EXPERIMENTS ON THE FORMATION OF BEACH CUSPS

BY

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Summary.

Experiments are described in which artificial beaches were attacked by a combination of running waves parallel to the coast and superposed standing waves at right angles to the former. Beach cusps were formed only when a steep beach was eroded by the waves. Observations in nature are cited that appear to support the view that standing waves may be the cause of beach cusps, but further data are needed before a definite conclusion can be arrived at.

1. INTRODUCTION.

The interesting phenomenon of „beach cusps" has been reviewed extensively by D. W. JOHNSON in his book, „Shore processes and shore line development" (bibl. 1). P. D. TIMMERMANS attention was drawn to this phenomenon by JOHNSON's book, and although beach cusps are not frequent on the Dutch coast, TIMMERMANS was able to cite a few examples when treating them in his thesis (bibl. 2). During his experiments on other beach problems, small cusp-shaped markings sometimes developed, which he called „micro beach cusps". However, it remains doubtful whether these may be compared to the real beach cusps.

Prof. Dr. K. SCHLOSSMACHER of Königsberg, visiting our laboratory for experimental geology in May 1936, asked me if I could explain a phenomenon he had observed in the „Kuhrische Nehrung". This phenomenon consisted of small bays at regular intervals along the beach, combined with foam lines at right angles to the waves, the latter running straight into the beach. This combination appeared to me to indicate standing cross waves, from which both the foam lines and the bays originated.

As standing cross waves can be easily formed by our plunging machinery, I could immediately imitate the phenomenon for him. Actually some bays were formed on an irregular heap of sand in the basin.

Stimulated by this accidental succes I carried out some thirty experiments from June 11th till July 29th 1936, assisted by A. VERHOORN, technical assistant, and partly by Miss Dr. K. KOOMANS, incidentally also by a third assistant.

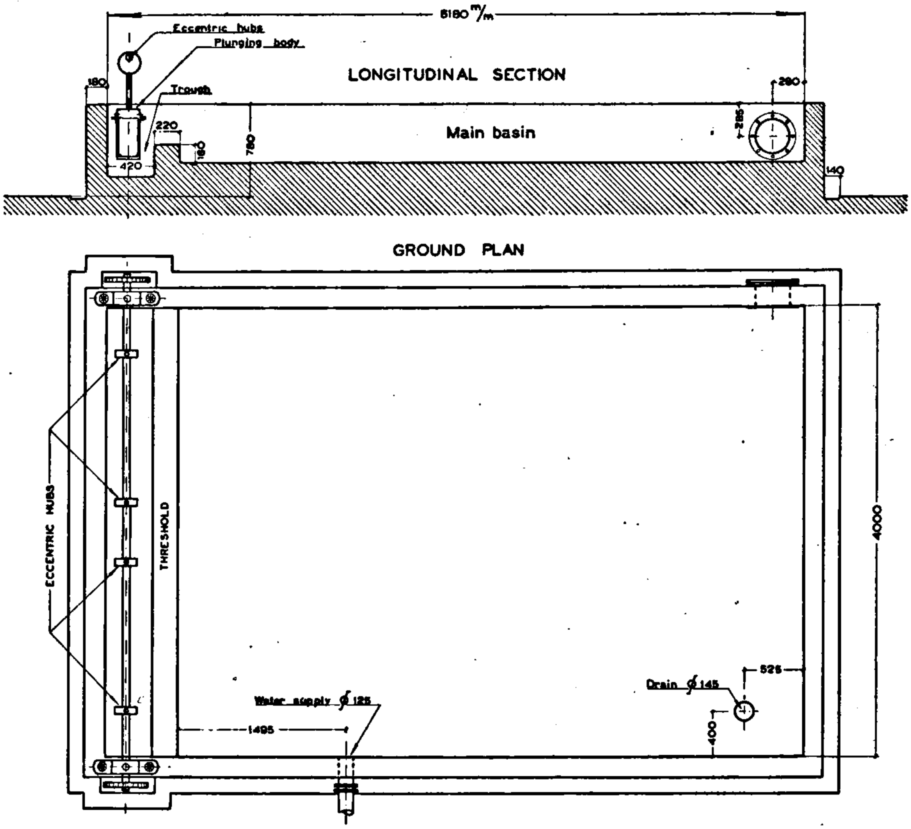

Fig. 1A.
Top view and vertical section of the basin.

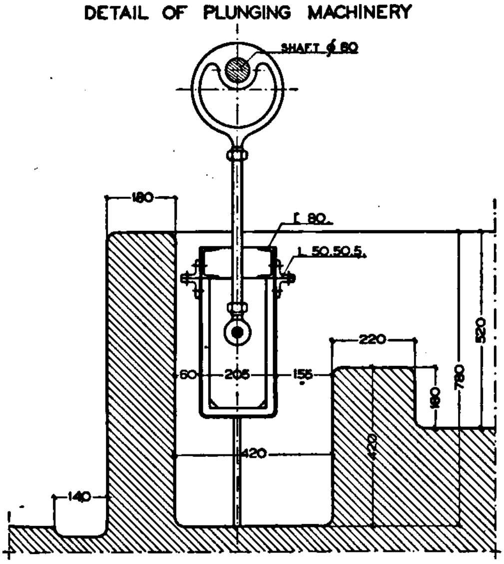

Fig. 1B.
Detail of plunging machinery.

2. THE STANDING CROSS WAVES.

The appliance for producing waves in our laboratory, consists of a plunging body, which is moved up and down by means of eccentric hubs mounted on a shaft and driven by an electric motor. The three pairs of eccentric hubs confer upon the plunging body a length of stroke of respectively 2, 6 and 10 cm (fig. 2 and 4).

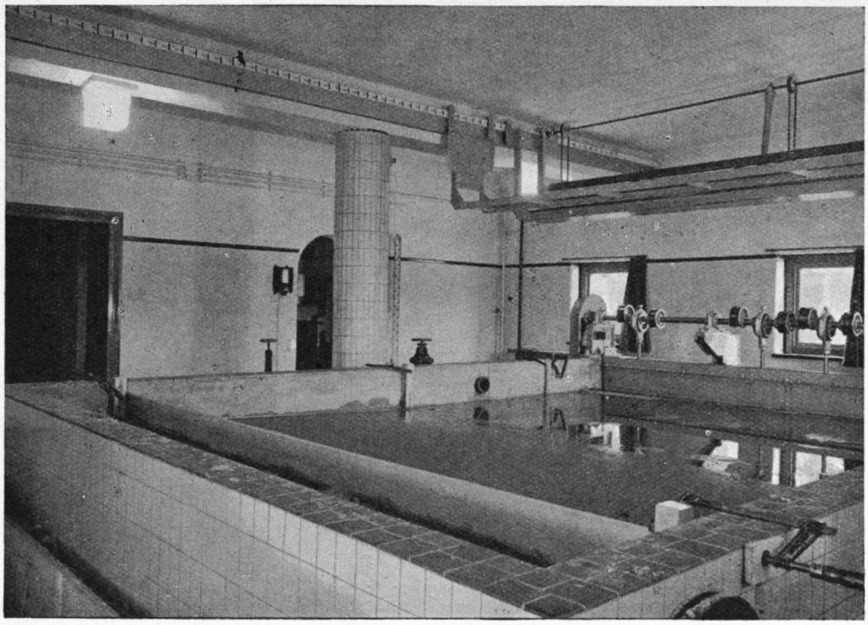

Fig. 2.

General view of the basin.

The plunging body (height 43 cm, breadth 25 cm) moves in a trough shaped basin (depth 76.7 cm, width 42 cm) separated from the main basin by a concrete wall (breadth 22 cm, height 16.3 cm above the floor of the main basin) (fig. 1). This concrete wall prevents sediments to enter the plunging basin from the main basin and thus damage to the plunging machinery. Between the plunging body and the concrete wall is a zone of 16 cm width, wherefrom a wave passing over the separating wall enters the main basin when the plunging body moves downwards.

This way of producing waves is not simple enough to allow a mathematical treatment of the problems involved. The occurence of the standing cross waves, viz. waves at right angles to the ordinary waves, the latter parallel to the length of plunging body, is dependent on the depth of water, the frequency of the ordinary waves and the length of stroke of the plunging body.

We did not succeed in applying to our problem the well known formula of **Merian** (lit. 3, p. 79) for standing waves:

