CHAPTER 167

Design and Evaluation of Beach Protection Schemes

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ABSTRACT

On the basis of eleven poster presentations on beach protection schemes and/or devices, at the recent 20th International Conference on Coastal Engineering, the various levels involved in the design and evaluation of beach protection schemes are discussed in this paper. These are: (1) the assessment of the problem and processes operative in the area; (2) the establishment of an overall master plan for development; (3) the design stage; (4) the construction phase, and (5) the post-construction phase. It is concluded that it would be useful if some form of international co-operation could be instigated to allow the collation of techniques used at the various levels in one handy location, for dissemination by all contributors.

1. INTRODUCTION

The International Conferences on Coastal Engineering, held every two years at a different venue, have traditionally brought together coastal scientists from more than twenty countries. The 20th such conference, held in Taipei, Republic of China, in November 1986, was attended by about 500 coastal scientists from around the world. During the conference two poster discussion sessions on beach protection devices were held, under the chairmanship of the authors of this paper. On the basis of the contents of the eleven individual poster papers presented in these two sessions, the various aspects related to the design and evaluation of beach protection schemes were discussed at the conference. Significant advances were made in bringing together data on these aspects. This paper contains an overview of the results achieved during the two poster discussion sessions.

It should be pointed out here that the discussions were held in a way which allowed the audience to contribute by filling in any gaps in knowledge that were apparent after the presentation of overviews by the chairmen.

After the discussion of the various levels of evaluation and design a wider perspective is taken in suggesting the comparison of techniques used worldwide. Means of achieving this are discussed.

The eleven papers under discussion can be subdivided as follows:

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(1) **those dealing with beachfill**
Möller, Owen and Swart (1986)

(2) **those dealing with offshore breakwaters**
Yeh and Ou (1986)

(3) **those dealing with combinations of beachfill and structures**
Deguchi and Sawaragi (1986); Pui (1986); Kana, Al-Sarawi and Holland (1986); and Suyama, Uda and Yoshimura (1986)

(4) **those dealing with offshore dredging**
Kojima, Ijima and Nakamuta (1986)

(5) **those dealing with river deltas**
Kadib et al. (1986); and Gambardella (1986)

(6) **those dealing with other related topics**
Hayashi (1986); and Kawata and Tsuchiya (1986).

The contributions by the above authors and members of the audience during the discussions helped make these poster discussions very successful and are gratefully acknowledged.

The rest of this section is devoted to a short summary of the key elements of the different papers referred to above, to serve as a basis for the discussion in the further sections of this paper.

Beachfill

Möller et al. (1986) describe a diamond mining operation on the west coast of Africa in Namibia, where a sea-wall of normal beach sand has been built out to a distance of more than 300 m seawards of the original coastline. The wall which runs alongshore (as shown in Figure 1) is maintained in the high energy environment, which is characterized by northbound longshore transport rates, by means of artificial suppletion at a rate of more than 300 000 m^3/month. The question which had to be answered before the project could commence was whether there would be enough overburden sand available on land to allow the completion of the project free of severe damage by wave action. The data set used consisted of wave measurements by Waverider and wave observations obtained from voluntary observing ships; aerial photographs at monthly intervals of the water line in the study area, and soundings of the beach, sea-wall and nearshore topography (using a helicopter as a platform).

The individual survey results were used to establish a sand budget for each survey period. These sand budgets were used as input to a N-line littoral, morphological model. This model was preferred to a one-line coastal model because of the large alongshore differences in profile shape. During the three years that the project has run to date this technique was used to project the required volume of sand to complete the project by the expected completion date of March 1988. The project can serve as a one-to-one scale beachfill test and could prove extremely useful to evaluate techniques for the design of beachfills.

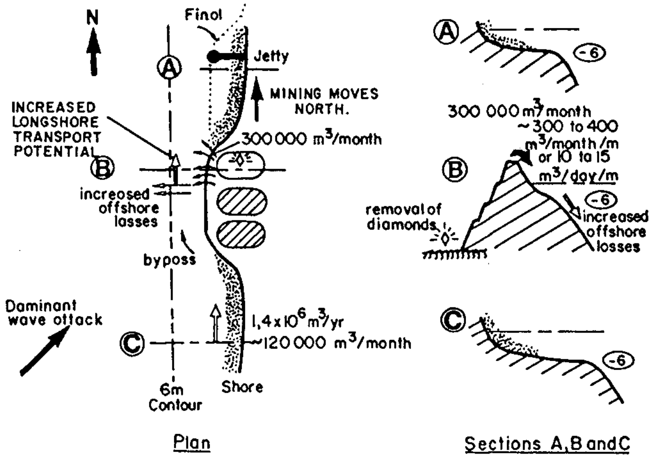

Fig.1 Oranjemund mining layout
(after Möller et al, 1986)

