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Effectiveness of Pocket Wave Absorbers in Vertical-Wall, Coastal Entrance Structures

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) provides preliminary information on the effectiveness of pocket wave absorbers (relative to wave conditions) in vertical steel sheet-pile coastal entrance structures.

OVERVIEW: The U.S. Army Corps of Engineers is responsible for dozens of harbor entrances in the Great Lakes constructed with parallel jetties. These jetties, many in operation for more than 100 years, were typically constructed of rock-filled timber cribs. Over time, the wood cribbing has experienced significant deterioration, thus causing the jetty to be rather porous. Many of these structures have been rehabilitated. The typical rehabilitation approach has been to drive steel sheet pile around the existing structure and place a concrete cap on top, thereby encasing the original structure. After completion of the rehabilitation projects, the wave climate between the jetties appears to increase significantly causing navigational difficulties and damage to moored vessels within the harbor. This is apparently due to the fact that the timber crib jetties were rough, porous structures, especially in their deteriorated state, and were much more effective at dampening wave energy than the rehabilitated, sheet-pile encased jetties. The steel sheet-pile structures, being considerably more reflective than the deteriorating timber structures, are largely responsible for the increasingly energetic wave climate. To mitigate for the more energetic wave climate, the Corps has removed short sections of steel sheet piling at selected harbors and replaced them with pocket wave absorbers.

A pocket wave absorber is created when a section of the sheet-pile wall is recessed from the remainder of the jetty and stone is placed in the area to provide a rough, porous sloping surface that is intended to dissipate wave energy. The crest of the stone is usually offset from the steel sheet-pile wall, thus creating a pocket. The typical length of a pocket is 61 to 91 m (200 to 300 ft). An example of a pocket wave absorber is shown in Figure 1. The U.S. Army Engineer District, Detroit, has installed 10 pocket wave absorbers in six Federal harbors. In some instances the pockets are located at the landward ends of the jetties, while others are situated more lakeward. The wave absorbers have been installed as a single pocket, and in pairs, on opposite sides of the channel. Little or no design guidance was available for predicting the effectiveness of the many variations of wave absorbers.

BACKGROUND, PHYSICAL MODEL STUDIES: To predict design performance of pocket wave absorbers, physical model experiments were conducted by the University of Michigan, Department of Civil and Environmental Engineering (Wright and Carpenter 1999; Carpenter 2001). A generic model, representative of typical dimensions for various rehabilitated harbor jetties, was constructed to a scale of 1:50. The model layout consisted of two parallel jetties 1.2 m (4 ft) apart and 9.4 m (31 ft) long with a water depth of 0.09 m (0.32 ft) (corresponding to prototype dimensions of 61 m (200 ft) in width and 1,550 ft in length with a water depth of 457.2 m (16 ft)). Design parameters such as pocket length, slope of stone, and stone size were varied.

Figure 1. Pocket wave absorber at Pentwater, MI

Strengths and limitations of the physical model experiments are summarized in Table 1. The experiments were conducted under controlled conditions, enabling various experimental parameters to be changed and evaluated relative to pocket wave absorber performance. Wave gauges were initially placed adjacent to the jetty on both the lakeside and harbor side of the pocket wave absorber to determine percent dissipation. However, observed nonuniformity across the channel width prompted additional experiments in which 3-gauge arrays were placed across the channel width lakeward of the pocket and at two locations landward of the pocket. Incident waves were generated to produce near-breaking heights, prototype wave periods ranging from 5.2 sec to 6.7 sec, and wave angles of 0, 15, and 30 deg relative to the channel alignment. Although most experiments were performed with a single pocket, several other configurations were constructed and evaluated (Figure 2). Waves were reproduced by a plunger-type wave machine that was capable of producing only monochromatic waves.