$$Tn = \frac{2\,l}{n\sqrt{gh}},$$

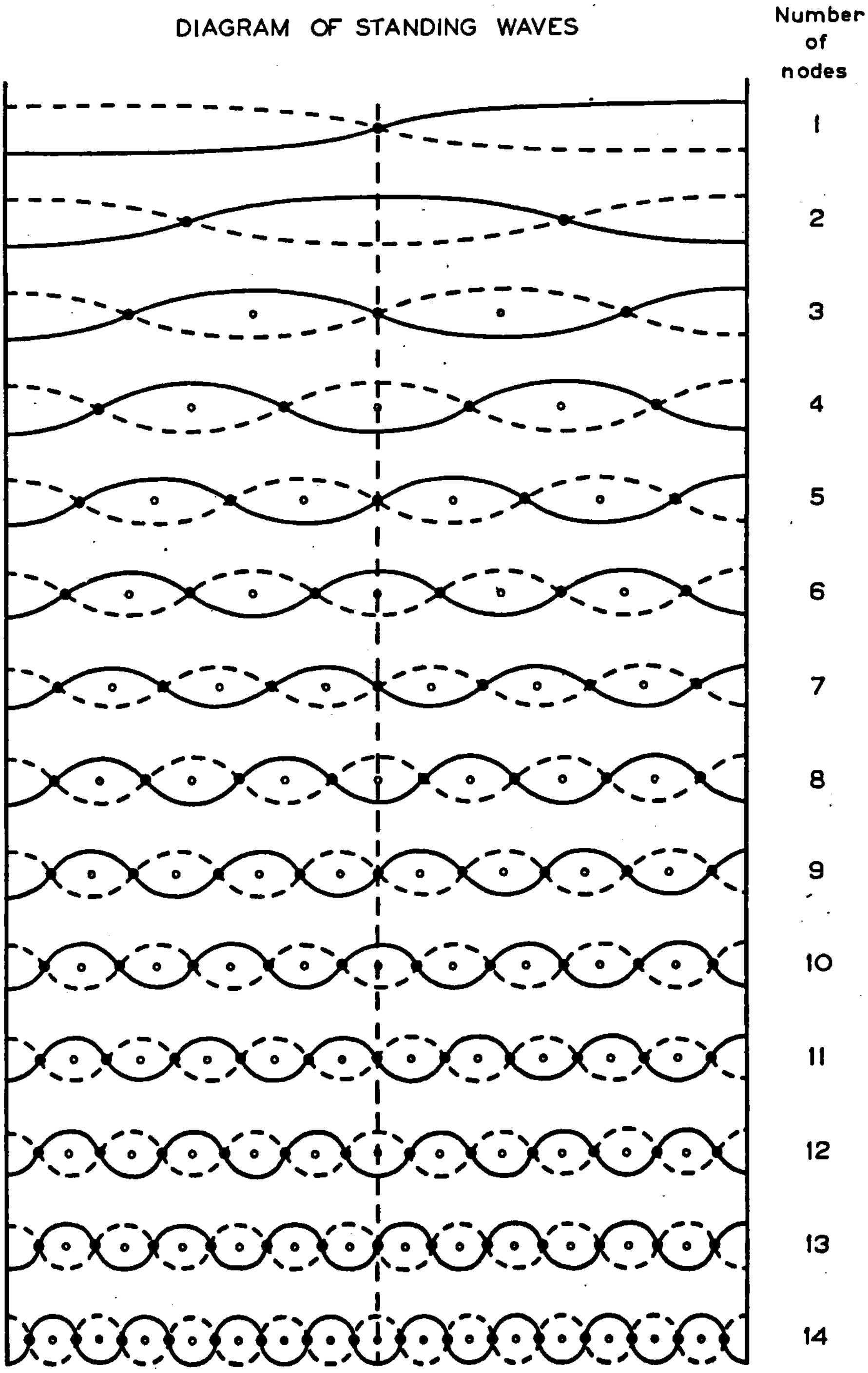

Fig. 3.

Diagram of standing waves with 1 to 14 nodes.

where Tn is the period in seconds for a standing wave with n nodes, l the length divided in n nodes (in our case the width of the basin = 400 cm), h the depth of the water in cm. In our case the depth of immersion of the plunging body also plays a part.

Only with a length of stroke of 10 cm distinct standing waves could be formed. A length of stroke of 6 cm gave difficulties and one of 2 cm gave very poor results.

In a basin bounded at the ends by vertical walls, standing waves originate with the ventral segments along the walls. Thus fig. 3 shows in principle some waves that are possible in the case dealt with. The waves in the main basin were running waves, with standing cross waves superposed.

Thus the running waves, with their culminations and depressions (fig. 4) attacked the beach, which was laid out with varying inclinations and varying distances.

Naturally the period of the standing waves was equal to that of the running waves. Obviously a culmination of a running wave, reaching the beach, will run to a higher level than a neighbouring depressed part of the same wave. Hence the culminations will erode bays, whereas opposite depressions cusps will be formed.

At first sight it appears easy to determine from the wave length of the running waves, the distance at which the beach has to be laid out, in order to get the maximum differentiation in erosion by the culminations and depressions. But the problem is complicated by the strong influence of the beach profile on the shape of the waves.

The beach was laid out at varying distances without applying any rules. During the experiments it became clear that among other things the depth of the water and the period of the plunging body determined, as already mentioned, the formation of distinct standing waves.

Some experiments were executed with a constant depth of water, in which case it was possible at a certain period to produce standing waves with a definite number of nodes. In other experiments the period was kept constant, but the water level was slowly lowered. At a certain level standing waves with for instance 9 nodes originated, which, after having reached a maximum amplitude, slowly disappeared. Then at a still lower water level standing waves reappeared with 10 nodes.

As the length of stroke of the plunging body is only 10 cm, the variation of the water level is limited.

Most of the experiments were performed with a depth of the water in the basin of 29 cm, or $29 + 25 = 54$ cm in the plunging trough. For experiments with varying water level the depth was lowered from max. 35 cm to min. 21,5 cm. In the graph (fig. 5) the period of waves varying from 0.66 to 0.86 sec. are plotted on the abscissa, the depth of the water on the ordinate in centimeters.

The period of the standing cross wave with 8 nodes in the series of experiments with constant water levels, seems to decrease with the shoaling of the water (line AB fig. 5). This is not in accordance with the formula of MERIAN.

In general the graph shows, in accordance with the formula of Merian, that the smaller the period, the larger the number of nodes.

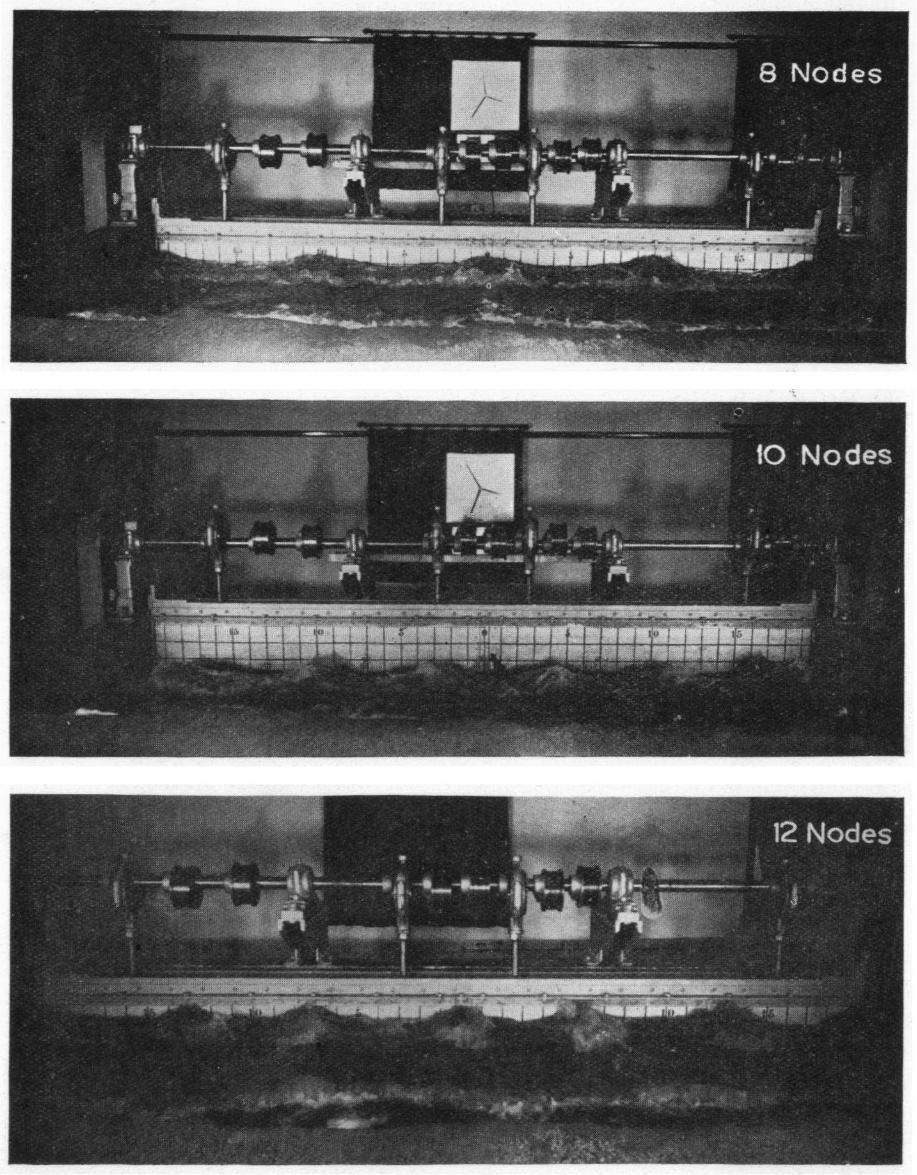

Fig. 4.

Examples of standing waves.
A with 8, B with 10, C with 12 nodes.

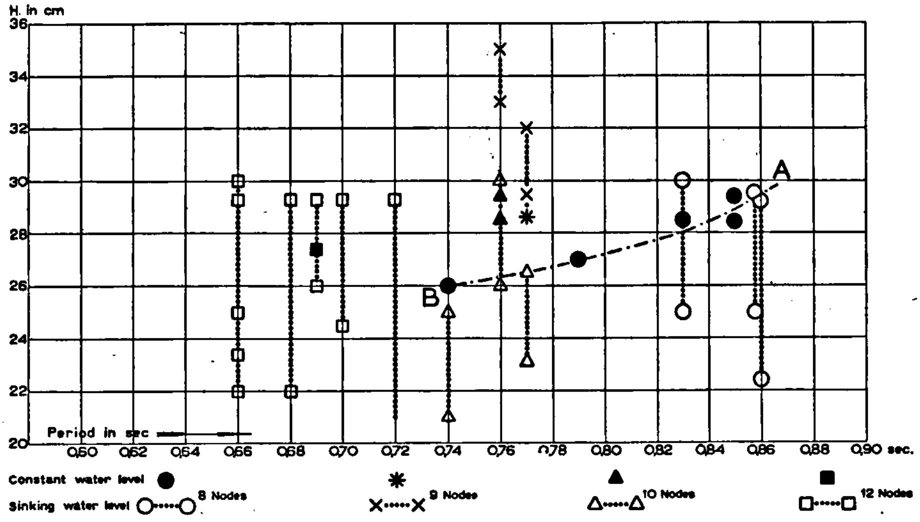

Fig. 5.