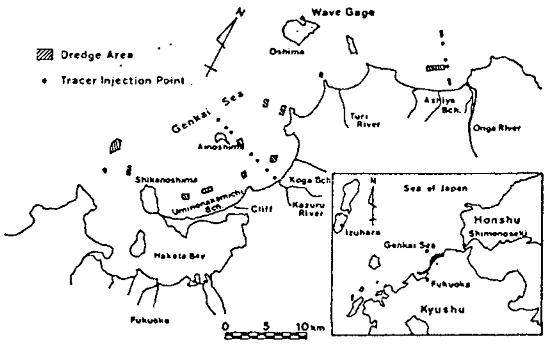

Figure 2 Vicinity map of the study area
(after Kajima et al, 1986)

Offshore breakwaters

This type of structure has found widespread application in the protection of eroding beaches. 8ecause of the formation of cuspate forelands behind such breakwaters and the attractive embayments that are formed between them, bathing conditions are created which are both safe and of a varying nature. The design of offshore breakwaters involves the choice of the breakwater length, distance offshore, crest elevation, the gap/length ratio and the necessity of supplementary beachfill landwards of the breakwaters. The paper by Yeh and Ou (1986) discusses the application of offshore breakwaters to the Redhill coast of Taiwan in the Republic of China. The coastline in the area consists of sandy eroding cliffs 6 to 10 m high and has a limited natural sand supply. In 1978 seven detached, offshore breakwaters with a length of 80 m each and a gap spacing of 30 m were built at mean sea level to protect the beaches. Field observations were done over a period of 3 years covering pre- and post-construction phases. The data were analysed using eigenfunction techniques. In 1985 laboratory tests were done to supply design data for determining gap spacings. Substantial improvement in beach stability has been experienced since the construction of the breakwaters.

Combined beachfill/structures

8eachfill is often used in combination with structures, especially in areas where it is expected that the natural littoral drift will transport sediment out of the area too quickly, thereby reducing the effective life-time of the beachfill. Three of the papers listed above fall in this category. Deguchi and Sawaragi (1986) describes how sand was placed in the lee of a 80 m long offshore breakwater in 1984, one year after construction of the breakwater was completed. Surveys were done 4 to 6 times a year. Immediately after construction of the breakwater both longshore and offshore sediment transport took place as the beach reacted to the changed littoral regime. Thereafter longshore transport dominated until the beachfill was placed. Within two months after placement fifty per cent of the beachfill was lost from the area behind the breakwater, and a further 10 per cent of the initial volume lost in the next two months. This study clearly indicated the benefit of using a mathematical simulation model to help interpret the field results. In the model used, wave deformation, wave-induced currents, sediment movement and associated bottom changes were simulated.

Pui (1986), on the other hand, shows how as a result of land reclamation to meet the increasing needs of the fast-growing Singapore population, the shore was built out to such an extent that the littoral processes were accelerated, thereby necessitating the simultaneous construction in some areas of revetments or headland breakwaters. In a few cases additional measures were not required owing to the favourable alignment of the beachfill. An interesting aspect of the work carried out in Singapore is that it is quite possible that beach protection carried out on Singapore beaches could influence beaches in the adjacent Malaya. This aspect was not formally addressed in the paper and poses the question of how such cases should be handled.

Kana _et al_. (1986) give a very good example of a combined beachfill/structures approach. It is most probably one of the most extensive recreational waterfront projects ever designed. The results of a field-monitoring programme, which started in 1977, were used to draw up a master plan for beachfront improvement as well as a series of design criteria. The scheme includes artificial beaches, promenades, revetments, outfalls which also serve as headland breakwaters for the artificial pocket beaches and an artificial island. On the basis of the wave data longshore transport calculations were done and were used to orientate the pocket beaches to the waves, thereby largely eliminating longshore sediment losses. An interesting aspect of the design of the beachfill is that a berm elevation of 1 m above mean high water springs was used. This allowed washover and as a result the beaches attained a natural appearance soon after construction. Two years of post-construction monitoring has been done to evaluate the behaviour of the artificial beaches. Typically, ten days of recordings are done every three months. Wave energy levels are compared with pre-construction levels, and profile data are used to compute sediment budgets for the various beach compartments. The monitoring shows that the sand losses from the scheme are low and it is not expected that renourishment will be required later.

