CHAPTER 127

Bragg Reflection Breakwater: A New Shore Protection Method?

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ABSTRACT

The feasibility of a new type of breakwater is explored through a combined program of theorteical analysis, laboratory experiments and a prototype field test. The breakwater consists of a series of low height, shore-parallel bars which are placed just outside the surf-zone. The incident wave field is strongly reflected when the incident wave length is equal to twice the distance between adjacent bars. The breakwater acts to shelter the beach against storm wave attack and to build a tombolo sand deposit behind the breakwater. Theoretical and laboratory studies indicated that the Bragg reflection breakwater concept may have considerable merit, however, a small scale field test served to demonstrate the many practical difficulties in implementing the concept.

INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) has been involved in a multi-institutional program to explore low cost, rapidly deployable techniques for reducing beach erosion during storms. One concept under consideration is the Bragg reflection breakwater. Theoretical and

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laboratory studies have shown that a series of periodically spaced, low height bars, oriented parallel to the beach, can produce a strong reflection of the incident wave field. A reasonant condition (termed Bragg reflection) occurs when the incident wave length is equal to twice the separation distance between bars.

The Bragg reflection breakwater concept involves placing a series of artificial bars just outside the surfzone. Referring to Figure 1, the effect of the bar field is two-fold: to shelter the beach from storm wave attack; and, to create a large sand volume behind the breakwater by way of the induced nearshore circulation. Both effects serve to protect the beach against storm wave attack: the first by reducing the rate of offshore sand transport, the second by increasing the erodable sand volume.

The objective of the research program was to explore the feasibility of the Bragg reflection breakwater concept through a combined program of numerical and laboratory modeling and a prototype field test. The present paper presents an overview of the program with an emphasis on the planning and results of a small scale field experiment.

BACKGROUND

Theoretical and Experimental Basis

Davies and Heathershaw (1984), Mei (1985) and others have shown that a series of low amplitude sinusoidal undulations on the seabed can be an effective reflector of surface gravity waves. The reflected wave energy varies as a function of the ratio of the incident wave length to the spacing between bottom undulations. A reasonant condition, termed Bragg reflection, occurs when the incident wave length is equal to twice the distance between undulations. When resonance occurs, a small number of bars can reflect a substantial portion of the incident wave energy.

Technical Issues

At the onset of the research program, there were a number of unresolved technical issues relating to the feasibility of the Bragg reflection breakwater concept. These included: the response characteristics of non-sinusoidal bars on a sloping beach; the effects of finite bar length and the resulting wave-induced circulation; the morphological response of the beach in the presence

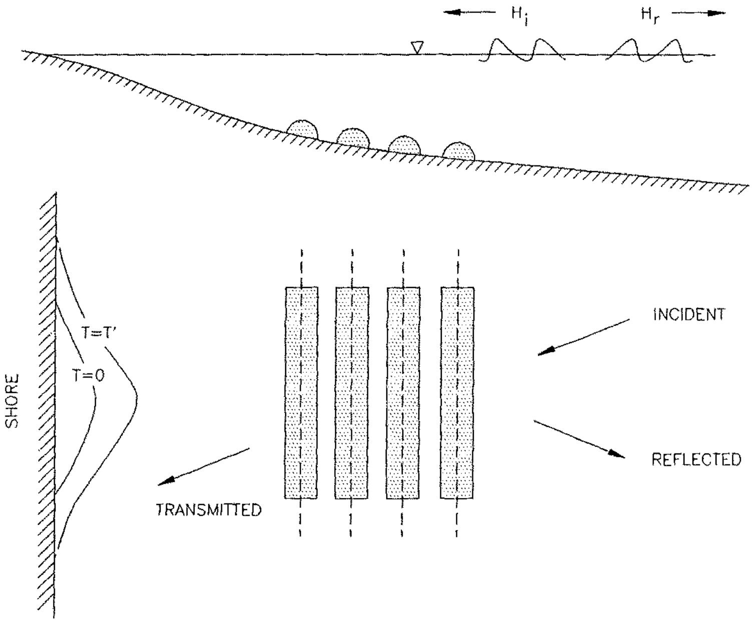

Figure 1. Schematic drawing of Bragg reflection breakwater concept.

