CHAPTER 29

LONGSHORE CURRENT FLOWS IN A WAVE BASIN

by P.J. Visser *)

ABSTRACT

This paper describes the investigation into a method how to adjust the proper longshore current in a wave basin. In this method the basin geometry and the proper recirculation flow (outside wave guides) are determined by minimising the circulation flow (between wave guides). Using one wave field and one uniform beach the length of the downstream wave guide wall, the distribution of the recirculation flow at the upstream wave guide wall and the recirculation flow were varied. The investigation shows that the adjustment of the longshore current has to be done carefully in order to get uniformity along the beach and the correct magnitude and distribution normal to the beach.

1 INTRODUCTION

Since the introduction of the concept of radiation stresses by Longuet-Higgins and Stewart (1964) considerable progress has been made in the understanding of the physics of longshore currents induced by obliquely incident breaking waves on beaches. The investigation of the uniform (along the straight shoreline) longshore current profile has been first undertaken by Bowen (1969), Thornton (1969) and Longuet-Higgins (1970). The investigation has been continued by, among others, Battjes (1974) using irregular waves, Jonsson, Skovgaard and Jacobsen (1975), Liu and Dalrymple (1978) and Skovgaard, Jonsson and Olsen (1978). Although some assumptions done in above mentioned studies are rather crude, the achievements obtained by these authors are considerable and call for an accurate comparison with experimental results. Moreover, most of above mentioned models comprise coefficients which, for the present state of knowledge, have to follow from experiments. Comprehensive experiments, in which the longshore current profile was measured are, however, scarce.

In most of the published laboratory and field experiments of longshore currents, see for instance the reviews of Galvin (1967) and Komar (1975), the "longshore current velocity" was measured. In general this longshore current velocity is defined as the averaged (over the width of the surf zone) current velocity. In fact only Galvin and Eagleson

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(1965) measured the variation of the longshore current across the surf zone in extensive series of laboratory experiments. Unfortunately the measured currents were not uniform along the beach. Therefore care must be taken in comparing these experiments with theoretical longshore current profiles.

Dalrymple, Eubanks and Birkemeier (1977), see also Kamphuis (1977), measured circulation streamlines and "longshore velocities along surf zone" in the three commonly used wave basin configurations:

(1) A basin as used by Brebner and Kamphuis (1963) with surf zone openings in both wave guide walls to allow recirculation outside the wave guide walls. The recirculation flow takes place behind the wave generator or through a pipe under the beach.
(2) The completely enclosed wave basin: used by Putnam, Munk and Traylor (1949) and Saville (1950).
(3) A basin as used by Galvin and Eagleson (1965) with an opening in the downstream wave guide wall and with an opening under the wave board to allow recirculation.

Dalrymple et al. (1977) concluded in their paper that if a working recirculation procedure could be devised for the type (1) basin that this would reduce the amount of return flow in the offshore region. It has been the objective of the investigation described in this paper to develop such a procedure, resulting in a uniform longshore current, for a basin similar to that of type (1) but equiped with a pump to effect the recirculation and with longshore current openings in the wave guides rather than surf zone openings. This investigation is a first step to a theoretical and laboratory study of longshore current and wave set-up induced by obliquely incident breaking waves on beaches. The longshore current study will probably be followed by a laboratory investigation of sediment transport caused by this current.

2 CRITERION FOR PROPER LONGSHORE CURRENT FLOW

To approximate the longshore current flow generated by a uniform (along the shoreline) wave field on an infinitely long and uniform (along the shoreline) beach, a wave basin configuration was chosen with longshore current openings in both wave guide walls and with a recirculation outside the wave guide walls which is effected completely by a pump (fig. 1). Very likely the choice of such a wave basin is the only way to obtain a uniform longshore current in a wave basin, it also yields, however, the following unknown quantities:

- the width of the longshore current openings in both wave guide walls,
- the recirculation flow rate.

These quantities have to be determined preceding to a longshore current or littoral transport investigation in a basin as shown in fig. 1, preferably in a relatively short period of time.

The criterion for the proper longshore current flow generated by a uniform wave field is that the profile is uniform along the beach, or also that the slope of the mean water in longshore direction is zero.