Table 1
Strengths and Limitations, Available Physical Model Experiments

Strengths	Limitations
Controlled experiments with accurate measurements	Unidirectional, monochromatic waves
Multiple gauges	No incident wave data lakeward of entrance
Multiple incident wave conditions	Flat bottom, rather than representative channel bathymetry
Multiple pocket configurations	No river currents

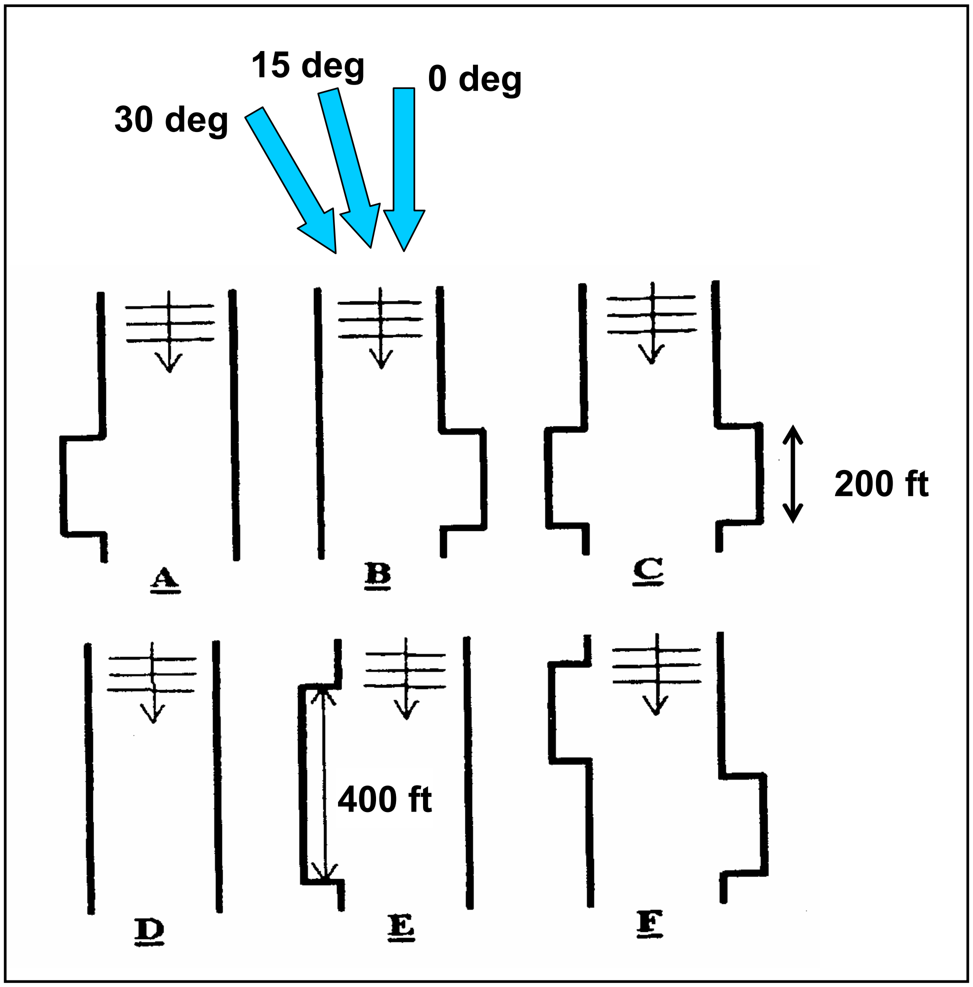

Figure 2. Pocket configurations evaluated in physical model studies (prototype dimensions)

The constraint of unidirectional, monochromatic waves is a major limitation. Wave irregularity is an important component of wave interaction with harbor entrances, and monochromatic waves are prone to exaggerating reflections and spatial variability in both physical and numerical models. However, wave irregularity may be less critical in applications involving wave propagation between long, parallel jetty walls. Since experiments were limited in this study, several of the pocket wave absorber parameters tested yielded inconclusive results. It was recommended that a more detailed study be conducted before significant conclusions could be made for some of the configurations tested.