Suyama et al. (1986) describes a field experiment on the Shimoni-Ikawa coast on Toyama Bay in Japan. Downdrift of Miyazaki fishing harbour the coast is eroding owing to the interruption of littoral drift by the harbour. The purpose of the field experiment was to investigate the effectiveness of sand bypassing as a method of combating beach erosion and to evaluate the degree to which offshore breakwaters in the downdrift area can serve to minimize sediment redistribution after replenishment of the beach. The measuring program included wave measurements (height, period, direction), nearshore bathymetric surveys and a tracer experiment. It was concluded that a slow longshore movement of sand took place without appreciable sand losses through the gaps between the three breakwaters, which were situated about 20 m offshore. The artificial sand infill into the area behind the breakwaters helped to create tombolos, which would not have formed otherwise, and reduced wave overtopping of the structures due to shallower water at the structures.

Offshore dredging

The supply of sand for building and other purposes is posing an ever greater problem in many parts of the world. Offshore sand bodies are frequently exploited. In such cases where offshore dredging is done, it is necessary to establish the best location and dimensions for the borrow pit. Aspects which have to be carefully considered are the following:

- the relation of the location of the borrow pit to the dynamic swept prism and the corresponding effect it has, either directly or indirectly, on the sediment transport processes in the area;

- the effect of the borrow pit on wave propagation patterns and the associated effect on wave focusing and hence on beach erosion at the shore; and

- the potential effect of the dredging operation on the general ecology of the area, and the degree to which recovery of the sub-bottom faunal life will take place.

The paper by Kojima et al. (1986) discusses most of these aspects, with the exception of the ecology. Figure 2 shows the areas on the Genkai coast where offshore dredging has been done. Kojima et al. describe a wide range of measurements done to establish whether or not the offshore dredging has accelerated beach erosion in the area. Typical elements of the data gathering and analysis exercises were the following:

- an analysis of aerial photography in the period 1947 to 1982;

- hydrographic surveys and sediment sampling to establish recent trends;

- fluorescent tracer experiments in which the fate of underwater injection at water depth intervals of 5 m in the area between 10 m and 30 m water depth is investigated with the aid of underwater observations; and

- extensive wave and weather surveys, supplemented by a compilation of available old data dating back to 1945, where, amongst others, it has been shown that the frequency of occurrence of high wind speeds (> 10 m/s) has decreased steadily over the last ten years.

It is concluded that although beach erosion has taken place before dredging started due to mainly high incident storm-energy, it was more than likely that offshore dredging did affect shore processes. It was furthermore concluded that borrow pits situated in water depths shallower than 30-35 m filled in readily from the landward direction, thereby showing that the borrow pits should be situated further offshore in deeper water. This is interesting since it is deeper than is traditionally recommended.

River deltas

When dealing with shore protection schemes on river delta coastlines the general problem is compounded because of the added processes associated with the river delta itself. Here specific attention should be focused on current patterns related to the river delta formation and orientation, decrease in the shore area, relative sea-level rise (relative shore drop) and shoreline protrusion with the associated effect on morphological processes.

The papers by Kadib et al. (1986) and Gambardella (1986) serve as reference. Kadib et al. describe the development of the Nile river delta. Up to the end of the 19th century the supply of sediments to the delta generally exceeded the losses due to wind, current and wave processes in the shore area. After construction of the lower Aswan Dam on the Nile in 1912 beach erosion at a rate of 30 m/year commenced. This increased to more than 170 m/year after 1966, when the Aswan High Dam was built. The Egyptian Government recognized the seriousness of the situation, and instigated an extensive investigation programme. On the basis of an analysis of the field data gathered as part of this programme, the 350 km coastal area was subdivided into six morphological regions. Various shoreline protection schemes are being evaluated against each other, each taking into account the specific morphological behaviour of the region under consideration. Protection devices which are being considered are shoreline hardening with the use of armour units, sand nourishment, groyne systems or detached breakwaters in conjunction with sand nourishment, "no action" with assessment of the economic consequences and other options.

