CHAPTER 38

FIELD MEASUREMENT OF WAVE SET-UP

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Abstract

A new, efficient and cheap method is described for obtaining field measurements of surf zone mean water levels. The method applies manometer tubes rather than the traditional pressure transducers. Together with simple stilling well measurements of the water table the results obtained from manometer tubes demonstrate for the first time a complete mean water level profile, from offshore of the break-point to the back-beach region.

While some previous studies have provided information about the average position of the waterline, the present study is the first to provide comprehensive field data on the position of the shoreline defined as the intersection of the mean water surface and the sand. The difference between average position of the waterline and the shoreline is not trivial.

1. Introduction

1.1 Concepts and Definitions

When waves break on a beach the water line moves back and forth with the arrival of individual waves. Its instantaneous co-ordinates are x_W and z_W. Correspondingly, the average position of the water line defines $\overline{z}_W$ (see Figure 1).

When the local surface elevation $\eta(x,t)$ is averaged over a time span much longer than the wave and surf beat periods but shorter than the tidal period the result is the local mean water level $\overline{\eta}(x)$ which traces mean water surface MWS.

The still water level SWL is the level of the still water surface (i.e. the sea surface in the hypothetical situation of no waves). For practical purposes, the SWL can be taken as the mean water level at infinite depth: SWL = $\overline{\eta}(\infty)$.

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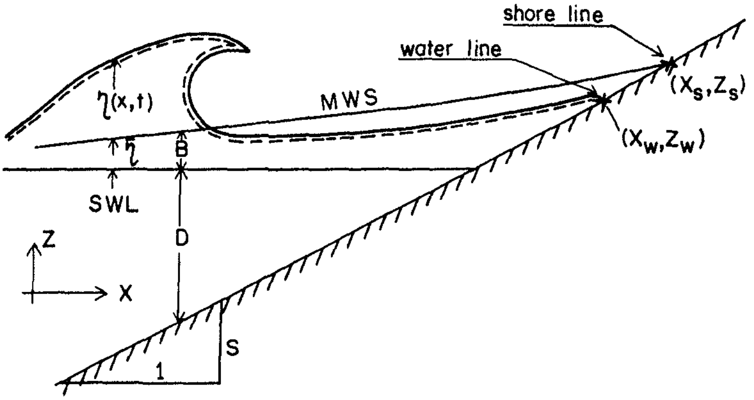

Figure 1: Definition diagram for instantaneous water surface parameters, mean water surface and shore line.

The local setup (and setdown) B(x) is defined as the local super-elevation of the mean water surface above the SWL.

Tides, barometric pressure fluctuations, and changes in wave height cause variations to the mean water surface $\bar{\eta}(x)$ on time scales ranging from a few hours to a few days.

The shoreline and hence the shoreline elevation z_s $(=\bar{\eta}_s)$ and the shoreline setup B_s are defined by the intersection of the mean water surface and the beach.

For the intersection between the still water surface and the beach, we shall use the term Still water shoreline SWS.

Note that the shoreline MWL is in general different from the average runup level.

Field measurements of z_w can be obtained with capacitance runup meters (e.g. Guza and Thornton, 1981) or with down-looking cameras (e.g. Holman and Sallenger 1985), and the amount of field data on z_w is large, while field measurements of are virtually non-existent. On the other hand, theoretical models are generally aimed at $\bar{\eta}$ because it is more easily tractable by theory than is $\bar{z}_w$.

The continuation of the mean water surface landward of the shoreline is the water table, which is the surface where the mean pore water pressure is zero. The local level of the water table $\bar{\eta}(x)$ is thus the level of the free surface in a suitably responsive stilling well.

There are practical difficulties in measuring mean water levels in the surf and swash zones and until now no detailed field measurements have been made of a wave set up profile. A couple of studies (Guza and Thornton 1981, Holman & Sallenger 1985) reported field measurements of the mean elevation of the water line, but this is different from the set up as defined above.

2. Previous Setup Observations

The phenomenon of super-elevated water level at the shoreline on a natural beach is important for a number of reasons. The run up component is important in determining design set-backs and crest-levels for shoreline structures and vulnerability of shoreline protection and natural dunes. The set up component is important to the dynamics of near-shore currents such as undertow, rip currents and longshore currents arising from longshore variations of wave height.