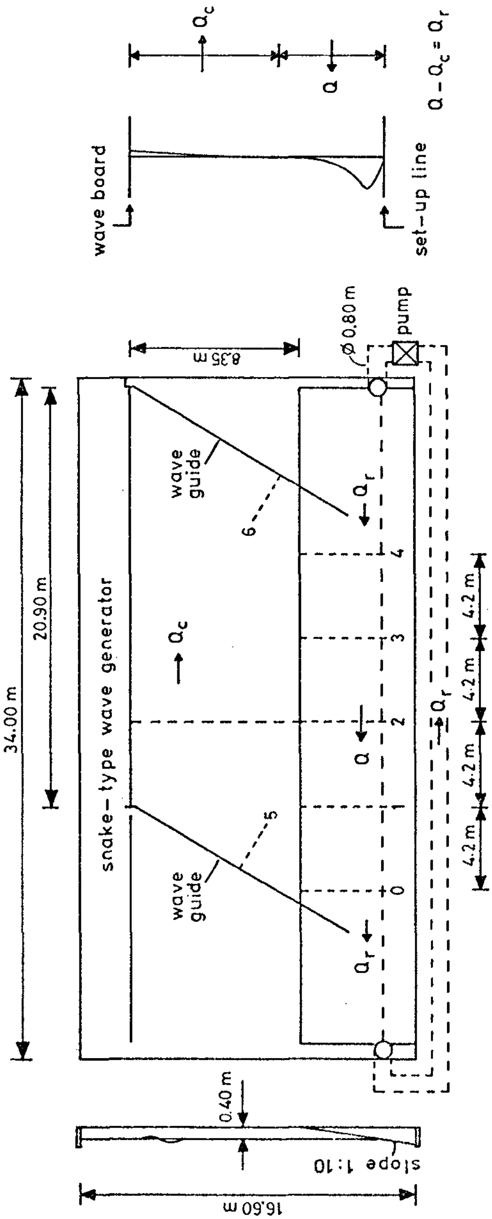

Figure 1 - Wave basin configuration.

It is, however, impossible to optimise the recirculation procedure from measurements of mean water level in longshore direction. This is caused by the inevitable small variation along the shoreline of wave set-up and set-down and the limited length of a wave basin. This paper describes the investigation into an alternative method. In this method the wave basin geometry and the proper recirculation flow (outside wave guides) Q_{ru} are determined such that the circulation flow (inside wave guides) Q_c is minimised (fig. 1). Q_{ru} is the recirculation flow Q_r which yields the uniform longshore current flow Q_u. This method is based on the physical consideration that in an optimised wave basin geometry Q_c is minimal if $Q = Q_u$:
because if $Q_r < Q_{ru}$ the shortage returns offshore in Q_c and Q_c will increase and if $Q_r > Q_{ru}$ the surplus generates a circulation flow, also yielding an increase of Q_c.

To verify the method outlined above, experiments were carried out in which the following quantities were varied:

- the width of the longshore current opening in the downstream wave guide wall,
- the distribution of the recirculation flow in the longshore current opening of the upstream wave guide wall,
- the recirculation flow Q_r.

The completely enclosed wave basin and the basin with surf zone openings in both wave guide walls and a recirculation achieved outside the wave guide walls without a pump were also investigated. The wave field quantities and beach slope and beach roughness were not varied as yet.

3 EXPERIMENTAL PROCEDURE

The experiments were done in a 16.60 * 34.00 m^2 wave basin (fig. 1) equiped with a snake-type wave generator. Opposite to the (regular wave) generator a smooth concrete 1 : 10 slope was constructed in the basin. The wave guide walls were composed of concrete elements and installed at an angle of 31 degrees with the normal of the wave board. The recirculation has been effected through a Ø 0.80 m pipe by means of a pump. The adjustment of the desired recirculation flow Q_r was done with the help of an orifice plate.

Figure 1 shows the position of the 7 sections in which measurements of current velocity were performed. In each experiment the current velocity was measured in section 2, which extends from the wave board to the wave set-up line. In some experiments the velocity was also measured in sections 5 and 6 perpendicular to the wave guide walls and/or in the "longshore current zone" in sections 0, 1, 3 and 4 parallel to section 2. The distance along a section between two measuring points was 0.20 m in and near the surf zone and 0.40-0.60 m in the other region.

In the measuring points the current velocity was measured near the surface, at mid-depth (with exception of sections 5 and 6 and the shallow zone between plunge line and wave set-up line) and near the bottom. The current velocities were measured by timing the travel (along 0.80 m, 0.50 m or 0.30 m, depending on the velocity) of dye ($KMnO_4$) perpendicular to a measuring section. To this end, near each measuring section strings were stretched parallel to the section and just above the waves. In the surf zone dye was followed over a distance of 0.80 m and not longer because of the rather fast spreading of dye by turbulence in this zone. To serve accuracy, the number of readings giving one measurement result (that is a velocity at a certain depth) was increased and the measurements were conducted by two persons in this zone. Outside the surf zone, the spreading of dye was rather small and there the measured travel time of dye was at least 3 seconds. The number of readings which gave one measurement result are as follows:

- in the surf zone : at least 20,
- near the surf zone: at least 10,
- remaining region : at least 5.

