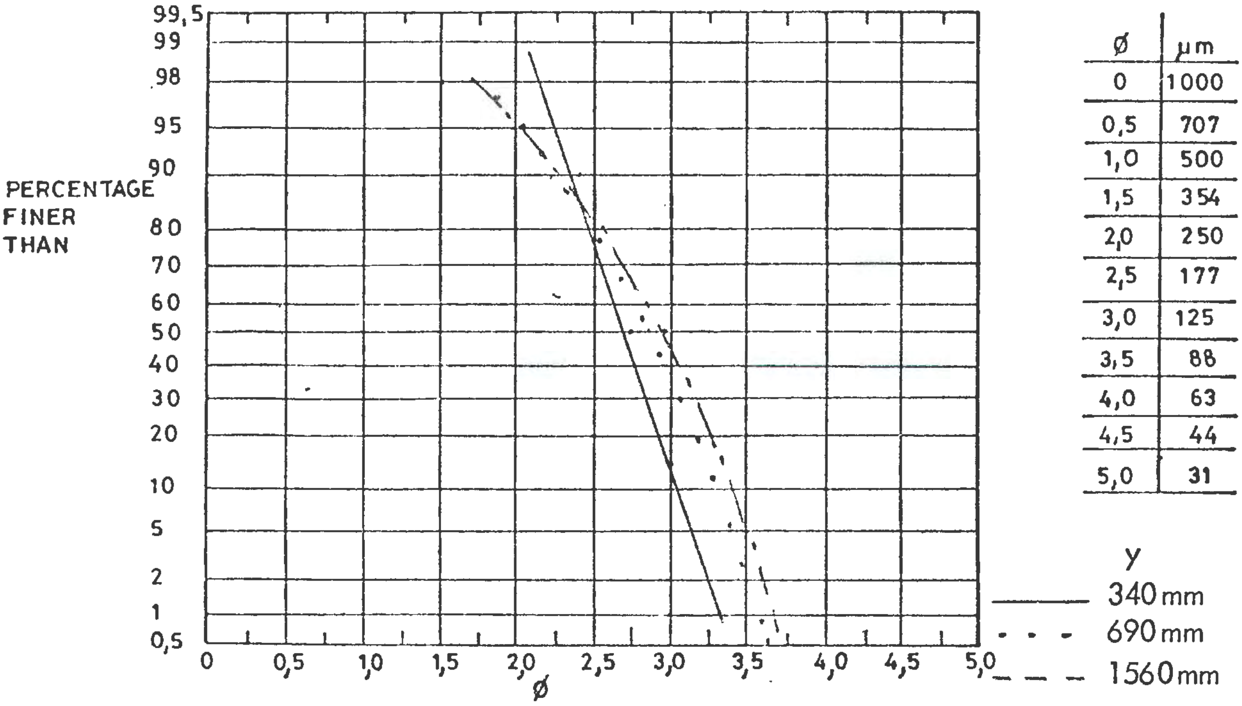
SAMPLING DATE AND TIME :- 8-12-1975 14h25 to 16h00
SAMPLE POSITION :- 350m from P13 in surf zone
WATER DEPTH :- 3m
WAVE HEIGHT :- Hmax 3m Hs 2m $H_{1/10}$ -
WAVE PERIOD :- 10 seconds
WAVE DIRECTION :- 250°
BREAKER POSITION :- 400 to 500m from P13
WATER TEMPERATURE :- 13°C
CURRENT VELOCITY :- 0,1 to 0,15 m/s to S.E.