Holman and Sallenger, (1985) report that the study of wave setup was prompted by the hurricane that hit the East Coast of the USA in 1938. Observations of the hurricane event showed a discrepancy of one metre in shoreline elevation between two nearby locations. One location was the relatively exposed area of Narragansett Pier, where wave energy was dissipated as surf. The other location was the relatively calm waters of Newport. Subsequent model tests by Savage (1957) and Saville (1961) verified the existence of wave set-up.

The earliest field measurement of wave set up are reported by R. Dorrestein (1961). He made field observations of set up at various locations across the surf zone. He set up his experimental apparatus at Fernandina Beach on the Atlantic Coast of Florida. He used a pier extending into the sea from a straight beach on which two tide gauges were installed to give offshore water level. On the beach near the shoreline adjacent to the pier, four to six transparent plastic tubes were inserted into the beach to act as stilling wells. The water level in the swash and run up zone could be recorded by filming floats in the plastic tubes.

The experimental method is flawed, however, because the data sampling period of 72 secs is not long enough to average out the effects of surf beat.

Guza and Thornton (1981) used a combination of offshore pressure transducers and a runup gauge in the swash zone to gain information about the shape of the mean water surface. There are two main difficulties with their approach. Firstly, the average position of the water line which is measured by the runup gauge is not related in a simple way to the shoreline setup (Guza and Thornton assumed they were identical) and the absolute levels of the offshore pressure sensors had to be inferred because surveying was impossible.

Holman and Sallenger (1985) applied a similar approach to that of Guza and Thornton, only the resistance runup gauge was replaced by down-looking cameras. Again the average position of the water line was misinterpreted as being equal to the shoreline position.

The present approach differs from the latter two in that the measured quantity is the mean water level and from these measurements the shoreline is found directly as the intersection between the MWS and the beach. Also, the manometer tubes have the great practical advantage over pressure transducers that the elevation of the seaward ends need not be known.

3. Field Measurements

3.1 Field Site

Field measurements of wave set-up were performed at Dee Why beach, an open coastal beach located about 5 km north of Sydney, New South Wales, Australia. The beach faces the south east which is the dominant direction of the swell from the Tasman Sea (see Figure 2).

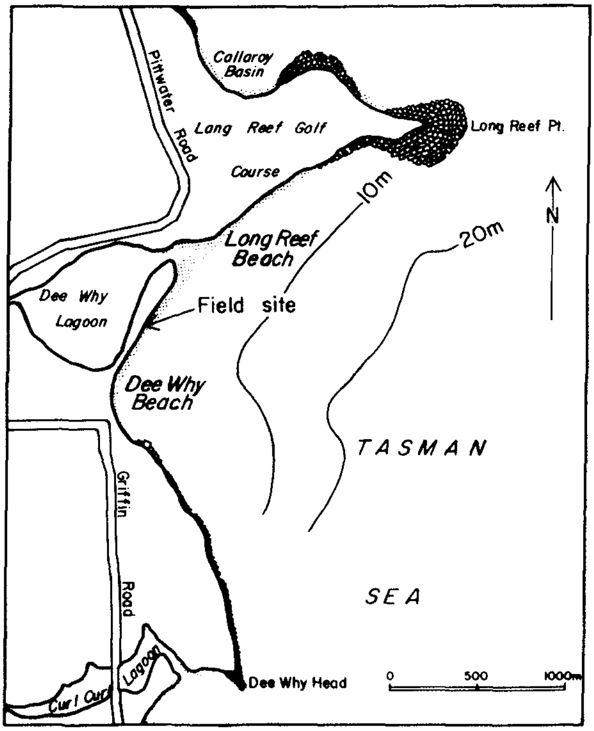

Figure 2: Location diagram for the field site at Dee Why Beach, Sydney, Australia.

The sand grain size varies somewhat across the profile, being coarsest in the swash zone. A sample taken on 17th November 1987 from the swash zone had the following size characteristics: d50 = 0.30mm; d10 = 0.13mm; d90 = 0.95mm.

Topographically, the beach varies between a rip current topography, with rip spacings of a few hundred metres under high energy conditions, and a steep reflective topography with regular beach cusps after extended periods of calm weather.

A sample of surveyed beach profiles are shown in Figure 3 which shows that the profile envelope corresponding to the field data is quite wide.

Offshore wave height data was provided by two Waverider Buoys, one located in deep water offshore of Botany Bay, 20 km to the south and one directly offshore from the field site.