To eliminate the influence of the orbital velocities on the measurement results, the velocities were measured in different phases of the waves. Dye was chosen in accordance with the choice of dye by the Delft Hydraulics Laboratory (1977) after a series of experiments in which the application of floats, dye, the propeller-type miniature current meter and the Ott propeller-type current meter was investigated.

Wave set-up and set-down were measured in sections 1 and 2 with tappings, flush-mounted in the beach. The horizontal distance between 2 tappings was 0.10 m in the surf zone, and 0.20 m outside the surf zone. The tappings were connected with pots, in which the static head was measured.

Measurements of wave heights were performed with resistance wave probes. The distance between two measuring points was 0.10 m in the surf zone and 0.20 m outside this zone. In the constant depth part of the basin wave heights were measured in 5 sections (yielding a number of 100 measuring points). In the slope zone wave heights were measured in sections 1 and 2 and, to measure the position of the breaker line and the mean breaker height, in 3 sections parallel to the wave board at and near the breaker line, each section containing 29 measuring points on a mutual distance of 0.20 m.

Measurements of angles of incidence were done:

- in the constant depth part of the basin with wave probes directly after the start of the wave generator,
- on the breaker line by photograph.

The results of the measurements of wave heights, breaker depths, angles of incidence, wave set-up and set-down are listed in table 1. These wave field quantities were measured in the optimised wave basin geometry with the uniform longshore current flow. The breaker line is defined here as the averaged (along the shoreline) position of the measured breaker points. A breaker point is defined here as the point

wave period	= 2.01 sec	sloping beach with tgα = 0.101
still water depth	= 39.9 cm	in constant depth part of the wave basin
mean wave height	= 7.1 cm	
adjusted angle of incidence	= 31.1^o	
measured angle of incidence	= 31.6^o	
mean breaker depth	= 10.4 cm	mean breaker height = 10.5 cm
mean maximum set-up	= 4.2 cm	mean max. set-down = 0.32 cm
mean width surf zone (from wave set-up line to breaker line) = 1.45 m		
angle of incidence on breaker line = 20.9^o		
mean wave run-up	= 7.2 cm	

Table 1 - Measured wave field quantities.

in which the wave height is maximal (in a section normal to the coast) : at the shoreward side of this point the wave height decreases (more or less) continuously.

The velocity measurements which are described in this paper can be summarized as follows:

A. first series of experiments in which
   - width opening in upstream wave guide (= 1.90 m) = 1.3 * width surf zone,
   - width opening in downstream wave guide varied from 1.0 * width surf zone to 2.0 * width surf zone (ratios of 0.97, 1.17, 1.31, 1.45 and 2.00),
   - recirculation flow Q_r varied from 0 l/sec to 59 l/sec.

B. second series of experiments in which
   - distribution system in longshore current opening of upstream wave guide wall,
   - width opening in downstream wave guide wall varied from 1.0 * width surf zone to 1.6 * width surf zone (ratios of 0.97, 1.17, 1.31, 1.45 and 1.59),
   - recirculation flow varied from 25 l/sec to 50 l/sec.

C. measurements in completely enclosed wave basin.

D. measurements in wave basin with surf zone openings in both wave guides rather than longshore current openings and a free recirculation (no pump).

The distribution system in the longshore current opening of the upstream wave guide wall is 1.20 m long (in longshore direction) and 2.40 m wide (in the direction normal to the wave board) and consists of 12 channels each 1.20 m long and 0.20 m wide. With gates, slide-valves, etc., it is possible to vary the rate of flow in each channel.

4 EXPERIMENTAL RESULTS

The mean velocity in a measuring point was calculated from the measured current velocities as follows

$$\bar{v} = \frac{1}{4}\,(v_{surface} + 2\,v_{mid\text{-}depth} + v_{bottom}).$$

The rate of flow between two adjacent measuring points followed from the mean velocities and mean water levels measured in these points. The enumeration of these flow rates between adjacent points gave the longshore current flow Q and the circulation flow Q_c, as defined in fig. 1. By comparing the difference $Q - Q_c$ with the adjusted flow rate of the pump Q_r an indication of the accuracy of the experiments was obtained. At the end of this chapter the accuracy of the experiments will be discussed.

