CHAPTER 86

GROIN LENGTH AND THE GENERATION OF EDGE WAVES

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ABSTRACT

A series of wave basin experiments were undertaken to better understand the selection of groin spacings and lengths. Rather than obtaining edge waves with the same period as the normal incident waves, subharmonic edge waves were produced with a period twice that of the incoming waves and a wave length equal to the groin spacing. Rip currents were therefore not formed by the interactions of the synchronous edge waves and normal waves as proposed by Bowen and Inman (1969). Rips were present in the wave basin but their origin is uncertain and they were never strong enough to cause beach erosion.

The generation of strong subharmonic edge waves conforms with the work of Guza and Davis (1974) and Guza and Inman (1975). The subharmonic edge waves interacted with the incoming waves to give an alternating sequence of surging and collapsing breakers along the beach. Their effects on the swash were sufficient to erode the beach in some places and cause deposition in other places. Thus major rearrangements of the sand were produced between the groins, but significant erosion did not occur as had been anticipated when the study began.

By progressively decreasing the length of the submerged portions of the groins, it was found that the strength (amplitude) of the edge waves decreases. A critical submerged groin length was determined whereby the normally incident wave field could not generate resonant subharmonic edge waves of mode zero with a wavelength equal to the groin spacing. The ratio of this critical length to the spacing of the groins was found in the experiments to be approximately 0.15 to 0.20, and did not vary with the steepness of the normal incident waves.

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INTRODUCTION

Rational criteria for selecting groin lengths, spacings, heights, and angles to the shoreline for a given beach and wave conditions are not well developed. Some general criteria, founded on past experience, are mentioned in the literature. For example, Coastal Engineering Research Center (1973) recommends that groins be spaced two to three times the offshore groin length. A general review of beach protective structures, including groins, can be found in Bruun (1972).

In this study a series of wave basin experiments were undertaken for the purpose of better understanding the selection of groin spacings and lengths. It was initially supposed that a certain groin spacing would cause resonant conditions with the incoming waves such that strong edge waves would be generated with the same period as the normal waves. As shown by Bowen (1969) and Bowen and Inman (1969), such edge waves can interact with the incident waves to generate steady rip currents. Our working hypothesis was that such resonant conditions should be avoided as the resulting rip currents would be a hazard to swimmers and the rips would wash the sand offshore, defeating the purpose of the groins. We felt that some groin failures might have been an inadvertent selection of a groin spacing that resonated with the existing beach and wave conditions.

Our experiments quickly demonstrated that our initial hypothesis was incorrect, at least for the wave-basin scale and groin geometry tested. Rather than obtaining edge waves with the same period as the normal waves in the basin, subharmonic edge waves were produced with periods twice those of the incoming waves so that rip currents were not formed by the interactions of the edge waves and normal waves as proposed by Bowen (1969) and Bowen and Inman (1969). Rip currents were present in the wave basin but their origin is uncertain and they were not strong enough to cause beach erosion. They commonly originated at the node position of the subharmonic edge waves, but then migrated alongshore to the antinode positions, obtaining their best development when adjacent to a groin.

Guza and Davis (1974), Guza and Inman (1975) and Guza and Bowen (1975) had previously demonstrated theoretically and experimentally that the subharmonic edge wave with a period twice that of the incident waves is most

easily generated and the one most often occurring. The second most likely edge wave to be generated is that with a period equal to the incoming wave (termed the synchronous edge wave) of low modal number. Our wave basin experiments, therefore, agree with their conclusions. In all our experiments, subharmonic edge waves were eaily generated in the wave basin, while synchronous edge waves were not detected even when the appropriate boundary conditions were employed. Guza and Inman (1975, p. 3005) found that when the incident wave period was chosen so that the groin and beach geometry excluded subharmonic resonances, synchronous edge waves were sometimes clearly visible in the run-up. This was not the case in our study. The reason is unknown; perhaps it is due to the smaller scale of our wave tank.

Our finding strong subharmonic edge waves in the wave tank tests also agrees with the field studies of Huntley and Bowen (1973, 1975a). Through measurements of the horizontal water particle velocities across the nearshore on a steeply sloping beach, they obtained clear evidence for the existence of subharmonic edge waves; synchronous edge waves were not detected.

Because we obtained only subharmonic edge waves, our study shifted to an investigation of their effects on the beach between the groins, and to the strength of the edge waves as a function of the groin geometry and wave conditions. The strength of the edge waves was taken as indicated by its swash distance up the beach face and its amplitude computed from this swash distance. As will be seen, the strength was found to be a function of the groin length and spacing.