Tide level data was provided by the Fort Denison Tide Gauge, located inside Sydney Harbour.

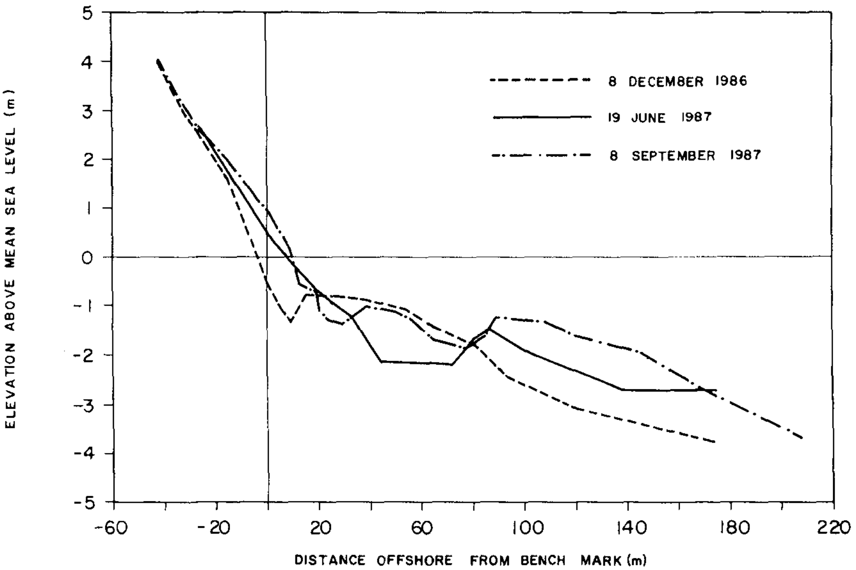

Figure 3: Selected surveys of the line along which the mean water level measurements were made. The setup data was collected between December 1986, and September 1987.

3.2 Field Equipment

The basis of the success of the method described here is the use of simple and reliable equipment. In essence, hydrostatic pressure at different points across the surf zone was "translated" through rigid plastic tubes to a central array of riser tubes. The plastic tubes "damped" the response of the system in such a way as to effectively filter out individual waves and surf-beat, leaving the mean water surface over a period of a few minutes (this process being further enhanced by taking a number of observations over a couple of minutes and averaging them).

The equipment comprising the offshore water level "sensors" consists of a stabilising steel chain, and a bundle of plastic tubes of different lengths, deployed permanently (in this case for over one year) across the surf zone. The longest rigid plastic tube extended 204 metres seaward of the bench mark, which is a stilling well positioned close to the average shoreline (see Figure 4).

Figure 4: The "barometer" mounted on the stilling well which served as a bench mark for the surveys for reference it can be compared with the schematic representation in Figure 5.

In order to roughly maintain the same damping effect within the array of tubes of differing length, the inner diameter of the longer tubes was chosen to be 6mm while the shorter ones were 4mm. In hindsight these dimensions must be said to have been well chosen, except perhaps for the longest tube, which ought to have had an i.d. of 8mm in order to obtain optimal response characteristics.

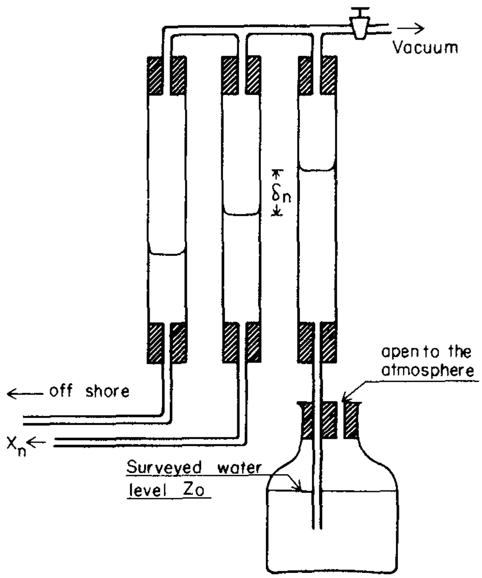

Figure 5: Schematic diagram of the apparatus used for measuring water table levels and hence, setup.

Deployment of the tubes had to be undertaken with some care to ensure no damage occurred to the tubes. All tension was taken by the steel chain, not the plastic tubes.

The tubes, once deployed, were left permanently on site. It is important that the tubes are permanently submerged so that any air bubbles in the system dissolve over time. Air bubbles would contaminate the readings of the system by offsetting the water levels in the riser tubes.

