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Research and Development Needs in Coastal Engineering

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ABSTRACT

There is need now and again to take stock of the direction in which research and development is headed to see if funds and energy are being spent wisely. This requires a critical look at failures which, unfortunately, are not publicised widely. Research is mainly carried out at Universities where limited thesis goals are attempted by individuals or groups. It is necessary to relate this output to the overall needs of the profession. In the development phase the constant tendency is for engineers to repeat what has been achieved previously whether it is successful or not. Knowledge of such inadequacy is hampered by reports in the literature appearing soon after construction, before any malfunctioning has been exhibited. The role of the critic is difficult to assume but is paramount if progress is to be made from past experience.

INTRODUCTION

The author has examined this problem previously (Silvester 1979) where he discussed nearshore structures, offshore structures, data collection and environmental problems. Research needs and facility requirements have more recently been discussed by an erudite group of engineers and scientists (Lee 1982). Its report is also divided into coastal and offshore engineering. Besides theory and modelling the topic of field measurements was also examined.

The participants at Hawaii in 1982 were divided into working groups which concentrated on certain topics. That on coastal protection and field measurements stated: "Yet, it is clear that understanding the basic coastal processes was, and in the future will be, the key to good coastal engineering." Such basic understanding is sometimes overshadowed by the tools used in analysis, such as the computer. The group on mathematical modelling expressed this possibility as follows: "Some words of caution are appropriate. Mathematical models are not an end in themselves; they require laboratory and field input and verification. Numerical models can become mildly addictive since, once running, they give nearly instant gratification. Time spent doing numerical modeling can displace thinking as the programmer who tinkers with the model becomes part of the outer DO loop of job submission and resubmission."

Another disturbing tendency is that numerical models are applicable to only a limited number of variables, for example currents generated in a system. In a mixing or diffusion problem wave action cannot be incorporated even though its presence may predominate over tidal or wind shear currents. Equally the mass-transport due to waves, which has not yet been fully analysed for turbulent conditions, must also necessarily be omitted. Researchers, in drawing conclusions from such studies, tend to omit reference to inputs that have not been included, or if they do so discount their importance.

Of all the branches of engineering perhaps that dealing with the wroth of the sea should accept that it is futile to fight Nature. Either you work in concert with her or you fail, ultimately if not before. One of the great qualities in natural phenomena is change. The swift variation in energy applied to a section of coast by a storm sequence must be accepted as a fact of life and should be incorporated into the design programme. Fluctuations in littoral drift must result but the underlying mechanism should be recognised. Nature never takes notice of an average.

Interuptions to the transport of material alongshore are known to cause instability on the coast, accretion in one place and erosion elsewhere. This is quite obvious with a structure such as a groyne or breakwater. But is equal recognition given to the influence of a deep channel dredged from a port across the continental shelf? It is equivalent to building a structure of that length from the coast out to sea, since any sand accumulated in the channel will be dumped offshore for convenience. Hence the transport of sediment along the coast beyond the breaker-line is stopped and the offshore area downcoast of the channel will suffer scour. This deepens and steepens the profile up to the waterline and results in beach erosion. By-passing the littoral drift (that within the surf zone) to the downcoast zone does not make up the lack of supply in the offshore area and hence does not obviate the erosion process.

Data gathering and presentation is the predominant contents of many consulting reports and published papers. Their value is sometimes questionable as little reference may be made to them in the conclusions or recommendations. In fact, the data collected may not be applicable to the problem because it has not been well thought out initially. If a preconceived hypothesis takes over, the data gathering may be restricted to proving it, with other variables omitted or discounted. In the ocean situation sediment at the bed may be moved by tidal currents or mass-transport due to the waves. If the former is accepted as the sole energy input instruments will be employed to measure them whereas the unmeasured waves may effect the transport.

Even when all the input variables are recorded to some degree of accuracy it must be recognised that these data are measured in one spot at one time. Conditions should then be compared with the general "climate" of the area. Normally field trips in the sea are carried out in good weather, what will a storm sequence do to the variables? Were the swell waves during measurement those to be expected throughout the rest of the year? What stage of what tide operated during the field measurements? What was the strength and direction of the wind?

SHORT-CRESTED WAVES

The groups dealing with waves concentrated on breaking, attenuation and wave set-up. In their interaction with mobile beds the formation of dunes was considered as requiring attention. The incidence of spectra rather than mono-chromatic waves was examined. However, no mention was made of shortcrestedness which the author believes is more pronounced than progressive waves across the continental shelf.