Figure 6.9 : Profile No. 7

CONCENTRATION CURVE



GRADING ANALYSIS



ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

SAMPLING DATE AND TIME:- 12-3-1976 11h20 to 12h15

SAMPLE POSITION :- 430m from P 13 in surf zone

WATER DEPTH :- 5m

WAVE HEIGHT:- Hmax 3,5m Hs - $H_{1/10}$ 2,7m

WAVE PERIOD:- 11 seconds

WAVE DIRECTION:- -

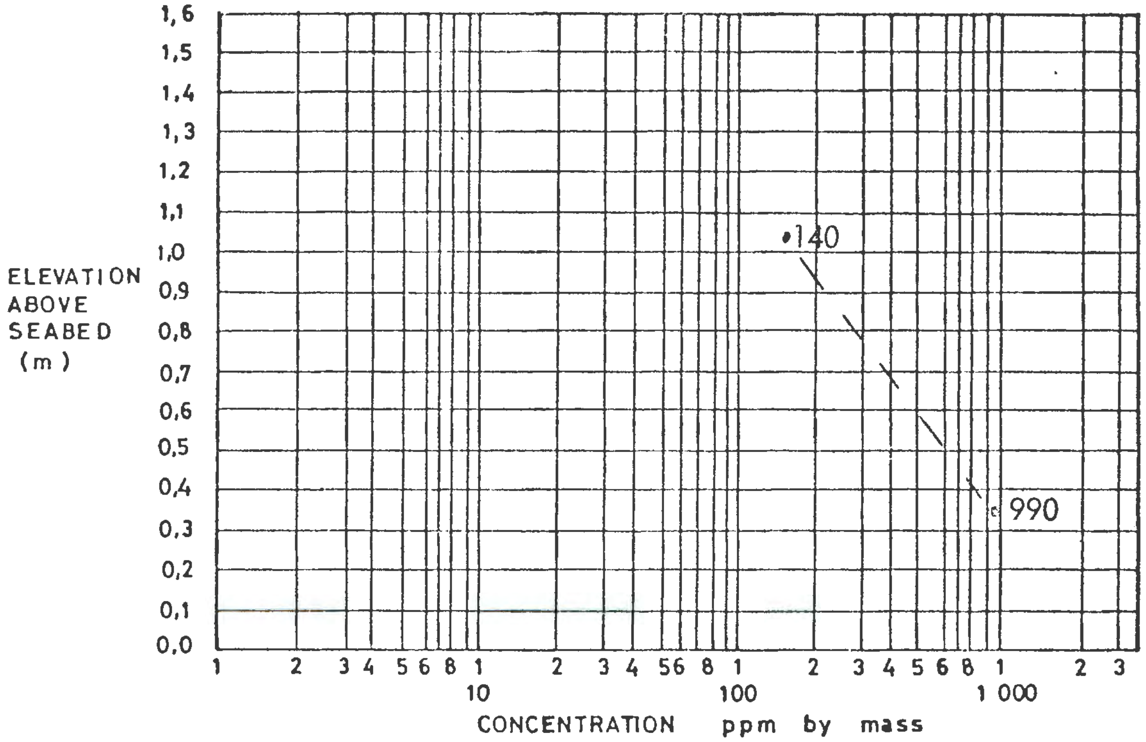
BREAKER POSITION :- 500m from P13

WATER TEMPERATURE :- 14°C

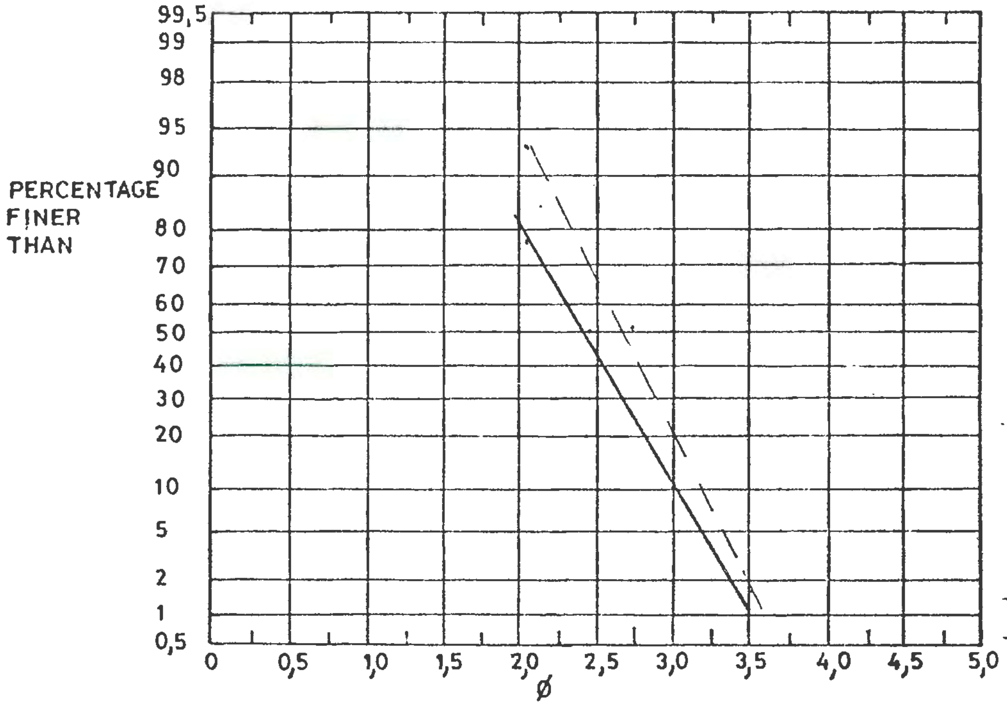
CURRENT VELOCITY:- -

Figure 6.10 : Profile No. 8

CONCENTRATION CURVE



GRADING ANALYSIS



ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

y

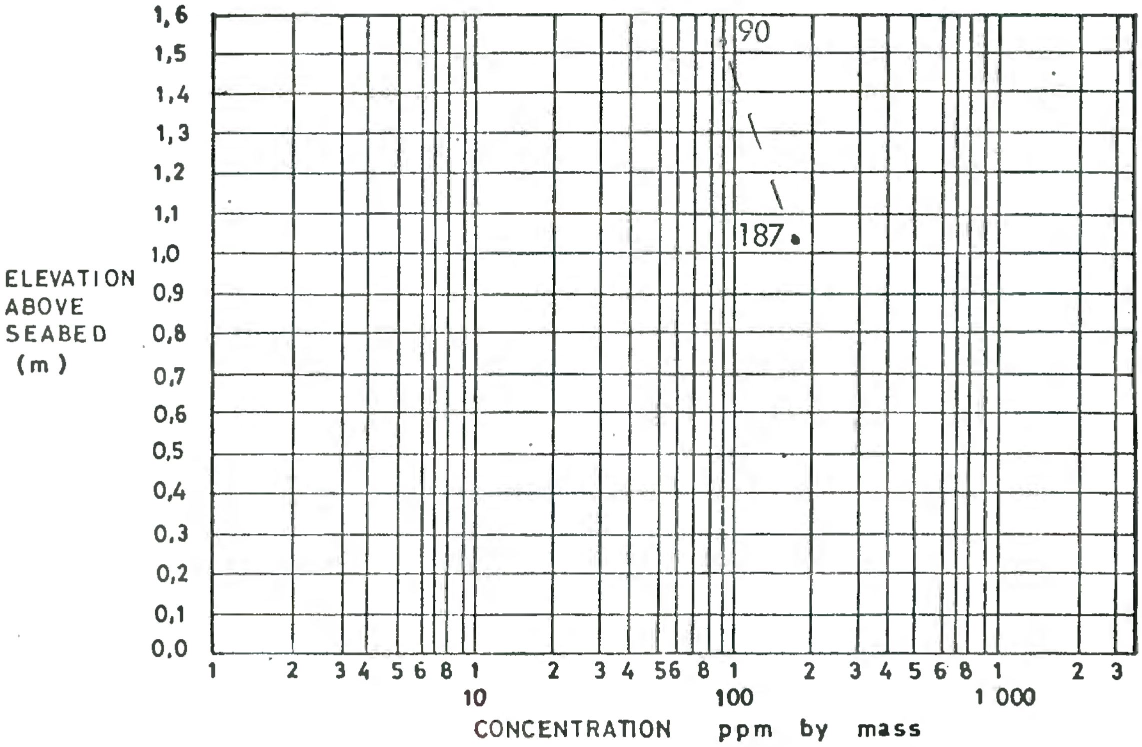
——— 340mm

— — — 1030mm

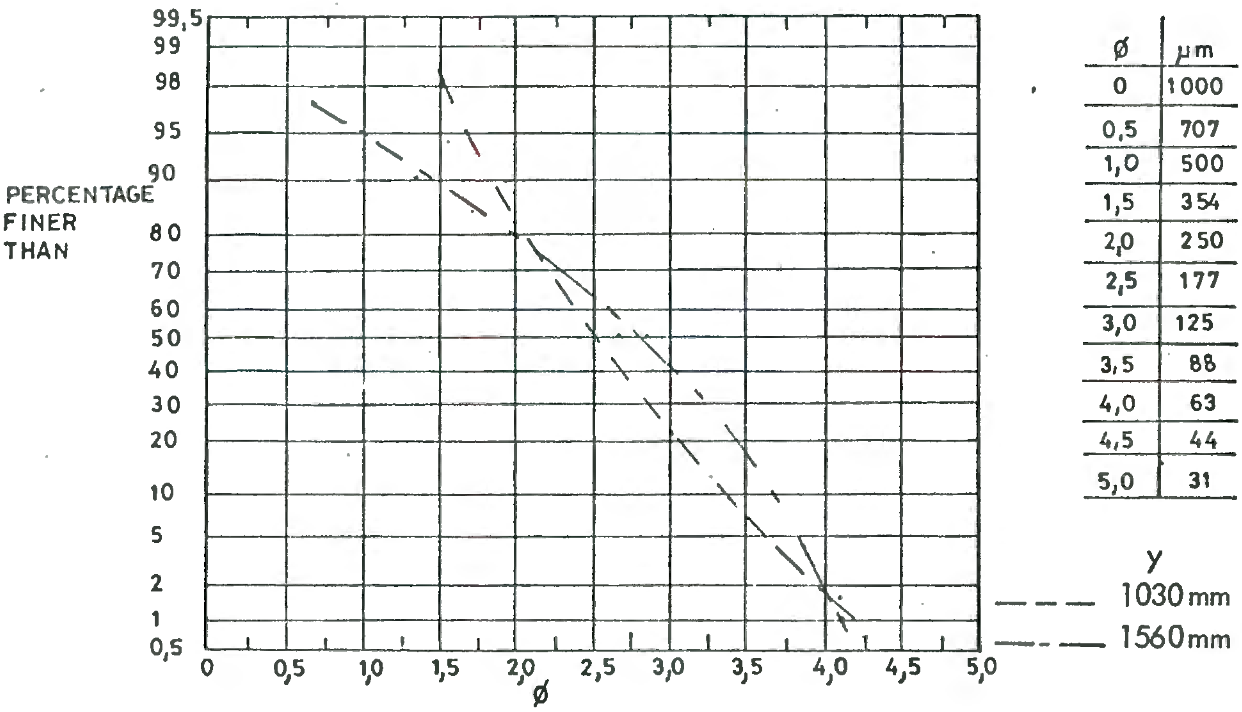
SAMPLING DATE AND TIME:-	12-3-1976 12h15 to 12h40
SAMPLE POSITION:-	530m from P13
WATER DEPTH:-	6,5m
WAVE HEIGHT:-	Hmax 3,5m Hs - $H_{1/10}$ 2,7m
WAVE PERIOD:-	11 seconds
WAVE DIRECTION:-	-
BREAKER POSITION:-	500m from P13
WATER TEMPERATURE:-	14°C
CURRENT VELOCITY:-	-

Figure 6.11 : Profile No. 9

CONCENTRATION CURVE



GRADING ANALYSIS



ø	µm
0	1000
0,5	707
1,0	500
1,5	354
2,0	250
2,5	177
3,0	125
3,5	88
4,0	63
4,5	44
5,0	31

SAMPLING DATE AND TIME:- 8-6-1976 13h15 to 13h40
SAMPLE POSITION :- 1550 m from P13
WATER DEPTH :- 15 m
WAVE HEIGHT:- Hmax 8 m Hs 6 m $H_{1/10}$ -
WAVE PERIOD:- 12 seconds
WAVE DIRECTION:- 254°
BREAKER POSITION :- up to 1400 m from P13
WATER TEMPERATURE :- 13,5°C
CURRENT VELOCITY:- -

Calculated values of various parameters needed for the computation of the parameters e_1 and b_1 in equations (3.18) and (3.20) respectively, are given in Table 6.2. The e_1 and b_1 values will be calculated using the shear stress formulae given by Yalin in equation (3.3) and Bijker and Swart in equation (3.6).

Table 6.1

Profile No.	Elevation z (mm)	Dmax (µm)
2	280	420
2	630	380
3	280	740
4	280	440
4	875	380
4	970	330
5	340	450
5	690	500
5	1030	320
6	340	550
6	690	400
6	1030	400
7	340	290
7	690	200
7	1560	400
8	340	390
8	1030	320
9	1030	400
9	1560	770

The values of b_1 and e_1 are estimated from the field data by plotting the volumetric concentration against the elevation above the sea bed, y, for evaluating b_1 ; and against the parameter $\frac{d-y}{y}$ for evaluating e_1. The slope of the straight line through the data plotted on a log-log scale, gives these values.

Graphs of the plots for each profile are given in Appendix 3, Figures A.1 to A.9, and a comparison between the calculated and experimental values of e_1 and b_1 is given in Table 6.3.

If the expressions (3.17) and (3.19) are assumed to hold true above the reference level, the concentration at this level is determined using the value of r, given in Table 6.2, as the elevation of the reference levels above the sea bed. The logarithmic mean of the reference calculation is then determined for each profile using the concentrations determined by (3.17) and (3.19), and is then plotted against the value of parameter $\frac{Hd}{T^2}$ for each profile in Figure 6.12.

Table 6.2 : Calculated Values of Parameters e_1 and b_1

	Profile Number								
Parameter	1	2	3	4	5	6	7	8	9
L (m)	65	122	101	61	68	53	76	85	135
D_{50} (μm)	135	130	175	185	160	210	150	170	155
ν (mm^2/s)	1,18	1,15	1,15	1,20	1,20	1,17	1,15	1,15	1,15
U max (m/s)	0,65	0,64	0,81	3,4	1,09	2,54	3,8	1,7	2,78
a (m)	0,99	1,2	1,55	5,36	1,56	4,01	2,42	3,0	5,3
Re	74L	71L	123T	519T	145T	279T	180T	253T	374T
(m/s)	0,014	0,014	0,019	0,021	0,018	0,025	0,017	0,019	0,017
Yalin Theory :-									
δ (mm)	12	13	22	55	21	46	29	35	53
v_{*w} (m/s)	0,015	0,014	0,039	0,149	0,054	0,116	0,175	0,078	0,120
e_1	2,46	2,63	1,28	0,37	0,89	0,57	0,26	0,64	0,37
b_1	2,1	2,18	1,23	0,39	0,88	0,59	0,28	0,65	0,39
Bijker Theory :-									
Δ r (mm)	11	13	23	8	13	8	9	10	8
λ r (mm)	95	113	189	107	108	103	99	133	108
r (mm)	25	37	70	15	35	16	21	22	15
C	61	64	56	63	63	60	62	64	73
U_B (m/s)	0,078	0,050	0,098	0,433	0,196	0,52	1,04	0,479	0,354
v_* wc (m/s)	0,082	0,081	0,103	0,433	0,139	0,319	0,485	0,297	0,354
e_1	0,45	0,45	0,49	0,13	0,34	0,21	0,09	0,17	0,13
b_1	0,47	0,47	0,49	0,15	0,36	0,23	0,10	0,19	0,15

The abbreviations L and T after the Reynolds number indicate laminar and turbulent boundary layers respectively.

