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SEGMENTED OFFSHORE BREAKWATERS: AN ALTERNATIVE FOR BEACH EROSION CONTROL

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Abstract

Segmented offshore breakwaters protect the shore by attenuating wave action and by promoting the deposition of drifting sediment in the lee of the structures, resulting in the development of a beach salient. The concept is not novel, but simply combines the wave attenuation of a natural shore-parallel sand bar or reef system with the wave diffraction effects of a nearshore island. Segmented breakwaters locally reduce incident wave energy and alter wave direction to create a "shadow zone" where longshore transported sediment or placed beachfill is retained. The philosophy and history behind the use of segmented breakwaters for beach erosion control, as well as advantages, disadvantages, and some design considerations are presented, together with example illustrations.

Segmented breakwaters have many advantages over other, more conventional forms of shore protection. Unlike groins, segmented breakwaters do not create a total barrier to littoral transport, nor do they promote offshore losses. Unlike revetments, bulkheads, and seawalls, they aid in the retention of a recreational beach. If the breakwater system is properly sited and designed, and beachfill is included as an item of construction, the impact to neighboring shores will be minimal. The main disadvantages of segmented offshore breakwaters are that they are more expensive to construct than land-based structures and that there are no standardized design criteria.

Although segmented breakwater systems have been previously implemented in Japan, Italy, Israel, Australia, and other countries, experience in the United States has been very limited. Breakwater systems have been constructed in areas such as Massachusetts, Ohio, Pennsylvania, and Virginia, and plans exist for incorporating their use at other sites. The design and application of the segmented breakwater concept at any particular site must be based on an evaluation of the local wave climate and littoral transport regime plus a review of the lessons learned from previously constructed projects. There are a few numerical and modeling procedures which may be applied to optimize a breakwater system plan, but the eventual design must heavily rely on engineering judgement and coastal experience.

Introduction

Although the concept of beach erosion control may be a subject of some technical controversy, there still is a real need for an effective way to preserve our recreational beach resources. Not only are opportunities for public access to beach front areas dwindling due to a boom in private development, but also overall beach area is gradually decreasing due to sea level rise and a loss of sediment sources. Shore erosion control is typically accomplished in one of three ways:

(1) By stopping shoreline recession through the use of onshore, shore-parallel structures such as seawalls or revetments.

(2) By adding new beach material through nourishment or sand by-passing operations.

(3) By reducing the rate of littoral transport.

The conventional structural approach used to reduce the local rate of longshore sediment transport is a groin or a groin system. Another mode available for influencing the longshore transport rate is the use of detached, or segmented, offshore breakwaters.

Segmented offshore breakwaters protect the shoreline by attenuating wave action and by promoting the deposition of drifting sediment in the lee of the structures. This results in the development of a beach salient. If the salient grows to the degree that it becomes connected to the structure, it is called a tombolo. The concept of segmented offshore breakwaters is not novel, but simply imitates the wave attenuating effect of a natural shore-parallel sand bar, reef, or nearshore island.

The Philosophy Behind Segmented Offshore Breakwaters

Segmented offshore breakwaters protect a zone of the beach from direct wave action and also cause a transformation of the incoming waves. The area directly behind the breakwater is sheltered as wave energy is dissipated on the structure. The wave energy in the gaps is also reduced as waves diffract, or bend, around the ends of each breakwater resulting in a lateral spread of wave energy and a net reduction in energy reaching the shore at any given point. The resultant effect, illustrated in Figure 1, is to drive sand into the sheltered area behind the breakwater where it is deposited.

Any structure whose function is to cause a local accretion of sand may cause damage to downdrift beaches if it traps material from the longshore system. The addition of beach fill to the project site is therefore highly recommended as a part of the project design. Enough sand should be placed to equal the amount which would be removed from the littoral system by the breakwater-induced beach. Designing a

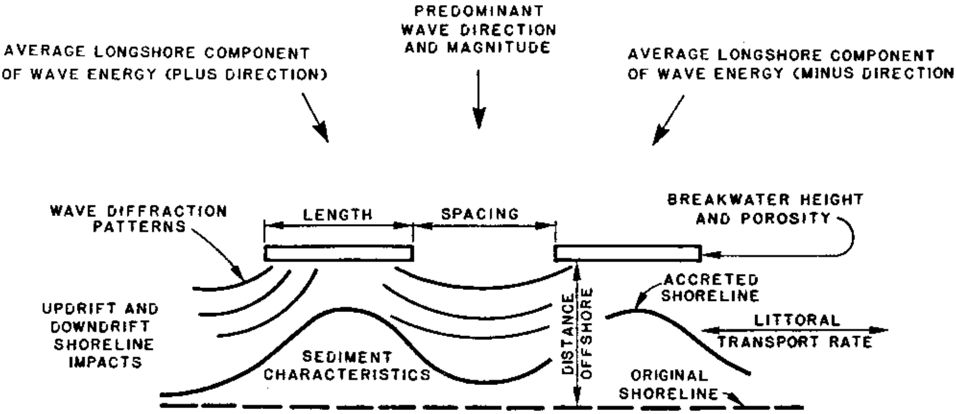

Figure 1. Segmented Offshore Breakwater Design Considerations.