Gambardella (1986) shows that the shoreline of the Po river delta in Italy receded dramatically since the 1950's. Two main processes can be identified as being causative factors. Natural subsidence of the more than 2 000 m thick, unconsolidated post-Pliocene sediments which is about 1,5 mm/year, increased to about 15 mm/year due to water and gas extraction, reaching a maximum of 3 m/40 years locally. Secondly hydraulic works, industrial installations and extensive reclamation works altered the natural equilibrium of the outer coastal area, thereby giving rise to shoreline recession. It is not always possible to shift back the protective sea-walls because settlements have been established in the coastal area immediately behind the sea-walls. Figure 3 shows the cross-section of the standard dike-breakwater construction which was traditionally used as beach defence. Due to the substantial erosion of the delta beachfront the dike/breakwater systems proved ineffective to prevent beach erosion. The application of 1 m to 1,8 m diameter sand-filled "Longard" tubes in a configuration as shown in Figure 4 has to date proved very effective and is considered the mechanism to combat future erosion.

Other beach protection techniques

Two papers fall in this category. Hayashi (1986) described the use of beach-walls as opposed to sea-walls, to serve as an effective beach erosion protection in the Hawaiian situation. Kawata and Tsuchiya (1986), on the other hand, describe the use of a sub-sand filter system as beach erosion control mechanism. Using the Hawaiian experience as an example, Hayashi shows that by using sea-walls with a nearly-vertical seaward face to protect properties and maintain the certified shoreline, beach erosion is frequently enhanced and extends to the adjacent properties, thereby giving rise to the so-called "domino" effect. The use of beach-walls, a concept developed by Hayashi, however, leads to much more natural beach processes. Experience over two years has shown that beaches are retained more readily in front of beach-walls (see Figure 5 for typical cross-section) than in front of sea-walls or other hard structures.

Kawata and Tsuchiya (1986) discuss both theoretical and experimental studies to investigate the effect of a sub-bottom filtration system whereby water is drawn into the bed. As is to be expected, the increased inflow velocity into the bed causes the threshold velocity of bottom sand to be increased, as can be seen in Figure 6. Although the laboratory experiments showed conclusively the benefit of such a filtration or draw-off system, the main problem that remains is the manner in which such a system can be constructed and maintained on a natural beach.

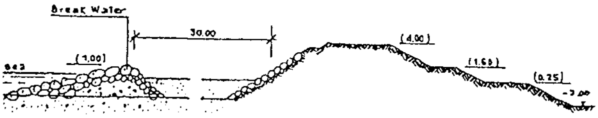

Fig. 3 - Cross-section of a standard dike-breakwater system, in the Po river delta area.

(after Gambardella, 1986)

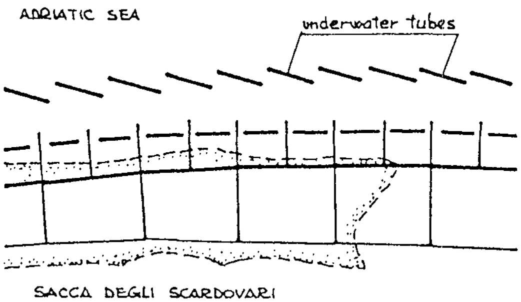

Fig. 4 - Plan of progressive reconstruction of an eroded sand spit, at Sacca degli Scardovari, southern Po river delta, using the 'Longard - tube' system. The dotted line indicates the shoreline prior to the tube installation. Thick and thin lines indicate 1.8 m and 1.0 m tubes, respectively.
(after Gambardella, 1986)

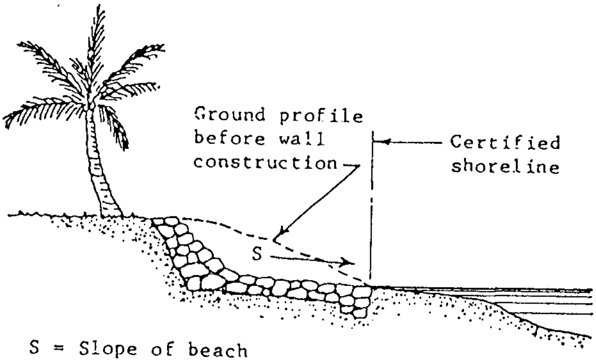

Figure 5 ´ Typical beachwall section

(after Hayashi, 1986)

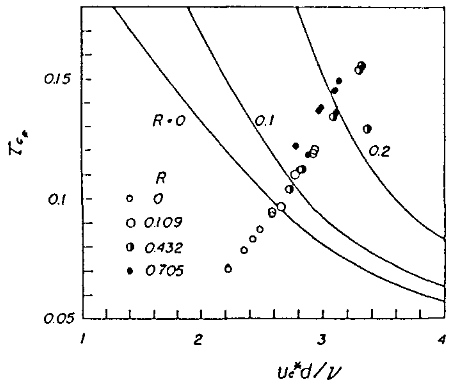

Fig. 6 Comparison between theoretical threshold of sediment movement and experimental one

(after Kawata and Tsuchiya, 1986)

2. PROBLEM/PROCESS ASSESSMENT

The first level at which a beach protection design needs to be addressed is the "problem or process assessment" stage. It is always advisable to know not only what is happening but also how and specifically why it is happening. With this background knowledge it is then possible to proceed with the further steps of the design.

