CHAPTER 114

SOME FACTS AND FANCIES ABOUT BEACH EROSION

by

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ABSTRACT

Coastal defense up to the present has employed seawalls, groynes and renourishment, all of which do not tackle the basic problem of lack in sediment supply from upcoast. The need is for sufficient sand to be continually available for the formation of the defensive offshore bar. If means are provided for this material to be returned directly on shore by subsequent swell, a stable situation ensues. Such normal re-deposition occurs within bays formed between headlands which have reached equilibrium shape or nearly so. Comparisons are made between various stabilization procedures. The influence of sand characteristics in renourishment is discussed.

Stabilization of coasts has been carried out over many decades. The remedies have taken three major forms, namely, seawalls, groynes, and in more recent times sand renourishment. Whilst shapes and orientation of these structures have been varied in order to optimise protection, engineers in the main have relied upon bigness for greater reliability. Investment in dredging to supply sediment "temporarily" to beaches is growing prodigiously. It is now time to sit back and reassess the situation, so as to determine a change of outlook, be it only slight, that may effect greater long term economies.

AXIOMS OF BEACH PROCESSES

There are certain theorems respecting beach processes which, although proved separately, are not normally considered conjointly in the stabilization issue. These are:

(a) On oceanic margins and even along coasts of enclosed seas there is a predominant or resultant wave direction which is usually oblique to the coastline.
(b) The longshore component of wave energy both in the surf zone and offshore can transport a specific load of sediment across a given bed profile normal to the beach.
(c) Flunctuations in river discharge of sediment, in wave incidence along the coast, in man's interception of littoral drift, and in storm

activity, cause continual variations in supply of material from upcoast on any section of shoreline.
(d) The transfer of sand from beach to offshore and back again in an oceanic margin during storm and swell sequences results in different beach and nearshore profiles than on shores of enclosed seas where swell is minimal.
(e) Waves reflected obliquely from walls, cliffs or submerged reefs create a short-crested wave system that generates strong vortices, resulting in increased macro-turbulence which magnifies sediment suspension in a situation of excessive mass transport.
(f) Groynes have no influence on bed erosion beyond their toes and cannot retain material collected between them during storms because of their promotion of rip currents.
(g) If waves arrive nearly normal to the coast the offshore slope must be very flat before the waves can effect longshore transport of sediment at the rate it is being supplied.
(h) An eroded shoreline will absorb a large proportion of sand renourishment supplied to it in order to construct the equilibrium profile appropriate to the wave energy normally present.
(i) Persistent swell arriving obliquely to alignments of headlands will form crenulate-shaped bays between the fixed points which have a limiting indentation and specific curved shape.

By combining the effects in these truisms one may be led to a solution of beach erosion which is economic in both investment and maintenance. It is the purpose of this paper to examine the real problems in littoral drift and suggest a comprehensive plan for management of the coast.

PAST MISTAKES

Remedial measures for beach recession have taken various forms, with periodic changes similar to those in womens' fashions. The reason for this copying sequence in engineering might be blamed on the control effected by some eminent or prominent person. The neophytes of the profession tend to emulate their peers, for purposes of promotion if nothing else. It is very difficult in a conservative atmosphere to introduce innovations. Engineering suffers as much from this as the medical profession where the caution is "Be not the first to adopt the new, nor the last to cast the old aside". This leads to the sequence: "When first discovered it is not proved. Twenty years later it is proved but not important. Thirty years more it is proved and important, but it is fifty years old - we have something better now!"

The phases in coastal engineering have been seawalls, groynes and the latest panacea is renourishment. It is well to see where these three concepts went astray, or to compare the disadvantages against the purported benefits.

Seawalls It was believed, even by eminent oceanographers and presumably by many engineers, that if the energy of incident waves could be thrown back to the sea all was well on the coastal front. Little was it realised that re-application of this energy to the seafloor, particularly if it involved oblique reflection, would expedite sediment removal and suspension. (1) Not only does scour occur in front of a wall but also downcoast of it, where the diffracting reflected waves combined with the incident to continue the short-crested wave system. (See Figure 1) The rapid removal of material results in a shoal further downcoast because the incident waves cannot cope with the increased load removed and hence a shoal and even shoreline protuberance occurs. The sight of erosion between an accretion and the wall extremity has prompted the extension of walls downcoast and the displacement and expansion of the problem.