A series of experiments were conducted with a thin layer of sand covering the otherwise evenly sloping solid beach for the purpose of determining what effects the presence of the sand might have on the edge wave strength and how the sand is redistributed on the beach by the combination of edge waves and incoming waves. The interest was whether general erosion or accretion of the beach would result from the presence of the subharmonic edge waves, and therefore whether they are to be avoided in the design of groin fields.

COMBINED FLOW OF EDGE WAVES AND NORMALLY INCIDENT WAVES

Recent research by Bowen (1969), Bowen and Inman (1969, 1971), Guza and Davies (1974), Guza and Inman (1975), Guza and Bowen (1976), and Huntley

and Bowen (1973, 1975a) have shown that waves incident on a beach can generate standing edge waves. Standing edge waves have their crests normal to the shoreline and their wave lengths from crest to crest parallel to the shoreline. Thus they are rotated ninety degrees in orientation to the incident swell waves. As shown in Figure 1, there are alternate positions

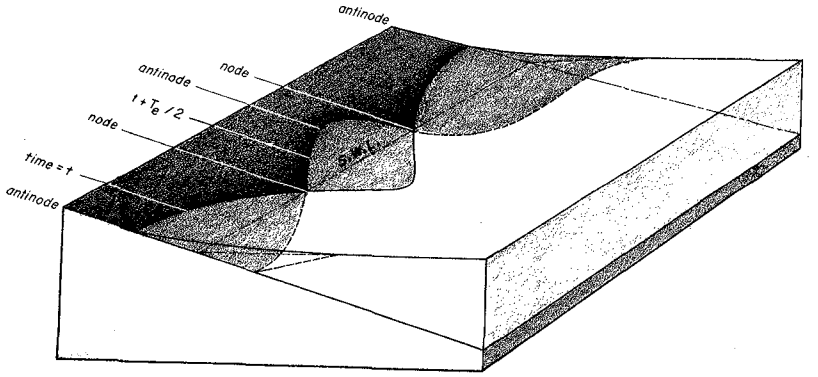

Figure 1: One possible type of standing edge wave (zero mode) with nodes and antinodes along the beach length, and decreasing in amplitude offshore. Higher-mode edge waves have a more complicated offshore variation in amplitude.

of nodes and antinodes along the beach. At the nodes there is no up and down motion of the water surface due to the edge waves, and at the antinodes the full edge wave height can be observed. The edge wave oscillations are best detected as run-up on the sloping beach. The edge wave height is maximum at the shoreline and decays offshore in a manner depending on the offshore modal number (Ursell, 1952).

Since in our experiments we obtained only subharmonic edge waves, our discussions will be limited to their interactions with the incoming waves and the resulting effects on the beach. The combined motion of the incident waves and the generated subharmonic edge waves is shown in Figure 2. The groins are located along the right and left hand boundaries, defining a

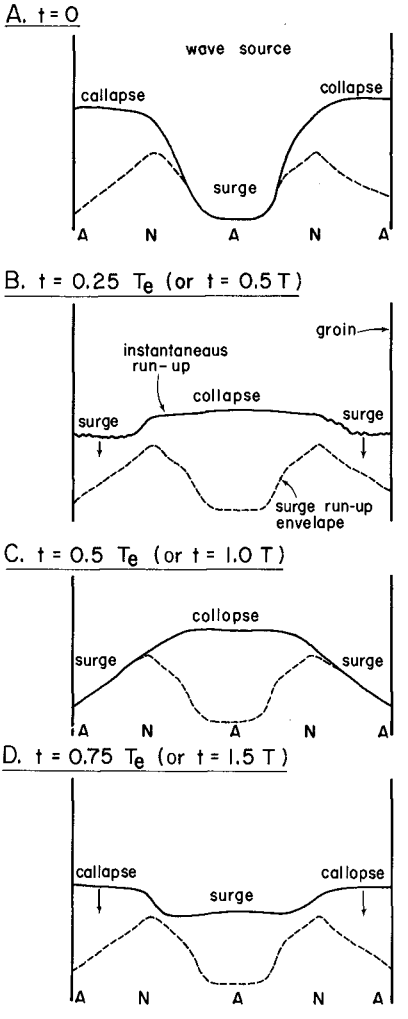

Figure 2: The interactions of the subharmonic edge waves with the normal waves to give a varying pattern of run-up and breaker type. Note that the edge wave period T_e is twice the period T of the paddle-produced waves.

limited length of beach. Figure 2 is based on actual photographs of the wave basin tests. The continuous line indicates the instantaneous position of the leading edge of the combined wave run-up, while the dashed line depicts the maximum wave run-up envelope. The groin spacing is 3.0 meters, and antinodes (A) are located at each groin and midway between them. The two nodes (N) are midway between the antinodes. The wave run-up at the edge wave nodes is approximately equal to the run-up due to the paddle-driven waves alone.