The following types and sources of data can prove useful/essential in acquiring the necessary background knowledge:

- old maps and charts;
- aerial photographs;
- topographic/hydrographic surveys;
- wave/weather data;
- landward needs/problems;
- geomorphology; and
- ecology.

It is always advantageous to review old and/or existing data to gain an idea of the processes/trends operative in the area, before embarking on a new measuring campaign. The same pre-screen of available data also applies to wave data, where observations made by merchant shipping (the so-called VOS wave data) give a good first idea of the wave climate in the area, including seasonal changes, and also helps in designing the measuring exercise. In any beach protection design it is important to make a sediment budget analysis. It is usually possible to make a first stab at such a budget by using the shoreline position on old charts to estimate volumes. With the aid of all the preceding it is possible to design a measuring exercise in relation to old/available data.

Hydrographic data usually play an important rôle in assessing sediment budgets. Because the sediment budget is frequently determined by taking the difference between two large volumes, it is essential that the surveys used for this purpose should be as accurate as possible.

In this respect it is appropriate to examine the closure depth for repetitive surveys carefully, to decide whether the observed closure depth can be explained in terms of physics. Another check for accuracy is to compare elevations in an area of overlap between land-based and sea-bed survey data.

It is important that the coastal engineer should realize that the quality of the project may be vastly improved by close liaison during the problem/process stage with scientists of other disciplines, be they geomorphologists, planners, landscape architects, geographers and/or ecologists. It is also particularly important to the client that he does not get conflicting advice from the various disciplines, but one sensible answer. It is in this respect that the engineer can play an important rôle in bringing together the other disciplines to assess processes and evolve working concepts as a basis for sound coastal engineering design.

3. ESTABLISHMENT OF MASTER PLAN

Having established the exact magnitude and nature of the problem, the next level of attack is to determine an overall master plan which will allow one to foresee future problems in other areas and give one the opportunity of gaining a wider perspective of the beach protection problem. It is important, therefore, never to treat problems in isolation. It is also appropriate to establish future requirements at the site or in the vicinity, and to decide on the optimum manner in which work needs to be phased to best solve the problem in the long run.

Although this may sound rather early to talk about the optimum solution, it is quite foreseeable that there are some specific site problems such as the non-availability of rock, which preclude certain solutions. This may also be the case with the specific culture or requirements of the locals/beach-users.

In all cases it is of the utmost importance to start with a public relations exercise as early as possible to make the public aware of what is at stake and what they can expect from such a beach protection scheme.

In deciding how far to go with the establishment of a master plan, it is important to realise that by deciding on, for example, a long-term policy of beach nourishment, it helps one to phase other activities such as the development of a market, determining dredging capacity, etc.

At this early stage one has to clearly address the question of what the feasible options are for beach protection, with the relative merits of each. One viewpoint expressed during the discussion is that in making this decision one should look to nature to see how it would do it, and what would happen. Dr Silvester, in making this comment, ended up saying that headland embayments are natural features optimizing energy losses in the most efficient manner. However, it is the belief of the authors that this philosophy of looking to nature for the wider clue to the solution is a sound one and may result in different solutions under different circumstances.

4. DESIGN STAGE

The next and most important level in the establishment of a beach protection scheme is the design stage. The following aspects are all relevant in this respect:

- the various elements of the type of solution, and the phasing of the work/needs; which necessitates an evaluation of the alternatives;
- the design technique(s) used, whether involving
  - field data
  - laboratory experiments with fixed and/or movable bed models
  - mathematical/numerical simulations or
  - some (hybrid) combination of the above

- whichever of the above techniques are used, the design approach should include an appropriate calibration condition and a predictive mode/data set;

- it is important to consider the **interaction** between the beach protection scheme and the nearshore environment, that is, the effect of the solution/scheme/structure on the morphology, as well as the effect of the nearshore environment on the solution/scheme/structure, and

- for a proper evaluation of each alternative it is essential that the initial (construction) costs and subsequent maintenance costs should be separated.