Even rubble-mound structures can reflect a large proportion of the wave energy, particularly that of the longer period components of the spectrum. Also submerged walls or reefs will reflect the lower sections of the wave motion and hence create water particle motions equivalent to short-crested waves at the surface. (2) This is a problem not fully realised with pipe outfalls experiencing angled waves, which fail due to scour, some little distance back from their extremities. The local phenomenon of vortex generation at sharp ends of walls or objects is another matter, but a very serious one for caisson type breakwaters.

Groynes Since man could observe the excessive turbulence and suspension of sediment in the surf zone, plus the current produced by oblique breaking of the waves, it was assumed that all important transport of material was occurring in this water strip at the beach margin. It was concluded, therefore, that an impediment placed across this pathway should retain sand on that section of coast. Thus groynes have been constructed out to the limit of normal breaking waves on the beach.

In recent years the importance of the offshore zone in transmitting sediment downcoast has been illustrated in the knowledge of mass transport and the influence of multiple wave trains in disturbing the bed. The added effect of swell waves angled to each other has not been examined thoroughly enough to date but the possible increase in transmission can be surmised. It has been propounded that the complete continental shelf can serve as a highway of this transport. (3)

Beyond the tip of a groyne the waves move sediment and hence any imbalance between material removed and that replenished from upcoast is unaffected by this structure. Many cases can be cited of continued deepening and steepening of the bed offshore from a field of groynes, which were constructed due to an erosive tendency, which will continue. (4). This offshore deepening permits subsequent waves, be they storm or swell in character, to approach at a more oblique angle and at a greater celerity, both adding to the longshore transporting capacity of the system.

But even the material blocked in transit by the groynes adjacent to the beach is in jeopardy during a storm. Waves will arrive from all seaward directions as the low pressure centre traverses the coast. Thus whilst they consume the adjacent beach to form a protective offshore bar the associated changeable longshore drift is deflected seawards by groynes to form strong rip currents. Material is thus carried seawards and when brought back to the beach by subsequent swell waves is deposited much further downcoast than if it had been just offshore. (See Figure 2)