Table 6.3 : Calculated and Experimental Values of e_1 and b_1

	e_1 Values			b_1 Values		
Profile No.	Yalin	Bijker	Experimental	Yalin	Bijker	Experimental
1	2,46	0,45	2,0	2,1	0,47	2,3
2	2,63	0,45	2,6	2,18	0,47	2,8
3	1,28	0,49	3,0	1,23	0,49	3,2
4	0,37	0,13	1,1	0,39	0,15	1,0
5	0,89	0,34	2,0	0,88	0,36	2,3
6	0,57	0,21	1,1	0,59	0,23	1,3
7	0,26	0,09	0,9	0,28	0,10	1,0
8	0,64	0,17	0,8	0,65	0,19	0,8
9	0,37	0,13	1,6	0,39	0,15	2,0

6.3 Comments on Results

A significant difference is observed in the calculated and experimental values of e_1 and b_1. As the value of b_1 is determined from e_1, it can be considered to be dependant on e_1. The value of e_1 is calculated from the fall velocity on the particle, von Karman's coefficient and the shear velocity. The fall velocity and von Karman's coefficient are practically constant for all the profiles, as the range of the representative sediment size, D_{50}, is small and varies between 0,130mm and 0,210mm as seen in Table 6.2. The smaller calculated values of e_1 thus indicate that the bed shear stress is overestimated, and if used to predict the distribution of suspended sediment concentrations will result in lower reference concentrations occurring at higher elevations above the bed.

The calculated results in best agreement with the experimental values were those obtained using the expression for shear strees in a laminar boundary layer, as quoted from Yalin (33). The values were used for Profiles 1 and 2.

The plot of $\frac{Hd}{T^2}$ versus C_r shows that the plotted points lie in a broad band rather than described by a single line. As the values of b_1 and e_1 are determined by drawing straight lines through experimental points, the order of accuracy is not very high for the number of results obtained. In order to evaluate the values of b_1 and e_1 more accurately, more samples must be taken on a particular vertical profile. The value used for the elevation of the reference level above the sea bed was determined by theory only. The estimation of the width of the bed load therefore determines the reference concentrations, and could result in a large scatter of reference concentrations as determined by the e_1 values for Profile 9.

A value of 2×10^6 ppm by volume is obtained, which is impossible as the maximum concentration of close packed sand particles is approximately $0,52 \times 10^6$ ppm, as given by Fleming and Hunt (38). A more reliable estimate of evaluating the thickness of the bed layer or elevation of the reference concentration is thus needed.

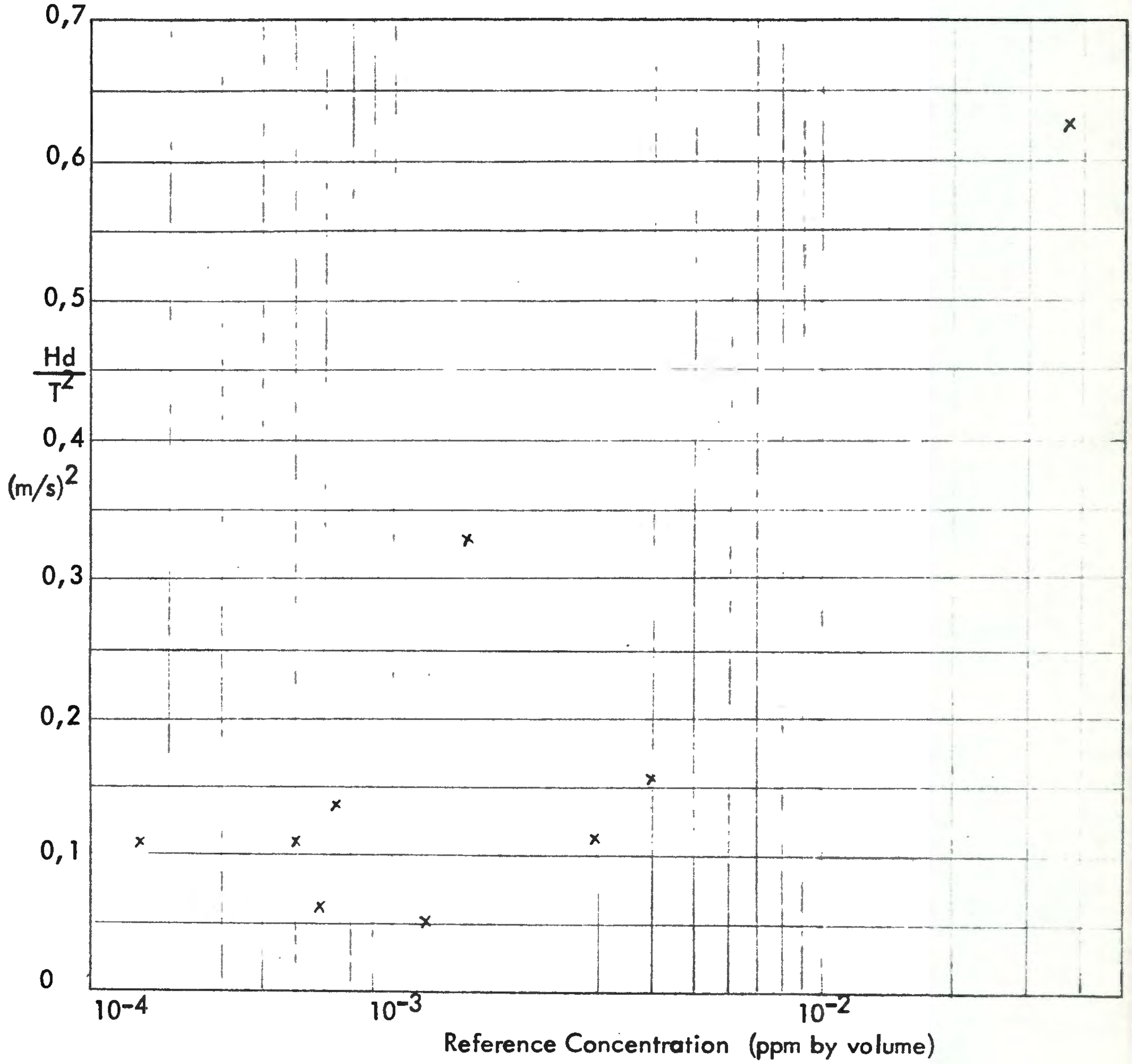


Figure 6.12 : $\frac{Hd}{T^2}$ versus Reference Concentration

CHAPTER SEVEN

Conclusion and Recommendations

Sampling of suspended sediment concentrations was successfully carried out in the nearshore region under high wave conditions where sampling had not previously been achieved.

The Mark I prototype sampler needed minor modifications and these were incorporated into the design of the Mark II sampler. The main problem in the operation of this system was the uneconomical use of a helicopter. The helicopters used had a lifting capacity of greater than 1600 kg, whereas the sampler only weighed a maximum of 250 kg. The length of the lifting tackle used proved to be the deciding factor for the power needed to manœuvre with the sampler effectively. The smaller helicopter was not equipped with a winch and thus a long lifting tackle was needed.

The following recommendations are made for the future use of a pump type sampler using a helicopter to place and retrieve the unit :-

(a) The sampling unit must be kept as small and as light as possible, without sacrificing the submerged weight needed for stability of the sampler on the bed.

(b) In order to use the smallest size helicopter available, a winch system must be used, able to be attached to the bottom of the helicopter. This would reduce the pendulum action of the unit and helicopter, and cut costs considerably.

(c) To further achieve a more economical use of the helicopter, a sampler should incorporate apparatus to sample at two elevations simultaneously. This may necessitate the power source needed for the pumps to be kept on the helicopter and fed by cable or air hose to the sampling unit. This may result in problems in handling the unit, particularly if this power link becomes tangled with the lifting rope.

Field operations using the Mark II sampler were not successful due to the action of the littoral currents and breakers on the rope causing significant forces to be generated in the rope which the winch system could not handle. The author believes that with more powerful equipment, the Mark II sampler would be able to be reasonably successful under moderately low wave conditions.

The author concludes that for the field measurement of suspended sediment concentrations, the pump type sampler is the only type that can, at present, be used, unless major advancements are made in the development and calibration of the indirect types, such as sonic absorption.

The system using a helicopter to place and retrieve the instrument needs only a relatively simple sampling unit, although the cost per sample is high. Other systems proposed can reduce the cost per sample, but cannot operate under as high a wave climate as that using the helicopter.

Field results show a larger scatter than that obtained in the laboratory, which is understandable as the conditions in the field are far more variable than those in carefully controlled laboratory experiments. In order to evaluate the parameters needed for the evaluation of the reference concentration, a larger number of readings is needed for field measurements than for laboratory measurements.

The reference concentrations for profiles determined by field results are used to calibrate sediment transport models which evaluate the movement of sediment in areas influenced by coastal structures. The theory on which these models are based is basically derived from those expressions determined for unidirectional steady state flow. In order to evaluate the accuracy of the sediment transport models and the values of the reference concentration used, extensive measurement of the sediment transport in the areas under consideration should be conducted after the structure is completed. This would lead to a better understanding of the complex phenomena controlling sediment transport in the coastal environment.