Despite limitations of the physical model study, some preliminary conclusions could be deduced. For uniform stone size, the study revealed that the effect of stone size on dissipation was negligible, and that graded stone yielded slightly lower wave dissipation rates than uniform stone. The study also suggested that dissipation rates based on slope variation were similar. It was found that dissipation increased erratically with pocket length. This observation led to the consideration that the pocket length alone may not be a determining factor in wave energy dissipation, but rather the ratio of pocket length to wavelength might be more significant, at least for pocket lengths less than about one wavelength. Figure 3 shows the parameter $(H_{landward}/H_{lakeward})^2$ versus pocket length, where $H_{landward}$ is average wave height measured at a 3-gauge array on the landside of the pocket and $H_{lakeward}$ is average wave height measured at the array on the lakeside of the pocket. The square of the ratio indicates the fraction of wave energy passing the pocket. Local wavelength for the wave periods shown ranges from 33.2 to 38.1 m (109 to 125 ft).

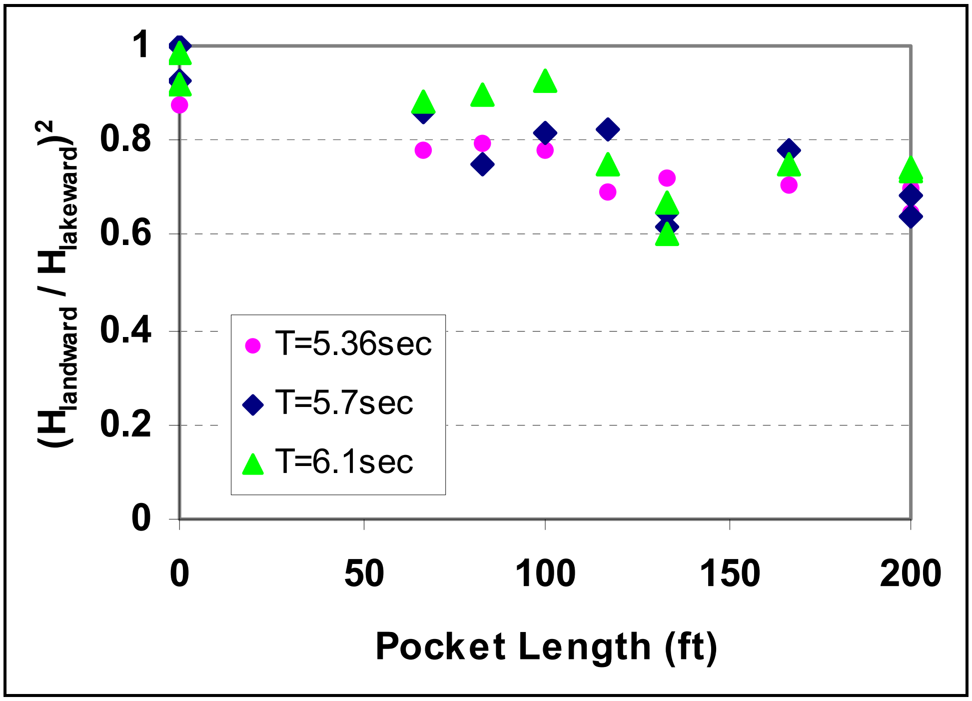

Figure 3. Wave energy fraction passing single pocket for various pocket lengths; wave direction aligned with channel; from physical model (prototype dimensions)

From experiments in which direction of wave approach varied, it was determined that waves approaching from straight down the channel represent overall worst-case scenarios in the channel (as opposed to waves approaching from various angles). Figure 4 shows wave energy parameter $(H_{landward}/H_{lakeward})^2$ values for each configuration in Figure 2 for 0-, 15-, and 30-deg wave direction. For every configuration tested, wave energy past the pocket decreases as incident wave obliquity increases. As would be expected, pocket configuration can have a major impact on performance. Figure 5 shows wave energy parameter averaged over the three periods and directions tested, which is more representative of the overall effectiveness of the various configurations. Configurations C, E, and F would be expected to perform better than A, B, and D, based on the general expectation that wave dissipation correlates with total length of pocket, regardless of configuration details. Configuration C, the double pocket similar to those constructed at Pentwater and White Lake Harbors, Lake Michigan, appears to be most effective at reducing wave energy in the channel. For configuration C, only about one-third of the energy remains after waves pass the pockets. configuration F, identical to configuration C except that the pockets are offset along the channel length rather than opposite each other, performs similarly to C for 0- and 15-deg wave directions.