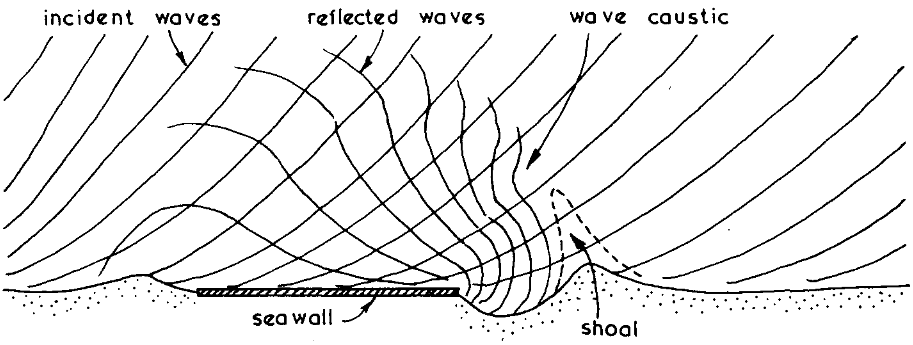

Fig. 1 Interaction of incident and reflected waves at a seawall

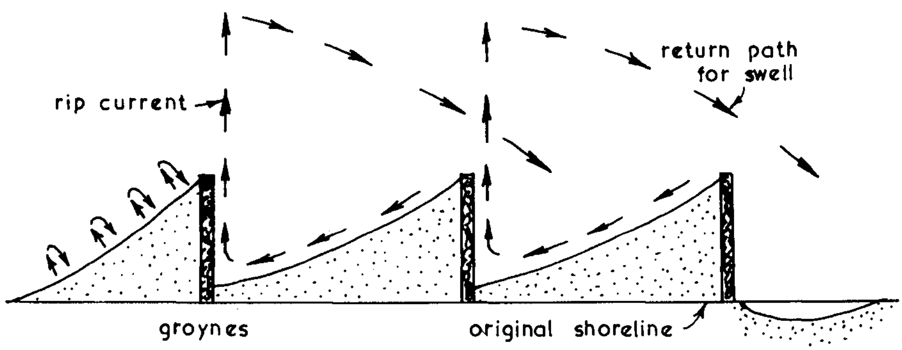

Fig. 2 Groins with erosion beyond toe and rip formation

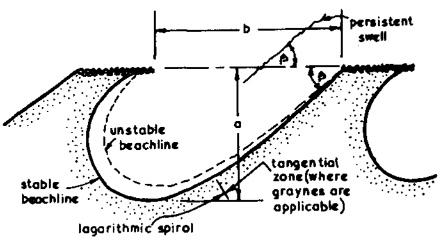

Fig. 3 Crenulate shaped bay in stable and unstable condition

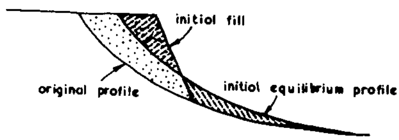

Fig. 4 Profile of stable beach profile plus fill

Groynes could thus be considered to enhance downcoast drift.
Because more than normal volumes of sand are removed between groynes the subsequent filling process during the swell season results in erosion downcoast of the groyne field.

There is one location where a structure running normal to the shoreline can be effective in accreting a beach. This is along the tangent section of a crenulate shaped bay, but this is unlikely to be in an erosive situation because the waterline is controlled by the downcoast headland. (See Figure 3) This tangental zone is little affected even when the bay is becoming more indented due to reduction or cessation of littoral drift upcoast. Instances can be cited where fluctuations in littoral drift have either buried groyne systems or inundated them as though they did not exist.

Renourishment This is the latest panacea of the erosion problem, with the more expensive alternative of dredging from the sea being promoted. Since the whole shelf can be considered the highway for transport any substantial holes dug in it can influence the sediment somewhere along the coast, not necessarily in the affected area. (5) But it is the benefit to the community as a whole from such artificial widening of a beach that should be of concern.

That there is a strong longshore drift resulting from oblique predominant waves must be accepted, otherwise there would be no erosion problem. This downcoast component will still exist after the refill and hence will transmit sooner or later (more likely the former) this expensive material in the same manner as the original coast. In fact, it will move it more rapidly, especially at first, because it is perched against the coast with a steeper than normal profile, almost the angle of repose of the sediment. (See Figure 4) Even just swell waves will spread this material both downcoast and over the eroded offshore region in an attempt to produce the original equilibrium profile appropriate to the wave climate for the area. Initial losses of 30 to 50% have been recorded (6)

Renourishment is a palliative which eases the problem but does not remedy the cause. This can be likened to the pill prescribed by the medical profession to get rid of the pain without attacking the root of the disease. Whilst the pain is gone there is less incentive to work on the real problem. Most engineering "doctors" applying this solution recognise the transitory nature of the benefit and recommend annual additions of the pain killer, possibly of 10 to 20% (6).

BASIC REQUIREMENTS

The essence of the beach erosion problem, or its solution, is to have sufficient sand on the beach to form an adequate offshore bar during any severe storm sequence. This natural defense mechanism cannot be bettered by man. Even if he were to place a fixed mound parallel to the coast to replicate this bar, it would serve as a reflecting wall during periods of swell and hence expedite transport of sand downcoast. Thus it is the swift construction of this feature in times of need that is so helpful to mankind, and its subsequent dismantling by the swell waves a few days later.

Whilst man cannot assist nature in this valued erosion limiting process he can assist by providing milder slopes to the offshore profile of the beach. Such a flatter bed requires less beach material to construct a bar of sufficient size to break incoming storm waves. It is a case of more material being maintained in the region, with a large proportion of it being submerged. This mode of storage inhibits the possibility of wind blowing it inland to form sand dunes.

The question is how to create this seaward accretion without it being subject to longshore wave energy and hence transport downcoast. Again nature has provided the answer because where the coast is so oriented that it is parallel to the crests of the persistent swell waves the offshore bed is mildly sloped, as can be gauged by the number of simultaneous breakers visible in the surf zone. (7) This is also understable because a near-normal approach of waves makes it difficult for them to transmit material downcoast. Material is deposited until the depths are reduced to such a degree that the waves can disturb the bed sufficiently to balance the energy available with the load to be carried.