There is a dire need to study the kinematics and mass-transport involved in these complex water motions, even of simplified form. They are conducive to sediment suspension and transport, much more so than even spectral components of two dimensional wave systems.

Short-crested waves are formed from oblique reflection from seawalls or submerged objects, from differential refraction across the shelf, and from diffraction around the ends of island structures, to name a few sources. (Silvester 1974). They are, of course, present in storm waves due to the generation process. Very little work has been carried out on this phenomenon due, no doubt, to its complexity both mathematically and in its reproduction in models. But any enquiry into the future of coastal engineering should recognise this dearth of information.

The group on coastal structures concluded that: "There are many more possibilities for breakwater design than are now being pursued (for example, composite designs)." These consist of a rubble-base on which are placed concrete caisson-type elements filled with sediment. Such structures are very narrow compared to a wave length and can therefore suffer great turbulence at the tip with wave diffraction. This action is amplified when long period swell waves arrive obliquely to a breakwater. (Chang 1977). As an island crest of the short-crested system reaches the tip of the structure the water level on the seaward face is nearly double the incident wave height whilst that on the leeward side is still-water level. Flow ensues in the form of a vortex. A vortex with opposite rotation occurs when the trough reaches the tip. These in turn pentrate to the bed whilst being oscillated back and forth in the region of the breakwater extremity. Their severe suction forces can suspend sand or even rocks of large dimensions. Wave period is more influential in this scouring propensity than wave height and hence the more persistent swell can effect damage rather than the more infrequent storm waves.

As noted already the submerged sections of breakwaters can readily reflect waves. In the same way bodies which do not protrude through the water surface can equally reflect the portion of the water motions that impact a face. Vortices at sharp edges can be formed in the same way as with tips of breakwaters due to differential pressures as crests and troughs traverse these extremities. Thus there is a strong scouring action as has been observed around submerged reefs, sunken ships and large man-made facilities on the seafloor. A disturbing fact is that monitoring is not instituted by many of the authorities in control of such structures. The consultant, contractor and owner have not seen the need to conduct surveys of the bed in the vicinity as would be the case of settlement of foundations under landbased buildings. Perhaps the installation of instruments to record sediment suspension at various distances from the bed would provide a warning of scouring taking place.

Another type of submerged structure important in offshore activities is the pipeline resting on the bed, such as sewerage outfalls. Whilst waves in shallow water may propagate parallel to the pipe, in the deeper zone they could well approach it obliquely. The short-crested water particle motions near the bed can scour a trench on one side with subsidence a possibility. Such lines tend to break some metres from the extremity as the reflection does not take its full effect till some fraction of the wave length from there.

SEDIMENT TRANSPORT

The group on sediment transport recognised at the outset the difficulties in studying this subject, stating: "Sediment transport phenomena in shallow water was extremely complex and beyond our capability of quantitative description at present." They suggested the use of tracers for measurements over time, and also the simultaneous record of sediment particle motion to elucidate the detailed mechanism of sediment transport.

Both the above approaches should take cognisance of the wave climate which includes periods of storm waves and swell. These each have a different influence on sand at the beach, the former removing material from the beach berm and placing it offshore whilst the latter replace it. (Silvester 1984). During the short period of time for this return a large pulse of littoral drift occurs due to the excessive turbulence and longshore current as waves suddenly encounter this mound with a steep offshore face. These large fluctuations of transport are the baine of mathematicians in their attempt to verify formulae relating sediment movement to wave input. The storm waves virtually place a large volume of sand into circulation. This is then subjected to oblique swell until it is back on the beach and the normal beach profile is reformed.

The two or three weeks over which sediment transport is optimum requires that monitoring be carried out during such short periods. Accretion against some natural or man-made structure or on a sand spit should be measured at the same time as the offshore bar is profiled. The group on coastal protection and field measurements acknowledged this requirement in their statement: "Additionally, the working group recognised the urgent need for a rapidly deployable, beach survey system. Such a system would be very useful in measuring shoreline elevation and profile changes on a routine basis, but it would be particularly desirable for documentation of large beach changes as soon as possible after severe or catastrophic storms."

BEACH STABILIZATION

No mention was made of novel methods to stabilize coasts which copy that of nature by the formation of zeta shaped bays between headlands. This phenomenon is ubiquitous as such physiographic features are prominant along coasts where waves arrive persistently from an oblique direction. The combined diffraction and refraction occurring in the lee of headlands sculptures the beach into a consistent logarithmic spiral shape with a more straight tangential downcoast zone. (Silvester 1970). Modelling and field measurements of bays where sediment supply is zero have produced parameters to predict stable beaches. In this situation the persistent waves arrive normal to the complete periphery of the bay. This implies that sand removed offshore during a storm is replaced directly onto the beach from whence it came without any longshore transport.