APPENDIX 1

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APPENDIX 2

List of Symbols

Co-ordinate System

x - offshore - onshore
y - vertical from bed
z - longshore
d - water depth
D - particle diameter
a - amplitude of orbital motion (horizontal)
A - horizontal diameter of orbital motion
ω - angular velocity
ν - Kinematic viscosity
μ - absolute viscosity
K_s - sand roughness
c - volumetric concentration
w - fall velocity
l - Prandtl mixing length
η - $\frac{y}{d}$ - dimensionless ht above sea bed
k - Von Karman's coefficient
v_* - shear velocity
ρ - density
τ - shear stress
γ - specific weight
g - acceleration due to gravity
r - elevation of reference level
Δr - ripple height
λr - ripple length
δ - boundary layer thickness
U - orbital velocity
C - Chezy coefficient
n - Manning coefficient

Figure A1 : Profile No. 1

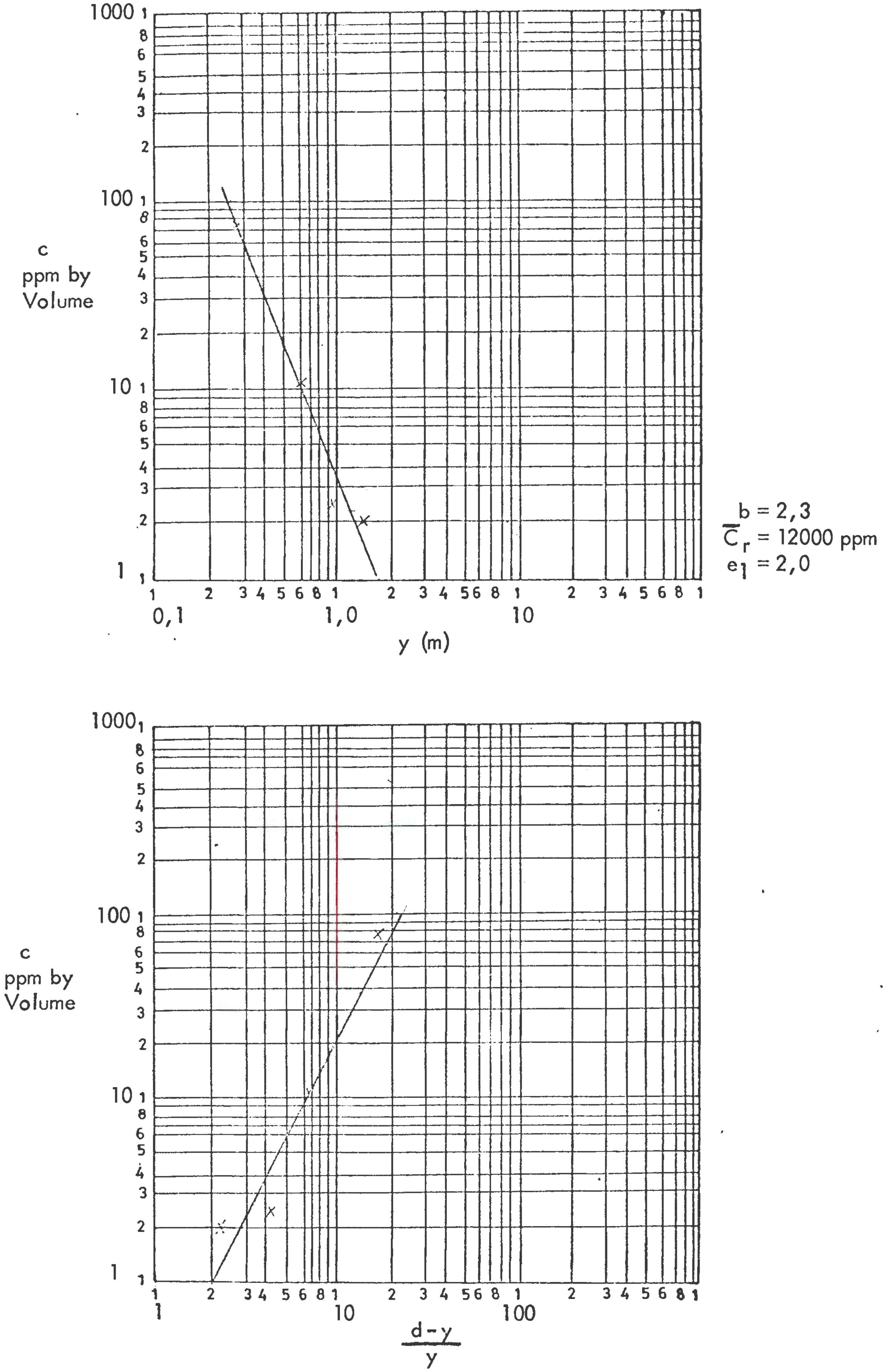
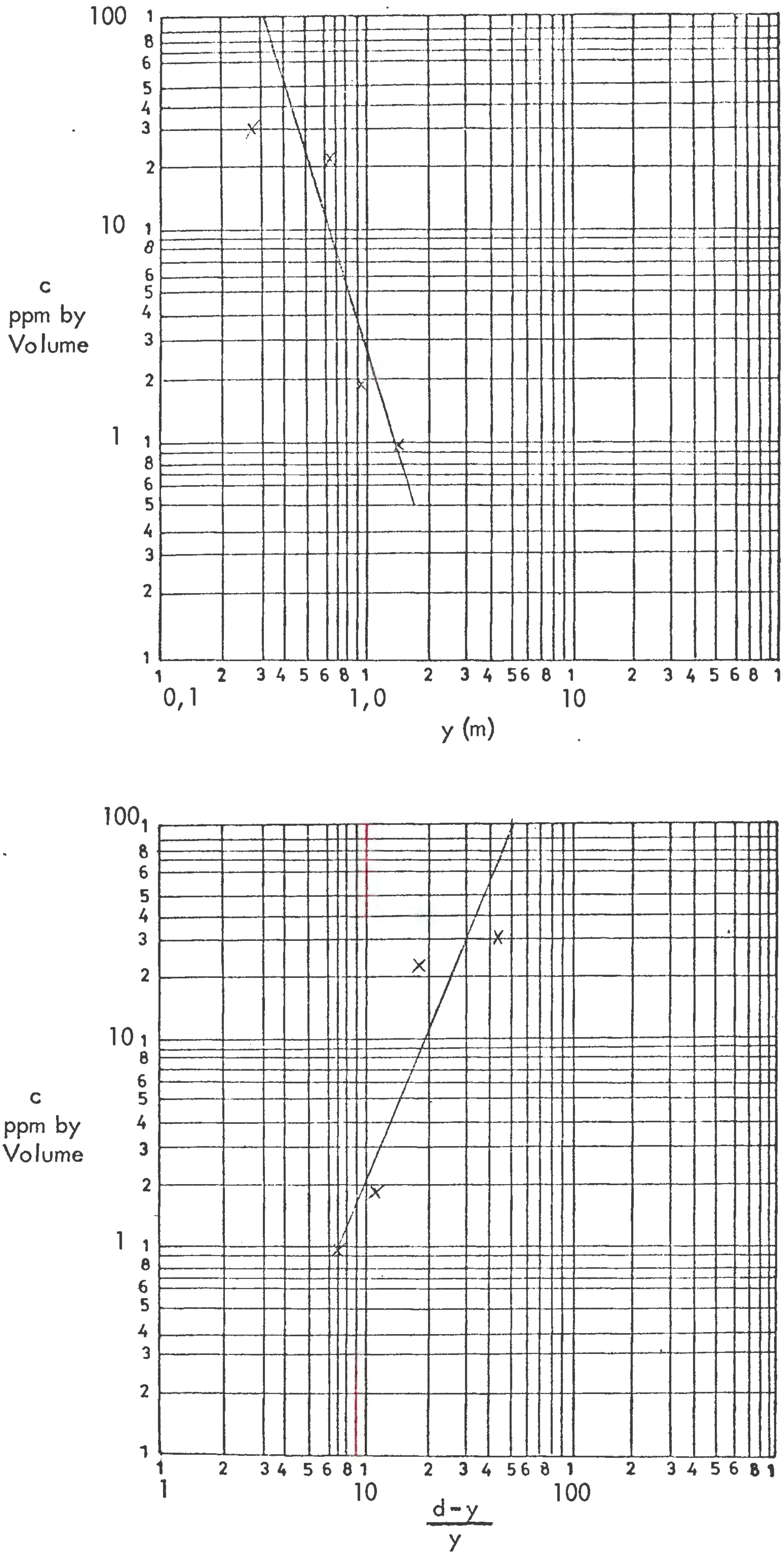


Figure A2 : Profile No. 2

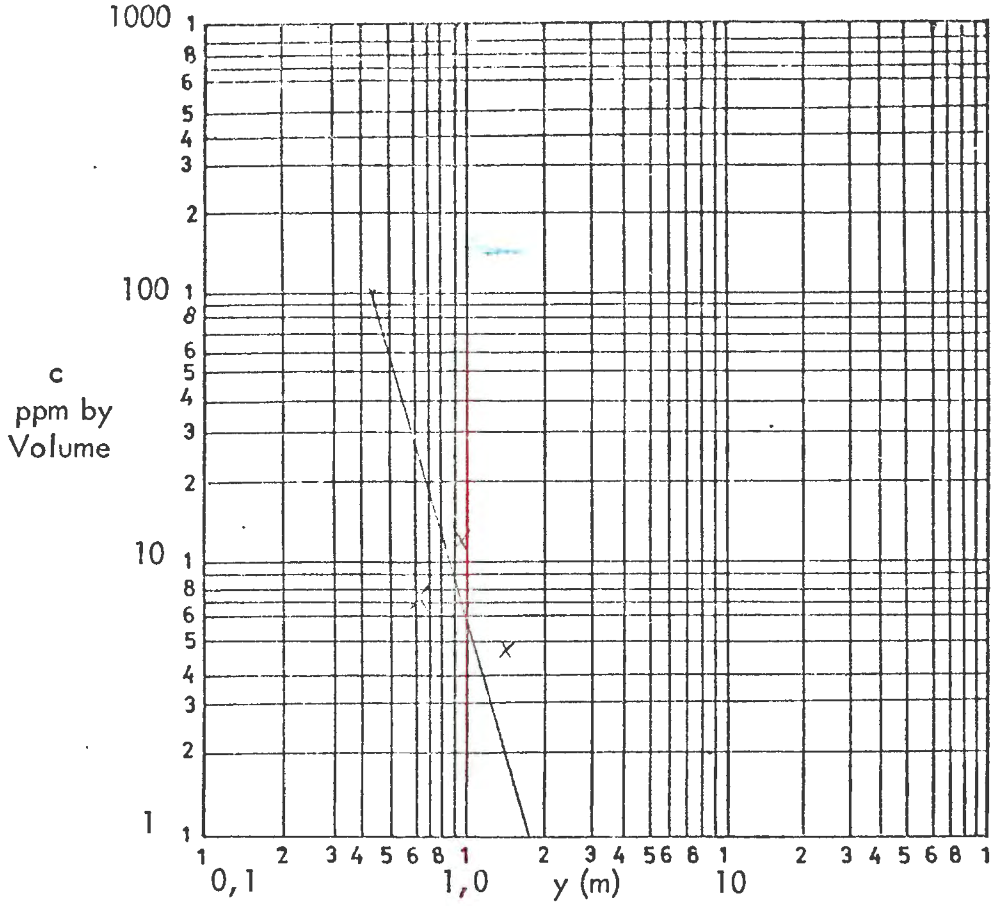


b_1 = 2,8

$\overline{C}_r$ = 15000 ppm

e_1 = 2,6

Figure A3 : Profile No. 3.