CRENULATE SHAPED BAYS

This necessary reshaping of the coast for it to receive the persistent swell (or predominant waves in the case of enclosed seas with little or no swell) normally has been carried out by nature over geologic time. When headlands or control points exist the sedimentary shoreline between has been sculptured into bays with specific curved outlines. Where the waves of greatest duration arrive obliquely to the headland alignment such bays assume a crenulate or zeta shape. (See Figure 3) These are the most abundant physiographic features on all coastlines of the world, whether they be on oceanic margins, in enclosed seas, or inland waterways where wave action is significant. (8)

Although these bays can be of any dimensions, hundreds of metres between headlands or even kilometres, they will be exact models of each other if the obliquity (β) of the persistent waves is the same. For a specific angle of approach to the headland alignment and a condition of no sand supply from upcoast or within the bay certain characteristics of the bay are now known. (9) (10). These are the ratio of maximum indentation (measured normal to the headland alignment) to the clear distance between the headlands, and the curvature of the logarithmic spiral which is applicable to the curved section of the bay. (See Figure 5) With knowledge of the limiting values of these parameters for specific wave obliquities (which angle is the same as that between the downcoast tangent section of the crenulate shape and the headland alignment) a tool is available to check the stability of any bayed coastline. (See Figure 3) If the values plotted do not fall on the equilibrium line further erosion can be expected if and when sand supply decreases or ceases in the future. Complete cessation is prevalent in modern times with the need for dredging deep channels across the shoreline to ports.

When a bay is nearing this final stable shape the incoming persistent swell will diffract and refract in the lee of the upcoast headland in such a way that it will break simultaneously around the whole

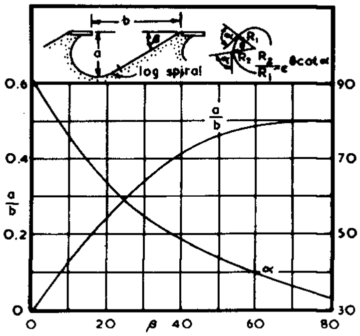

Fig. 5 Stability criteria for equilibrium shaped bay

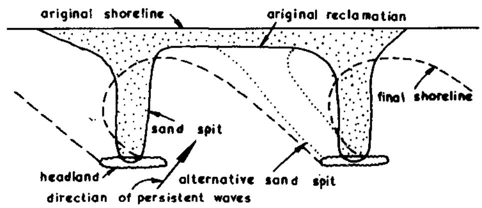

Fig. 7 Utilization of sand spit for headland construction

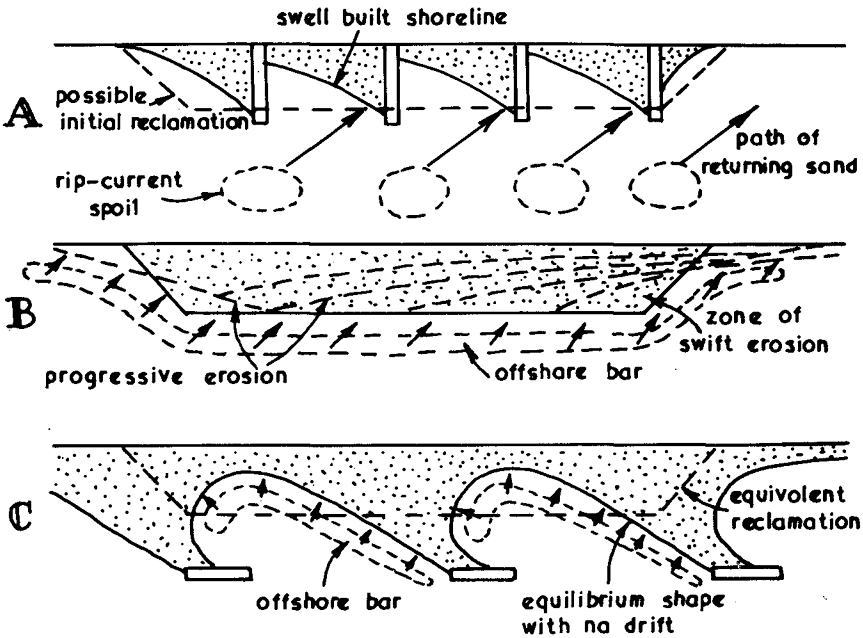

Fig. 6 Comparison of renourishment schemes A: with groynes B: with no assistance and C: with headland control

periphery of the bay. This has been proven in model studies (11), as well as in this field (12). At this stage longshore drift cannot occur. Hence any offshore bar formed during a storm will be carried back to the beach by the swell and placed in its original position. Certainly there will be negligible loss of material between one bay and the next.