It is also important that the tubes are firmly anchored or buried in the sand so that movements (acceleration) of the tubes are avoided. Such movements would otherwise generate oscillations of the riser tube water levels.

All the tubes were laid out on the beach and bundled together with electrical cable ties. The bundle in turn was tied to a long length of 6mm steel chain. The steel chain was about 10m longer than the longest tube and had a large steel mass attached to the seaward end to help in anchoring. The landward end was fixed to a steel well in the swash zone. This steel well was permanently on site. It was about 300mm o.d., with 6mm thick walls.

The seaward ends of the plastic tubes were covered by geotechnical filter cloth, in order to prevent the intrusion of sand. The landward ends were capped and stowed inside the steel well.

The whole length (some 200m) of bundled up plastic tubes and steel chain was then man-handled out to waist-deep water, and from there a powerful boat dragged the seaward end of the chain out shore-normal from the beach until it was straight and then dropped it. Needless to say, reasonably calm seas and low tide were necessary for this operation.

A few days after deployment, the tubes and the steel chain had been covered by sand and only occasionally did sections of the tubes become exposed due to local erosion.

At the shoreward end, at the steel well in the swash zone, was mounted the "barometer box" (see Figure 4). This heavy steel box was fixed sturdily to the beach well on the day of an experiment at low tide. The permanently deployed plastic tubes had their shoreward ends uncapped and each was connected to the bottom of a vertical glass riser tube, i.d. 22mm, mounted in the barometer box.

The glass tubes were closed to the atmosphere and in turn inter-connected at their tops, so that the air pressures inside were at all times identical (see Figure 5).

An extra glass tube was connected to a reservoir bottle (about 2 litre capacity) partially filled with water to known (surveyed) level, open to the atmosphere, to provide an absolute reference level.

3.3 Experimental Procedure

The system is partially evacuated by sucking by mouth on a vent tube in the riser tube array. This is in order to bring the water levels in the tubes up above the sand to a level where they can be observed. Dye was introduced into the riser tubes to enhance contrast in the photographic observations.

After an initial settling down period of about 20 minutes, recordings were made every half hour throughout a half-tidal cycle, generally starting at low tide and finishing at high tide. With tidal ranges of up to 1.9m and the profile not being linear, this led to considerable variation in the effective beach profile through each field day.

Recordings were made by photographing the vertical glass tubes and the rulers on either side of them, 3 to 5 times with a 20 to 30 second interval, in order to average out traces of surf beat. A "data-back" camera was used so that accurate time was logged with each photograph.

Actual measurements were made by reading the slides off a micro-fiche reader, and adjusting the observed levels in the riser tubes by the absolute water level in the reservoir.

3.4 Water Table Measurements

Water table heights were measured in a series of simple stilling wells installed at four to eight metre intervals along the test traverse of Dee Why Beach.

The wells consisted of plastic pipes of 2.5 to 5 centimetre i.d., capped at the bottom end with geotechnical filter cloth to prevent the intrusion of sand.

The bottom of each well was sunk to a few tens of centimetres below the lowest position of the water table, and the well tops were surveyed.

Measurements of the water levels in the wells were made every half hour with a Geotechnical Instruments "Dip Meter". This is essentially a measuring tape with a conductivity sensor at the end, enabling measurements of the distance between well top and water surface to the nearest centimetre.

The "Dip Meter" measurements were aimed at the details of the water table shape between the shoreline and the runup limit, and the region immediately shoreward thereof. Complementary long term measurements were obtained with a MACE datalogger recording from a Druck pressure sensor inside the permanent stilling well, about 27 metres landward of the average shoreline. Pressure readings were taken every ten minutes for a period of four weeks.

The main purpose of these measurements was to obtain quantitative information about the influence through runup infiltration, of incoming wave height on the average water table height.

4. Study Results

4.1 Setup Profiles

Figure 6 shows a time series of measurements taken at twenty second intervals over about four minutes. A surf beat crest is visible in the readings from the two shortest tubes (3m and 7m) at time 90 seconds. The suppression of the reservoir tube at the same time is also forced by the surf beat. The standard deviations are 2.0 centimetres for the reservoir tube and 0.7 centimetres for the most dynamic offshore tube leading to a combined standard deviation of at most, 2.7 centimetres.