Diagram of the relation between the depth (h in cm) of the water in the main basin, the period of the waves in sec., and the number of nodes of the standing waves.

As an example of the variation in the number of nodes with falling water level, we refer to the graphs fig. 6 (exp. 10) and fig. 7 (exp. 13)

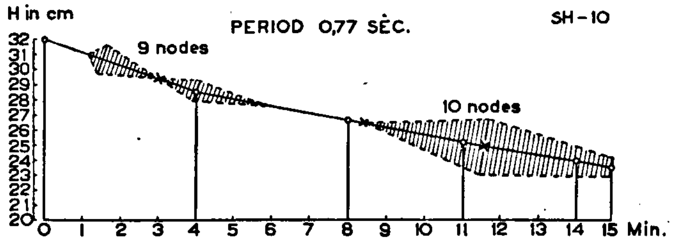

Fig. 6.

Diagram of the occurrence of standing waves with 9, afterwards with 10 nodes with a period of 0.77 respectively 0.78 sec., and a sinking water level from 32 to 23.5 cm. The width of the hatched area indicates the amplitude of the waves.

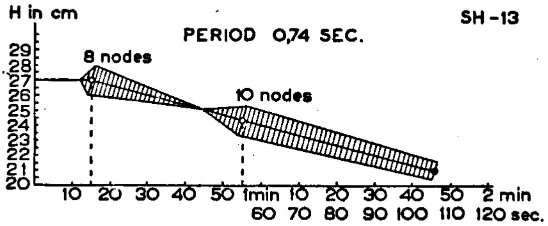

Fig. 7.

Diagram of standing waves with 8 and 10 nodes with a period of 0.74 sec., and a sinking water level from 27 to 21.5 cm.

with periods from 0.77 to 0.78 sec. and 0.74 sec. and a number of nodes varying from 9 to 10 and from 8 to 10 respectively.

If the purpose of the experiments had been to find the relation between wave period, water level and number of nodes, then many more experiments ought to have been made with constant water level. Our main interest however, was, the erosive effect of the waves on the beach.

Finally it must be admitted that a few mistakes in counting the number of nodes may have been made. Two, at max. three observers for the complicated experiments were not enough to allow of a calm observation of all details. We had to regulate the period with the resistance of the electric motor, to read the time in minutes and seconds on a stopwatch, to count the number of strokes of the plunging body, to regulate the draining of the water in the experiments with falling water level, and finally we had to observe the erosion of the beach. In some experiments the taking of a film and also the manipulation of a board were added. The board was used to hold up the waves until a good standing wave had developed, which was then released on the beach by removing the board.

Thus the experiments are not perfect, and probably can be improved upon. However, as the experiments, notwithstanding their obvious short-comings, are believed to show useful geological results, we decided to publish them. Only those which are trustworthy are treated in the sequel.

3. THE INFLUENCE OF THE WAVES ON THE BEACH IN THE EXPERIMENTS.

A. Experiments with constant water level.

Exp. SH 2.

Water level 28.5 cm, period 0.832 sec, 8 nodes, slope of beach 4° and of foreshore ± 20° (fig. 8). Duration of wave erosion rather more than 20 minutes.

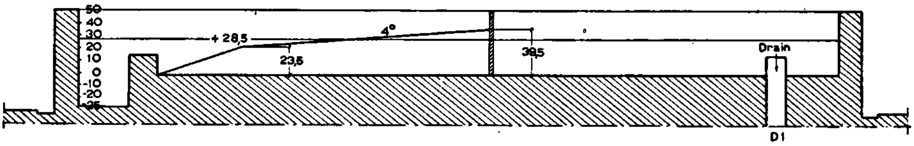

Fig. 8.

Section through the beach belonging to experiments SH 2 and SH 3.

The shape of the beach profile in relation with the water level, caused not only erosion but also accumulation of a beach ridge showing curves above the average water level. In front of this ridge erosion occurred below water level.

The photograph of fig. 9A, taken in two parts vertically downwards, shows the result of experiment SH 2. After the experiment a thread was placed along the beach at water level. This was repeated every-time after the water was drained off to a level 3 cm lower. Thus the threads are situated at 0, —3, —6, —9, —12, —15, and —18 cm.

As the photographs were taken vertically and the beach had a strong inclination, the two parts can only be fitted together either at the top or at the bottom. In this and following experiments the two halves were always joined in such a manner that they fit at the higher part of the beach.

In fig. 9B the standing wave with 8 nodes is indicated in outline below a sketch of fig. 9A. Opposite the wave culminations 1 and 3 we find outward curves of the beach ridge, and below water beach cusps like extrusions. Opposite 2 we find irregular shapes. Corresponding to the wave depressions I, II, III and IV we find pits in the inclined beach below water level.

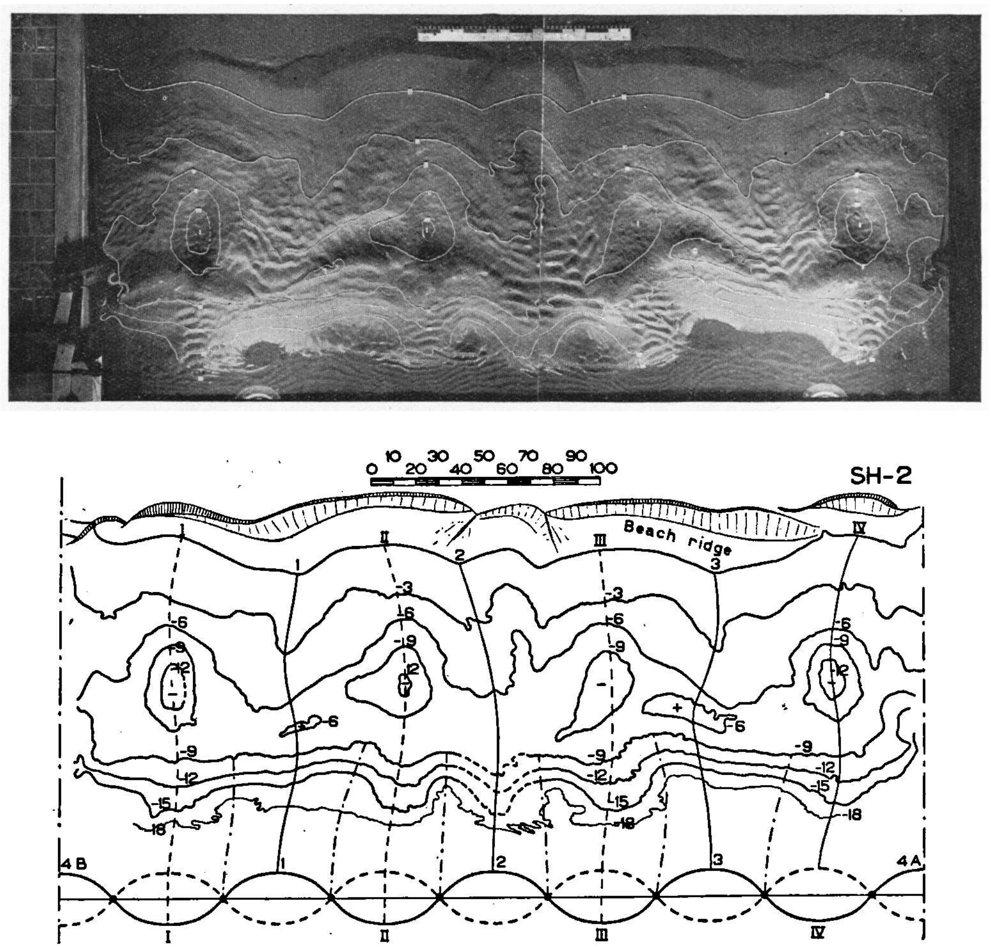

Fig. 9.

Result of exp. SH 2.
A photograph, B analysis.

Although the shapes are not quite regular, they clearly show the influence of a wave with 8 nodes. The shape of the beach profile in connection with the water level prevented the moulding of distinct beach cusps.

Exp. SH 3.

Water level 28.5 cm, period 0.76 sec, 10 nodes, same beach as in exp. SH 2 (fig. 8). Duration of wave erosion 30 minutes.

As water level and beach profile agreed with those of SH 2, we find again a curved beach ridge. The relation between the curves and the culmination and depression of the waves, is, however, hardly noticeable (fig. 10 A and B). On the other hand the morphology of the deeper