In Figure 2A the run-up is maximum at the central antinode where the breaker surged up the beach face. Figure 2B shows the next wave collapsing at the central antinode due to its interaction with the backwash from the previous surging breaker. In addition, in Figure 2B the breakers at the bounding antinodes can be seen beginning to surge up the beach slope. In Figure 2C the run-up is maximum at the bounding antinodes and minimum at the central antinode; this run-up pattern occurs one half of an edge wave period (equal to one period of the incident waves) after the run-up pattern in Figure 2A. Figure 2D displays the run-up approximately one-fourth edge wave period later. The incident wave at the central antinode is beginning to surge up the beach face while the breakers at the bounding antinodes are of a collapsing type.

As the wave height of the incident paddle-driven waves was increased, the breaker types become more plunging, and the edge wave amplitude decreases until it is no longer observable in the run-up pattern. Guza and Inman (1975) obtained the same results. The indication is then that under larger waves on beaches the edge waves will be relatively less important and may disappear altogether. However, the measurements by Huntley and Bowen (1973, 1975a) of standing subharmonic edge waves even under plunging wave conditions suggest that they do not disappear entirely, although they may not be observable in the swash run-up.

Reflection of the incident waves from the beach face is important in the generation of edge waves according to the theoretical considerations of Guza and Davis (1974) and Guza and Bowen (1975). This again appears to be borne out by the field measurements of Huntley and Bowen (1973, 1975b) who did not find incident-wave related edge waves on a low sloping beach (slope

tangent 0.014) but did on a steep beach (slope tangent 0.13). Our laboratory tests are limited to a steep beach (slope 0.125) where wave reflection and edge wave development can be expected to be important.

Longshore periodicities observed on laboratory beaches may be due to cross waves produced at the wave paddle and extending down the entire wave basin length (Garrett, 1970). Cross waves can be ruled out as producing the run-up patterns observed in the present study. In most tests, wave periods were selected so as to give resonant conditions for the generation of subharmonic edge waves. In addition, the run-up patterns already described closely conform to those recounted by Guza and Inman (1975) for edge waves.

GROIN LENGTH ON NONERODABLE BEACHES

A series of experiments were conducted to determine the effect of the groin length and spacing on the run-up and amplitude of the generated edge waves. As in the other tests, the wave basin in the hydraulics laboratory of the School of Engineering, Oregon State University, was employed. This wave basin is 6.1 m wide and 9.1 m in length along the direction of wave propagation. Wave guides were placed parallel to the side walls and adjacent to the paddle edges to eliminate wave reflection and diffraction as the waves travel toward the sloping beach. Because of the relatively short length of the basin, a steep beach slope $s = 0.125$ had to be used. Wooden impermeable groins were placed perpendicular to the shoreline a distance b apart.

To satisfy the boundary conditions of no flow through the groins,

$$b = m L_e / 2 \qquad (1)$$

for the groin spacing b, where m is an integer equal to the number of half edge wave lengths in the longshore direction, L_e denoting the full edge wave length in the longshore direction. Using this equation and the dispersion relationship for standing edge waves (Guaz and Inman, 1975), the relationship

$$b = g T_e^2 m (1 - 2p) s / 4\pi \qquad (2)$$

is obtained where g is the gravitational acceleration, T_e is the edge wave

period, m the modal number of equation (1), p is the slope truncation effect, and s is the beach slope. For the conditions of these experiments, $m = 2$ and $p = 0$, yielding the simplified equation

$$b = \frac{g T_e^2 s}{2\pi} \qquad (3)$$

To generate the resonant edge waves associated with a groin spacing b, the normally incident paddle-driven waves must have a period equal to one half the edge wave period T_e in equation (3). For the groin spacings used, $b = 2$ m, 2.5 m, 3 m, and 3.5 m, the corresponding edge wave periods are $T_e = 3.20$, 3.60, 3.92, and 4.24 sec respectively.