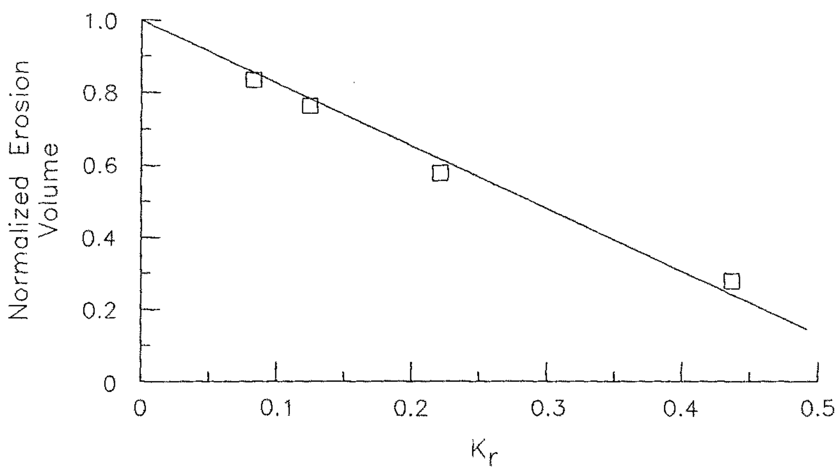

Figure 2. Beach profile response model results.

of the breakwater; the practical design, installation and recovery of a breakwater; and, the effects of waves on bar stability and scour. An additional issue was how to measure spectral wave reflection in the field.

PRELIMINARY ASSESSMENT

As a means of exploring the feasibility of the Bragg reflection breakwater concept, a series of preliminary studies were conducted. These studies were to culminate in a small scale field test of the concept. The results of the preliminary studies can be summarized as follows.

Wave and Current Modeling

Numerical and laboratory modeling studies were conducted at the University of Florida to examine the effects of bar shape, bar placement, beach slope and bar length on the reflection characteristics of a Bragg reflection breakwater. Details of these studies may be found in Anton et al. (1990). Specific results included:

- The primary effect of beach slope is to require an adjustment in the spacing between each bars to accommodate the change in incident wave length.
- The reflection from a non-sinusoidal bar field can be calculated by expanding the bottom shape function as a fourier series and linearly summing the response characteristics for each component of the series.
- Finite bar length causes a longshore variation in the wave-induced setup leading to the formation of a rip current flowing outward over the bar field. The rip current acts to broaden the reasonant peak.

These studies indicated that a Bragg reflection breakwater, constructed from a small number of practical-shaped (i.e. non-sinusoidal) bars, could be expected to generate a reflection coefficient in the range of 0.2 to 0.4.

Beach Response Modeling

A Bragg reflection breakwater protects a beach from storm wave attack by reducing the rate of offshore sand transport via decreased wave height and increasing the erodable sand volume via creation of a tombolo behind the breakwater. The former is a two-dimensional effect which is independent of breakwater length. The latter is a three-dimensional effect which results from the formation of a nearshore circulation cell with a rip current flowing outward over the top of the breakwater.

NCEL conducted a numerical model study to determine the impact of a Bragg reflection breakwater on the two-dimensional response of a beach profile during a simulated storm. The model study utilized an energetics-based beach profile response model developed by DeVries and Bailard (1988). The model was run for a simulated 5 day storm assuming varying wave reflection coefficients. The effectiveness of the breakwater was expressed in terms of the normalized erosion volume. This was defined as the ratio of the eroded sand volume in the presence of the breakwater divided by the eroded sand volume without the breakwater.

Model inputs were as follows:

- o Initial equilibrium beach slope = 0.03
- o Grain size = 0.4 mm
- o Storm duration = 72 hr
- o Peak wave height = 2 m
- o Peak wave period = 9 sec

Without the breakwater, the beach eroded approximately 205 cubic meters per meter of beach. Referring to Figure 2, the breakwater reduced the storm erosion volume by an amount which was inversely proportional to the wave reflection coefficient, K_r. The degree of reduction is quite significant, amounting to 35% for a reflection coefficient of 0.2.

A movable bed physical model study was conducted at the University of Florida to qualitatively examine the three-dimensional beach changes induced by a Bragg reflection breakwater. The model confirmed the presence of a nearshore circulation cell with a rip current flowing outward over the bar field. The circulation cell caused a tombolo to form behind the breakwater, with the outer edge of the tombolo perched on the shoreward-most bar.