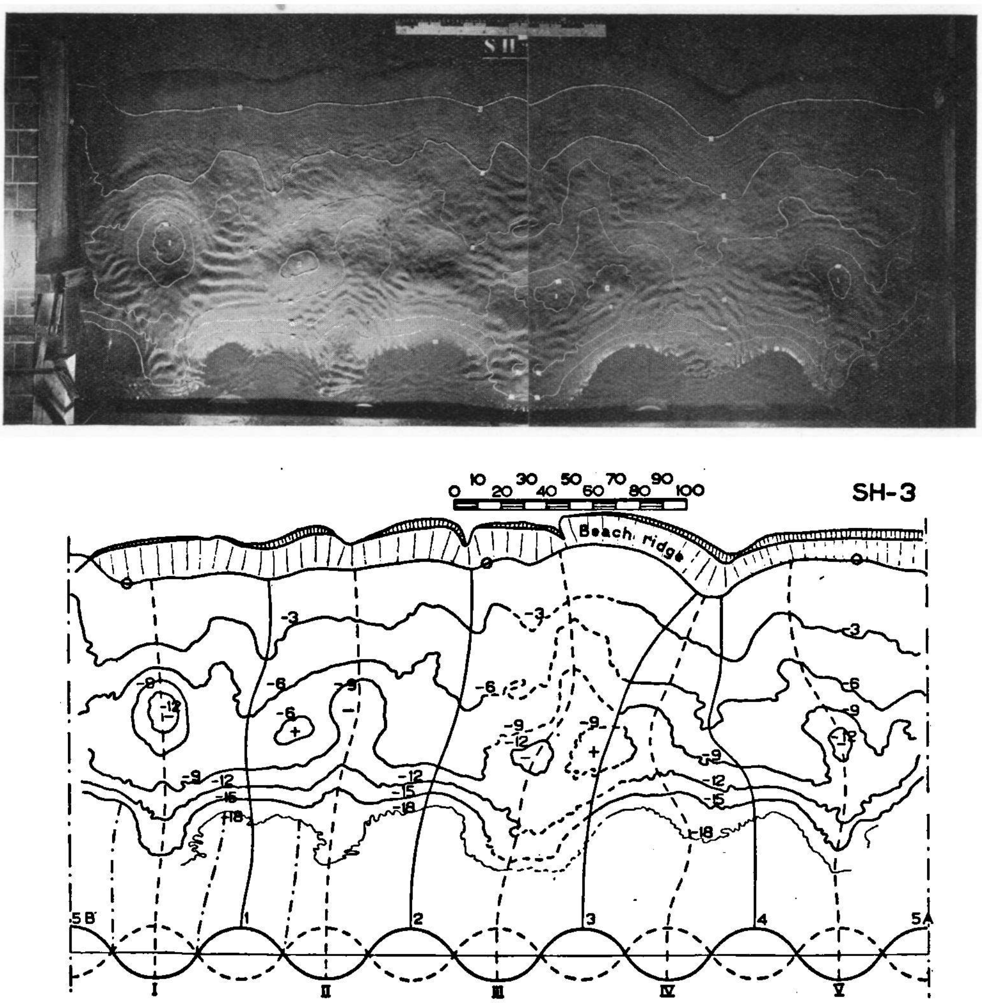

Fig. 10.
Result of exp. SH 3.
A photograph, B analysis.

part in front of the steep beach agrees very well with a standing wave of 10 nodes. Towards the flat part of the beach the erosion becomes less regular.

Corresponding with the wave depressions I, II, III, IV and V we find ridges, each except IV separated from the beach by a small basin. Corresponding with the wave culminations we find bays ending in a ridge. As in exp. SH 2, the shapes are not regular enough to be compared to real beach cusps.

Exp. SH 6.

Water level 29.5 cm, period 0.856 sec, 8 nodes. Dry beach with a slope of 4° down to water level (29.5 cm), then a sharp bend to a steep-slope of 22° (fig. 11). Duration of wave erosion 30 minutes.

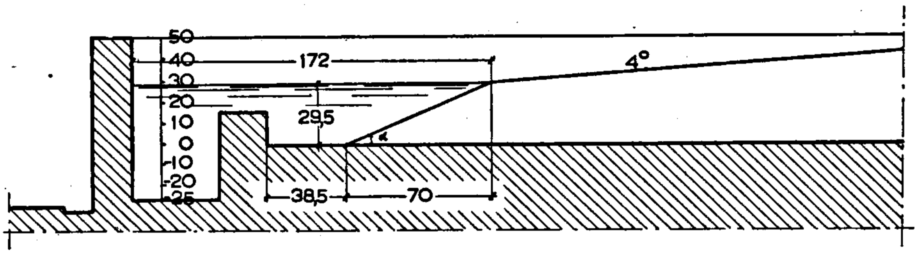

Fig. 11.

Section through the beach belonging to experiments SH 6, SH 12, SH 16 and SH 17.

Also in this experiment we find both erosion and accumulation, the result being shown by fig. 12 A and B. The 0-line is not very characteristic. The shape below water level, shown by the contours of —3, —6, —9, —12, —15, —18, —21 and —24 cm, exhibits culminations corresponding more or less to the wave depressions I, II, III and IV. Behind the culminations we find depressions in the wet beach. The influence of the standing wave with 8 nodes is clear, but beach cusps were not formed.

Exp. SH 12.

Water level at start 27 cm, or 2.5 cm below the sharp bend of the beach slope, which was shaped the same way as in exp. SH 6. Period 0.79 sec, 8 nodes. Duration of wave erosion 1 min 49 sec (138 waves).

The water level was lowered from 27 to 26.5 cm, therefore almost constant. The result of this experiment is totally different from the foregoing ones, because the water level from the start was 2.5 cm below the sharp bend in the beach profile.

The steep shore was immediately attacked; above water level only erosion took place, no accumulation. The very regular erosion shape corresponds perfectly with the culminations and depressions of the standing wave with 8 nodes. The morphology of the beach can be compared to beach cusps. The photograph fig. 13A was taken with a water level of 26.5 cm.

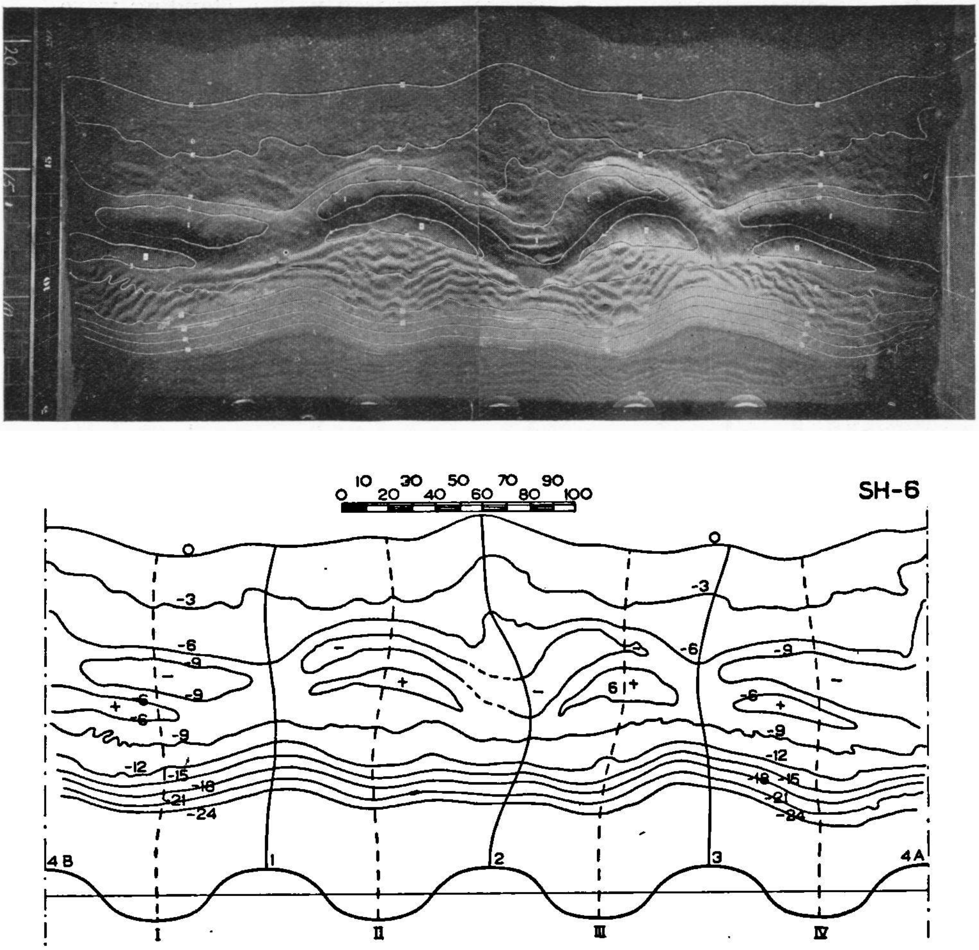

Fig. 12.

Result of exp. SH 6.
A photograph, B analysis.

B. Experiments with falling water level.

Exp. SH 16.

Water level decreasing from 29.5 to 25 cm. Period not measured. 8 nodes. Beach as in exp. SH 6. Duration of wave erosion 110 waves.

No steep shore such as in Exp. SH 12, was formed, because the water level started at the same height as the sharp bend in the beach profile.

The photograph (fig. 14A) was taken with a water level of 25 cm. In fig. 14B the morphology below water level was sketched.

Ridges like beach cusps were formed but less regular than in exp. SH 12.

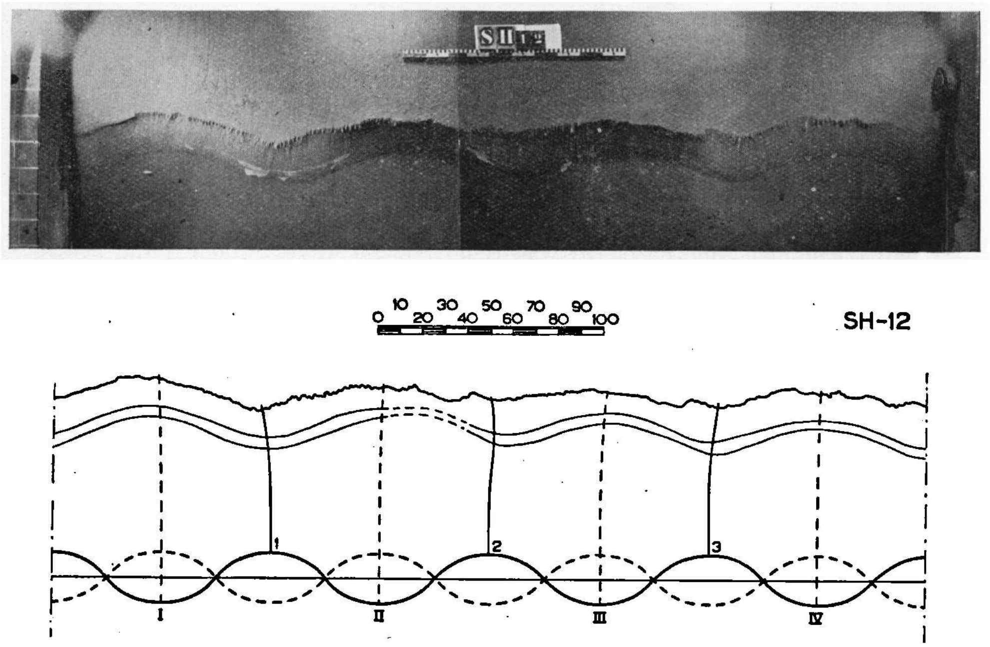

Fig. 13.
Result of exp. SH 12.
A photograph, B analysis.