The following are some general points related to various types of beach protection device which were discussed in the two sessions:

Filtration systems

The idea of increasing the inflow of water into the bed in order to increase the threshold velocity and reduce the movement of sand is sound and its effectiveness has been demonstrated both numerically and in the laboratory. Before it can be applied in the field, however, the researchers responsible for promoting the idea should collaborate with contractors capable of applying these thoughts in practice, in order to sort out the various problems associated specifically with securing such a system in nature and making it a low-maintenance system.

Beach-walls

With reference to the paper by Hayashi (1986) it would appear that beach-walls would be preferable to sea-walls not only on account of their lesser interference with morphological processes, but also on aesthetic and ecological grounds. The importance of the latter will be appreciated if one recognizes that the ecology reacts to changes in the natural, physical environment. As it is expected that beach-walls will change the natural environment to a lesser extent than sea-walls, the ecology will also be less affected. Although not called beach-walls (a term coined by Hayashi) such structures have been built in numerous locations around the world, with great success. Aspects of beach-walls which need to be addressed further are the optimum crest elevation and the degree of damage which can be tolerated. Obviously the crest elevation will be a function of the application: for example, the Dutch have buried a protective wall in their vulnerable coastal foredunes in areas where the protection afforded by the dunes alone was insufficient. In this case the crest elevation approaches the dune crest elevation. However, for more traditional applications such as those referred to by Hayashi (1986) it should be possible to establish some guidelines for the preferred crest elevation.

Detached breakwaters

Over the last twenty years or so hundreds of detached breakwaters have been constructed in widely different environments. The behaviour of a fair percentage of these has been monitored. Because the design geometries of these breakwaters, as depicted by breakwater length, gap size, offshore distance, water depth at structure and crest elevation of structure, also vary greatly, it should be possible, and highly profitable, to characterize the behaviour according to design geometry. Rosen and Vajda (1982) and Schoonees in CSIR (1986) have attempted to do so. This does not mean that one can get away without a detailed design stage; it merely allows one to make a very intelligent first guess at a scheme. Aspects of the design of beach protection schemes by means of offshore breakwaters which require specific attention are the following:

- the volume of sediment which needs to be moved by the waves to reshape the beach and, related to this, the time reguired to do so as well as the extent of possible areas of erosion;
- with the first point in mind, the necessity for artificial nourishment of sand to aid the reshaping process;
- the aesthetic appearance of such offshore structures, with specific reference to the "requirement" of bathers to be able to see the sea, to allow them to feel they are on the beach and not only at some inland water pool, and
- the structural design of these structures, which is frequently neglected and which necessitates either costly maintenance at an early stage or the redesign of the scheme in total.

Groynes

In the first half of this century groynes were mostly seen as the ultimate solution to beach erosion problems. Usually, not enough attention was given to the process assessment stage and the end result was that downdrift beach erosion was enhanced. Groynes are only effective against long-term erosion due to longshore gradients in the longshore transport. Even then they do not prevent erosion but only retard it while the longshore drift fills up the updrift beach before bypassing commences. A major problem with groynes is the extent of the downdrift erosion. Downdrift erosion can be curtailed/minimized by using different types of partially permeable groynes which do not present such an impermeable barrier to the longshore drift. Groynes of this type are low-level groynes which allow part of the drift to pass over the low-level portion of the groyne, which could, for example, be sloped to a desired beach profile, or piled structures which allow part of the drift to pass through the piles, or combinations of these two types, or short groynes which fill quickly and have a shorter offset. In all these uses it is important to assess **quantitatively** beforehand what proportion of the sand will bypass, and when and how, as well as the type of flow field which will be set up updrift of the groyne, for example, an eddy or a rip current, and the extent to which this flow will influence the morphology in the vicinity of the structure.

Another important aspect which needs to be taken into account at the design stage is that if vertical walls (such as closely spaced piles) are to be incorporated in the design, it would be essential to consider the extent of scour which would result on the updrift side of the structure in the area where increased turbulence results from interactions between reflection off the structure and the updrift rip current, should it occur.

Recently the tendency has been to use permeable groynes of one type or another **in conjunction with** beachfill, to achieve a minimum guaranteed beach width.

Beachfill

Beachfill is perhaps the type of beach protection scheme most-favoured today, mainly because of its natural appearance upon completion. Ecologically this is also preferred because natural habitats can re-establish themselves - although during placement fairly substantial mortalities of sub-bottom communities could occur, mainly as a result of the pumping exercise.

In designing a beachfill it is imperative that the designer understands the processes at work. It is particularly important that he understands the mechanism(s) by which material will be removed out of the fill and where such material will end up.