COMPARISON OF DEFENCE PROCEDURES

Consider a reasonably short section of straight coast requires stabilizing because of the investments already in jeopardy along the beach. The basic need as stated above is to maintain a reserve of sand in the area, which is readily available from year to year, to service the storm waves in constructing the defensive offshore bar. The alternative of building seawalls or revetments instead of providing this sand reserve is not worthy of discussion, because of the high maintenance cost, the high risks taken and the lack of aesthetic appeal.

Thus the solutions to be compared are plain renourishment, a field of groynes, or several headlands (offshore breakwaters). With sand placed on the beach in the affected area there will be a downcoast extremity to the widened beach. This will involve a more oblique approach of the waves in this region and therefore swifter removal than along the general shoreline. (See Figure 6). This in time will reorient the whole renourished beach to a more oblique line and hence downcoast removal is expedited. This will result in a hump of sand proceeding along the shoreline which could well silt up waterways and other marine facilities. Continual maintenance of this fill will be necessary.

The second alternative of groynes, even if provided concurrently with renourishment, will retain perhaps half the volume during the subsequent swell season. However, when the storm waves arrive they will take portion of the reserve to form a bar and the remainder will be carried further out to sea by rip currents. This latter material will be re-deposited on the beach beyond the field of groynes by the oblique swell. (See Figure 6) This means that the groyne field must now be partly refilled by littoral drift coming from upcoast. During this process the downcoast region will suffer erosion.

The third alternative of headland control implies structures which will be positioned further offshore than the tips of the groynes discussed above. Their spacing also should be great enough for the bays to be significant features on the coast. (See Figure 6) In this way a new equilibrium shape can be developed which involves milder offshore bed slopes. The reserve of sand, which may again be that available from renourishment, is not only stored on the beach but also under water. Less is taken from the beach during a storm and what is can be replaced directly back whence it came. No sand is exchanged between bays except the net littoral drift that existed in the first place. This drift will still pass through the bay system and hence give the same supply downcoast as before, but without the eroded load from the short section of beach being stabilized. The security obtained is that if all littoral drift ceases the bays in front of the important beach site will indent to a predictable limit and no further.

An ultimate aim by coastal engineers should be to reduce littoral drift along the whole coast to zero. If this could be accomplished the cost could in the long term be met by the savings in erosion, silting, by-passing and bar formation at river mouths and harbours. In this procedure new land could be won from the sea, which would be stable enough for maximum employment in recreation, housing or industry.

COMBINED RENOURISHMENT AND CONTROL

It is often recommended that groynes should accompany renourishment (6) (13). The author is not against such reclamation per re, but would recommend structures other than groynes for retaining this newly won but costly material in position. He has written on several occasions to local authorities, where renourishment has just been reported in the technical literature, suggesting that headlands be spaced along the resulting waterline. By such an economical expedient it would immediately be learned that about half the material would be kept as beach, probably one quarter would be stored offshore, and the remainder might possibly go downcoast. This would be a better balance sheet than 100% lost in a matter of three to five years. The cost of dumping rubble-mound rock or its equivalent at around mean tide level would be minimal compared to the overall investment in transitory reclamation.

It is instructive to discuss a method of headland control in combination with a renourishment scheme. Since dredging generally involves pipeline discharge onto the beach it is most inconvenient to concentrate deposition at certain points on the coast rather than spreading uniformly. (See Figure 7) In fact, this economical mode of operation has been utilised for filling beaches within a groyne field (14). If stone were deposited promptly at the tip of the sand spit the man-made tombols could intercept littoral drift from upcoast, whilst the downcoast beach would be sculptured into a logarithmic spiral, to connect with the adjacent downcoast headland. This spit construction could be aided by earthmoving equipment. The head and sides could be quickly protected if necessary by blocks placed there temporally and later shifted to the main structure.

When it is realised that a reef at low-low-water is sufficient to maintain a shoreline in place, the design of headlands can be quite economical. Natural or fabricated armour units can be dumped on the beach face in the knowledge that they will progressively slump seawards as waves reflect obliquely from them. Sufficient material should be supplied initially to cater for this spreading action, to ensure that waves are broken even at the highest tide and storm surge. Random placement and shape can make the structure appear as a natural feature.