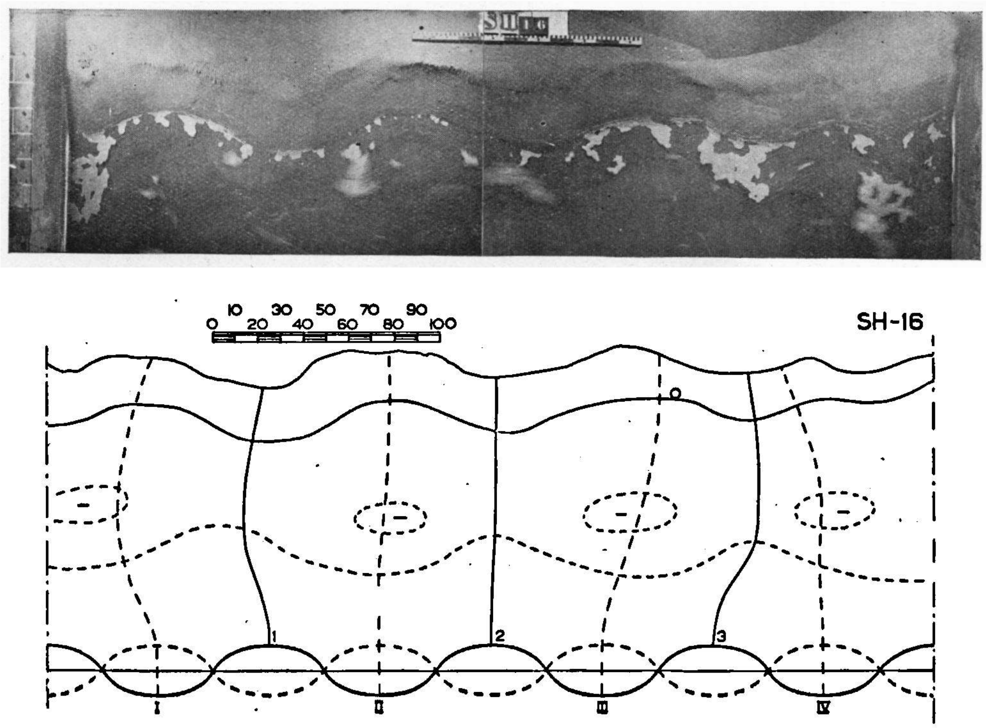

Fig. 14.
Result of exp. SH 16.
A photograph, B analysis.

Exp. SH 17.

Water level first constant, then falling from 29.5 to 22.5 cm. Period 0.86 sec. 8 nodes. Beach as in exp. SH 6. Duration of wave erosion on beach 19 + 96 sec = 1 min 55 sec.

An attempt was made to obtain a steep erosion shore, unlike exp. SH 16, by placing a board between the main basin and the space where the waves were formed. After 45 strokes distinct waves with 8 nodes had developed and the board was removed. 25 waves attacked the beach with a water level of 29.5 cm; then the drain was opened and during 92 strokes the waves were released on the beach with a sinking water level. Then the board was replaced and the machinery stopped.

The notes on this exp. are:

min.	sec.	number of strokes	remarks
0	0	0000	
		0020	a standing wave with 8 nodes starts to develop.
0	37	0045	board removed.
0	56	0070	stopper of drain removed.
2	20	0162	board replaced.
2	32	0177	machinery stopped.

$$\text{average } \frac{60 \times 177}{152} = 70 \text{ strokes (waves) per minute}$$

$$\text{Period } = \frac{60}{70} = 0.86 \text{ sec.}$$

On the photograph fig. 15A threads are laid at an equidistance of 3 cm. The 0-line corresponds with 22.5 cm water, the other lines are the —3, —6, —9 contours, corresponding with depths of 19.5, 16.5 and 13.5 cm.

A beach ridge (accumulation) has been formed on the flat beach. A distinct steep erosion shore did not develop. The morphology is regular and corresponds well with the 8 nodes. Shapes like beach cusps were formed.

Exp. SH 18.

Water level first constant, then falling from 29.5 cm to 25 cm. Period 0.86 sec. 8 nodes. Slope of beach at the back 4°; at a height of 34 cm a sharp bend to the steep front beach with a slope of about 26°. Distance from sharp bend to concrete wall 110 cm (fig. 16). Duration of wave erosion 39 + 55 sec = 1 min 34 sec.

As we did not succeed in exp. SH 17 in developing a steep erosion shore, we built up the beach higher, the sharp bend now being 4.5 cm above water level. Again, as in exp. SH 17 and the next ones, we manoeuvred with a board. Forty waves ran on the beach with a water

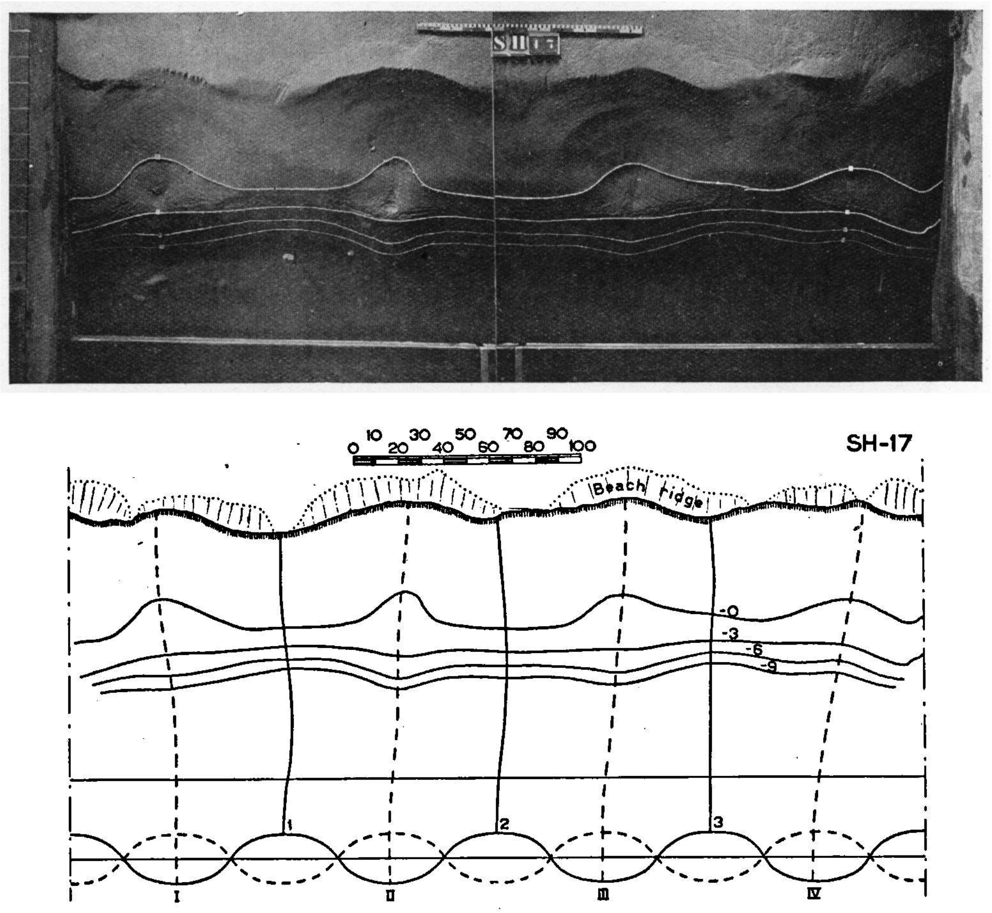

Fig. 15.
Result of exp. SH 17.
A photograph, B analysis.

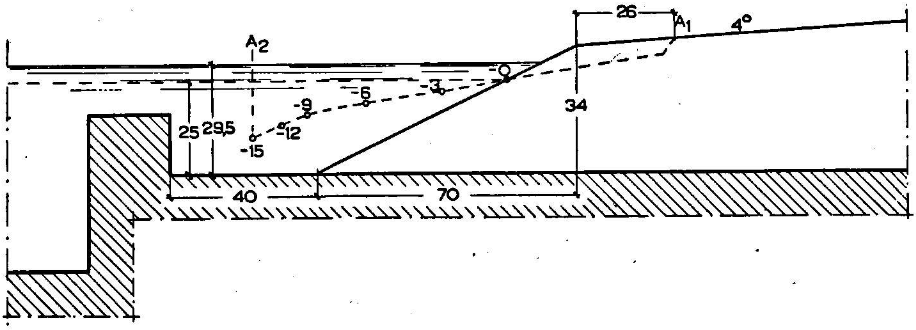

Fig. 16.
Section through the beach belonging to experiment SH 18.

level of 29.5 cm (highwater), followed by 66 waves during ebbtide. Fig. 17 A and B shows the result.