In the first series of experiments (A) the width of the longshore

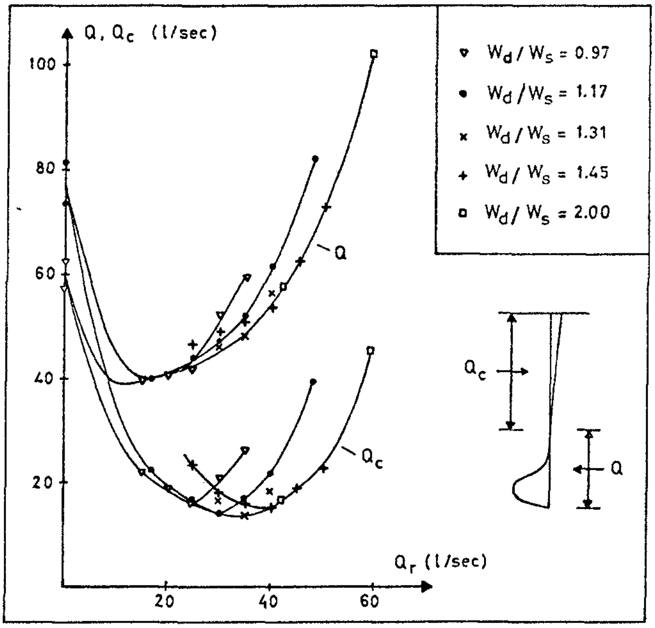

Figure 2 - Longshore current flows Q and circulation flows Q_c measured in section 2' in first (A) series of experiments.

current opening in the upstream wave guide was constant, namely $1.3 * w_s$ (w_s = width surf zone), which after the completion of these experiments turned out to be a fortunate choice. The width w_d of the longshore current opening in the downstream wave guide and the recirculation flow Q_r were varied. Figure 2 gives a graphical representation of the longshore current flows Q and circulation flows Q_c measured in section 2 (25 measurements) in the first series of experiments. From this figure it can be seen that Q_c is more or less a parabolic function of Q_r for a given w_d/w_s-ratio. The locus of the minima of these parabolas gives a graphical relation between w_d/w_s and Q_r (such that Q_c is minimal for a given Q_r or w_d/w_s-ratio). In the first series of experiments the circulation flow Q_c is minimal for $w_d/w_s = 1.31$ and $Q_r \doteq$ 35 l/sec : Q_c = 13.6 l/sec and Q = 48.4 l/sec. In this situation (here labeled as $\hat{A}$-experiment) also velocity measurements were done in sections 5 and 6 and, to examine the uniformity along the beach, in sections 0, 1, 3 and 4. The results of these measurements and of the measurements in section 2 are shown in fig. 3. From this figure it can be seen that from section 2 to section 0 the longshore current profile is uniform, but that almost half a wave basin length is necessary to establish this uniform longshore current. In order to increase the length of uniformity, a distribution system was installed in the longshore current opening in the upstream wave guide wall after the completion of the first series of experiments.

The distribution of the recirculation flows Q_r in this system was adjusted according to the measured distribution of the longshore current flows Q in the first series of experiments. In the second series of experiments (B) the number of measurements in section 2 was restricted to 11 : 6 with $w_d/w_s = 1.31$ and a Q_r-range from 25 to 50 l/sec, 5 with a varying w_d/w_s-ratio (according to the locus of the minima in fig. 2) and a Q_r also ranging between 25 and 50 l/sec. The longshore current flows Q and circulation flows Q_c measured in this series of experiments are shown in figure 4. Also in the second series of experiments the circulation flow Q_c is minimal for $w_d/w_s = 1.31$ and Q_r = 35 l/sec : Q_c = 19.2 l/sec and Q = 52.1 l/sec. The results of the velocity measurements in section 2 and the results of the measurements in sections 0, 1, 3, 4, 5 and 6, which were also performed in this situation (here labeled as $\hat{B}$-experiment), are shown in figure 5. This figure shows that the longshore current is uniform from section 3 to section 0: due to the distribution system the distance along which the longshore current is uniform increases substantially.

The smallest Q_c in the second series of experiments is Q_c = 19.2 l/sec, in the first series of experiments: Q_c = 13.6 l/sec. The influence of