$b_1 = 3,2$

$\overline{C}_r = 30\,000$ ppm

$e_1 = 3,0$

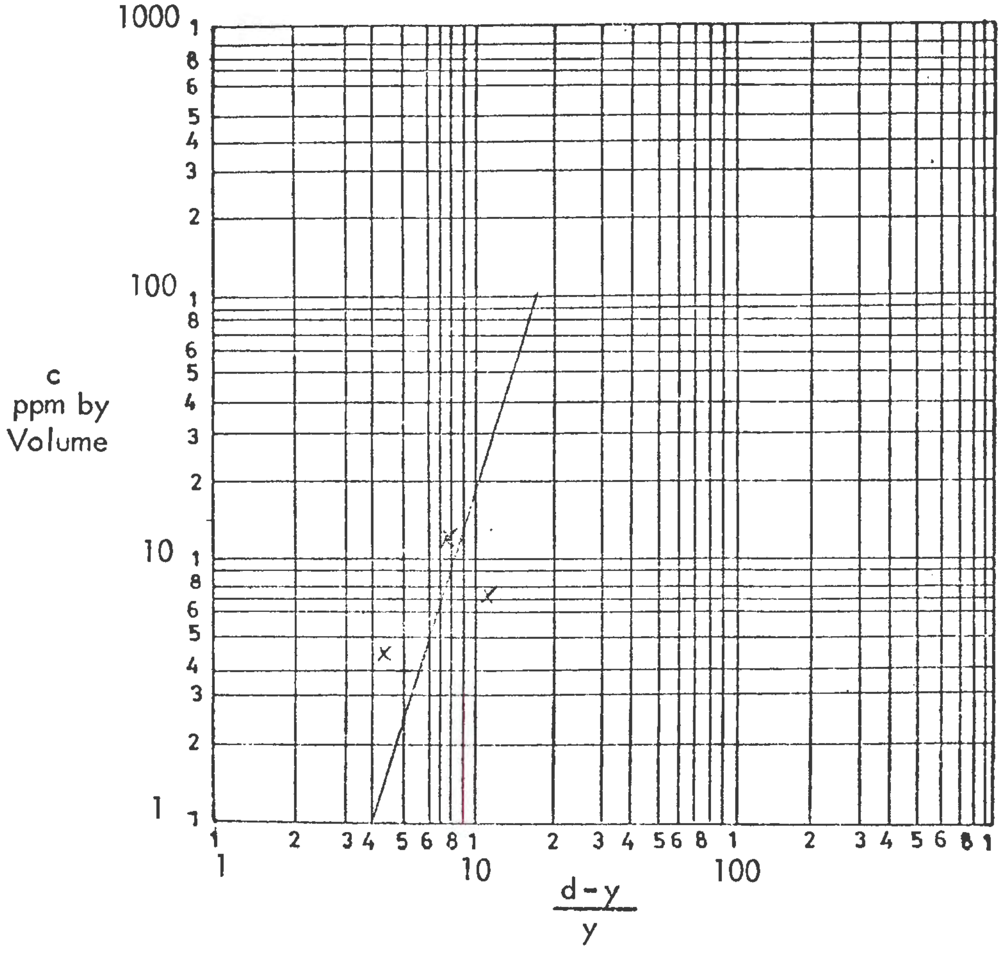
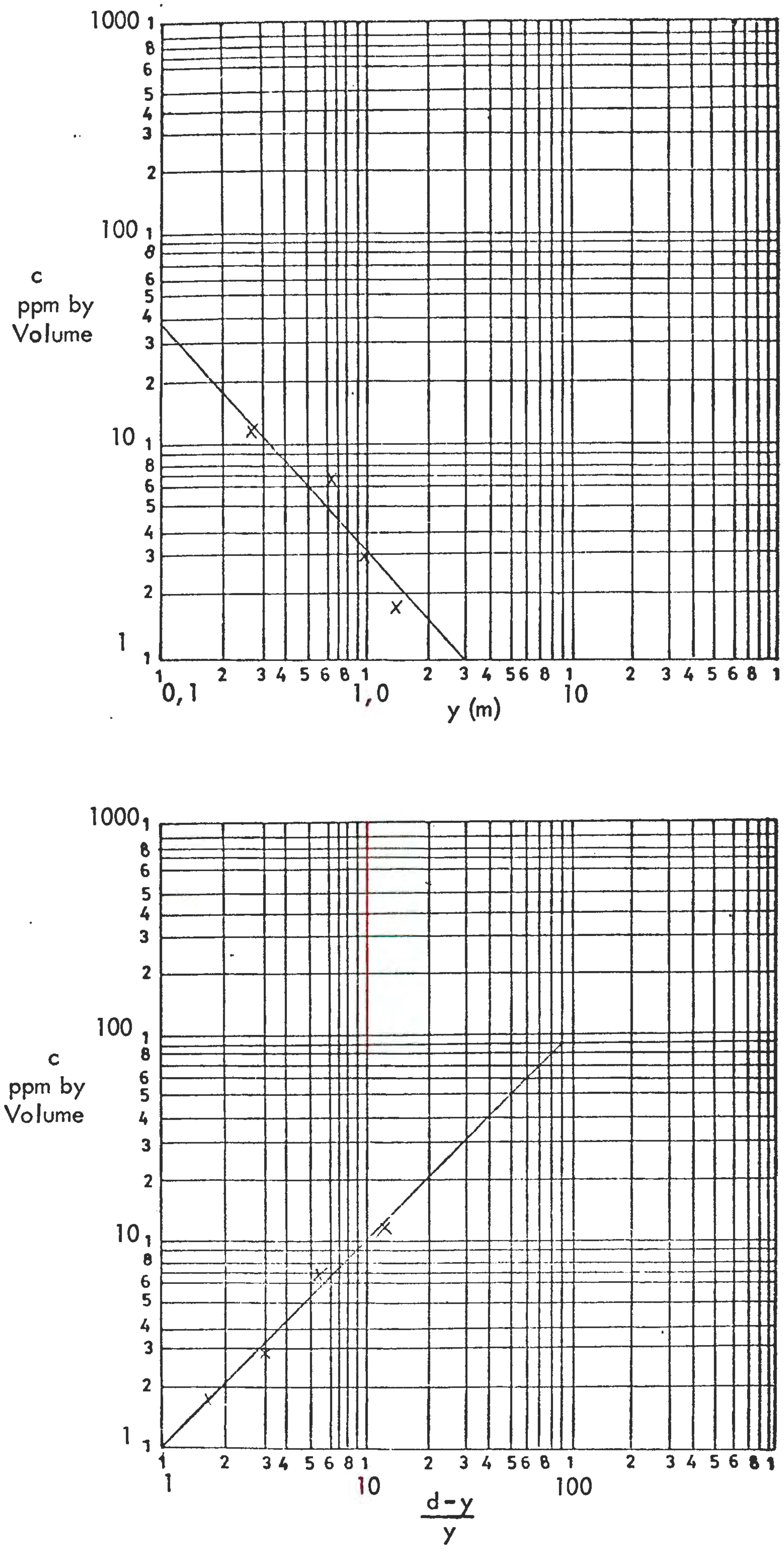