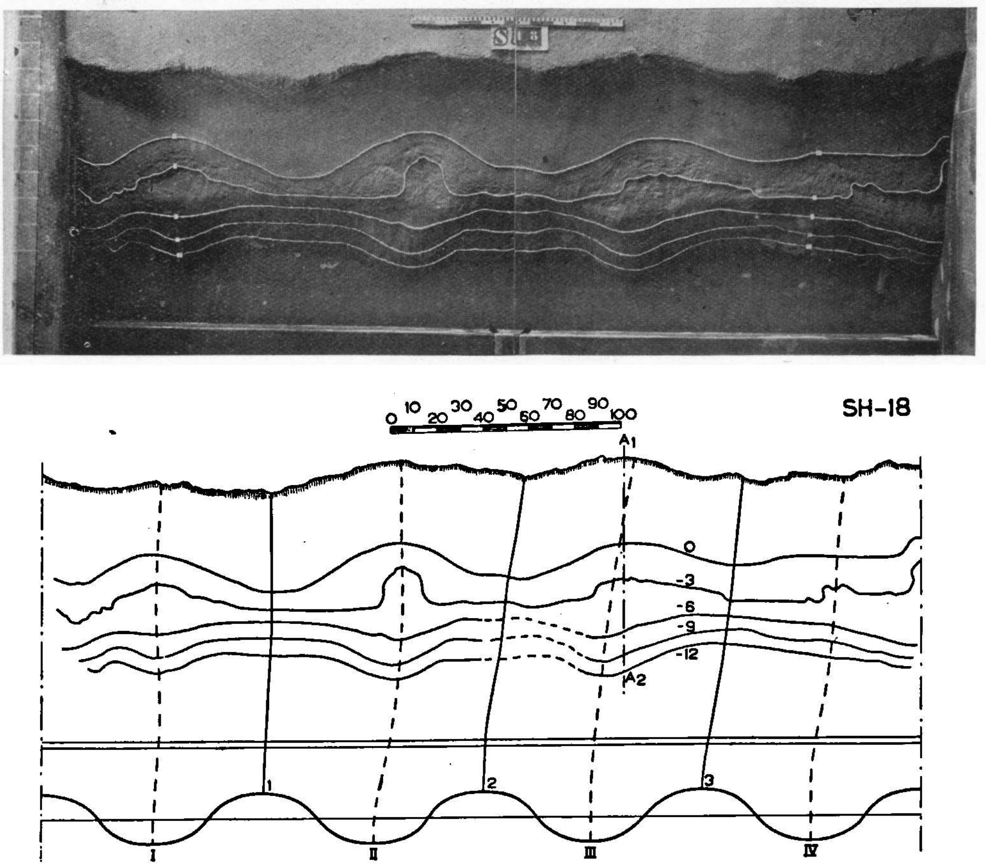

Fig. 17.
Result of exp. SH 18.
A photograph, B analysis.

As was expected no accumulation took place; a steep shore was developed with bays and beach cusps. Contours with an equidistance of 3 cm at 0, —3, —6, —9 and —12 cm correspond with water levels of 25, 22, 19, 16 and 13 cm. The beach cusps are situated opposite the wave culmination 1—3, the bays opposite the depressions I—IV. The diagram (fig. 17B) of the standing wave, represents the shape of that wave on top of the running wave when the latter passed the concrete wall.

Exp. SH 20.

Water level first constant, then falling from 29.5 to 22 cm. Period 0.66 sec. 12 nodes. Beach profile: first inclination of 4°, then, at 31 cm height, sharp bend to a slope of 27°. Distance from sharp bend to concrete wall 62 cm (fig. 18). Duration of wave erosion 28 + 79 sec = 1 min 47 sec.

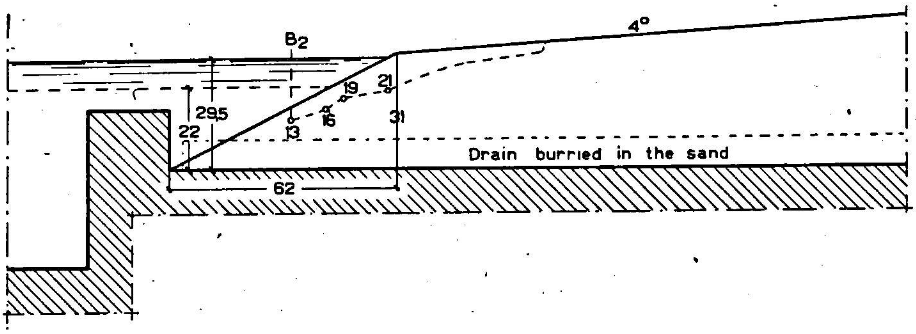

Fig. 18.
Section through the beach belonging to experiments SH 20 and SH 21.

At high water level 45 waves attacked the beach, then 114 waves during ebbtide (from 29.5—22 cm). Results shown in fig. 19 A and B

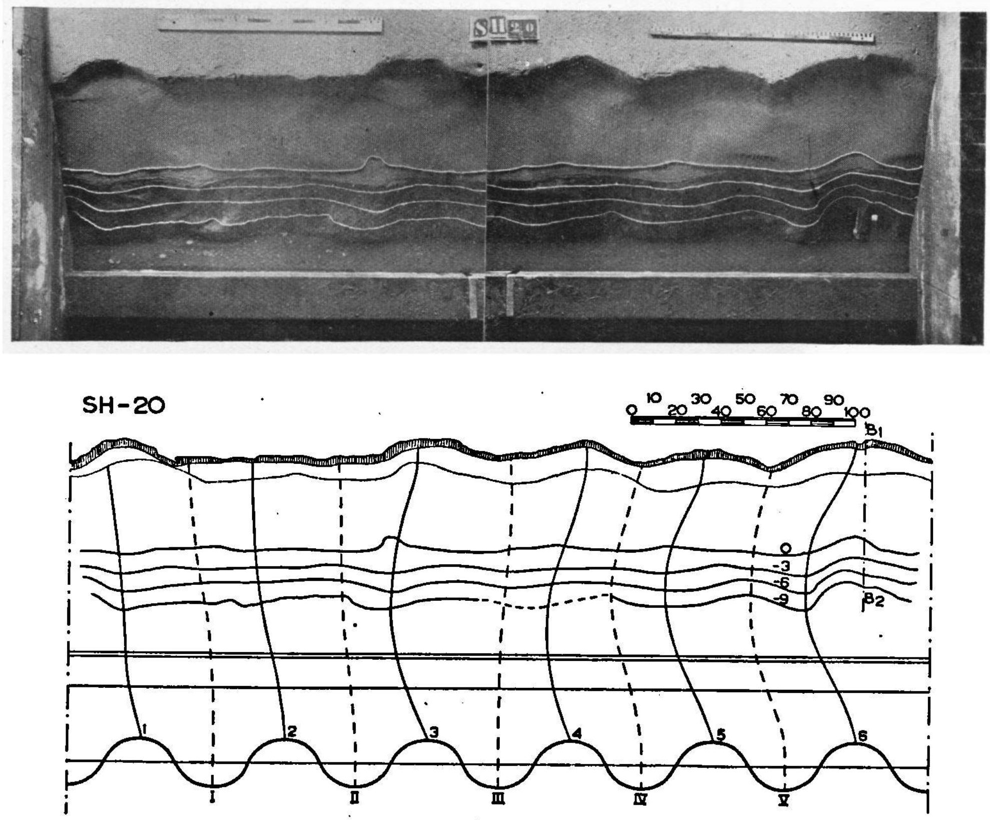

Fig. 19.
Result of exp. SH 20.
A photograph, B analysis.

Curiously enough one bay is lacking, viz. opposite wave culmination 2. No explanation can be offered. In the right half of the experiment distinct beach cusps have developed opposite III, IV and V. The upper contour is at 22 cm, the next ones at 19, 16 and 13 cm, the water level is at 10 cm. In this experiment the steep beach was very near the plunging trough.

Including the missing bay we count 6 bays at rather regular intervals. The top of the running wave passed the centre of the concrete wall with a depression (fig. 19B). The bays developed opposite the wave culminations 1—6, the beach cusps opposite the depressions I—V. This is in direct contrast with exp. SH 18, where the bays were opposite the depressions I—IV, and the cusps opposite the culminations 1—3. The explanation of this reversion of the phenomenon must be sought in the smaller distance between beach and plunging body.

Exp. SH 21.

Water level first constant then falling from 29.5 to 23.5 cm. Period 0.66 sec. 12 nodes. Same beach as in exp. SH 20. Duration of wave erosion 33 + 109 sec = 2 min 22 sec.

After the first 36 waves of 12 nodes, eroding the beach with a constant water level of 29.5 cm, came 168 waves with a sinking water level (29.5 to 23.5 cm).

The result (fig. 20 A and B) is in fair agreement with the 12 nodes of the standing cross wave. The beach cusps opposite 2, 3, 4 and 5 are distinct. Probably as a result of complications, caused by the wall of the basin, the beach cusps opposite 1 has become indistinct, and that opposite 6 is lacking altogether. This disturbing effect is partly due to small poles along the wall, between which the board was placed. These poles were removed before the photograph was taken. Moreover, at the right side of the basin, the drainpipe, laid out below the sand, caused disturbances. In the bay opposite 6 the sharp bend in the beach profile receded 23 cm as a result of erosion.

While in exp. SH 20 6 bays developed theoretically, we find only 5 here. This is probably due to an error in the observation of the situation of the culminations and depressions on the wave top of the running wave, when the latter passed the threshold. It ought to be as the dotted line in fig. 20B shows.

Exp. SH 24.

Water level first constant, then falling from 29.5 cm to 21.5 cm. Period 0.72 sec. At the start 12 nodes. The steep part of the beach as in experiment SH 20, but sharp bend at a height of 29.5 cm, then beach with a slope of 4°. On the dry beach a strip of about 60 cm breadth covered with pumice gravel. Duration of wave erosion 22 + 127 sec = 2 min 29 sec.

This experiment is noteworthy because at the start 12 nodes developed; but as this standing wave did not agree with the period of 0.72 sec an 11-node wave developed later on.