The traditional techniques advocated for the establishment of the magnitude of the fill required, for example by Krumbein and James (1965), Dean (1974), James (1974) and SPM (1984) do not take the mechanisms of movement into account **and can therefore at best provide a first estimate of the required placement.** In addition, most of these techniques exaggerated the required placement because they depart from the premise that the grain size distributions of native and borrow material must be similar.

Nowadays it is recognized that a more detailed design of a proper beachfill is required, especially as it is now such a popular protective technique and because of the high cost, both in the initial stages and thereafter, if maintenance is required. The Dutch have just published a manual for artificial nourishment (Manual on artificial beach nourishment and coastal processes, 1985) which covers most of the aspects to be considered in a beachfill design very adequately. This document is a must for every designer using beachfill.

The following techniques exist for a more detailed design of beachfills:

- One-line coastline evolution models such as that by Pelnard-Considerè (1954), but modified to include diffraction effects. This type of model will only have limited application because of the nature of the assumptions, that is, transport takes place in one layer, profile shifts as a geometrically undistorted profile, the difficulty of defining the effect of the beachfill on the amount of longshore transport "by-passing" the beachfill and the fact that onshore-offshore transport cannot be accounted for.

- Two-line coastline evolution models such as that by Bakker (1968) are more relevant because of the inclusion of onshore-offshore transport but its application is still limited because the coastal constants required for predictive purposes with this type of model are functions of the profile geometry, which makes it impossible to use the model in a predictive mode before a series of measurements in the full-scale had been made of the evolution of the beachfill.

- N-line or multi-layer coastline evolution models (N > 4), such as that by Perlin and Dean (1983) may give a very good indication of the reshaping of the coast in the vicinity of the beachfill. Möller et al. (1986) used such a model for Oranjemund with great success. It is essential that good field data are available to calibrate the model. A problem of this and all other predictive models is that it is difficult to cater for the effect of differences in the grain size distribution of the native and borrow materials. It is possible, however, to obtain bracketing answers.

- Longshore transport predictors may have some limited merit to show the extent to which the longshore transport regime in the beachfill area is modified.

- Onshore-offshore predictors such as the method by Swart (1974, 1986) are extremely useful to evaluate the effect of a beachfill geometry that is different to the original beach profile. This technique has been used effectively by Campbell, Macleod and Swart (1985) to bracket the losses from a beach nourishment project in Durban, South Africa.

- Mathematical models which model the nearshore water and sediment movement accurately are better than any of the preceding methods but are very costly to execute and still suffer from the deficiency of not catering adequately for differences in the grain size distribution of the native and borrow materials. References which can be consulted in this regard are Watanabe (1982), Boer et al. (1984), Coeffe and Pechon (1982) and Sheng and Butler (1982).

- Physical models with a movable bed are also a possibility but are expensive to construct and take long (6-18 months) to execute, if one takes into account the construction, calibration and predictive stages. Proper scaling to allow the model to cater for a beachfill of limited geometrical proportions is also a problem.

- Field observations from the area may give a good first indication of the expected behaviour of the beachfill. For all of the above, field data are needed in any case to calibrate the respective techniques.

Experience has shown that in most cases the use of some sort of hybrid technique, that is, a combination of some of the above techniques is the most effective. In this respect a **mathematical or physical model** which will predict only the **water movement** can prove useful in conjunction with some of the above techniques.

Other aspects of beachfill which are important and which were discussed during the poster discussion sessions are:

- How do you define the required volume of sand related to the lifetime of the beach nourishment. In this respect the concept of a beachfill **half-life** was raised. During the design stage one should establish the future behaviour of the beachfill and decide whether it is a once-off exercise, whether it would have to be repeated from time to time (when the so-called half-life principle comes into the picture) or whether it should be maintained continuously. It is also important that these aspects are communicated to the public at an early stage so that they know what to expect.

- The design technique chosen should provide for the evaluation of the actual wave climate, to allow for the inclusion of extreme wave events and the cumulative effect of a number of extreme wave events in a short time span (the El Niño effect reported on by Seymour et al., 1984).

- The choice of a borrow area in relation to the littoral active zone or dynamic swept prism is of extreme importance, particularly as related to possible aggravated beach erosion elsewhere in the vicinity if located too close by. The borrow area also needs to be "designed". From both the physical and the environmental point of view it will be advantageous if the borrow area is a large flat area, that is, if only a thin layer of sand is removed.

5. CONSTRUCTION PHASE

It is not the purpose of this review to discuss the construction phase in detail. The reader is referred to the Dutch beachfill manual mentioned above in the case of beachfill design. Considerations similar to those covered in the manual for the construction phase will apply to other types of beach protection devices. However, the following few items are of particular relevance to the establishment of a good design for a beach protection scheme.