breakwater system requires the prediction of the equilibrium beach and the amount of sand necessary to maintain that stable shoreline. By artificially adding an amount of fill equal to that required by the breakwater-induced salients, there will, in principle, be no net adverse impacts on the neighboring shores. This is a general statement which should be rigorously examined for any proposed project. Even with the initial placement of beach fill, variations in the wave climate at a site may make the range of erosion experienced by neighboring shores unacceptable.

The advantages of a segmented offshore breakwater system are best understood by comparison with the traditional sand accreting shoreline structure, the groin. Both methods of beach erosion control involve the use of a group of structures designed as a system. Groins are generally built perpendicular to shore. Segmented breakwaters are generally built parallel to the shore. Groins do not reduce the wave energy striking the shore. They are dependent on the presence of a trapped beach in order to provide some level of protection for the back beach. Breakwaters, however, do reduce a certain amount of the incident wave energy, depending on how much of the shore is fronted by the structure and the height of the structure. Groins tend to compartmentalize the shore and the longshore current system. Sediment moving alongshore is forced into deeper water in order to move around the structure ends, thereby increasing offshore losses. Frequently, the presence of a groin field will displace the nearshore bar system seaward. If breakwaters are designed properly, sediment will continue to move longshore behind the structures. The degree of reduction is a function of the design. Breakwaters have not been observed to increase offshore losses of sediment and, in fact, they may even reduce the offshore transport rate. Therefore, unlike groins, breakwaters do not promote offshore losses, do reduce the rate of longshore movement, and do allow regular longshore transport patterns to continue.

There are several disadvantages to the use of segmented breakwaters. They are expensive to construct, often involving the use of marine-based equipment. Also, available design experience and guidance is very limited. There is no handbook which contains rules and regulations for designing a segmented breakwater system. The parameters which control the complex interaction of sediments and structures are poorly understood, setting the stage for potential judgmental errors. But probably the greatest disadvantage is a perceived one. The lack of functioning examples in the United States reduces the public and even technical confidence level. People are reluctant to provide money for a project if they cannot walk down the beach and see a similar structure that is working.

History of Segmented Offshore Breakwaters

Although experience in the United States in the use of segmented offshore breakwater systems is limited, there have been a number of applications in other countries. In addition, single breakwater structures have a long history along the American shore. These structures may range from a low structure near the shoreline, which is frequently overtopped and functions as a perched beach, to a high, deepwater structure built in association with a harbor. Single breakwater structures exhibit different intents, designs, and construction. They have been built by individual property owners and by all levels of the Government.

A few major projects illustrate the typical types of single breakwater applications (U. S. Army Engineers, 1984). One of the first major single breakwater projects was the Venice, California, 183-m-long rubblemound breakwater, built in 1905. This structure was originally built to protect an amusement pier, and although the tombolo has been periodically eroded by storms, the beach has always returned. Other example projects where a single breakwater was built for erosion control are at Lincoln Park in Illinois and at Haleiwa Beach in Hawaii. Breakwaters built in the 1920's and 1930's at Santa Barbara and Santa Monica, California, were originally intended to create a harbor of refuge. However, both of these projects ended up trapping significant amounts of sediment, causing either a salient or a tombolo to form. An interesting multipurpose single breakwater was constructed in 1960 at Channel Islands, California. This structure overlaps the harbor entrance, helping to shield boats using the harbor from wave energy, and trapping material adjacent to the entrance, making it available for sand bypassing operations.