The first waves with constant water level having at the start 12 nodes, running on the dry beach, built up a beach ridge of gravel

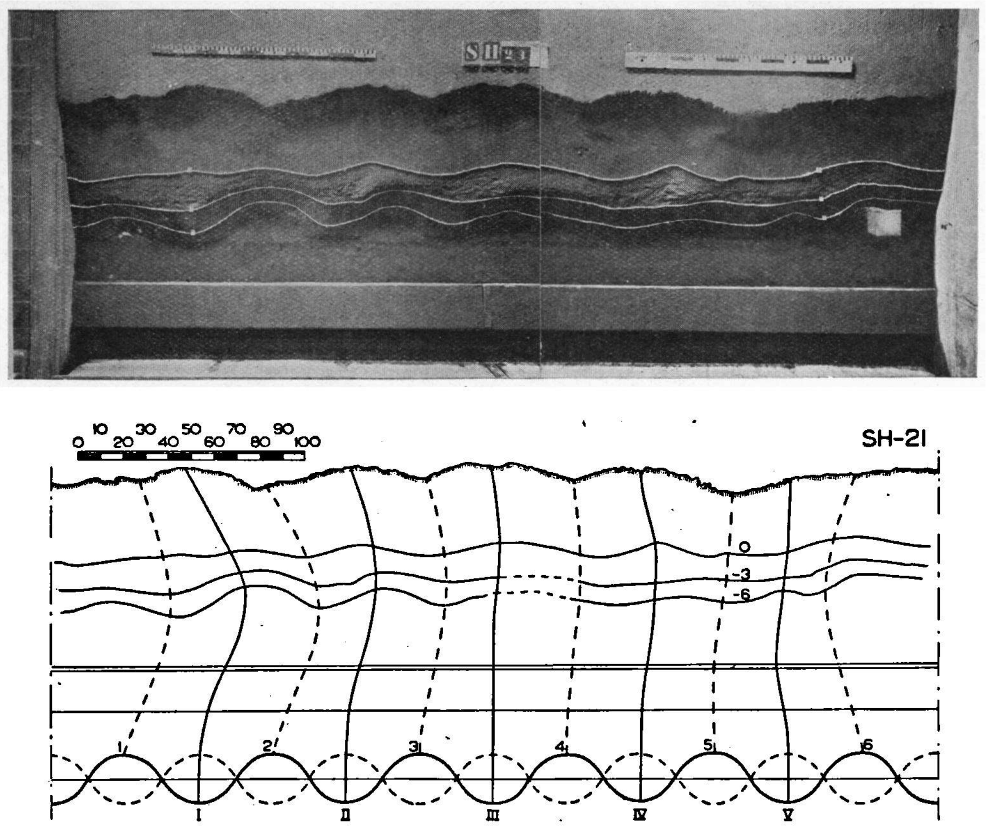

Fig. 20.

Result of exp. SH 21.
A photograph, B analysis.

(fig. 21 A and B). In this ridge we recognize distinctly the remains of 5 beach cusps A, B, C, D and E; but the steep cliff-like shore, eroded during the second period of the experiment is irregular as waves of both 12 and 11 nodes caused the erosion.

Exp. SH 26.

Water level for the first constant at 29.5 cm, then falling to 22.5 cm. Period 0.68 sec, 12 nodes. Beach profile with steep front of 24°, sharp bend at 28.5 cm height, and then flat beach with a slope of 4° (fig. 22). Duration of wave erosion 3 + 94 sec = 1 min 37 sec.

Only a few waves reached the beach at constant water level, while 139 waves attacked the beach during ebbtide. The photograph was taken with a water level of 22.5 cm (fig. 23 A and B).

Beach cusps were formed at A, B, C, D and E but those of A, C and E were eroded again later on. Probably in the beginning depressions of the standing waves arrived at A, B, C, D and E, but later on the conditions were reversed and culminations partly eroded the cusps first formed.

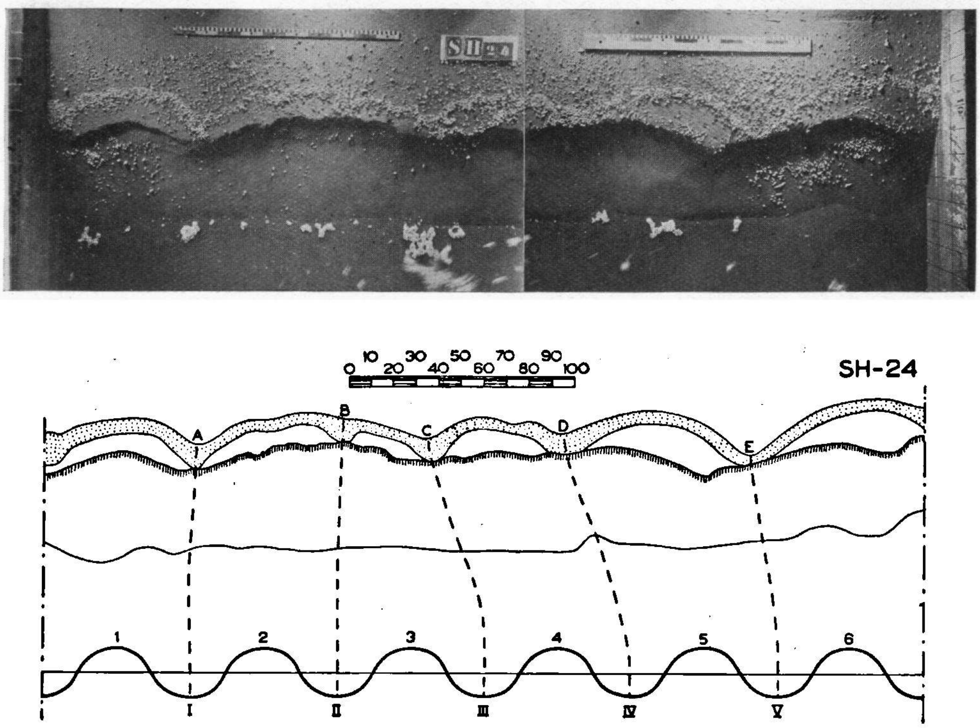

Fig. 21.
Result of SH 24.
A photograph, B analysis.

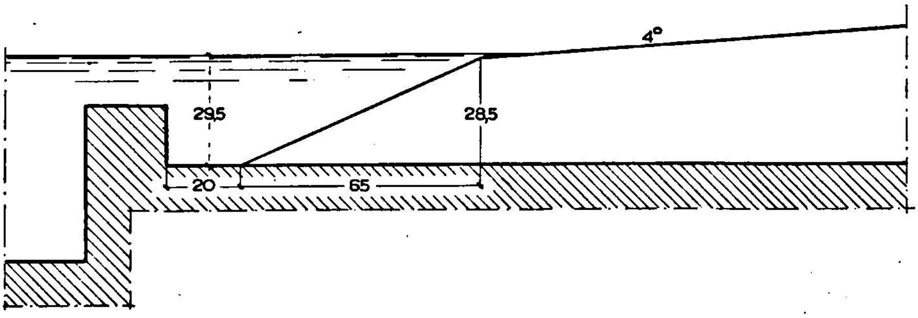

Fig. 22.
Section through the beach belonging to experiment SH 26.

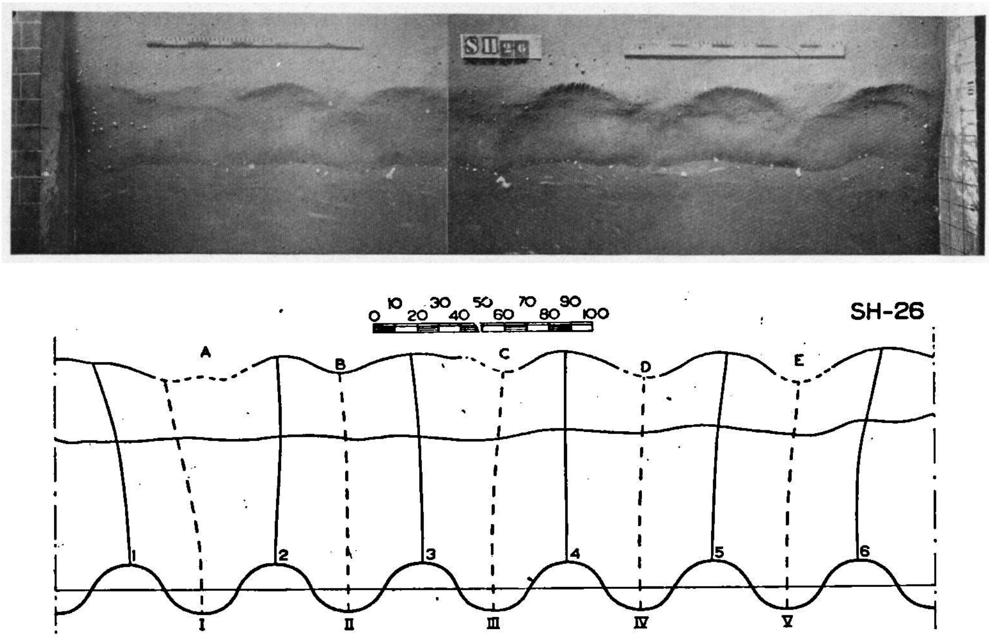

Fig. 23.
Result of exp. SH 26.
A photograph, B analysis.

Exp. SH 28.

Water level first constant at 29.5 cm, then falling to 26 cm. Period 0.69 sec, 12 nodes. Beach profile with steep front with slope of 30°, sharp bend at 33.5 cm, then slope of 4° (fig. 24). Duration of wave erosion 36 + 59 sec = 1 min 35 sec. At the beginning 51 waves eroded the beach with constant water level, afterwards 89 waves with sinking water level.

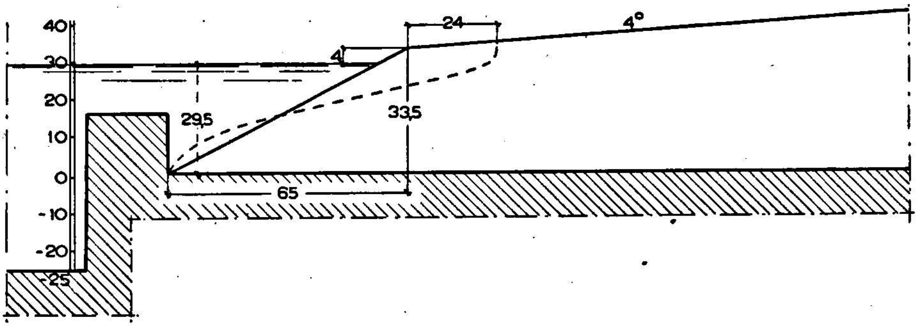

Fig. 24.
Section through the beach belonging to experiment SH 28.