Bar Module Tests

It was anticipated that developing a practical breakwater would be a significant design challenge. Our limited budget necessitated coming up with a breakwater which could be rapidly assembled, installed and recovered using a minimum of people and equipment. In order to explore various design and installation concepts, NCEL conducted field tests of two bar designs at a Port Hueneme beach. Both designs featured modular constructions consisting of skid-mounted bar modules which could be assembled on the beach and dragged offshore.

Referring to Figure 3, the first design consisted of a geotextile bag attached to a skid-mounted steel frame. The concept was to drag the modules into place with the bags empty, and then fill the bags with sand using a small dredge pump. When the breakwater was no longer needed, the bags could be slit, allowing the sand to disperse and the bars dragged back ashore. The advantage of this design was that the bar modules would be light and easy to move when empty, but heavy and difficult to move when full.

An attempted field test of the geotextile bar design ended in failure. Although assembling and positioning the bar module proved simple, filling the geotextile bag with a small dredge pump proved difficult. The pump was mounted on an amphibious LARC vehicle, parked in the surfzone. The principal difficulties were maintaining an adequate supply of sand to the pump and handling the intake and discharge hoses. When, after a few hours of filling, little sand had been pumped into the bag, the test was abandoned. In retrospect, the test might have been more successful had a larger, perhaps land-based dredge pump had been used.
Nevertheless, the installation procedure was judged to be too cumbersome for the planned field experiment.

Referring to Figure 4, the second bar module design consisted of a corrugated steel arch attached to a skid-mounted steel frame. The concept was to assemble the modules on the beach and drag then into position. When the breakwater was no longer needed, the modules would be dragged back onto the beach and removed. The advantage of this design was that the modules were ready to go once they were moved into position. The main drawback was that the modules were relatively light weight and could be moved about by large waves. Although pinning the modules with uplift resisting anchors was considered, it was judged unnecessary for the anticipated wave climate.

The field test demonstrated that the arch module design could be rapidly assembled and installed. Provided wave heights were less than 1 m (rms), the module tended to remain in place. The primary problem was a scouring of the seabed underneath the bar module. This was caused by wave-induced flow passing through the narrow gap between the leading and trailing edges of the bar and the sand bottom. The scour depression acted to further enhance the venting flow, reducing the reflectivity of the bar module.

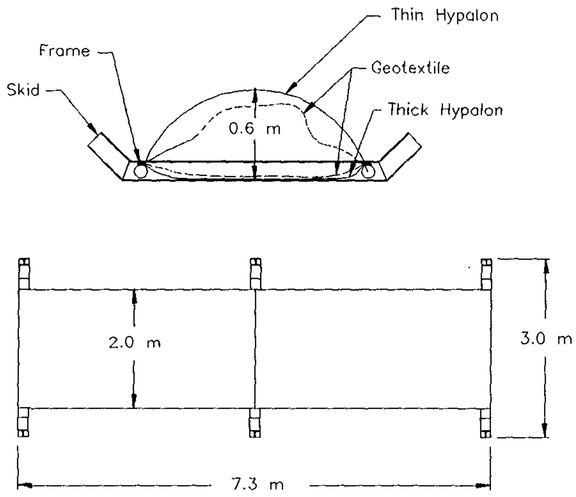

Figure 3. Geotextile bar module design.

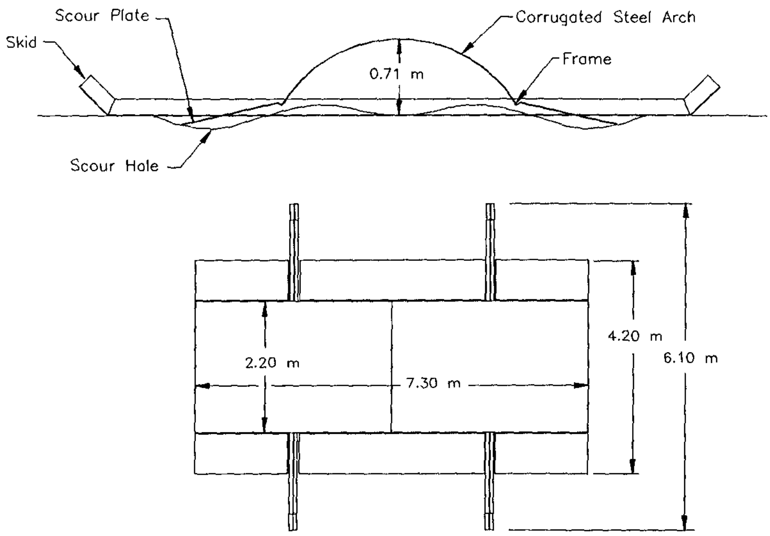

Figure 4. Steel arch bar module design used in the field test.