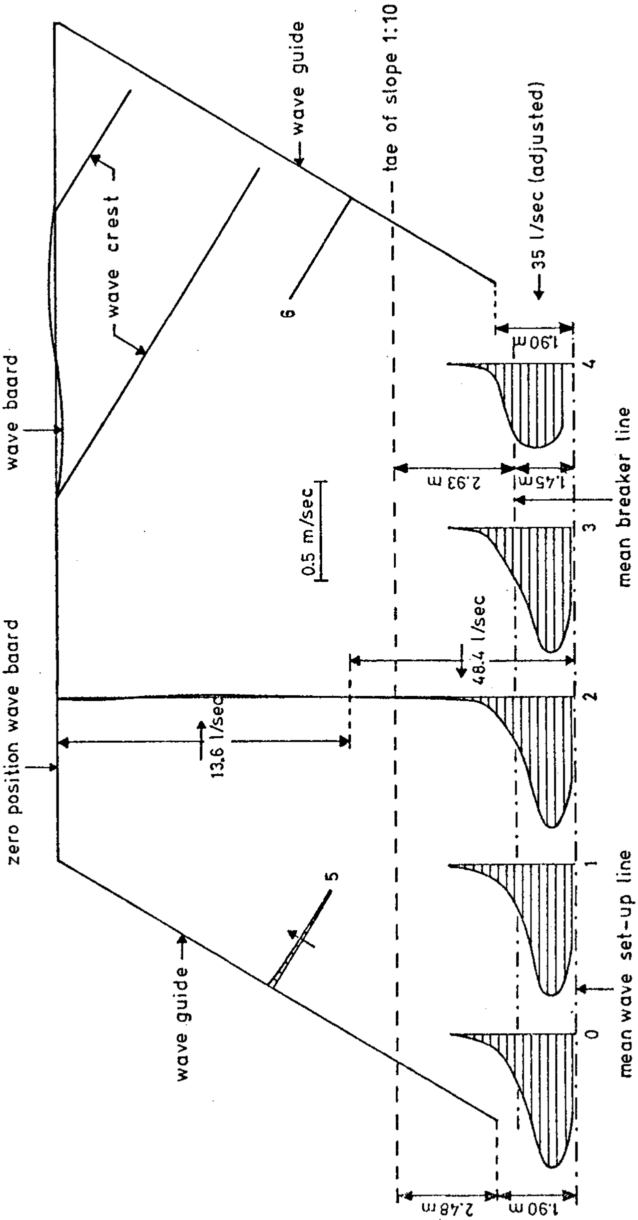

Figure 3 - Depth averaged longshore current and circulation velocities (Â-measurements).

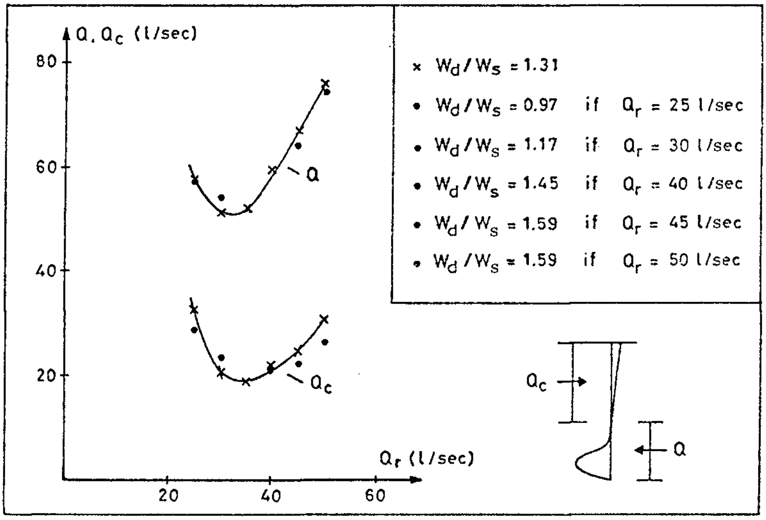

Figure 4 - Longshore current flows Q and circulation flows Q_c measured in section 2 in second series of experiments (B).

the distribution system on the rate of circulation flow Q_c does not follow from a comparison of these circulation flow rates due to the fact that not only a distribution system was installed but also some small (but not unimportant) leaks in the wave guides were closed. To investigate this influence an additional experiment was performed without the distribution system, with Q_r = 35 l/sec and with 1.31 * w_s wide openings in both wave guides. The result of this experiment: Q_c = 29.4 l/sec and Q = 62.2 l/sec.

The depth averaged velocities resulting from the measurements in the completely enclosed wave basin are shown in figure 6. The longshore current is clearly non-uniform; the profile is strongly disturbed by the significant large circulation flow ($Q_c \doteq$ 128 l/sec).

Figure 7 shows the depth averaged velocities which follow from the velocities measured in the type (1) basin, that is a basin with surf zone openings in both wave guides and with a recirculation outside the wave guides without the use of a pump. Also the longshore current measured in this type wave basin is clearly non-uniform. In this experiment the return flow took place directly alongside of the longshore current, yielding an anti-clockwise circulation in the offshore region. The "free recirculation flow" was also measured: Q_r = 12.4 l/sec, which is about one third of the proper Q_r.