As at the start the water level was 4 cm below tbe sharp bend, a cliff was formed (fig. 25 A and B). The recession of the sharp bend amounted locally to 24 cm. The highest contour is the 0-line, corresponding with a water level of 26.5 cm, the succeeding ones are at 23.5, 20.5 and 17.5 cm, indicated by —3, —6 and —9.

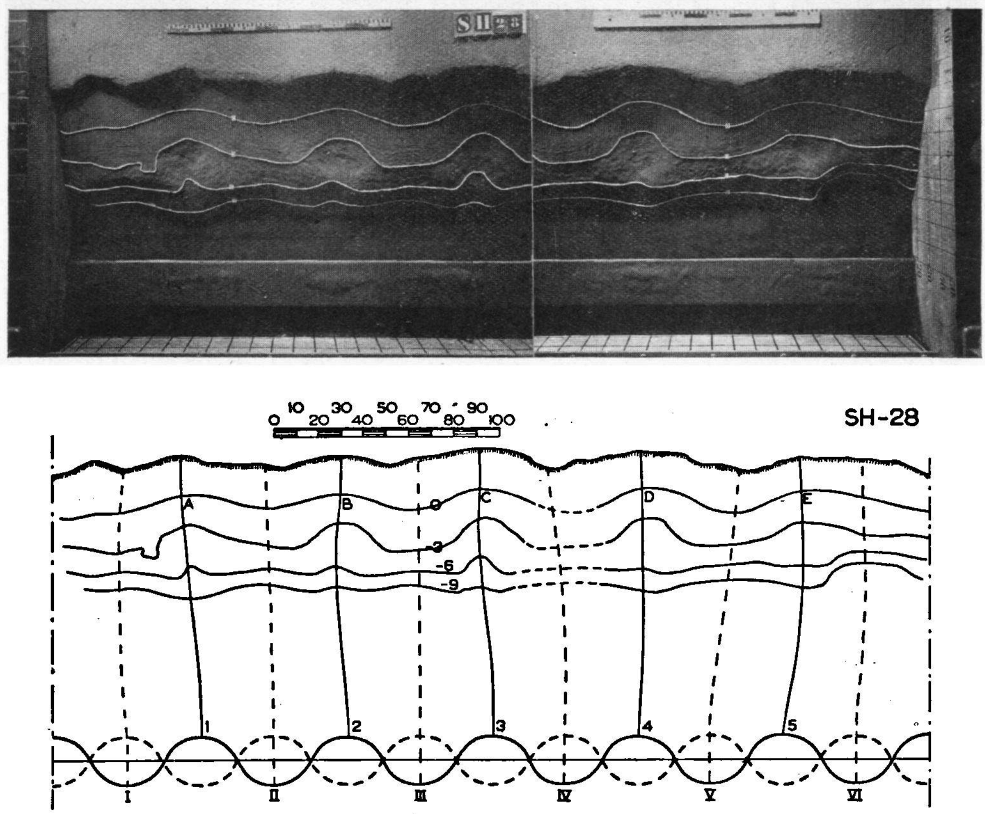

Fig. 25.

Result of exp. SH 28.
A photograph, B analysis.

The bays A, B, C, D and E are very distinct, corresponding with the culminations 1, 2, 3, 4 and 5 of the waves. The protruding parts of the beach are less distinct. Along the walls the poles belonging to the board again disturbed the effect, as did also the drain.

4. DISCUSSION OF THE RESULTS.

The experiments show that running waves with superposed standing waves erode a beach in such way that bays are developed. Between the bays ridges appear.

The ratio between the distance of base to apex and the cord of the bay segments in the experiments is as follows:

SH — 12 1 : 6.3, 1 : 6.5, 1 : 6.4, 1 : 6.6
SH — 16 1 : 5.5, 1 : 5.4, 1 : 8.2
SH — 17 1 : 4.7, 1 : 4.6
SH — 18 1 : 8.2, 1 : 8.3
SH — 20 1 : 5.6, 1 : 6.4, 1 : 5.4
SH — 21 1 : 7, 1 : 7.7, 1 : 6.9
SH — 26 1 : 3.5, 1 : 3.2, 1 : 3.1, 1 : 3.3
SH — 28 1 : 6.2, 1 : 7.3

The ratio is fairly constant in every experiment.

On photographs of natural beach cusps the ratio seems to be much larger. This is mostly due to the view from a comparatively low point parallel to the coast, shortening the chord.

P. D. TIMMERMANS (bibl. 2) gives the following values for beach cusps in sand:

p. 351. On steep sandy beach near high water line.
Chord 20—25 m, base to apex a few meters. A few meters interpreted as 3 m gives the relation as 1 : 8
„ 4 m „ „ „ as 1 : 6
„ 5 m „ „ „ as 1 : 5

p. 352. Steep slope, chord 7—14 m, base to apex 1.5—3 m, relation height: chord = 1 : 4.7.

D. W. JOHNSON (bibl. 1) gives the following values:

p. 466. Beach cusps in fine sand: base to apex 20—30 feet, chord 75—90 feet, or as 1 : 3.5 and 1 : 3.

Apparently only few values of the dimensions of natural beach cusps have been published, but the above mentioned data agree well with those of the artificial cusps.

Our problem now is whether in nature beach cusps can be formed in the same way as in our experiments.

Passing close along the north coast of Java between Semarang and Pekalongan, North of the Gn. Priska, on the 11th May 1929 I observed very regular beach cusps from the train. This coast is characterized by small patches of beach between rocky promontories (Lava?)

P. D. TIMMERMANS (bibl. 2, p. 364) concludes that bays flanked by protruding peninsulas offer favourable conditions for the development of beach cusps. These circumstances are also found on the west side of the tombolo connecting the peninsula of Penandjongan with the south coast of Java (fig. 26). A steady swell of the sea, running on a beach, flanked by two promontories, has apparently a good chance of acquiring superposed standing cross waves.

TIMMERMANS (bibl. 2, p. 351) mentions from the Dutch coast an observation during Sept. 1931, North of Callantsoog. Perpendicular to the coast spur dikes are built at distances of 300 meters. The beach cusps formed are those mentioned before with a chord of 20—25 m and a distance from base to apex of a few meters. The circumstances for the development of standing waves seem to be favourable. The width of the beach between the stone slopes of the spur dikes is ± 280 m.

To apply the formula of MERIAN $Tn = \frac{2\,l}{2\sqrt{gh}}$, the depth of the water, in which the standing waves developed, may be taken as one meter.

From the experiments we know, that to n nodes belong $\frac{n}{2}$ or $\frac{n}{2} - 1$ beach cusps. As the chord was 20—25, average 23 m, $\frac{280}{23} = 12$ beach cusps would have been formed. Therefore the number of nodes was 24.

The period of the waves would have been $Tn = \frac{560}{24\sqrt{9.81}} = 7.5$ sec.

Fig. 26.

Aerial view of the peninsula Penandjongan, South coast of Java.

The period of the waves on the Dutch coast has been determined by TIMMERMANS (lit. 2, p. 243) as varying from 4.9 to 7 sec under widely differing conditions. The two values for the wave-period agree very well, i. e. the example does not contradict the theory.

TIMMERMANS observed beach cusps also on beaches without spur dikes. In the winter of 1933, North of the beach stake 67 near Zandvoort, he found beach cusps on the steep slope to landward of a low on the beach.

According to TIMMERMANS (bibl. 2, p. 353) they were formed during a period of Eastern winds, that is winds blowing from the land. With such a wind we have a regular swell of low waves on the Dutch coast.

The regularity of the swell is favourable to the production of standing waves.

In this case the standing waves were formed in the low on the beach. This low is a trough-shaped basin on the beach, separated from the sea by a sandbar or ball, which is covered by the sea at high water and dries at falling tide.

We mentioned above that TIMMERMANS observed typical beach cusps in the steep slope of the beach. In one of his conclusions concerning the origin of beach cusps he says: „Beach cusps will be formed when the waves run up a steep slope, that is thereby eroded.". In our experiments too, typical beach cusps developed only when a steep slope was eroded. If this condition was not satisfied, only rhythmic shapes on the beaches were formed by accumulation of sand or pebbles, but those shapes never were typical beach cusps.

In the majority of experiments a certain number of waves eroded the beach at high tide and a greater number during falling tide. The idea we had in mind was, that beach cusps are ephemeral shapes, visible at low tide but probably again destroyed during rising tide. Or, even if they are formed during rising tide, they remain invisible.

Starting from our assumptions we can imagine two kinds of origin in nature.

In the first place, the period of the regular swell of the sea in a bay or beach-low, possessing a constant depth, corresponds with the period of a standing cross wave of *n* nodes. This condition can be satisfied irrespective of the presence or absence of tides.

A second mode of origin is possible on a coast with a difference of say more than 1 meter between low and high tide, as on the Dutch coast. Here the period of the regular swell may correspond during a short time interval at falling tide with the period of a standing wave in a beach-low, and beach cusps will be formed.

There is one phenomenon in our experiments, however, which is probably not matched in nature, viz. in our experiments the standing waves are steep, they are probably much flatter under natural conditions.

Finally I want the point out, that not all rhytmic hollows in beaches are beach cusps. Giant ripple marks are also rhytmic, but for a trained eye they are easily distinguishable from beach cusps.

The fact that TIMMERMANS, in his excellent experimental work, did not arrive at this explanation of beach cusps, is readily understood, because he actually avoided standing waves as much as possible. He studied the action of normal waves on the beach and used the small eccentric hubs with a stroke of 2 to 6 cm.

In future we will have: 1. to collect more data in nature on the dimensions of beach cusps, 2. to observe the development in nature, e.g. the shape of the wave has to be observed accurately.

Our hypothesis can only be proved, by the actual observation, preferably also the filming of running waves with a superposed standing wave and at the same time of beach cusps in statu nascendi, with a corresponding period.

Oegstgeest, June 1937.

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