Figure A4 : Profile No. 4



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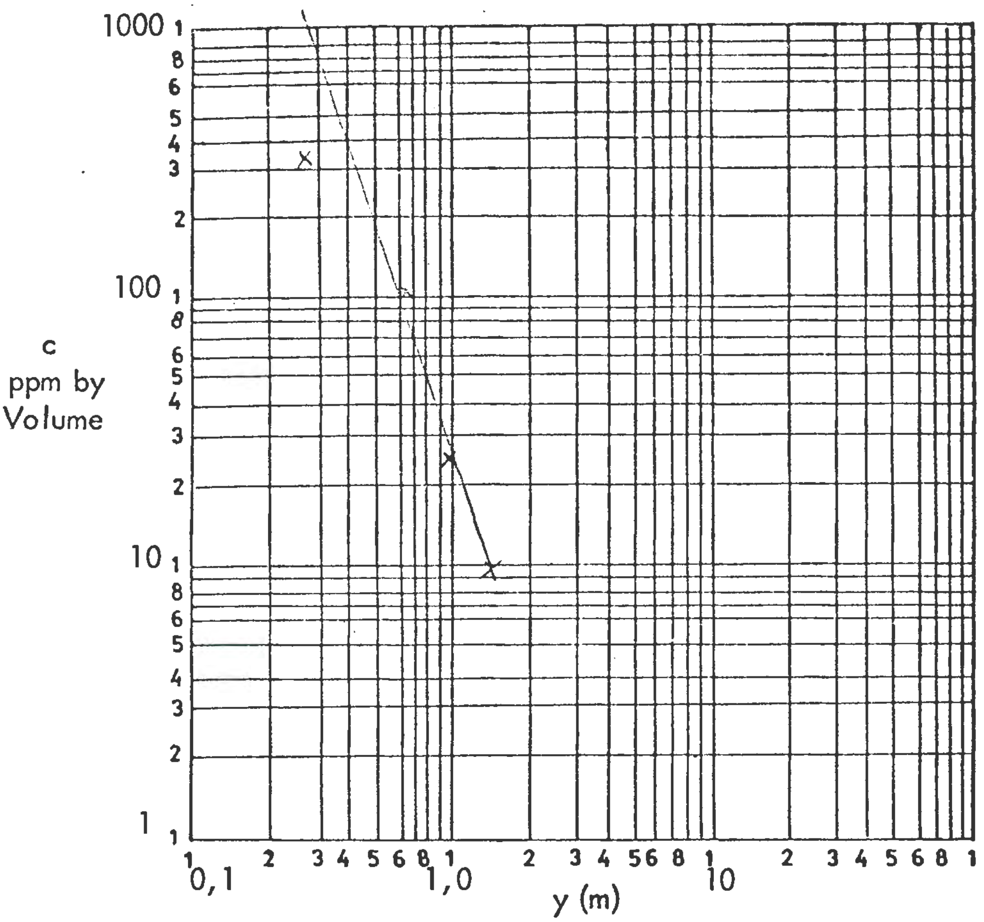
$\overline{C}_r = 2600\,\text{ppm}$

$e_1 = 1,1$

Figure A5 : Profile No. 5



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$\overline{C}_r = 40\,000$ ppm

$e_1 = 2,0$

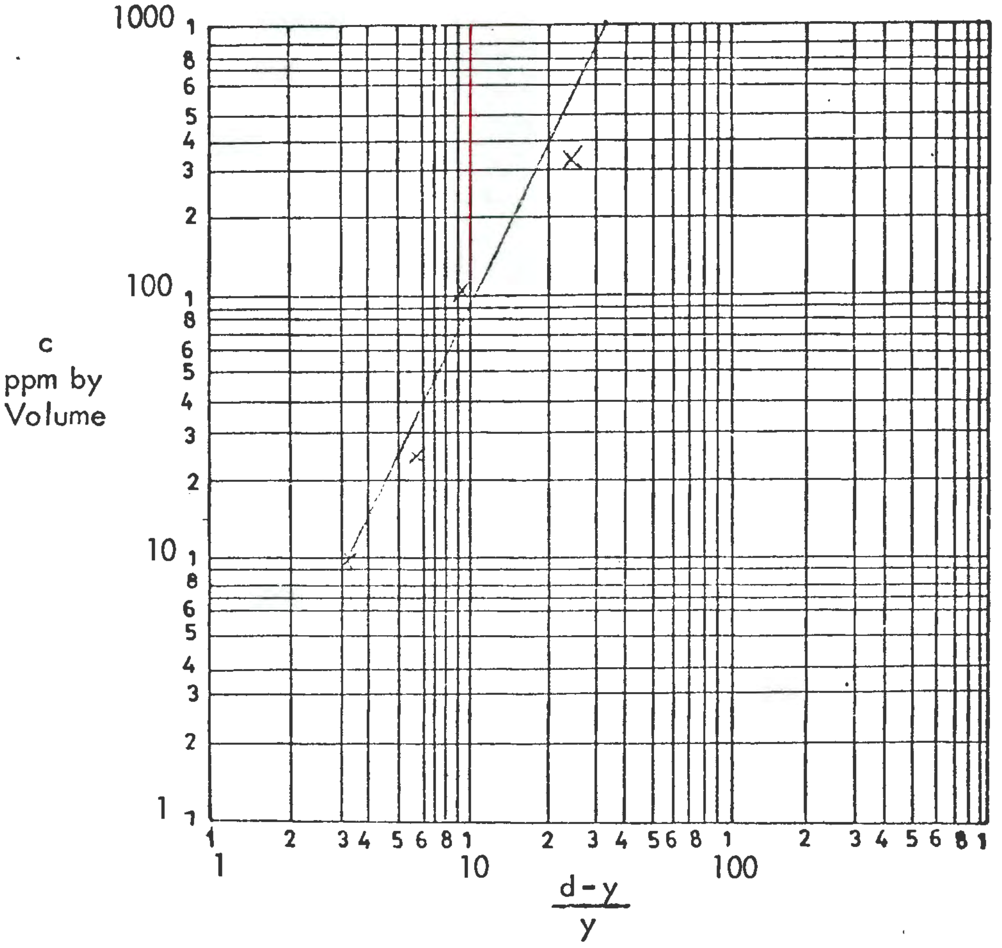
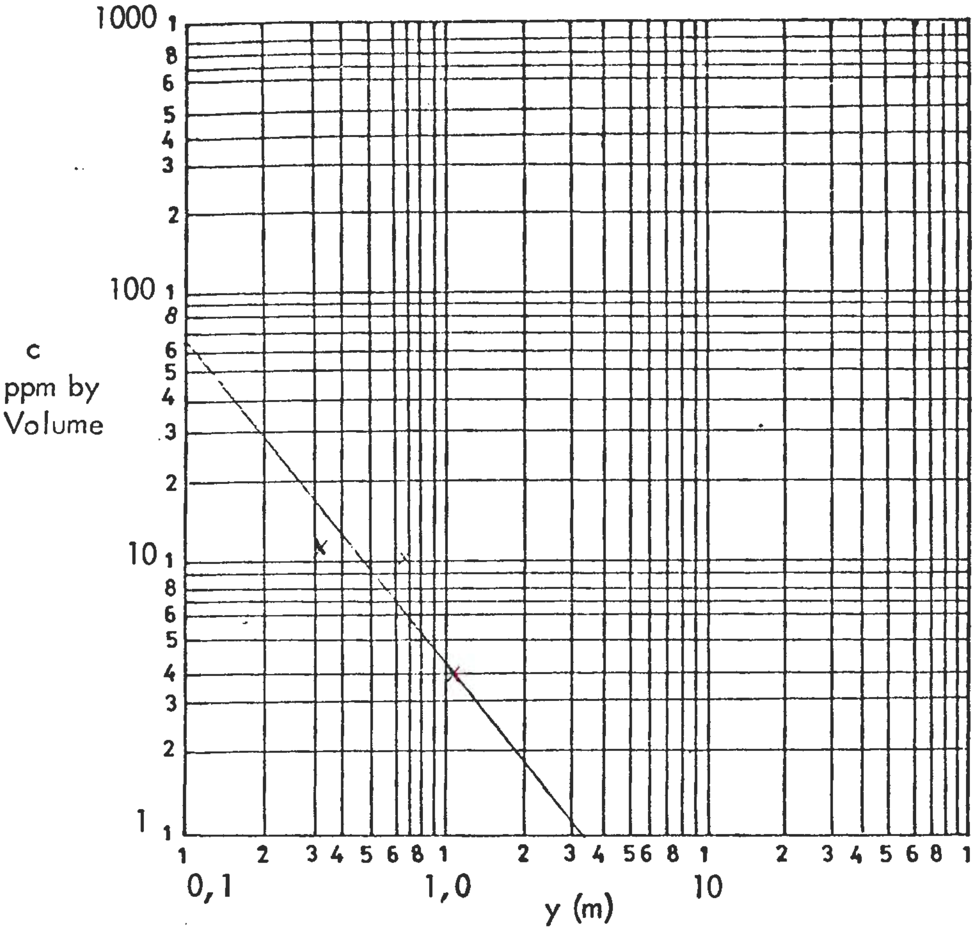