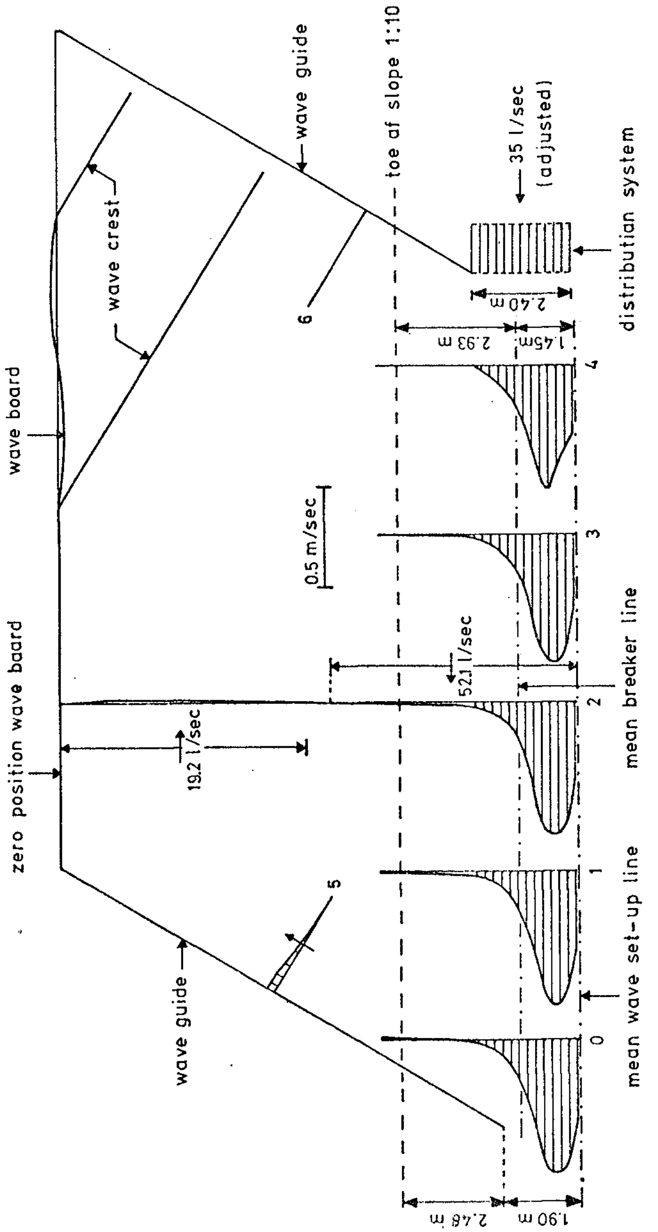

Figure 5 - Depth averaged longshore current and circulation velocities ($\hat{B}$-measurements).

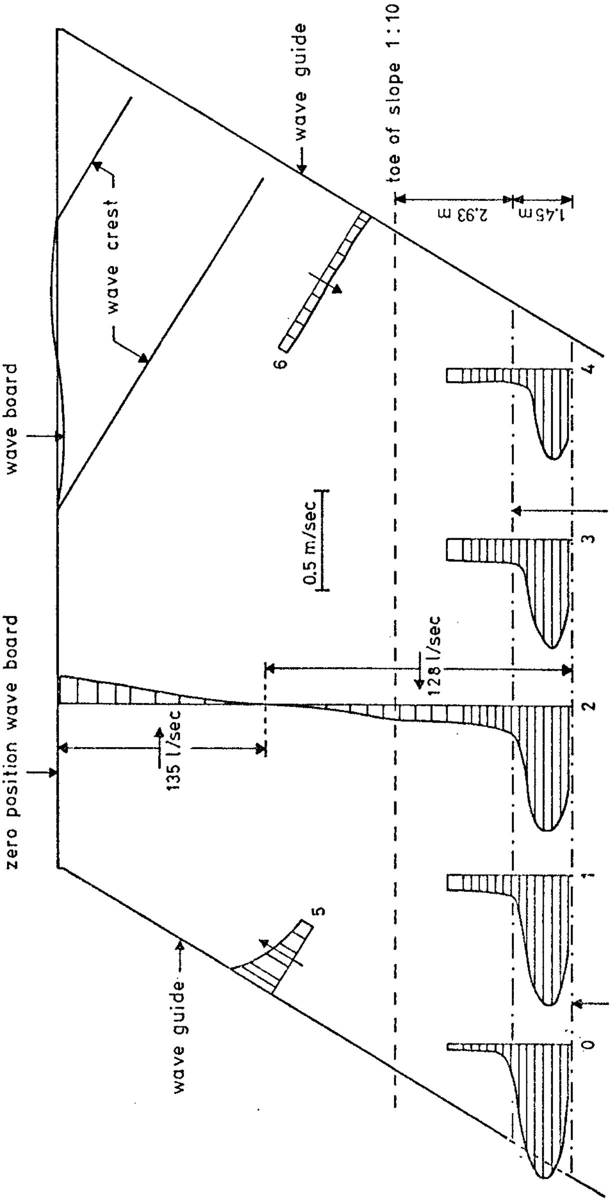

Figure 6 - Depth averaged longshore current and circulation velocities (C-measurements).