In order to observe the maximum possible run-up at the antinodes due to the edge waves alone, very long groins were initially used. The run-up due solely to the edge wave was determined at the central antinode by measuring the total maximum run-up at time intervals equal to the incident wave period. Subtracting two successive run-up measurements eliminated the run-up due to the incident waves and yielded the edge wave run-up portion. These measurements were repeated for ten waves and averaged. Once a run-up value for the long groins was obtained, both groins were shortened and the measurements repeated. The groins were thus progressively decreased in length until edge waves were no longer observed in the run-up.

Figure 3 and Table 1 summarize the results of these experiments for the series of groin spacings $b = 2.0$, 2.5, 3.0 and 3.5 m. The beach slope tangent was held at $s = 0.125$, and the deep-water wave steepness remained nearly constant at $H_\infty/L_\infty = 0.005$ to 0.0064. The ordinate in Figure 3 is the run-up R_e due to the edge waves, divided by the maximum edge wave run-up $R_{e\text{-}max}$ which occurred for the longest groin length. The abscissa is the ratio of the groin length L_g to the groin spacing b. The submerged groin length is used for L_g, and is defined as the offshore length measured from the intersection of the still-water line with the beach face.

From Figure 3 it is seen that for all four groin spacings, as the submerged groin length L_g is decreased, the run-up due to the edge waves is decreased. When the submerged groin length is decreased to about 0.15b,

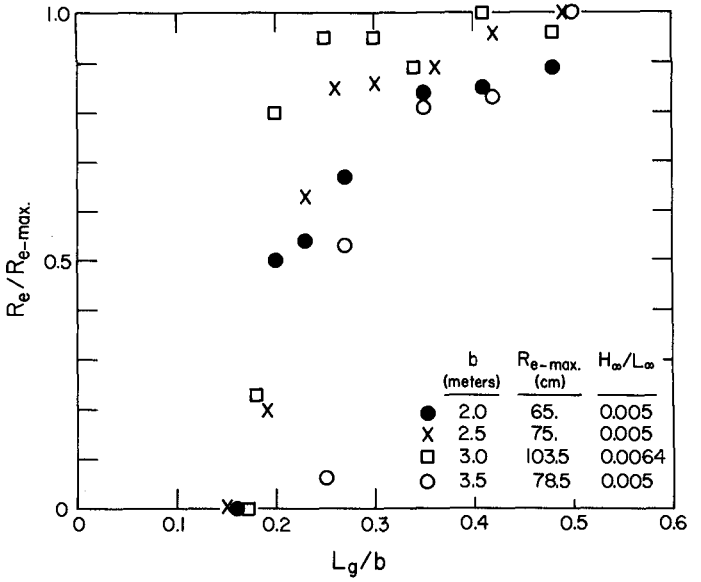

Figure 3: The strength of the subharmonic edge waves as indicated by their run-up R_e, the strength decreasing as the length of the groins L_g are decreased relative to the groin spacing b.

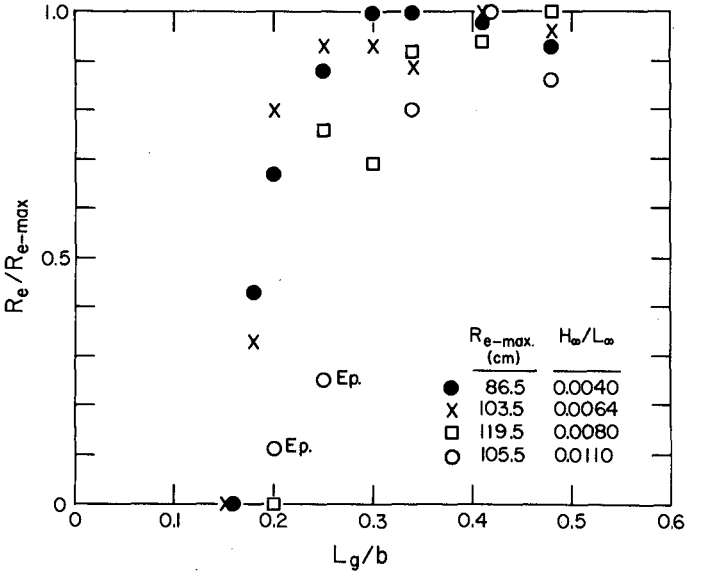

Figure 4: Experiments similar to those of Fig. 3 but where the groin spacing is held constant at 3 meters and the wave steepness varied.