To reduce the use of stone, which continually becomes harder to obtain and more expensive to transport, sand sausages are an alternative worth considering (15). Membrane materials are now becoming available which can be welded or sewn into large diameter tubes which can be filled with sand, cement mortar or concrete. The advantage is that the bulk of the material is available at the site and only requires some technique of pumping into the sausage skin located in position offshore.

The massive infra-structure of roads, trucks and cranes is thus obviated, which is particularly beneficial at remote points of the coast.

Another economical construction method for headlands, or other coastal structure for that matter, is the large bag which again can be filled with sand, mortar or concrete (16). The size of this armour unit is limited only by the size and strength of the bag that can be handled underwater or in the surf. The stability of such structures has only been tested in prototype situations, where they have withstood waves from some of the fiercest hurricanes in the Gulf of Mexico. Comparative tests with fabricated concrete units should be carried out, but it can be rationalised that such bags filled in situ develop very close contact, unlike monoliths which have only point contacts. Particularly difficult is it for a wave to overturn or dislodge a flexible mass such as a bag filled with sand.

Tubes of 1m diameter have been used to form groynes and pseudo-seawalls (17), but if used on a lattice fashion as depicted in Figure 8B each sausage could be safe from displacement by the largest waves. The alternative larger sausage is not cylindrical in shape (15) but assumes a profile as illustrated in Figure 8A. Such structures need only be built to mean-low-water for them to break waves at all times. The construction procedure lends itself to this reef concept because it is not necessary to provide access some meters above high tide to transport armour units. Its width also can be planned to meet the hydraulic needs rather than those of construction equipment.

DUNES VERSUS EMBAYMENTS

The real comparison to be made is between sand dunes, as the currently believed stalwarts against the sea, and crenulate shaped bays, formed between headlands of natural or man-made origin.

Because dunes are built by wind blowing dry sand from the beach berm into vegetation closest to the beach, it is believed they are God's given gift for defense of the coastline. When a particularly prolonged storm arrives the beach berm disappears offshore together with the face of the first dune. Later, when swell waves return this bar material to the shore (swiftly at first and then more slowly) the berm is wider than usual, thus providing a greater width from which the wind can lift sand and deposit it against the damaged dune.

But it is not the most erodable beach that has the highest dunes available. A large proportion of the bar material here does not return because it is compensating for the offshore deepening that is continuing in this erosive situation. On the other hand, in a stable or accretory situation the constant supply of sand to the beach permits an extra high first dune to exist. Seldom is such a feature attached and hence the anomaly that where least needed Nature provides the largest safeguard and where most needed this back-up structure is not well developed.

The idea is often expressed that it costs nothing to let Nature, through its dunes, provide us with our factor of safety, or more appropriately our factor of ignorance. Like the equivalent reserve in the