Figure A6 : Profile No. 6



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$\overline{C}_r$ = 6900 ppm

e_1 = 1,1

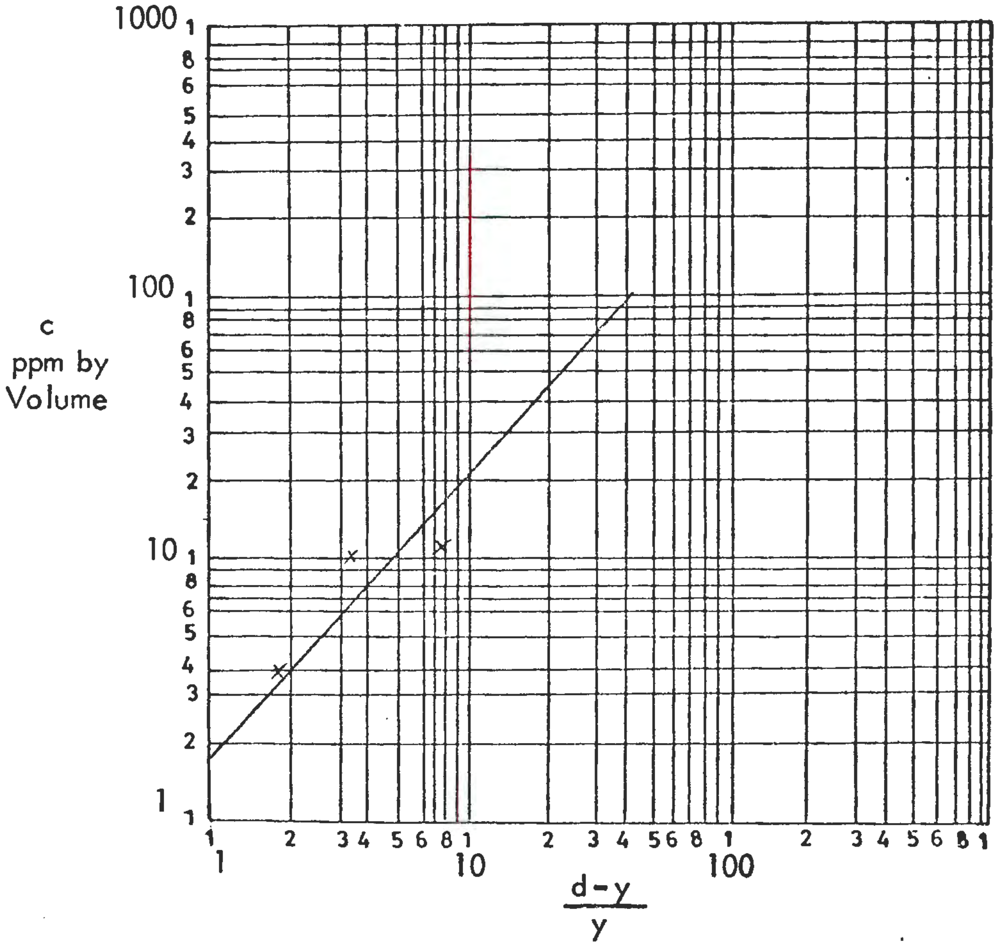
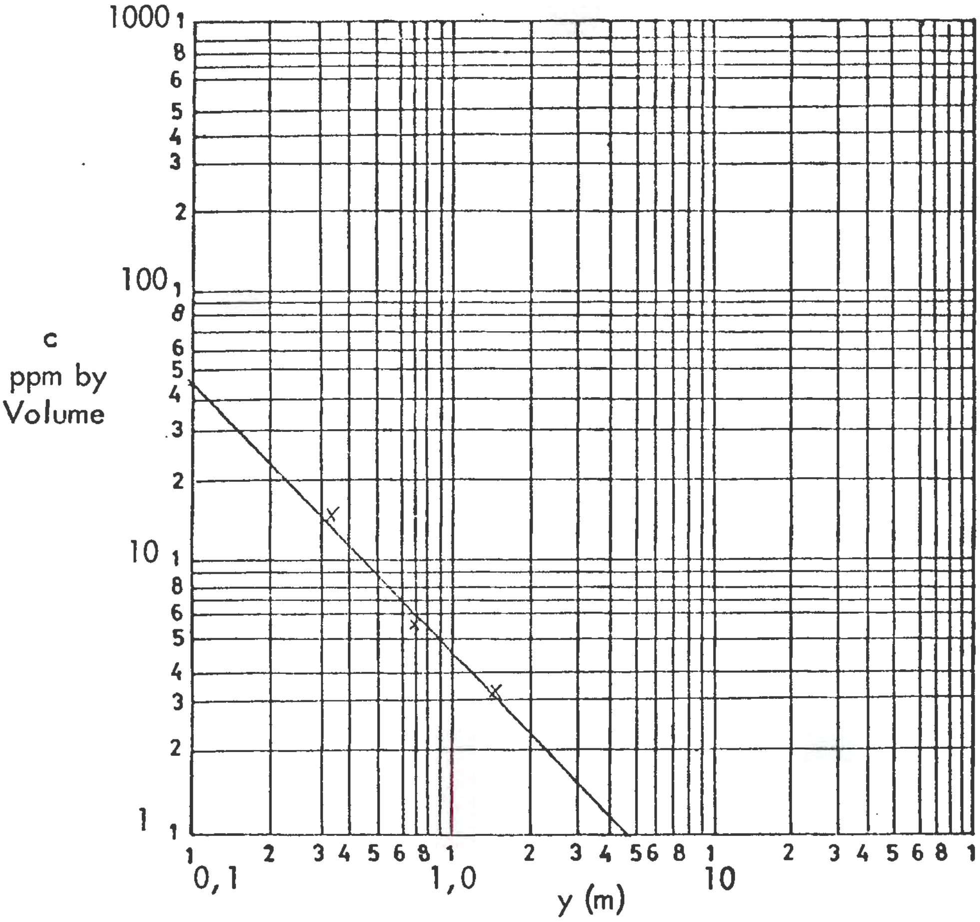


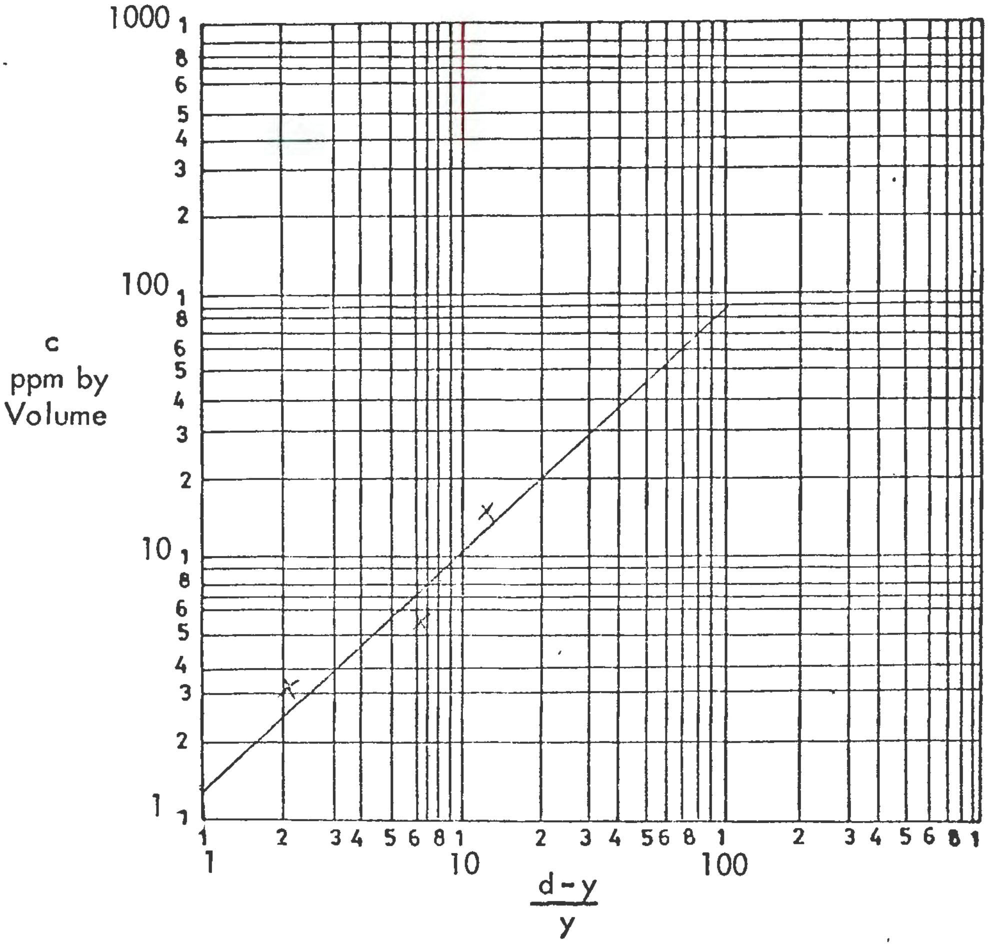
Figure A7 : Profile No. 7



b_1 = 1,0

C_r = 7500 ppm

e_1 = 0,9



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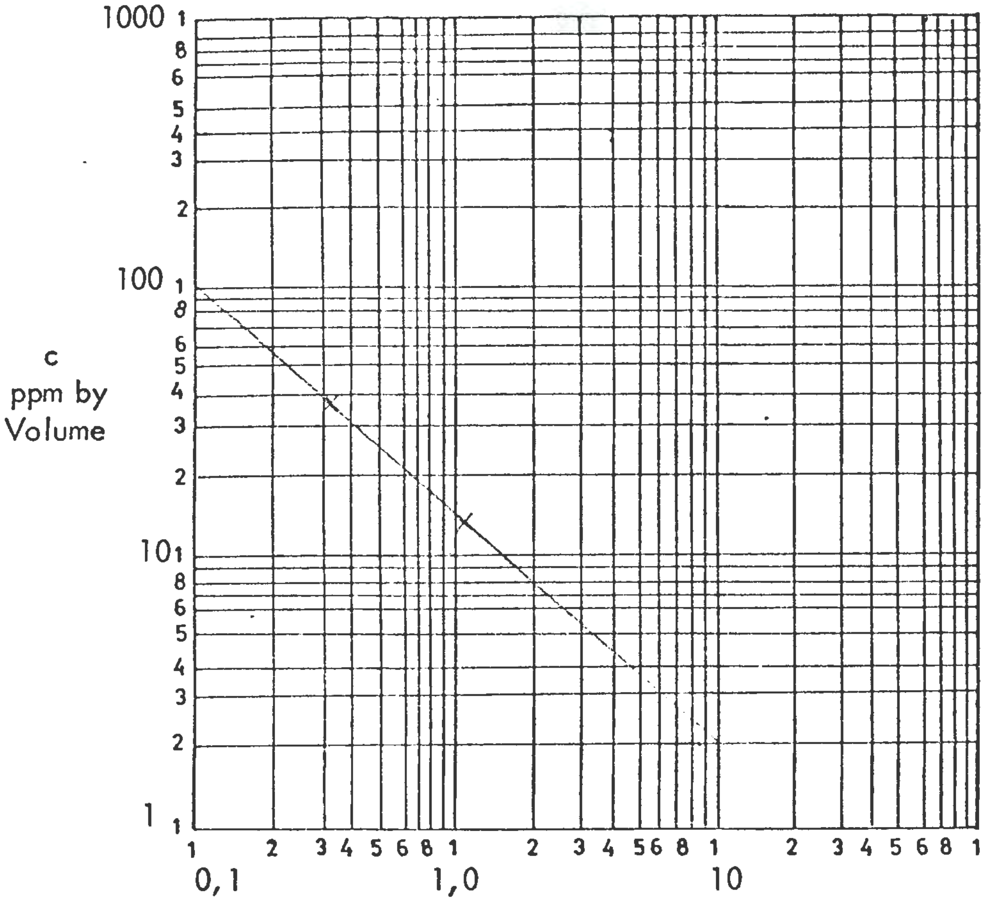