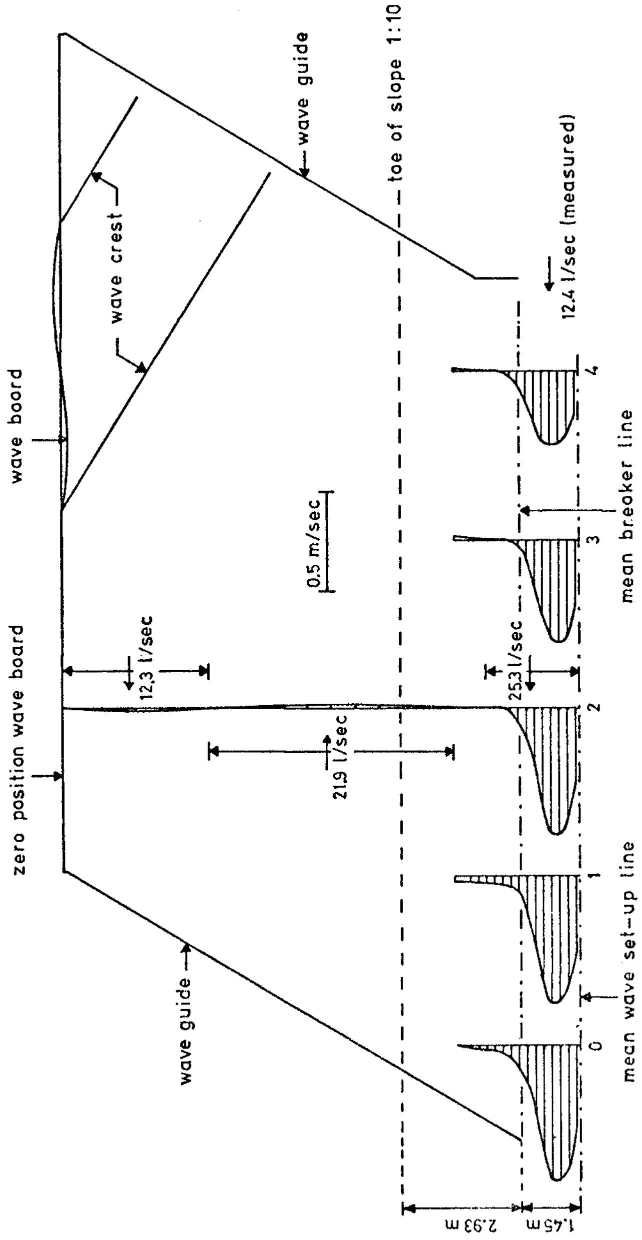

Figure 7 - Depth averaged longshore current and circulation velocities (D-measurements).

	$\hat{A}$-experiment					$\hat{B}$-experiment				
section nr	0	1	2	3	4	0	1	2	3	4
Q_s (l/sec)	29.0	27.9	28.4	27.3	24.5	28.3	28.1	28.0	26.8	26.4
Q_{2s} (l/sec)	45.1	43.4	43.6	42.9	39.9	42.5	43.3	42.9	41.2	39.6
v_{max} (m/sec)	0.67	0.66	0.66	0.61	0.42	0.67	0.67	0.66	0.64	0.62
v_{br} (m/sec)	0.24	0.21	0.22	0.27	0.36	0.23	0.22	0.20	0.20	0.22
	C-experiment					D-experiment				
ray nr	0	1	2	3	4	0	1	2	3	4
Q_s (l/sec)	30.4	25.8	25.5	19.2	12.2	24.9	23.5	22.9	17.5	16.2
Q_{2s} (l/sec)	42.5	48.4	50.9	49.2	29.8	34.6	34.9	25.3	16.6	17.6
v_{max} (m/sec)	0.67	0.65	0.63	0.55	0.45	0.67	0.63	0.65	0.52	0.39
v_{br} (m/sec)	0.21	0.14	0.15	0.12	0.07	0.14	0.10	0.10	0.06	0.10

Table 2 - Some results of the measurements along the shoreline.