- It is important to decide beforehand on the phasing of the various components of the beach protection scheme, with specific attention to the question of how each completed part of the scheme will influence the rest of the scheme and of the longshore direction in which the scheme should be developed (up- or downdrift) to gain the most benefit from the littoral drift.

- The best construction techniques and their effect on the design should be considered. In this respect it is important for designers and contractors to get together at an early stage to evaluate these aspects and perhaps cater for some predictions in the design stage of construction phases.

- Perhaps the most important aspect related to the construction phase is that of quality assurance. Each element/component of the design/construction phase needs to be evaluated and the risk of failure due to, for example, extreme wave events during construction considered. Alternatives should be provided for. In this way the preparation of the project is more costly but the possible risks are reduced.

6. POST-CONSTRUCTION PHASE

It is necessary in the design stage to address the following aspects and to discuss their importance with the client.

- The necessity for post-construction monitoring should be stressed. Aspects of particular importance are the frequency of monitoring as related to the forcing mechanisms, the nearshore environment and the expected/predicted behaviour of the beach protection scheme, the extent of the monitoring and, last but not least, the body with whom the responsibility rests to pay for the monitoring. It is usually advantageous to include some funds for monitoring in the construction vote, as it is after all this monitoring which is going to determine to what extent the design is successful.

- Linked to the previous point is the need for a re-appraisal of the shoreline stability in the area and again a decision as to whose responsibility it would be.

7. DISCUSSION

From the discussion in the preceding sections it should be clear that although the planning, design and execution of beach protection schemes have come a long way in the past few decades, there are still many areas requiring detailed inputs from scientists and engineers. To allow us as a community to learn from our mistakes, it would be advantageous if we could:

- establish international co-operation and exchange on all the levels mentioned in this review;

- exchange good quality field data suitable for the comparison/ verification of different design techniques and beach protection types;

- jointly address the matter of quality assurance and investigate the possibility of using a "half-life" concept as a measure of the effectiveness of any type of beach protection device.

In this respect the Dutch have indicated that they are willing to do the above as far as it relates to beachfill. The discussion at the conference indicated that initially there is no merit in establishing formal working groups, but that this should be done informally.

Let us make it our challenge when we have such a discussion again in the future, to be in a position by having addressed some or all of the points raised herein to say that we have advanced the science of planning, designing and executing beach protection schemes.

8. SUMMARY

With the exception of the paper presented by Kawata et al., all papers related results on the basis of practical experience gained through field works in various parts of the world, namely Eygpt, Hawaii, Italy, Japan, Kuwait, Singapore, South Africa and Republic of China, Taiwan.

It is true that a lot of case studies have been done during the last decades in various countries, states, counties, prefectures, cities and towns, and extensive data sets have been accumulated. However, only limited data have unfortunately been made available to the relevant scientific and engineering fraternity. At present shore protection problems are the serious concern of not only the inhabitants of the coastal area but also the governmental agencies who have responsibility to maintain or rather improve the coastal environment. Therefore shore protection studies are highly needed world wide in order to understand the coastal phenomena more clearly and then to apply our knowledge to the preservation of beaches as well as the production of a better environment in the coastal zone.

Shore protection studies should cover broad phases in the coastal and nearshore area. These are related not only to the coastal characteristics in the physical sense such as waves, nearshore currents, sediment transport, interaction between coastal structures and natural forces, but also the social circumstances including environmental concern.

Therefore shore protection is one of the important tasks of coastal engineers. At the same time shore protection is a subject of serious debate for other people such as politicians, land owners, property owners, lawyers, bankers, insurers and fishermen. That is to say, shore protection is really a multidisciplinary subject.

From such a view point, coastal engineers should take the heavy responsibility of offering a good service or good guidelines to the people who are seriously concerned with shore protection. Therefore they should always consider the complicated real situations which contain the following two aspects. The first one is the subject related to the natural conditions such as wave climates, beach slope, beach material, and beach width. The second one is that related to the social circumstances such as social demand, economic conditions and environmental impact in the broad sense caused by human activity.

It is natural that these stated conditions are quite different from one location to another. Therefore we should carefully observe the information and data presented here and elsewhere in order to evaluate the adaptability of the measures or the concepts to any given site.

As a conclusion of the present summary paper, we would like to stress the importance of information exchange on shore protection measures not only from the engineering point of view but also from the view point of social demand.

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