There is little necessity to repeat such experiments to verify this action but there is a great need to carry out pilot studies to determine key characteristics resulting from any local wave climate and sediment supply condition. The ratio of indentation to headland spacing can then be used to design other embayments along the adjoining coast.

The author believes this to be the only economical approach to beach erosion since groins can expedite longshore drift due to material being deposited further offshore by the rip currents formed at each structure. (Silvester 1976). When being brought back to shore it is transported further downcoast than if a normal bar is formed. The group on coastal structures admitted: "The present theory of groins is often inadequate because the important effect of wave reflection is not included." There would appear to be more than just reflection involved in this lack of knowledge.

The same group also discussed the latest panacea of beach erosion, namely, that of beach fill. They commented: "Artificial beach nourishment is done usually at great expense but the result is seldom monitored for important data on this subject." Such recording of waterlines over an extensive shoreline for a number of years was carried out where some beaches had received renourishment. (Winton 1983). This showed conclusively that beach fill erodes much more quickly than the original shoreline and that in a matter of 1 to 2 years has receded to this limit. Notification in the literature of these undertakings at particular sites recurs at about 18 month intervals, indicating the disappearance of this expensive material over this time. Not only does renourishment not stabilize the coast but it creates another by silting river mouths and harbours downcoast with this excessive load of material.

BREAKWATERS

The group on coastal structures had "a far ranging discussion on breakwater design, stability and modelling." Their conclusion was "that there was room for more imagination in breakwater design . . . ." The problem is that large organisations must undertake these tasks and these, by their very nature, are conservative. Past designs are more acceptable even though some may be proven failures, the explanations of which are not definitive nor widely accepted.

Design of armour units for breakwaters has been based on formulae derived for shallow-water conditions. Now that these structures are being taken into deeper water (up to 90 m in some cases) the wave period becomes as important as the wave height, inspite the conclusions of the group on coastal structures that "The greatest uncertainty in coastal design (breakwaters specifically) is the design wave height. This has the greatest effect on crown height and coastal structures, therefore on cost." More recent work on "wave resonance", in which outflow from the face coincides with an incoming crest, has shown the importance of wave period. (Sawaragi and Ryu 1983).

Besides the massive armour units, design of sublayers of rubble rock requires attention since pressure fluctuations inside the structure can cause sudden failures. It should be recognised that, although wave dissipation is exhibited from the trough to above the crest height, below this level the wave is encountering a steeply sloped body of smaller rock. The water particles are almost horizontal but there is little penetration within the voids. The face therefore acts almost like a plain concrete wall giving virtually 100% wave reflection for this lower half of the water column. The placement of impermeable filters just below the surface to protect smaller rubble or core material increases the percentage of reflected energy.

When waves arrive obliquely to the breakwater and are reflected over their lower water column zones they establish complex water particle motions near the bed similar to those in short-crested waves. These orbits vary across the normal to the breakwater or the crest length. (Silvester 1972). Next to the face the orbits are in a plane more or less parallel to the breakwater, as they are also one half crest-length away from it. Half way between these alignments the orbits are almost horizontal but are normal to the breakwater. Half way again or at (crest lengths/8) intervals vortices are established which apply suction to the bed which can readily suspend sand or even large pebble material. This, together with the mass-transport which can be double that for the progressive incident oblique wave, can scour the bed and move sediment along the breakwater. The resulting deep trench at the foot of the structure may have a slope equal to the angle of repose for the bed material. During a storm the pore pressure may build up quickly and cause a sudden subsidence of this supporting element. There is great difficulty in obtaining hydrographic survey data when breakwater failure has occurred, either because they are sub judice because of litigation, or they are considered as private property. Such secrecy impedes the full analysis of any event by the profession as a whole and therefore slows progress. If more sharing of knowledge took place, even at the expense of displaying a little incompetence, coastal engineering would not receive so much technical criticism as unfortunately it has done. The medical profession, to be sure, would not countenance so much cover-up.

FLEXIBLE MEMBRANE UNITS

The present design of breakwaters is concentrated on the stability of large armour units placed above and below the normal sea surface, ostensibly to break the incoming waves. This they do, and appear to do, which is accepted readily by the financiers. However it is only the top of the wave which suffers such dissipation. The submerged portion of the structure generally comprises smaller stone elements which are also subject to swashing motions and pressure fluctuations. Their stability is harder to analyse and has been evolved empirically. All of which points to the need for a new approach to breakwater design as noted by the coastal structures group above (Lee 1982).