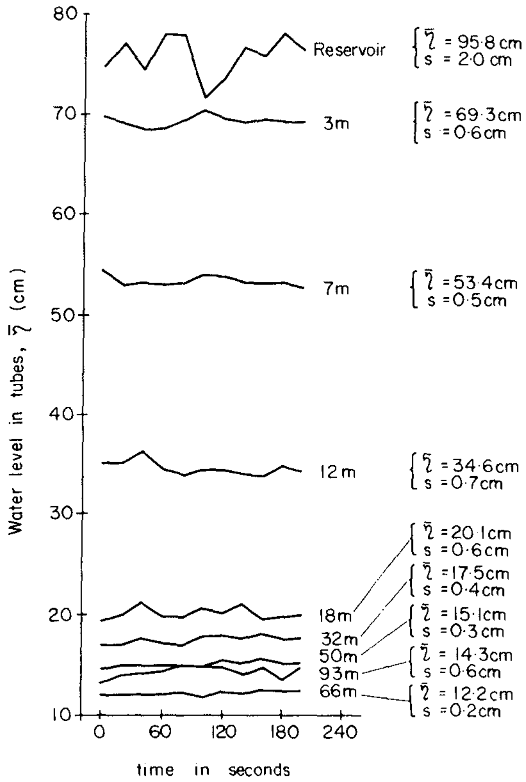

Figure 6: A time series of water level readings at 8 stations taken on 3rd June 1987. Numbers on the curves indicate the distance offshore of the open end. The two shortest tubes show a surf beat peak at t=90s, and correspondingly, the reservoir tube is suppressed at the same time.

A total of 120 setup profiles from 11 field days were obtained during the present study.

As an example, a sequence of setup profiles measured on 8th September 1987 are shown in Figure 7.

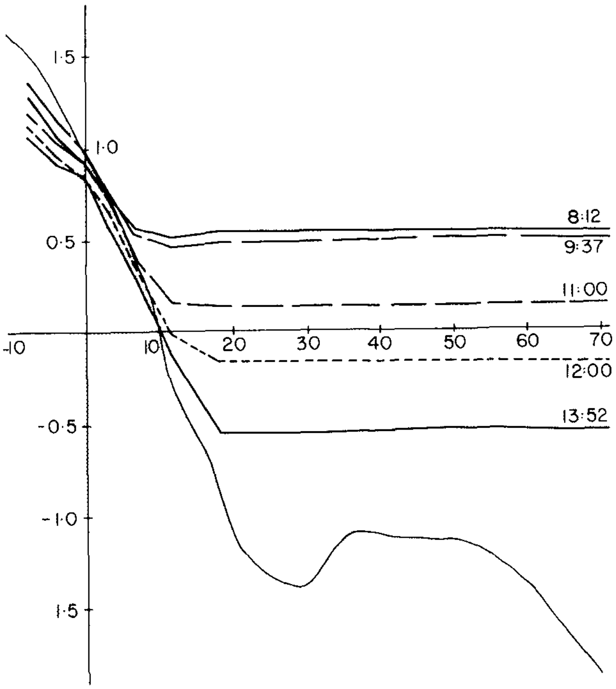

Figure 7: A series of setup profiles measured at Dee Why Beach on 8th September 1987. The offshore RMS wave height (H_{orms}) ranged from 0.69 to 0.82 metres during these tests.

All the data from one field day (4th August 1987) are shown in Figure 8. The setup is plotted in dimensionless form (B/H_{orms}) versus the likewise dimensionless total depth $(D+B)/H_{orms}$. For comparison, the predicted setup according to Bowen et al (1968), with γ= 0.5, is also shown.

The setup at the still water shoreline B_{sws} can bc found from the intersection of the line "D=O" with the data. We see that B_{sws} corresponds rather closely to the predicted value, while the setup is less than predicted seaward of SWSL and much larger than predicted between SWSL and the shoreline. The smaller values at the seaward end can at least partly be explained by wave height variability. For a more detailed discussion see Nielsen et al (1988).

The measured shape of the mean water surface between the still water line and the shoreline shows clearly that the simple model of Bowen et al (1968) does not apply in this area. This was foreseen by Bowen et al.

Quantitatively the data show that (within the data range) the shoreline setup was approximately 40% of the offshore wave height, which is about twice the predicted value from Bowen et al's model with reasonable choices of the wave height to depth ratio.

