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THE RELATION OF THE ACTION OF WAVES AND CURRENTS ON HEADLANDS TO THE CONTROL OF SHORE EROSION BY GROINS

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The great increase in the value of shore property during the past quarter-century has made the control of beach erosion one of the important engineering problems of our time, and in many places the Federal government as well as various states and municipalities are now spending considerable amounts each year in attempting to control the work of waves and currents along their shores.

Waves and currents resulting from onshore winds have the effect of picking up and moving any loose sediments that may be present. Such work is accomplished principally in two ways; by the littoral or longshore current and by beach drifting. A wind blowing onshore at an oblique angle sets up currents which move parallel with the shore and carry with them any sediment that may be in suspension in the water. Such sediment may be picked up from the bottom by the action of the current itself or it may be in suspension because of the agitation set up by the waves breaking in the relatively shallow water. In transportation of sediment by beach drifting the material is transported along the beach ridge by the swash and backwash. When the waves meet the shore at an oblique angle a part of the sediment in the beach ridge is thrown violently upward and forward by the swash of the waves and then moved farther forward as it is carried back down the slope by the backwash. On a sandy shore the amount of material carried in this way is very great.

Along an irregular shoreline where both processes are active the headlands are eroded faster than the indentations and the shoreline becomes straightened. This action has been analyzed by Johnson (1919) for the case where the waves advance with their crests parallel with the shoreline. However, it is evident that Johnson's analysis is a special case since he considers only that condition in which the waves are running in a direction perpendicular to the shoreline. Nearly always the wind is in such a direction that the line of wave crests make an oblique angle with the shoreline.

Consider the general case in which the forward movement of the waves is at an oblique angle with both the shoreline and the axis of the headland (see Fig. 1). A current is produced along the shore, as at "A", which carries with it any sediment that may be present in suspension. Also the sand in the beach ridge is forced forward by the swash and backwash of the waves as they beat on the shore. This beach drifting movement is slowed up where the shoreline begins to curve outward at the base of the headland until at "B", where the shoreline and wave crests are parallel, the forward movement ceases. The shore current is also checked here and is forced to drop its load. This results in rapid shallowing of the water and prograding of the shore. Little if any of the material obtained along the shore at "A" is carried down wind beyond the headland. Thus the indentation at "B" is rapidly filled. If the wind is strong, outward moving currents will be set up and some of this accumulated material carried out to windward and distributed over the bottom. However, should the wind be nearly parallel with the shoreline at "A" such currents com-

bine with the shore current and some of the sediment in suspension is carried rapidly along the headland and out past its end. Also some beach drifting will take place across the end of the headland at "C." This may result in the building of a spit to leeward. However, in either case no prograding of the shoreline occurs on the lee side of the headland. On the contrary there is some erosion at "D" and "E" because as waves pass the headland they are refracted so as to be more nearly parallel with the shore at "D" and thus cause some beach drifting which increases toward "E." If any part of the shore current moves past the end of the headland it is not at once turned back along the shore but continues on for some distance before again approaching it. As a result a reverse current is set up in the lee of the headland (see Fig. 1). A part of the sediment carried by this current may enter the main current at "F" or a part of it may be temporarily deposited in the slack water just inshore from where the two currents join. Thus there is deposition of sediment and prograding on the windward side near the base of the headland and erosion and retrograding on the lee side. At the same time at the outer end at "C" material is removed by the processes of beach drifting and current action and the headland is shortened.

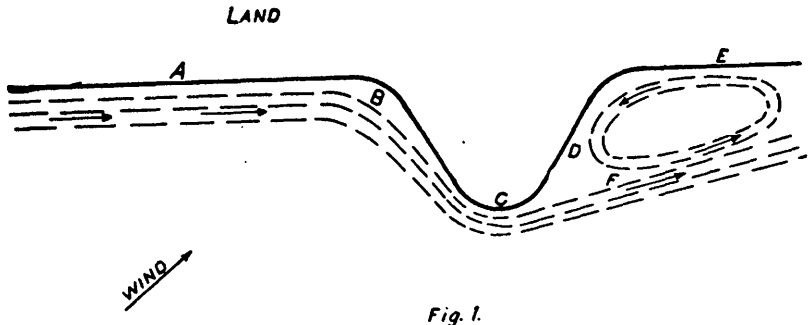


Fig. 1.

Some of the material carried beyond the outer end of the headland by the current is deposited on the bottom just to leeward. This may take the form of either a ridge or a broad shelf depending on the amount of sediment available and the strength of the waves and currents. Where this deposit joins the shore it may be added to by the material brought by beach drifting across the outer end of the headland. In this way the deposit is brought above the water and extended to leeward as a spit. This spit will be broad or narrow depending on the ratio between the strength of the waves and the amount of sediment available. At times when the energy of the waves is great as compared with the amount of sediment being carried wave refraction will cause the formation of a hook (Evans 1942).

Thus in the early history of the wearing away of a headland the usual result is filling on the windward side and erosion on the lee side with the partial formation of a bay. As the process continues and the headland is shortened the shoreline along the outer end of the headland becomes longer and longer and the spit to leeward is lengthened. Finally the reverse current to leeward disappears, the headland is reduced to a mere bulge in the shoreline and then disappears entirely. Of course the time required for this process is partly determined by the ratio between the resistance of the headland and that of the adjoining coast.