TABLE 1: Edge Wave Run-up Versus Groin Length

A. Experiments on nonerodable smooth slope

1. b = 2.0 m; T_i = 1.58 sec; H_i = 2.2 cm; h_i = 37.0 cm; $R_{e\text{-}max}$ = 65.0 cm; H_∞/L_∞ = 0.005;

L_g/b	0.77	0.48	0.41	0.35	0.27	0.23	0.20	0.16
R_e/R_{emax}	1.0	0.89	0.85	0.84	0.67	0.54	0.48	0.0

2. b = 2.5 m; T_i = 1.80 sec; H_i = 2.5 cm; h_i = 36.0 cm; $R_{e\text{-}max}$ = 75.1 cm; H_∞/L_∞ = 0.005;

L_g/b	0.49	0.42	0.36	0.30	0.26	0.23	0.19	0.16
R_e/R_{emax}	1.00	0.96	0.89	0.86	0.85	0.63	0.20	0.0

3. b = 3.0 m; T_i = 1.88 sec; H_i = 3.5 cm; h_i = 35.6 cm; $R_{e\text{-}max}$ = 103.5 cm; H_∞/L_∞ = 0.0064;

L_g/b	0.48	0.41	0.34	0.30	0.25	0.20	0.18	0.16
$R_e/R_{e\text{-}max}$	0.96	1.00	0.89	0.93	0.93	0.80	0.33	0.0

4. b = 3.5 m; T_i = 2.21 sec; H_i = 3.5 cm; h_i = 36.0 cm; $R_{e\text{-}max}$ = 78.5 cm; H_∞/L_∞ = 0.005;

L_g/b	0.50	0.42	0.35	0.27	0.25	0.23
$R_e/R_{e\text{-}max}$	1.00	0.83	0.81	0.53	0.06	0.0

5. b = 3.0 m; T_i = 1.88 sec; H_i = 2.2 cm; h_i = 35.6 cm; $R_{e\text{-}max}$ = 86.5 cm; H_∞/L_∞ = 0.0040;

L_g/b	0.48	0.41	0.34	0.30	0.25	0.20	0.18	0.16
$R_e/R_{e\text{-}max}$	0.93	0.98	1.00	1.00	0.88	0.67	0.43	0.0

6. b = 3.0 m; T_i = 1.88 sec; H_i = 4.6 cm; h_i = 35.6 cm; $R_{e\text{-}max}$ = 119.5 cm; H_∞/L_∞ = 0.0080;

L_g/b	0.48	0.41	0.34	0.30	0.25	0.20	0.18	0.16
$R_e/R_{e\text{-}max}$	1.00	0.94	0.92	0.69	0.76	0.0	0.0	0.0

7. b = 3.0 m; T_i = 1.88 sec; H_i = 6.0 cm; h_i = 35.6 cm; $R_{e\text{-}max}$ = 105.5 cm; H_∞/L_∞ = 0.0110;

L_g/b	0.48	0.41	0.34	0.30	0.25	0.20	0.18	0.16
$R_e/R_{e\text{-}max}$	0.86	1.00	0.80	0.00	0.23	0.11	0.00	0.00

8. Experiments on sand-covered slope

1. b = 3.0 m; T_i = 1.88 sec; H_i = 2.2 cm; h_i = 37.0 cm; $R_{e\text{-}max}$ = 36.4 cm; H_∞/L_∞ = 0.0022;

L_g/b	0.52	0.43	0.37	0.32	0.27	0.21
$R_e/R_{e\text{-}max}$	0.79	1.00	0.39	0.53	decay	decay

Definitions: L_g = submerged groin length; R_e = edge wave run-up; b = groin spacing; T_i and H_i are incident wave period and height; h_i = water depth in constant-depth portion of basin.

the characteristic combined flow pattern of subharmonic edge waves and normal paddle waves is no longer observed. There is some variation in this critical groin length, the value of L_g/b being 0.15 for three of the experimental groin spacings, and about 0.25 for $b = 3.5$ m. The decrease in the edge wave run-up is sharp, indicating an abrupt termination in the edge wave's presence. For groins shorter than the indicated critical value of L_g/b, the side-wall boundary conditions imposed by the groins are no longer effective in the generation of edge waves with a wavelength equal to the groin spacing.