The venting/scour problem was solved by adding steel plates to the leading and trailing edges of the bar. The plates were attached to the bar by hinges, effectively sealing off the gap underneath the bar. Although some scour continued to occur around the bar module, the plates continued to function by dropping down into the scour depressions. After a period of two days, the scour depressions appeared to stabilize at a depth of about 0.3 m. A few days later, a significant storm passed through the area destroying the bar modules. However, the successful performance of the module prior to the storm convinced us to that the steel arch design would be suitable for the planned field test.

Detection Method

An inverse method was developed to estimate the directional spectrum of the reflected wave field (see Herbers and Guza, 1990). The method requires simultaneous measurement of the incident wave field at a point offshore and the reflected wave field at a point immediately in front of the Bragg reflection breakwater. The procedure is as follows:

- o The incident wave field is estimated using the offshore wave measurements.
- o The incident wave field is transformed to shallow water using linear refraction.
- o The reflected wave field is estimated using the inshore wave measurements and subject to maximum compatibility with the refracted incident wave field.

PROTOTYPE FIELD TEST

Site Selection

In order to maximize the detectable reflected wave energy, we wanted to construct a breakwater that was significantly longer than the incident wave length and which produced a reflection coefficient of about 0.4. To minimize the size of the breakwater and therefor its cost, we decided to carry out our experiment in "super laboratory" conditions. These can be defined as significant wave heights less than 0.25 m, a wave period of about 5 seconds and an installation depth of about 1.5 meters.

A number of sites were considered for the field experiment. The desired site required small amplitude, short period waves, a long planar beach, limited public access and good logistical support. Based on these criteria, Cape Canaveral Beach, Florida, was selected as the preferred site for the field experiment. The site was located within the confines of Cape Canaveral Air Force Base, limiting public access and providing the necessary logistical support. Two years of wave data from the site indicated that during the month of July, we could expect significant wave heights of about 0.2 m with a 5 second period.

Breakwater Design

Referring to Figure 5, the prototype Bragg reflection breakwater was composed of three bars, 90 meters long. The offshore and middle bars were 0.7 meters high and 2.2 meters wide. The inner bar was 0.6 meters high and 2.4 meters wide. The spacing between the outer and middle bar was 9 meters versus 8 meters between the middle and inner bars. The breakwater was designed to be installed in a water depth of about 0.76 meters MLW.

Referring to Figure 5, each bar module was 7.3 meters long. The modules were fabricated from a pair of corrugated steel arches attached to a steel skid-mounted frame. The frame was composed of a pair of steel angle members attached to two steel skid beams. The angle members served as attachment points for the edges of the corrugated steel arches and the a series of steel scour plates hinged to the front and rear edges of the bar. The bar modules were designed to be assembled by a small crew using a crane and hand tools. Assembly was facilitated by prefabricating the components off-site and using nuts and bolts for fasteners.

The total weight of the bar modules was approximately 3300 lb. An stability analysis indicated that the modules would remain in place without anchoring if rms wave heights were less than 1 m (assuming a wave period of 5 to 6 sec).

Anticipated Performance

Figure 6 shows a plot of the estimated reflection characteristics for the prototype breakwater. These characteristics were estimated using a computer program developed by Kirby (1987). The response function shows a broad peak centered at about 6 seconds with a reflection coefficient value of 0.4. The adjacent narrower peak is the first harmonic resulting from the non-sinusoidal shape of the bar field (i.e. discrete bars resting on a planar bottom).

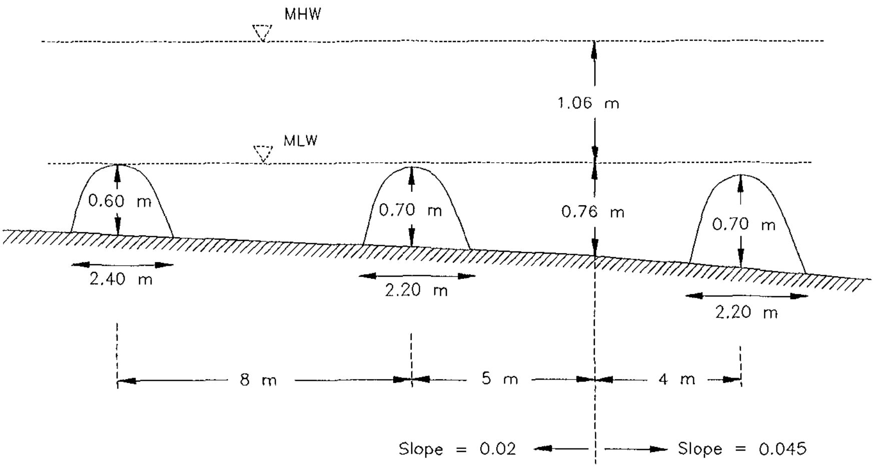

Figure 5. Bragg reflection breakwater design used in the field test.