The flows along the coast in the surf zone (Q_s) and in a section with a width of 2 times the width of the surf zone (Q_{2s}) measured in the four experiments $\hat{A}$, $\hat{B}$, C and D are given in table 2. The table presents also the depth averaged maximum velocities along the coast and the depth averaged velocities on the breaker line. Table 2 shows again the uniformity and non-uniformity of the measured longshore currents which is already depicted in figures 3 and 5-7. The depth averaged longshore current velocities measured in section 2 in the experiments $\hat{A}$, $\hat{B}$ (both with practically the same uniform longshore current profile), C and D are shown in figure 8. The differences between the uniform longshore current profiles and the non-uniform longshore current profiles near the middle (in longshore direction) of the sloping beach in the completely enclosed wave basin and the type (1) basin are clear, especially near the breaker line. Deviations from the uniform longshore current profile can become also considerable in the

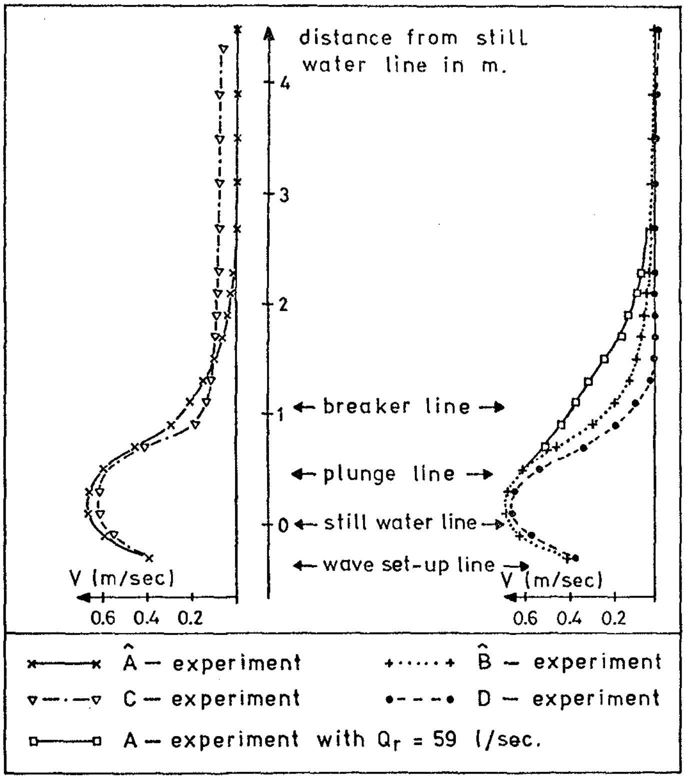

Figure 8 - Depth averaged longshore current velocities.

fig. 1 type basin, especially if the rate of recirculation flow differs substantially from the proper recirculation flow. This is demonstrated in figure 8 with the help of the longshore current profile measured in the first series of experiments with Q_r = 59 l/sec and w_d/w_s = 2.00.

Adding all recirculation flows Q_r, all longshore current flows Q and all circulation flows Q_c of the experiments described in this paper gives respectively:

$\sum Q_r = 1253$ l/sec,

$\sum Q - \sum Q_c = 2320 - 1080 = 1240$ l/sec.

The difference of 13 l/sec is for 70% due to the experiment with the completely enclosed wave basin (with the large circulation flow) and only 1% of $\sum Q_r$. So it can be concluded that the systematic error in the longshore current and circulation velocity measurements is small. The random error of one measurement result was restricted as far as the experimental time this permitted by the number of readings (5, 10 or 20) which gave this measurement result. From the above and from the smooth longshore current profiles reflected in the figures 3, 5, 6, 7 and 8 it can be concluded that rather accurate measurements of longshore currents are possible.

5 DISCUSSION

The investigation described in this paper shows that the adjustment of the correct longshore current flow in a wave basin has to be done conscientiously. Deviations from the uniform longshore current profile can become considerable

- in non-optimised wave basin geometries and/or if
- the adjusted recirculation flow deviates substantially from the proper recirculation flow.

One of the most important aims of this investigation is to set-up a method for the adjustment of the uniform longshore current flow (or profile) in a wave basin and to verify this experimentally. From the previous chapters it can be concluded that this objective has been attained, at least for the wave field/wave basin combination which was used for the experiments described in this paper. From this investigation a "wave basin prescription" will be set-up. With this wave basin prescription it has to be possible to create a uniform longshore current flow in a wave basin for given wave field and beach quantities in a rather short time. To verify this wave basin prescription the experiments will be continued with other wave fields on the same slope.

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