Figure 4 and Table 1 contain a similar series of experiments, but where the groin spacing was held at $b = 3$ m and the wave steepness H_∞/L_∞ varied. Although the scatter is large, the experiments yield the same range of critical L_g/b values for the termination of edge wave run-up as found in Figure 3. The indication in Figure 4 is that if there is any dependence of the critical L_g/b ratio on the wave steepness, it must be small. In the case of $H_\infty/L_\infty = 0.011$, Figure 4, as L_g/b approached the critical value, the edge waves were observed to be episodic, appearing for a time and then disappearing. These are labeled Ep. in the diagram.

Our results then indicate that there is a critical groin length to spacing ratio, L_g/b, below which subharmonic edge waves apparently are not generated, or are at least not observed in the run-up. This critical condition is not appreciably affected by the steepness of the normal incident waves. The basin utilized in our experiments is not sufficiently long to install low beach slopes, so we were not able to test for a beach slope dependence of the critical L_g/b value.

The reduction in the edge wave amplitude at the shoreline as the groin length is decreased can be related to the edge wave's amplitude dependence on the offshore distance. When the long groins are installed the edge wave is fully developed with its amplitude maximum at the shoreline and, according to theory (Guza and Inman, 1975), decaying exponentially offshore as shown by the dash-dot curve in Figure 5. The nondimensional offshore distance is zero at the intersection of the beach slope and the still-water level. Also graphed in Figure 5 is the measured edge wave amplitude at the shoreline for two of the groin spacings as functions of the nondimensional submerged groin length. The

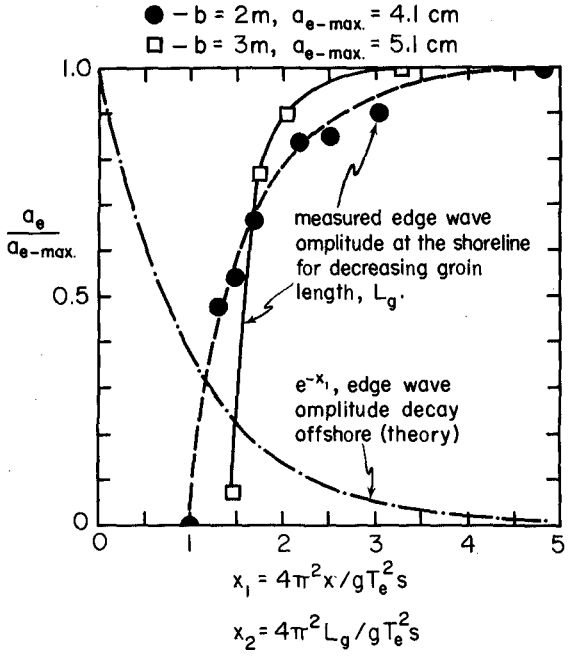

Figure 5: The edge wave amplitude a_e, obtained from the measured run-up, as functions of the submerged groin length and distance x offshore from the still-water line, both expressed in nondimensional form.

edge wave amplitude, a_e, is obtained from the measured run-up R_e by the equation (Guza and Inman, 1975)

$$a_e = R_e s/2 \qquad (4)$$

where s is the beach slope.

The measured edge wave amplitude at the shoreline ($x_1 = 0$) decreases to zero for nondimensional groin lengths between 1.0 and 1.5 (Figure 5). These lengths correspond to an offshore distance where the edge wave amplitude is equal to e^{-1} and $e^{-1.5}$ of its value at the shoreline for the fully developed state (which in these experiments occurred with the longest groin lengths). In other words, subharmonic edge waves were not generated when the groin

lengths did not extend seaward of the offshore distance where the maximum edge wave has an amplitude equal to approximately e^{-1} of its value at the shoreline. For groins shorter than the defined critical length the boundary condition of no flow through the groin wall is not a factor in enhancing the generation of the subharmonic edge wave corresponding to the groin spacing b.

EXPERIMENTS ON NONERODABLE BEACHES COVERED WITH SAND

A series of experiments were undertaken with a thin veneer of sand initially uniformly covering the solid evenly sloping beach. These were performed to determine if the presence of the sand appreciably changes the edge wave run-up values. The results also allow insight into the possible effects of the edge wave's existence on erosion or accretion between the groins.