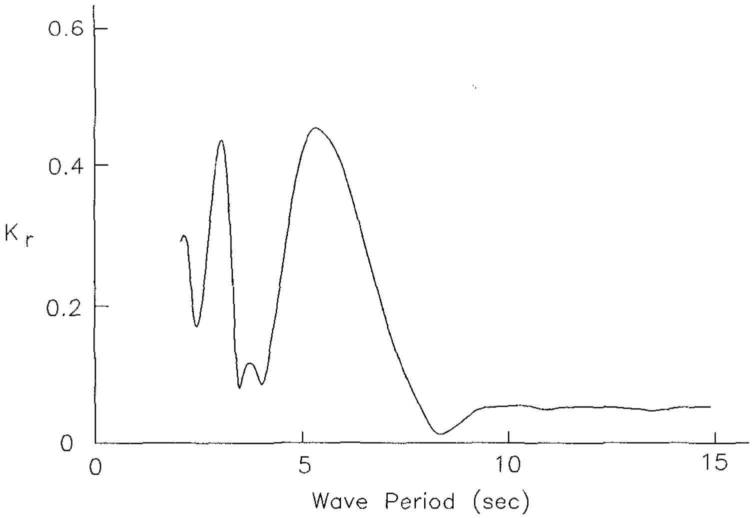

Figure 6. Estimated reflection characteristics for the field tested breakwater.

Installation and Recovery

The bar modules were assembled in a staging area located about 200 meters from the beach. After assembly, the modules were carried to the beach with a large front-end loader. The loader placed the modules on the upper beach face in groups of three, with their skids oriented perpendicular to the shore. Scour plates were attached to each module and tied up out of the way to facilitate module dragging.

Referring to Figure 7, the original installation plan called for dragging the modules into position in groups of three using a shore-based winch and a movable sheave and anchor assembly. In practice, we found that the waves at the site were too large to allow this method of installation. In particular, the LARC vehicle found it difficult to negotiate the surfzone while pulling a heavy anchor and cable. As a result, only one group of modules was installed using this technique. The rest of the modules were installed individually at extreme low tide using the front-end loader. Although rapid (all of the modules were installed in a single low tide), this alternative technique required placing the breakwater approximately 15 meters closer to shore. As a result, the breakwater was situated inside the surfzone for a substantial portion of the tidal cycle.

Monitoring Plan

A survey grid was established in the area of the breakwater and in an adjacent control area. Daily wading profiles were to be conducted in the test and control areas. These were to be supplemented by combined wading and fathometer surveys at the start and end of the experiment.

The incident directional wave spectrum was measured at a depth of 6 meters using a linear array of pressure sensors. A second array of pressure sensors and current meters was to measure the reflected wave field and the induced nearshore circulation field around the breakwater. The offshore array was constructed prior to the installation of the breakwater. The inshore array was to be constructed once the breakwater was in place. Unfortunately, this never occurred due to problems described below.

RESULTS

The Bragg reflection breakwater was deployed on 11 July 1988. During the week prior to installation, the significant wave height at the site averaged about 0.4 m.