Where solid piers, groins, or other artificial projections are built outward from the shore, erosion and deposition is very similar to that around

a headland. At Milwaukee, where the prevailing drift is from north to south, filling has occurred on the north side while to the south the shore has been "starved" until it has been necessary to construct groins in an attempt to prevent the undermining of the bluffs and maintain a bathing beach. On the other side of Lake Michigan, at Muskegon, the direction of the shore drift is in the opposite direction and filling has taken place on the south side of the harbor but on the north erosion caused by reverse current was so rapid following the erection of the breakwater in 1929-30 that about ten years later extensive repairs were necessary. However, about 30 miles farther south at Holland the shore current is still from south to north but the beach drifting is in the opposite direction. In this case the beach drifting is evidently the more efficient transporting agent as there has been filling on the north side of the piers while on the south severe erosion has occurred.

A groin is an artificial structure built outward from the shoreline for the purpose of controlling erosion. It is usually perpendicular to the direction of the shoreline although it may be placed at some other angle. Its purpose is either to prevent erosion of the shore material or to bring about prograding of a shore that has already been eroded. It is usually the latter because it is practically impossible to get appropriations for building structures until the necessity has been demonstrated by the damage done. The groin accomplishes its purpose by causing deposition of material carried by the shore drift. Of the two elements involved in shore drift, the littoral current and beach drifting, the beach drifting is perhaps the more important although the action of the littoral current is more emphasized in the text books.

If a groin is not designed properly it may make worse the conditions it is supposed to correct. In attempting to fit a groin to a particular environment it must always be kept in mind that any increase of current velocity is conducive to increased erosion, that reduction of velocity will result in deposition, and that the change in rate of erosion is several times more rapid than the velocity change.

Various forms of groins have been designed, of which some have been successful but others have failed to effect corrections or have even made conditions worse. The simplest form of groin is a solid wall extending some distance out from shore and having its top high enough to reach above the highest water. Such structures have several serious defects. If there is a prevailing wind the beach drift will be completely checked and while this will cause filling on the windward side there will be little or no filling on the lee side. In the presence of a strong shore current such a groin has the effect of a wing dam and results in an increased current around its outer end with consequent rapid erosion and deepening of the water. Also during heavy storms waves may overtop it and produce on the lee side an effect like that of a waterfall and dig out the sediment in the same way the pothole is formed at the foot of a falls. Such excavated material does not remain in the vicinity but is carried outward by the reverse current which is set up here in the same way as in the lee of a headland. While wave refraction is not so great as around a headland, yet the waves are turned inward to some extent and there is also some wave diffraction resulting from the passage of storm waves. When these waves reach the shore they cause beach drifting to leeward and consequent erosion. In some cases this action has been so severe as to allow the water to find its way back around the end of the groin. When this happens the waves and currents from windward begin passing through the opening and erosion of the shore continues at a faster rate than before the building of the structure. A bad case of this can be seen to the north of Port Washington, Wisconsin.

An improvement on the high solid groin is to reduce its height so that its top will be nearly at water level. This reduces the waterfall action and may also decrease the velocity of the outward current on the windward side by allowing some escape of water over the top. Another improvement is to gradually decrease the height of the groin from the shore outward until the outer end is at or somewhat below the surface during low water. This further decreases the waterfall action, gradually releases some of the water passing outward along the groin on the windward side and so lessens the channeling action along that side and at the end, and results in a weaker reverse current on the lee side. Such groins usually work well except with a strong current flowing steadily from one direction. If the winds and currents are not very strong or if the movement of sediment along the beach alternates in direction they are quite successful. Under some conditions a groin will cause accretion of sediment at its shore end at the same time that erosion occurs at the outer end. This can sometimes be remedied by cutting openings in the body of the groin toward the outer end and allowing a part of the water to escape. This reduces the amount of water around the end and slows up the current. This was done on a groin near Navy Pier, Chicago, with good results.

Another type of groin which has come into considerable use in recent years is the open type. It is usually built of concrete or timber and is more or less an open lattice work throughout its length. In the best design the openings increase in size with distance from the shore. Such a groin merely checks the movement of the shoredrift and thus causes it to drop a portion of its load instead of stopping it entirely as does the solid groin. Since a part of the water is allowed to pass through there is little or no outward moving current along the windward side of the groin and consequently no undermining of the structure occurs. Also during high water there is no waterfall action over the groin because the waves and the water in transport pass through the more or less open structure. Wave refraction around the outer end is less than with the closed groin and any reverse current on the lee side is not forced outward along the side of the groin but is broken up by the open structure and drops most of whatever load it may be carrying. Such groins appear to have been entirely successful under conditions of strong prevailing winds and shore currents where the solid groin or its modified forms have partly or wholly failed. It is also successful under the less exacting conditions of variable beach drifting and weak variable currents. It is no more expensive or difficult to build than the solid groin but in order to be most efficient it must be designed with care to fit the local conditions. In general the weaker and more variable the waves and currents the fewer openings are necessary while the stronger the currents the greater the amount of openings. The structure should be designed to take care of the average conditions prevailing but at the same time the openings must be sufficient to prevent erosion under the most severe conditions that may prevail. Since wind direction, wave size, current strength, and amount of sediment are all variables it is probably not possible to work out a formula for the design that will take care of all conditions. Therefore the correct design for the greatest efficiency will continue to depend on the experience and judgment of the designer. On the other hand the design is flexible and a considerable latitude of error can occur without complete failure of the structure to perform its functions. For this reason expensive and exact preliminary surveys such as have been deemed necessary for the design of the solid groin are not so necessary in fitting the open groin to the local environment.

Thus we see that headlands and solid groins are similar in their effects. Both cause deposition to windward and erosion to leeward. This brings about changes which finally result in the elimination of the headland. With the solid groin there often results an unevenness of current

action and consequent failure to produce the desired results. On the other hand the open groin by uniformly checking current and wave action brings about an even deposition of sediment and prograding of the shore.

LITERATURE CITED

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