The concept of a system of segmented offshore breakwaters has been used extensively in other countries, creating a broad experience base (Lesnik, 1979). One of the best documented projects is the series of shallow water "artificial headlands" at Singapore. Other projects may be found in Italy, France, Israel, and Denmark, to name just a few. Segmented breakwaters have been used for almost 30 years in Japan. The Japanese consider the preservation of their coastal lands to be a national priority. The coast is heavily developed and periodically exposed to extreme wave events, such as typhoons and tsunamis. They have developed a construction and general configuration plan which has been installed and is successfully functioning at more than 20 different sites. Typically, Japanese breakwaters are built fairly close to shore, causing the almost complete development of a tombolo. These breakwaters have no core and are fairly porous. Full tombolo formation is inhibited by the large amount of wave energy which is transmitted through the breakwater. One of the first applications of a segmented breakwater system in the United States was the 1935 construction of five breakwaters at Winthrop Beach in Boston, Massachusetts. These breakwaters were constructed to protect the shore and a seawall. The approximately 3-m tide range at this site causes two distinctive shoreline responses. During high tide, the five breakwaters act as one unit, resulting in the formation of a single salient, while the low tide shore features five separate but smaller tombolos.

In 1977, three rubblemound breakwaters were constructed at Lakeview Park, Lake Erie, Lorain, Ohio. This project has been carefully monitored since construction, resulting in a unique data base which documents the shoreline response to a group of structures (Pope and Rowen, 1983). The project was designed to allow sediment transport to continue behind the breakwaters by placing them 120-150 meters off of the original shore. The placed beach fill has been remarkably stable, exhibiting a slight average annual accretion of approximately 2,300 cubic meters. A very stable shoreline has developed which undulates seasonally, due to changes in water levels and the wave climate, but repeats the same patterns.

Other, more recent segmented breakwater projects in the United States include: a shallow water beach erosion control project at Colonial Beach, Virginia, which includes a 3-breakwater and a 4-breakwater section; a 3-breakwater prototype test constructed at Presque Isle, Pennsylvania; a 4-breakwater, moderate water depth, "no fill" project at East Harbor, Ohio; and a 3-breakwater "with fill" project at Lakeshore Park, Ashtabula, Ohio. All of these projects except for the one at East Harbor are being monitored by the Corps of Engineers in an effort to improve the "state-of-the-design."

Design Considerations

In order to successfully design segmented offshore breakwaters, the wave climate and the sediment transport characteristics at the project site must be known. This includes understanding the average range of conditions and predicting the extreme conditions. Shoreline response is based on the magnitude and direction of the predominant incident waves (Figure 1). From this information, the designer attempts to predict the amount of wave diffraction around the structures, the degree of overtopping, and the net and gross sediment transport under average conditions. The designer also wants the project to function without detrimental impact to the backbeach features and neighboring shores during severe storms or periods of unusual quiescence. Seasonal and periodic variations in the coastal climate will cause the beach morphology to fluctuate. The salients will erode and accrete within an envelope which is controlled by normal cycles and the extreme conditions.

The challenge is to predict an average, stable shoreline configuration for various breakwater designs, then select the best one. The designer manipulates the breakwater length, gap width, alignments, height, wave transmission characteristics, and distance offshore until the desired shoreline can be predicted for the least amount of structure expense (Figure 1). An estimate of how much sediment the structures would ordinarily trap is then made allowing original fill and maintenance fill quantities to be programmed.

Design tools currently available include the use of a simple diffraction analysis. The average wave climate from different directions is evaluated and a diffraction analysis performed. The different diffraction patterns are then compared and an average shoreline predicted. Another tool which holds promise for making qualitative predictions is the use of a movable bed, physical model. Each of these tools has been verified by comparison with the field data collected from the Lakeview Park project and found to accurately reproduce the prototype shoreline response of that project. Of course, in the case of a major project, the construction of a preliminary field test structure may be warranted. By constructing and monitoring a small-scale prototype structure at the project site, invaluable data can be collected and used to fine tune the full project design. The three breakwaters at Presque Isle were constructed with such a purpose in mind. The data collected from these structures is being used to assist in the development of a project design involving the protection of 5 miles of eroding shore.

A new tool, which is just becoming available for predicting sediment response to coastal structures, is the numerical model. There are a number of numerical models available, but only limited field verification tests have been made. Numerical models bring the design wave condition to the structure, then diffract, refract, and shoal the waves to breaking. Some models even allow for wave transmission at the structure. From this combination of effects, the incoming wave train is transformed as it would be in nature and a resultant shoreline is predicted.

Summary

The concept of segmented offshore breakwaters has theoretical promise. Such breakwaters have functioned successfully at a number of sites. Segmented breakwaters should not be indiscriminately applied to all projects and sites. Until more projects have been built and monitored at a variety of sites we will not know if they are suitable, for example, for use along shores with a high tidal range or for localized protection along a shore with a large littoral cell. Design mistakes will be made, but if we understand the design limitations and are sensitive to the demands of the environment we will have a means of controlling local beach erosion which works with the processes of the shore rather then against them.

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