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INFLUENCE OF THE WATER TABLE ON BEACH AGGRADATION AND DEGRADATION

By

U. S. GRANT

University of California, Los Angeles

INTRODUCTION

Observations for many years of the fluctuation in the width and slope of beaches in southern California have demonstrated that the position of the water table under the beach surface has an important bearing on deposition and on erosion of the foreshore and backshore. During winter storms, in the vicinity of Santa Monica and north along the Malibu Coast, a very rapid destruction of the beaches sometimes results. For example, at Coral Beach (12 miles northwest of Santa Monica) a series of large waves and a high tide may reduce the width of the backshore by as much as 40 feet or more within a few hours and sometimes in less than one hour. The mechanics of such rapid degradation appears intimately connected with the height of the zone of saturation under the beach surface. A high water table accelerates beach erosion, and conversely, a low water table may result in pronounced aggradation of the foreshore. Large waves, with the accompanying excessive turbulence, provide the dynamic factors in rapid beach erosion, but the wetness or dryness of the beach contributes in an important manner to its erosion or aggradation, the explanation of which is the purpose of this paper. A brief synopsis of this principle was presented (Grant, 1946) at the meeting of the Cordilleran Section of the Geological Society of America at Berkeley, April 1946. The recent results of some of Emery and Foster’s (1948) observations on beaches add to our knowledge of ground water conditions in the beach environment.

WAVE ACTION ON A DRY FORESHORE

When an incoming oscillatory wave breaks or spills in the plunge zone, propagates itself across the transitory zone and swashes up the foreshore, there is a gradual diminution of velocity. This diminution of velocity on the foreshore, which is a function of momentum, slope angle of the beach, flow depth and the foreshore roughness factor, decreases the transporting power of the uprushing prism of water so that toward the instant of zero velocity most of the sediment trans-
ported up the foreshore is deposited on the sloping sand surface. If we have a dry condition of the foreshore (i.e., a water table intersecting the beach surface far below the upper limit of the swash [see Fig. 1A]) water percolates rapidly into the sand above the water table, which reduces the flow depth of the swash and thus reduces the velocity beyond that value due to the operation of the other factors mentioned. The uppermost portion of the swash may all soak into the porous sand, thus depositing all upward transported sediment in that portion of the swash which vanished into the interstices of the beach sand. Furthermore, toward the termination of the time of upward motion of the swash the velocity will become low enough to decrease below the lower critical limit and the flow will change from turbulent to laminar. This change from turbulent to laminar flow can be seen by carefully watching the last moments of the swash on a gently sloping dry beach. Sediment is rapidly deposited when this flow transition occurs, leaving a thin deposit of sediment on the upper portion of the foreshore from

Figure 1. Hypothetical beach cross sections showing relationship of the water table to the infiltration zone and the effluent zone. A. Low water table with extensive infiltration zone. B. High water table with extensive effluent zone. C. Degraded beach due to water table coincident with surface of beach.
each swash episode. When large waves occur during a high tide the swash may reach beyond the upper limit of the foreshore and flow over the backshore. In this case the water on the backshore may all soak into the dry sand, leaving the sediment load as an accretion on the surface.

After the swash has reached its limit the backwash begins. At first the velocity is low, and laminar flow prevails for a short period. This laminar flow decreases the likelihood of transporting sediment in suspension down the foreshore. The laminar backwash flow persists for a longer time if the slope of the beach is small and if the depth of the film of water is likewise small. Hence, on a gently sloping beach which is dry, the acceleration due to the gravity component (the geodetic or geocentric head) is small and the flow depth, being reduced by percolation into the unsaturated sand, is likewise small. Therefore, under these conditions velocity will be low and laminar flow will persist for a significant time. Unfortunately the author has not yet had an opportunity to determine the Reynolds Number controlling the type of flow of sea water under the conditions of this environment, but the transition may be expressed approximately by the following equation from Jeffreys, 1925 (or Cornish, 1934: 146-147),

\[ Q = 300 \nu, \]

where \( Q \) = the quantity of water crossing unit width in unit time and \( \nu \) is the kinematic viscosity of water. Since the kinematic viscosity of water is about 0.01 cm\(^2\) per second, this indicates that a film of water one cm. deep cannot flow with a velocity greater than three cm. per second without turbulent flow occurring.

Thus it can readily be seen that a dry beach (low water table) facilitates deposition on the foreshore by reducing backwash flow velocity and thus prolonging the existence of laminar flow. Furthermore, where all of the swash percolates into the backshore or dry foreshore, the sediment transported up the beach by the swash is thus deposited. A gently sloping dry beach is conducive to deposition. As the slope is increased by greater deposition on the upper reaches of the foreshore, the equilibrium slope is gradually reached and backwash velocities prevent further net accretion.