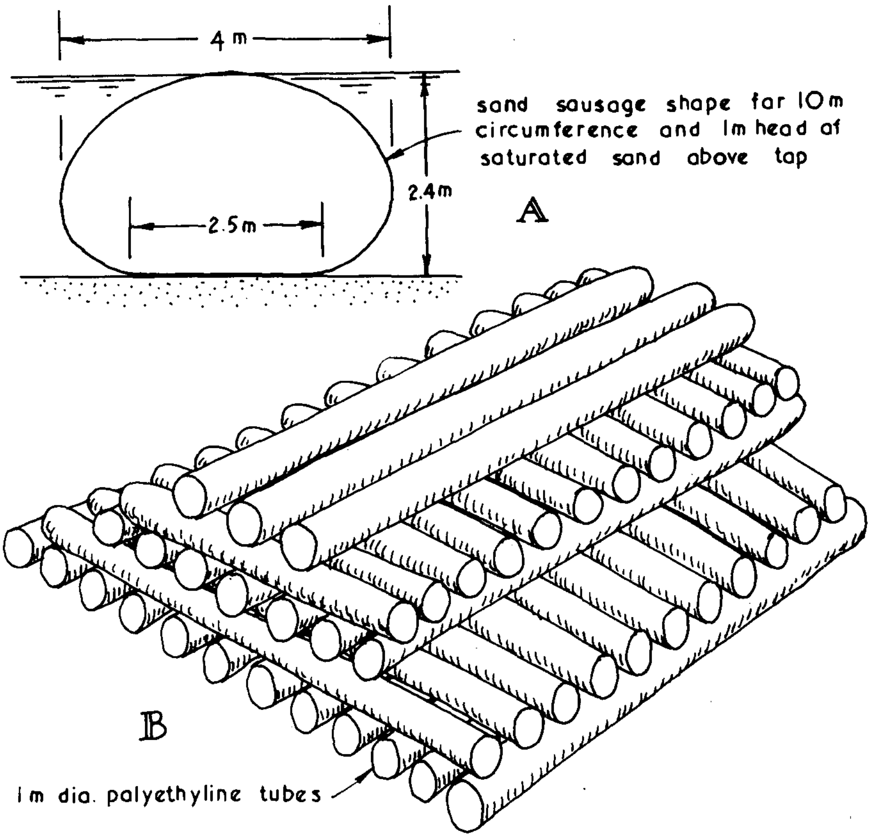

Fig. 8 Sand filled membranes A: large version, B: multiple tube construction

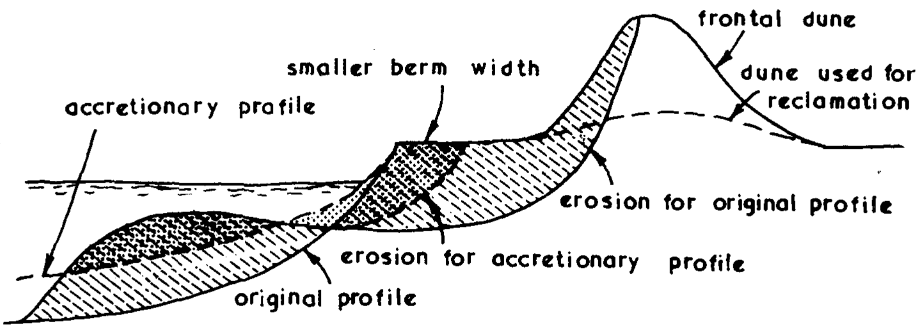

Fig. 9 Relative erosion for steep and mild offshore slopes

bank it costs money, because some of the most valuable coastal real estate is not available for development by the community for residential, recreational or commercial purposes. The sparcely vegetated white sedimentary hills create their own peculiar problems of wind blown sand and inaccessability to the water.

It should be kept in mind that the real defense of the coast is to have sufficient sand continually available for the offshore bar to be constructed by the storm waves. Dune storage involves loss to the inland by wind erosion. If the required volume of sand can be retained at the shoreline, partly as beach berm and the remainder offshore as a shoal then the aeolian denudation is minimised, with all its secondary problems. (See Figure 9) The advantages of providing this storage in an equilibrium bay feature is that material removed from the beach to form the bar is returned by the swell directly to its original position. Hence the same berm is available for the next year or the next decade. Because the bulk of the material is stored offshore, in its flattened slope, less demand is made upon the beach for an adequate structure to be built for stopping further erosion. The berm therefore is narrower and hence reduces the problem of wind blown sand.

Besides the aesthetic value of breaking the coastline into beautifully curved beaches there are many other benefits (18). The wave energy around each bay periphery varies considerably, so providing bathing conditions for the toddler to the surf-board rider. On oceanic margins, where persistent swell is ever present, the calmer zones in the lee of the upcoast headland can serve as launching sites for small craft, including those of the surf-life savers. The predictable limit of bay indentation (See Figure 5) gives an encroachment or usability line that is dependable, hence permitting full utilisation of the coastal strip. This situation should be compared with the dune system where people are prevented from walking for fear of blow outs or despoilation of the massive hills of sand that have insufficient nutrients to support vegetation.

SAND FOR RENOURISHMENT

Some papers have concentrated on the characteristics of sand to be used for renourishment, whether it should be coarser or finer in order to minimise removal downcoast. To the author this consideration is very unimportant, the waves will resolve this matter. The fines will be removed offshore, leaving the coarsest proportions on the beach face and berm. (12) If only coarse material is used the beach face will become steeper so promoting greater wave reflection, and thus increasing the energy available to transport this larger size material.

As stressed before, the most important factor for retaining or losing reclaimed land is the approach angle of the most persistent waves, generally the swell, to the beachline. When this is normal or near normal the longshore energy component is negligible and hence littoral drift in the surf zone, plus longshore movement further seawards, is zero or very low. Whether the sand is coarse or fine makes little difference to the overall profile. If very fine the bulk of the material will migrate offshore to make a wide shoal.