The data of the present study (reported in full by Nielsen et al, 1988) provide a considerable amount of information, which could serve as a guide line for the development of new models.

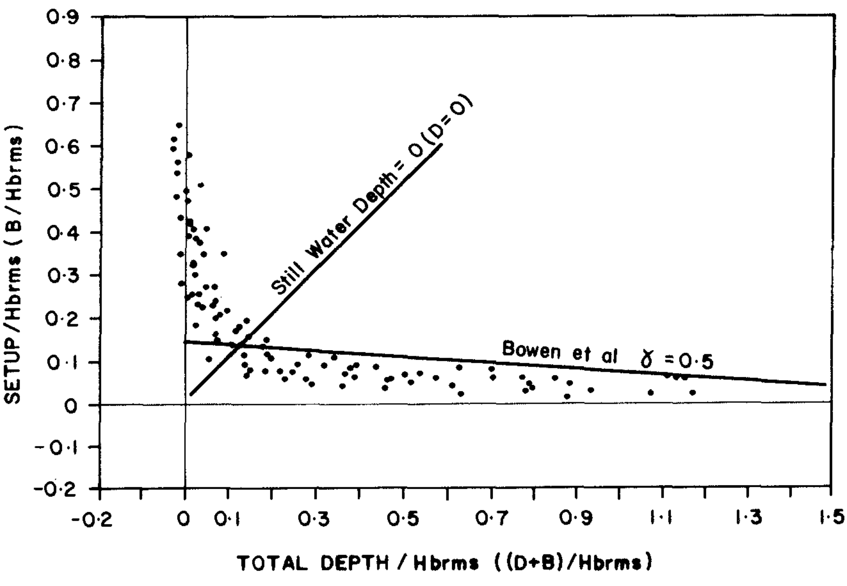

Figure 8: Dimensionless setup versus dimensionlcss total depth. Measurements from 4th August 1987.

4.2 Water-Table Profiles

The results of the integrated study shows that the input of a sinusoidal tide leads to a water table wave which is considerably skewed and on average, super-elevated above the mean shoreline level. This skewing and super-elevation originate mainly from the asymmetry (or non-linearity) of the boundary condition at the shoreline. A simple analytical model for this process is presented by Nielsen et al (1988).

Apart from the tidal fluctuations, the water table will move in response to wave height changes. The effects of these changes on the water table are twofold; firstly, the setup of the shoreline and secondly, a contribution to infiltration from runup. The nature of this interaction is discussed in detail by Nielsen et al, 1988.

5. Merits and Further Potential of the Method

The main advantages of the method are as follows:-

- No need to level offshore components. The surf is a very harsh environment in which to work. Once the gear is deployed, no surveying of "sensors" is required.

- The equipment is simple and robust. Even in the high wave-energy environment of Dee Why Beach, the gear performed without major fault for over one year, surviving numerous storm events.

- No electronic components. Delicate calibrations and considerations of "drift" not required.

- Low cost. All of the components are readily available and inexpensive.

Further application of the method would be in studies of hydraulic behaviour of river entrances, and also in the study of the behaviour of rips on coastal beaches. A further application may be to study the phenomenon of surf-beat.

Possible improvements to the system may include the following:-

- Instead of using the relatively thin rigid plastic tubes to provide an (uncontrolled) damping of the response of the system, it may be better to deploy larger i.d. tubes and add the capacity to dampen response (by a "choke" mechanism, say) at the manometer box. In this way, <u>all</u> the tubes may be "calibrated" to have similar response characteristics.

  The benefits of this may be a better ability to observe water level phenomena that vary within shorter or longer time scales, say for example surf beat instead of wave set-up.

- Use more than one line of tubes to provide a three-dimensional observation of water levels in the surf zone. This would enable the study of rips and rip feeder currents.

6. Conclusion

Manometer tubes of lengths up to two hundred metres have been applied successfully for measuring mean water levels in highly dynamic surf zones. The obtained accuracy was of the order $\pm$ 3 centimetres, but to obtain such accuracy it is essential that the tubes are permanently deployed with most of the length kept below the average water level. Then air bubbles will tend to dissolve with time and partial burying of the tubcs in the sand will prevent movements due to waves and currents. Such movements could otherwise cause disturbing oscillations of the manometer water surface levels.

The technique has enabled the collection of a unique data base on wave setup and it has great potential for direct measurement of the water level gradients which drive rip currents and rip feeder currents.

7. Referenccs

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