For each groin length the sand was initially smoothed out 1 to 2 cm thick, covering the beach slope between the groins from the still-water level to depths beyond the influence of the waves. After 1.5 to 2 minutes of normally incident, paddle-driven waves arriving at the beach, edge waves would appear, beginning the redistribution of the sand alongshore as well as in the on-offshore direction. After about 15 minutes the sand would reach an approximately unchanging configuration, although the sand diameter was not in equilibrium with the beach slope.

The general tendency of the combined edge wave and incident waves is to reform the sand into the characteristic pattern shown in Figure 6. The sand extends much further up the beach slope from the still-water level at the antinodes (located near both groins and midway between them) than at the nodes (located midway between the antinodes). This sand has been removed from the now barren slope section (Figure 6) at and just shoreward of the breaker zone. Most of the total volume of sand accumulated on the upper beach is at the edge wave antinode positions not only because it extends further up the beach there, but also because the sand is at least three times as thick. For the groin length in Figure 6, the maximum sand depth at the antinodes is 2.0 cm whereas at the nodes it is only about 0.5 cm. Note

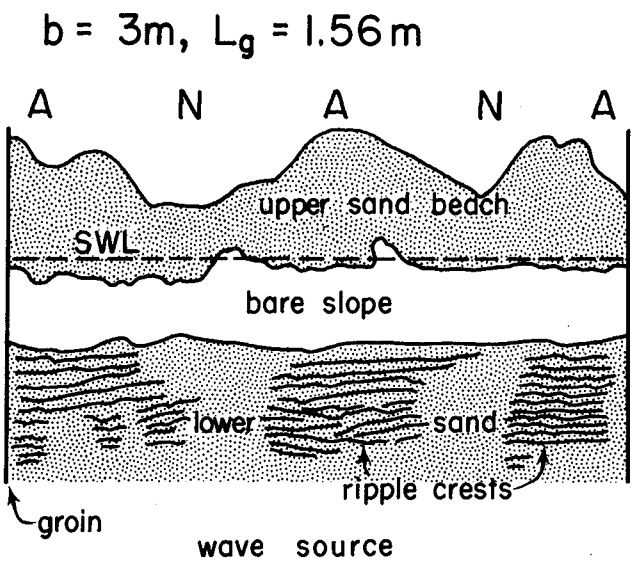

Figure 6: Redistribution of sand on beach face by subharmonic edge waves. Sand initially covered the solid beach in a thin even layer below the still-water level. A and N denote respectively the edge wave antinode and node positions.

that the barren section of the beach slope (the sand source to the upper beach) is very nearly uniform in the longshore direction, indicating that some of the sand seaward of the nodes is transported to the sand accumulations at the adjacent antinodes. The much larger flow velocities occurring at the antinodes are indicated by the sand ripple formations seaward of the barren slope; definite ripple patterns exist offshore of the antinodes while only very weak ripples or none at all exist seaward of the nodes.

When the beach slope is initially entirely covered with a thin layer of sand, rather than covered just below the still-water line as before, the subharmonic edge waves together with the incident waves reform the sand into a series of beach cusps. The intense swash at the antinode positions hollows out the beach sand, producing the embayments; the cusp horns were located at the nodes of the edge waves. This has already been demonstrated by Guza and

Inman (1975), also in a wave basin (see their Figure 8, page 3007). Beach accretion occurs at each cusp while erosion occurs in the embayments at the antinode positions of the subharmonic edge waves; this is just opposite to our previous test with sand initially only below the still-water line. Either way, the presence of the strong subharmonic edge waves caused local rearrangements of the sand on the beach face and local areas of erosion and beach accretion. However, there was no significant offshore losses of sand from the beach face as might have been the case had strong rip currents been produced as originally envisioned.

Experiments similar to those conducted on the nonerodable beach were executed to determine the effect of groin length on edge wave generation in the presence of the sand. For each groin length the maximum combined wave run-up at the central antinode was measured for successive waves and used to compute the edge wave run-up portion R_e as before. Because the sand is not in complete equilibrium with the beach slope, some difficulties were encountered in obtaining realistic edge wave run-up values for all groin lengths.

The general result of these measurements (Table 1) is that the critical groin length determined for the nonerodable solid beach (Figures 3 and 4) is still adequate in the presence of the sand. Although the $R_e/R_{e\text{-}max}$ values tend to decrease with decreasing groin length, a larger amount of variability about this trend is exhibited as compared to the experiments using no sand cover. Part of this variability is due to the uneven distribution of the sand cover alongshore; run-up just to the sides of the antinode positions is not opposed by as thick a sand cover. This run-up, in many cases, flows as high or higher up the beach face than the run-up at the antinode position. This pattern of run-up occurred for the steady sand cover condition described above.