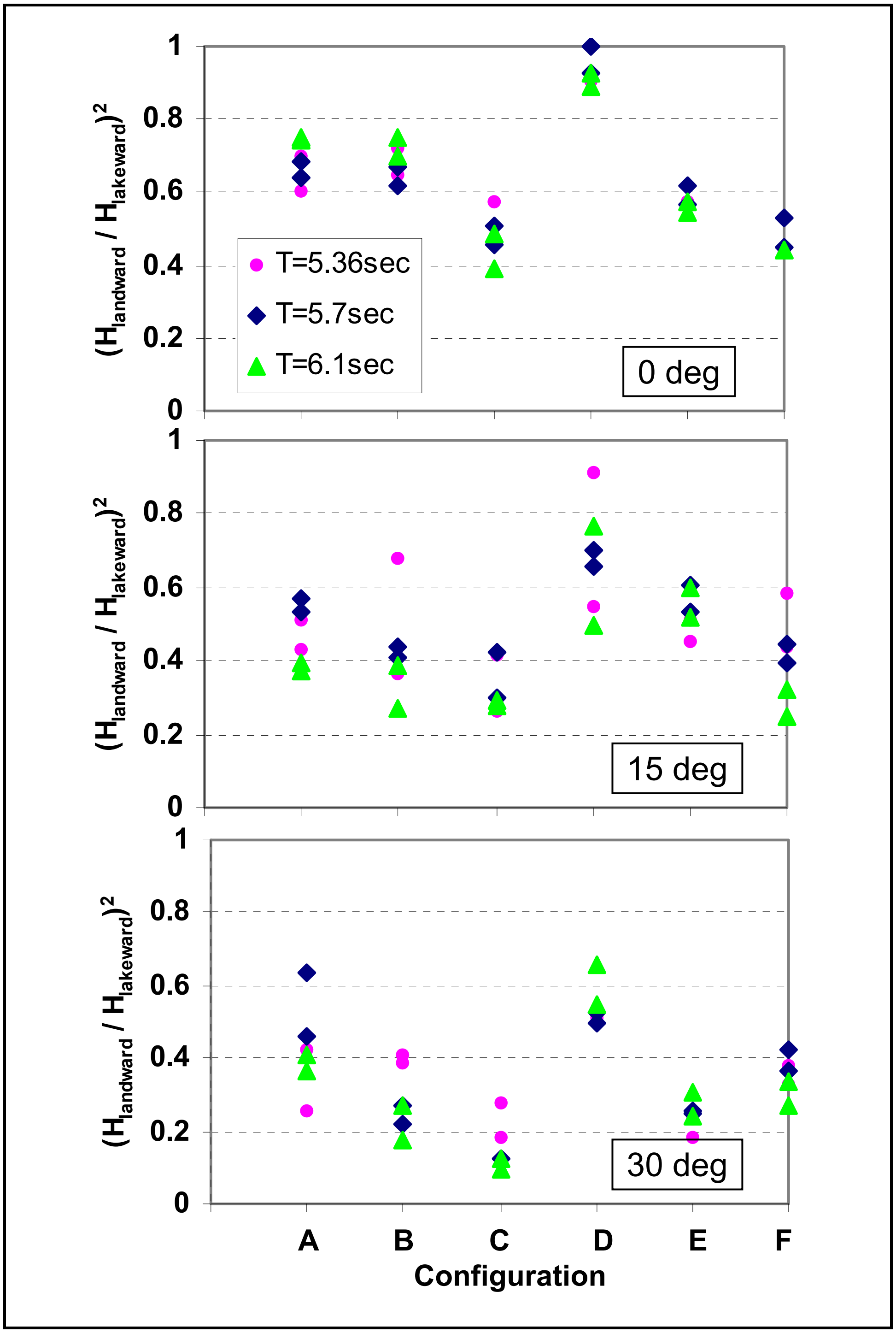

Figure 4. Wave energy fraction passing pocket for various pocket configurations and incident wave directions; from physical model (prototype dimensions)