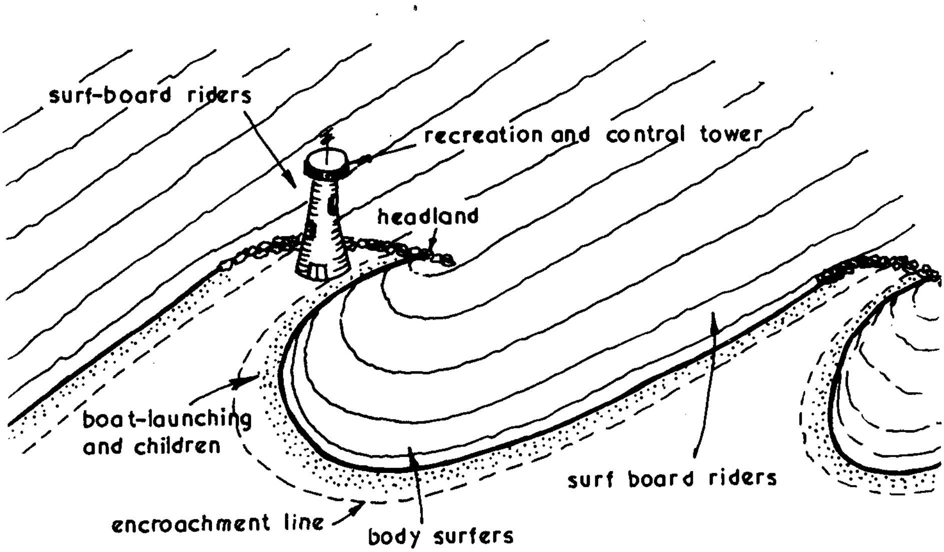

Fig. 10 Advantages from bayed beaches.

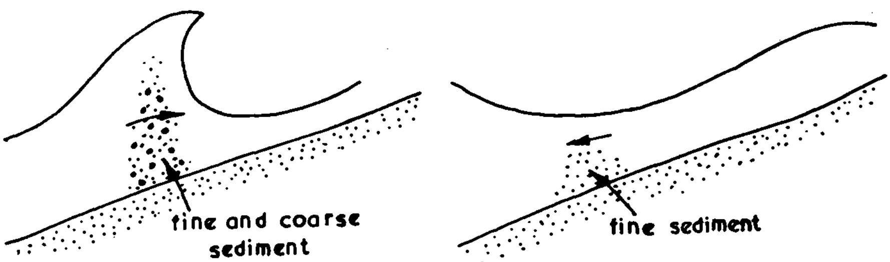

Fig. 11 Mechanism of sand sorting nearshore

If more coarse the bulk will be stored above water as beach berm, but because of the narrow exposed area and the larger diameter these grains are not so subject to wind transport.

Hence it would appear that a mixture of fine and coarse sand can serve the purposes desired, of providing material on hand for the construction of the natural defensive bar. The offshore zone of fine material is a ready foundation whilst the coarser fraction can form the top of this mound. During the transitional period of being returned shoreward both the fine and coarse grains will be mixed, until the waves can sort them once again. This makes the timing of sediment sampling for comparisons extremely important.

CONCLUSIONS

1. There are certain axioms or facts that can be accepted without question which, when considered together, point to new methods of coast stabilization.

2. Many mistakes have been perpetrated in the past because novel approaches to old problems are not readily accepted in conservative quarters of the engineering profession.

3. The basic requirement of coast stabilization is to have available from year to year sufficient sand to form an offshore bar which dissipates incoming storm waves.

4. The return of bar material to its original location (instead of downcoast) can be achieved in crenulate shaped bays where the persistent swell arrives normal to all points of the periphery.

5. Reclamation on its own suffers swift degradation, groynes expedite the transmission of sand downcoast, whilst headlands provide stable bays that can be used to the full.

6. When renourishment is carried out insurance against swift removal can take the form of headland construction which still permits the passage of littoral drift to downcoast areas.

7. The sand storage alternatives of dunes or shoals within embayments, indicate the need to seriously consider the latter for their long-term economic advantages.

8. When a shoreline is reoriented to receive normally the persistent swell, or resultant wave vector, the characteristics of the sand in a renourishment scheme are of little consequence.

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