The greatest effect of the sand on the run-up can be seen by comparing the maximum edge wave run-ups with and without the sand present. The $R_{e\text{-}max}$ value with the sand was 36.4 cm, and without the sand it was 86.5 cm.

The decrease in the edge wave run-up as a function of decreasing groin length is demonstrated in Figure 7, obtained from overhead photographs, where

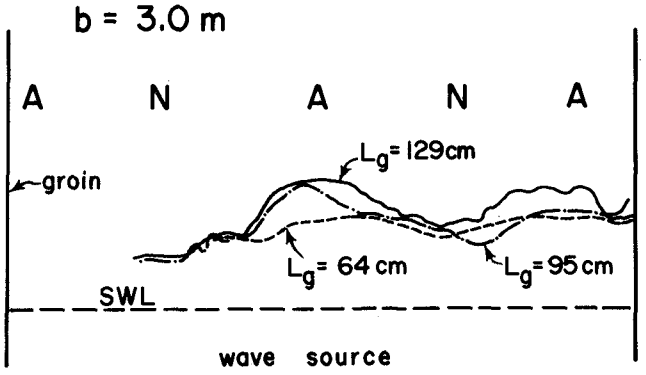

Figure 7: The decrease in the edge wave run-up as a function of the groin length L_g. Run-up lines determined from overhead photographs of sand cover, the sand initially being a uniform thin layer below the still-water level. Lines terminate on left due to inadequacy of photographic coverage.

the beach was again initially covered with sand only below the still-water line. Contours of the maximum distance up the slope of the sand covered beach are plotted for three groin lengths. The general trend of lower maximum contour with decreasing groin length is apparent. For L_g = 64 cm, the edge waves developed after two minutes and decayed after six minutes.

SUMMARY AND DISCUSSION

In all our wave basin experiments, we obtained subharmonic edge waves of period twice that of the incident paddle-produced waves. This lends additional support to the theoretical and experimental work of Guza and Davis (1974), Guza and Inman (1975), and Guza and Bowen (1975, 1976), who found that the subharmonic edge wave is most easily generated and the one most often occurring.

We were unable to generate synchronous edge waves with the same period as the paddle-driven waves. This precluded the formation of rip currents as outlined by Bowen (1969) and Bowen and Inman (1969), where the synchronous edge waves interact with the incident waves to produce longshore variations

in breaker heights and therefore a cell circulation. Rip currents were present in our tests, but at all times they were very weak, too weak to cause any erosion of beach sands between the groins. Initially, we set out to study the resonant conditions leading to strong rip currents, producing beach erosion and thereby defeating the purpose of the groins. Under prototype conditions rip currents do appear to be particularly strong between groins, causing offshore losses of sand. For example, Per Bruun (pers. communication, July 1976) indicated that rip currents were important in sand losses in the groin field at Miami Beach, Florida. Thus our initial working hypothesis seems to have been correct, but our inability to generate strong rip currents in the laboratory wave basin precluded its study. Why we were unable to generate synchronous edge waves and strong rip currents is uncertain; perhaps our wave basin (6.1 m by 9.1 m) is too small.

Subharmonic edge waves were readily produced so our study shifted to an examination of how the groin spacings and lengths control their strength, as manifested in the run-up on the beach face, and how they rearrange sand between the groins. We found that as the submerged lengths of the groins are decreased relative to the spacing, the edge wave strength and run-up decreased. When the ratio of groin length to spacing reached about 0.15 to 0.20, the effects of the subharmonic edge waves on the run-up were no longer observable. Thus subharmonic edge waves can be avoided in groin fields by making the groin lengths sufficiently short relative to their spacings.

A series of tests were undertaken with a thin covering of sand on the otherwise solid beach face to determine how much redistribution of the beach sand would be produced by the subharmonic edge waves. In all tests the edge waves produced a cuspate shoreline so there were local areas of erosion and deposition. However, there were no offshore losses of sand from between the groins so the presence of the subharmonic edge waves posed no threat to the groins nor defeated their purpose. When the beach was initially entirely covered with a thin layer of sand the beach cusps formed had their embayments at the antinode positions of the subharmonic edge waves and the cusp horns at the node positions. This agrees with the results of Guza and Inman (1975) and supports their contentions concerning the origin of beach cusps by subharmonic edge waves.

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