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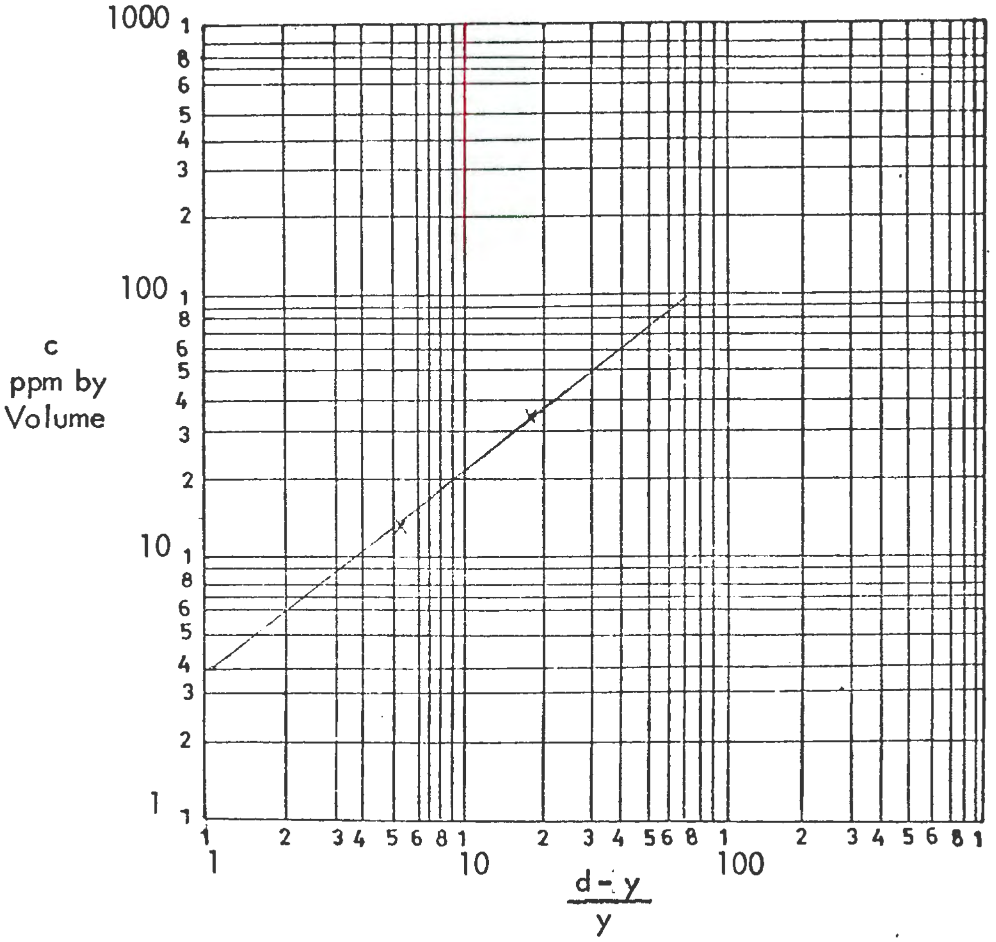
$\overline{C_r}$ = 7500 ppm

e_1 = 0,8



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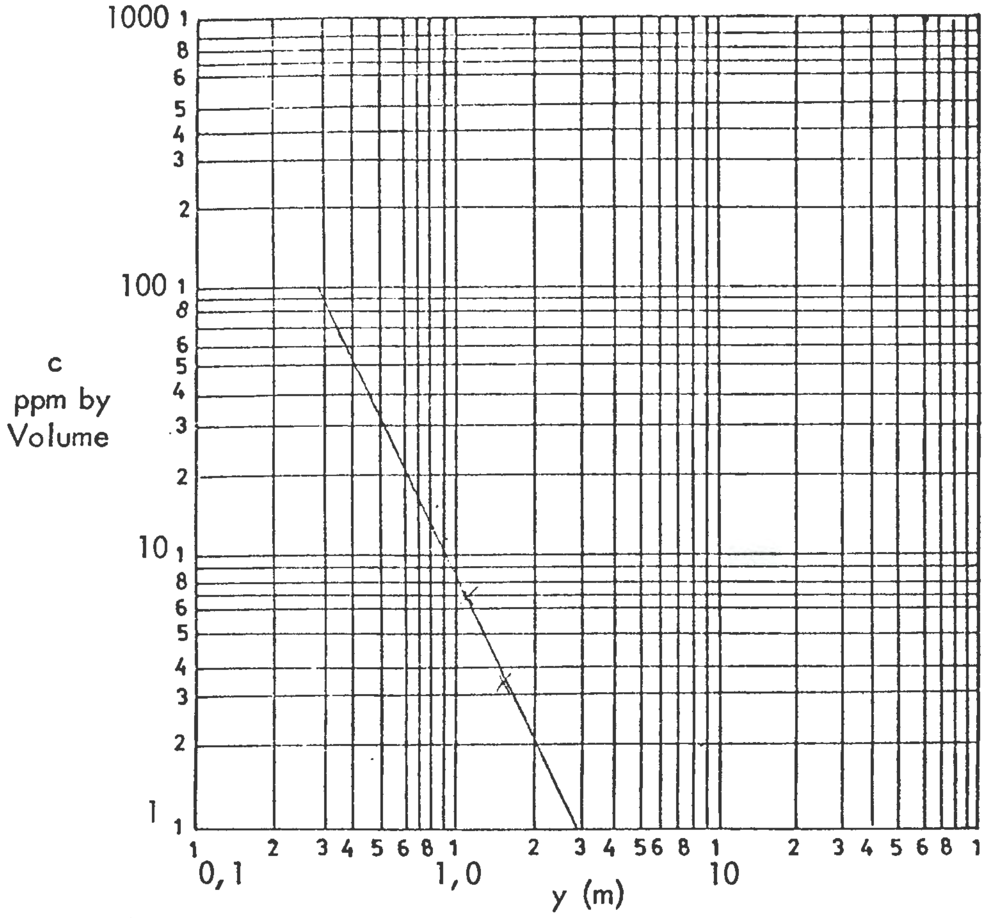

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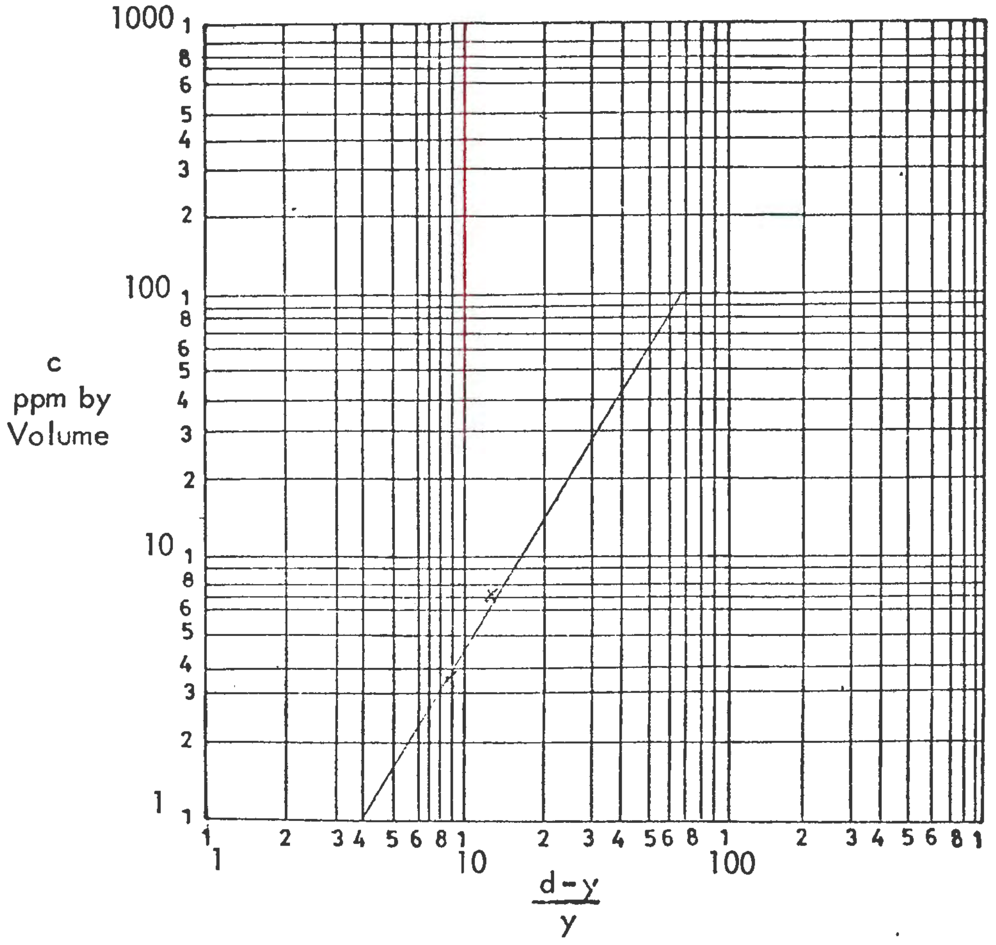

APPENDIX 4

Additional Course Work Completed

Additional Course Work completed by the author for fulfilment of the remaining requirements for the degree of M.Sc.(Eng) is given below :-

Year		Course	Credit Rating
1975	CE 516	Prestressed Concrete	5
1975	CE 522	Aquatic Chemistry	10
1975	CE 525	Coastal Engineering	5