Such a new approach has been developed over the past decade by the use of flexible membranes sewn into bag form which are then filled with a cement mortar mix. (Silvester 1982). These in-situ cast units can be of any size or proportion to resist wave forces. Their major advantage over rubble-mound or pre-cast concrete armour units is that they take-up the shape of those already in place. The large surface contact precludes their rocking or being plucked from the face by excessive internal pressures of the breakwater. The mortar consists of the sand available on site and hence avoids the necessity of long haulage of bulk material from a quarry. It is mixed on site and pumped to the location in the structure.

The flexible membranes are only required as temporary formwork for the mortar whilst it is setting, after that it can deteriorate without effect on the units. The complete structure could comprise these cast in place monoliths, commencing at the bed and proceeding upwards sufficiently to accomplish the task of breaking waves. Rubble-mound structures on the other hand have to be wide at the soffit to permit vehicular traffic plus cranes, and slope each side side at about 1:2. They are built many metres above HWM to permit continuous construction. The membrane structure is therefore smaller in cross-section, which must be taken into account when comparing unit costs of each.

Many workers have designed such mortar units with strengths equal to those of the precast concrete alternative, which makes them costly. But when rocking and placement forces are obviated the major stresses to be withstood are load from above and forces from the bending-moment resulting from wave forces. These are mild in character and could be catered for by a strength equal to that of limestone. Mixtures to achieve this desirable limit have been tested which include cheap additives to cement. (Silvester 1983).

This new approach has many attractions as construction is swift and requires very little infrastructure and equipment. It has been especially applicable to developing countries where local unskilled labour is available. (Porraz et al 1979). But the economies can be passed on to western technology where costs of marine structures is increasing exponentially. Because of the resulting near vertical face wave reflection will be pronounced, thus calling for protection of the bed adjacent to the structure. But even rubble-mound breakwaters should receive such treatment if failures are to be avoided when persistent swell arrives obliquely.

Should such a novel concept receive the same research input as have the various shaped precast concrete units in recent years the logistics and other minor matters could be overcome readily. The resulting breakwaters would be stable and not require continual maintenance as do the traditional rock alternatives. Whilst an erudite group of researchers may thus call for greater imagination in breakwater design the problem is in getting suggestions sanctioned, even to pilot-study stage, by the heirarchy of designers who are perceptive only to precedent.

CONCLUSIONS

When assessing the success or otherwise of a field of endeavour not only should specific issues of design and construction be examined but also the philosophy of approach. Of all the branches of engineering, that of civil would appear to be the most conservative. If electrical or mechanical engineers had rejected novel concepts at the same rate as civil engineers we would still be riding around on bicycles. This phase of engineering, particularly that relating to the sea, must be more inventive and more research effort put into new ideas, both in the laboratory and through pilot studies in the field.

The items included in this brief survey of the problems to be faced may be summarised as follows:

1. Mathematical models and computerisation should be recognised as tools which are part only of an overall problem encompassing many environmental issues.

2. As coastal engineering deals with Nature more than most other specialties its protagonists must work in concert with Her and provide assistance to achieve the goals of man.

3. Recognition must be given to sediment transport along the coast beyond the breaker line as well as within the surf zone where movement is more obvious.

4. In the collection of field data cognisance should be given to all possible variables entering the problem with full recognition that recordings are made in one place at one instant of time, thus calling for comparison of energy inputs over many years.

5. Concentration has been placed on progressive waves in sediment transport of the offshore zone, perhaps with spectral distribution of waves and periods, but the phenomenon of short-crested systems has been discounted with erroneous conclusions.

6. Rates of littoral drift are not readily amenable to mathematical formulation at the present state of the art due to the multitude of variables entering the problem.

7. The combination of storm sequences forming an offshore bar and the milder swell waves which return this to the beach results in impulsive littoral drift over a period of 2 to 3 weeks, which should be taken into account in sediment processes such as by-passing of river or harbour mouths.

8. In the stabilization of coasts the efficiency of headland control should be considered as an alternative to seawalls, groynes or renourishment as these have proved deficient in the past.

9. The possibility of scour adjacent to structures protruding above the sea or even submerged, due to oblique reflection of waves, should be researched fully to provide an alternative explanation of failures that have become prevalent in recent years.

10. To overcome the increasing cost of rubble-mound structures, with perhaps pre-cast concrete armour units, consideration should be given to the employment of cast in-situ members with flexible membrane formwork which provides for greater contact area and hence greater stability even when made of a mortar mix of modest strength.

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