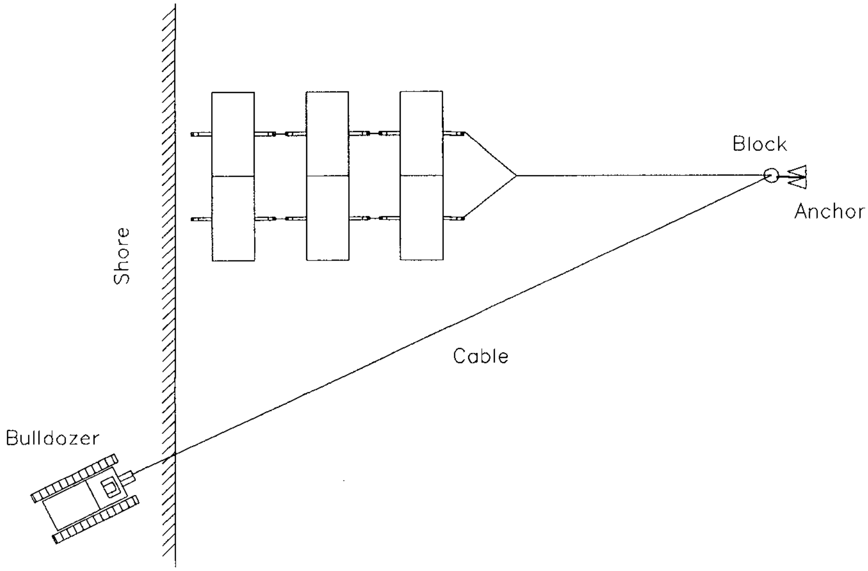

Figure 7. Planned installation method.

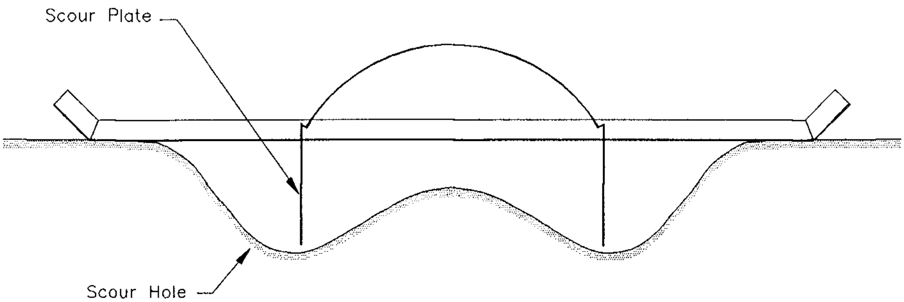

Figure 8. Observed scour pattern in field test.

This was approximately twice the anticipated wave height based on two years of measured wave data and essentially equal to the maximum design wave height for bar stability.

Immediately following breakwater installation, the significant wave height increased to about 0.6 m and remained at this level for the next 36 hours. These waves were significantly greater than the maximum design wave, causing the bar modules to slowly shift their positions. The modules rotated towards the direction of wave attack and moved shoreward about 1 to 2 m. The movement began with the outer-most bar and progressed inward through the middle and inner bars.

Another problem which developed almost immediately after installation of the breakwater was an intense scouring around the bar modules. As the tide rose, the bars were observed to be generating a significant degree of turbidity. On the following day we discovered large scour holes had formed in front of and behind the bars (see Figure 8). The scour holes slowly grew, becoming deeper and wider. Eventually they reached more than 2 meters deep, threatening the stability of the bar modules.

The observed scour was approximately an order of magnitude greater than the scour observed in the Port Hueneme tests. Since wave conditions were similar, we believe that the increased scour was attributable to the different properties of the two beach sands. At Port Hueneme, the sand was well sorted, having a median diameter of 0.25 mm and quartz and feldspar composition. At Cape Canaveral, the sand was poorly sorted, having a medium diameter of 0.14 mm and calcium carbonate composition. Apparently the lighter specific gravity of the Cape Canaveral sand, coupled with its smaller size and higher percentage of fines, resulted in increased sand suspension and enhanced scour.

After two days, the bar modules had become badly scattered. Some of the modules had shifted into their scour holes and begun to become buried. With bar burial becoming a growing problem, the decision was made to terminate the experiment and recover the bar modules while it was still possible. A bulldozer was used to pull the individual modules out of the surfzone and back up the beach face. From there, a front-end loader transported the modules back to the staging area where they were disassembled.

Because of the short duration of the breakwater deployment, the nearshore sensor array was never installed. As a result, no quantitative measurements were obtained.

Visual observations during the first few hours of deployment indicated that some wave reflection was occurring as evidenced by a standing wave pattern in front of the breakwater.

CONCLUSIONS

Theoretical and laboratory studies have indicated that the Bragg reflection breakwater concept may have merit as an expedient shore protection method. The wave sheltering produced by a small number of bars was found to significantly reduce the estimated erosion volume due to a model storm. The small scale field test, however, served to demonstrate many of the difficulties that will need to be overcome before the Bragg reflection breakwater concept becomes practical. Bar stability and sea bed scour appear to be the most troubling problems. Further tests are needed to determine the overall merit of the concept.

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