It should be pointed out that, although deposition may occur on the upper foreshore, the lower foreshore, being below the line of intersection of the water table and the foreshore surface, may be subjected to rill erosion, or deposition and erosion may counterbalance each other. This lower saturated foreshore is called here the effluent zone in Fig. 1. A and B.
WAVE ACTION ON A WET FOreshore

If the water table under a beach is very high and contiguous with the surface of most of the foreshore, a condition favoring beach erosion exists. This situation is illustrated in Fig. 1B. This high water table may be caused by large waves persistently propelling the swash onto the backshore where it has ample opportunity to soak into the permeable sand because surface drainage slopes are absent and surface runoff is negligible. Intermittent wet-weather rills from the coastland back of the beach may bring fresh water to the backshore during heavy rain storms and thus contribute to a high water table. Regardless of source of water, when the beach is in a saturated condition throughout all of the foreshore, the backwash of the waves, instead of being reduced in velocity, is accelerated by addition of water rising to the surface throughout the effluent zone. It can be shown by a simple mathematical demonstration (see Exner, 1931: 378-379) that the mean velocity of flow has the following relationship to slope angle, depth of flow and friction:

\[ U = (g \sin i \times h/K)^{1/2} \]

Here \( U \) = mean velocity, \( g \) = gravity, \( i \) = slope angle, \( h \) = depth of flow and \( K \) = a friction term. This can be expressed as

\[ g \sin i = K U^2/h, \]

which shows that if the expression on the left is of constant value, \( U \) must increase as \( h \) increases, assuming \( K \) is constant or varies more slowly than the other variables. Hence, the increased volume of backwash has a high velocity, and turbulent flow exists. This enhances erosion of the foreshore. The addition (instead of subtraction) of water to the backwash by ground water escaping to the surface of the foreshore not only increases backwash flow velocity but dilates the sand and propells the finer grains up into the turbulent flow. Emery and Foster (1948) consider this factor.

Another feature is sometimes produced by the increases in volume and velocity of the backflow of water on the foreshore. The backwash is often met by an oncoming translatory wave approaching the lower foreshore. If the backwash has a velocity greater than \((g \times h)^{1/2}\), the approaching water cannot progress against the current and a hydraulic

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1 Direct rainfall on the backshore is apt to contribute only a little in elevating the water table unless an unusually thin sand prism rests upon an impermeable substratum and unless the rainfall is very heavy.

2 The escape of ground water on the foreshore may reduce the value of the friction term, but this influence is difficult to evaluate. In any event it would serve to increase the erosion effect.
jump or a roll wave with high turbulence occurs. This excessive turbulence not only prevents deposition but removes all but coarse particles whose settling rates in sea water are so great that they are not readily transported. If this hydraulic jump or roll wave is often repeated in the same position, a small scour channel lined with coarse sand or gravel persists at the lower edge of the foreshore parallel to the trend of the beach. The scour channel due to the hydraulic jump appears to be developed only at the base of a steeply sloping foreshore.

The aggrading or degrading of a beach, and the value of the angle of beach slope, is a function of several variables, one of which is the position of the ground water table under the beach. A degraded beach, shown in Fig. 1C, may be in equilibrium during a saturated condition but may be aggraded when a dry condition and normal wave action returns.

REMOVAL OF BEACH BARS

Along the southern California Coast there are a number of aggraded valleys occupied by intermittent streams whose mouths are completely blocked from the sea by a beach bar during the dry season. When the wet season comes and stream flow begins, the runoff water is impounded back of the beach. If stream flow begins with a large volume of runoff, the water in the lagoon back of the beach may rise rapidly above the crest of the sandy beach bar and cut a channel to the sea. If the water in the lagoon rises slowly, then the beach water table at the blocked river mouth may rise enough to conspire with the first episode of large waves to greatly accelerate beach erosion locally and thus facilitate the removal of the beach bar. Quantitative studies of this phenomenon have not yet been made, but local narrowing of beaches opposite these bars have been seen where water is impounded in the valley mouth lagoons.

EFFECT OF THE WATER TABLE ON ARTIFICIAL SAND SPREADING

The dilating effect of escaping ground water in the effluent zone of the foreshore, the enhanced erosion there due to this decrease in compaction of the sand grains, and the increased velocity of the backwash on the foreshore by increase in flow depth, have an important bearing on the method of spreading sand on a beach by means of sluicing sand from sand dunes or from a dredger. On a narrow beach with a sensitive water table the sluice water carrying the sand must be effectively spread over the beach to prevent erosion counteracting the effect of the artificially added sand. Failure to consider these factors contributed greatly to the negligible aggrading effect of pumping sand
from the aggraded beach back of the Santa Monica Yacht Harbor (Grant and Shepard, 1939: 803-805) to the narrow degraded beach a few hundred yards south of that structure during 1939.

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