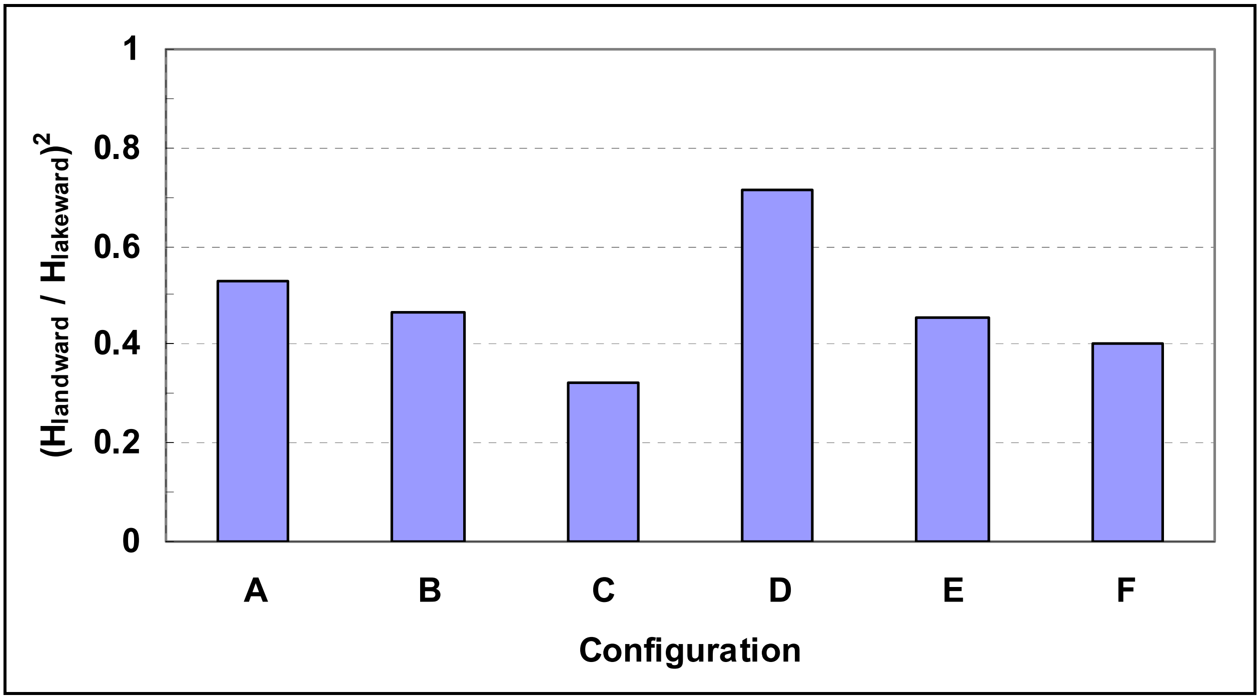

Figure 5. Wave energy fraction passing pocket for various pocket configurations; average from three incident wave directions studied in physical model (prototype dimensions)

However, F is not as effective as C for 30-deg wave direction. This behavior can be attributed to the pocket geometry of configuration F, which affords wave energy approaching at 30 deg a fairly clear path to reflect off the jetty walls and avoid direct impact with either pocket. The same process appears to be detrimental to the performance of configuration E for 15-deg wave direction.

BACKGROUND, FIELD STUDIES: The University of Michigan, Department of Civil Engineering, study also included a limited field measurement effort to supplement the physical model studies (Carpenter 2001). Field investigations were conducted at Pentwater and White Lake Harbors, Lake Michigan. Similar data also were obtained at Ontonagon Harbor, Lake Superior, during one week in November 2000 by Michigan Technological University, Department of Civil and Environment Engineering, as part of this effort. Pentwater has two 59.4-m- (195-ft-) long pockets opposite each other in a 44.2-m- (145-ft-) wide channel, similar to configuration C in the physical model experiments (Figure 6). White Lake has a similar configuration with 53.9-m- (177-ft-) long pockets. Ontonagon has a different configuration and wider channel (76.2-m (250-ft) wide). Ontonagon data were collected to quantify the effect of a single 61-m- (200-ft-) long pocket, comparable to configurations A and B in the physical model experiments.

Strengths and limitations of the field investigations are summarized in Table 2. Wave heights were measured adjacent to one of the jetties on lakesides and landsides of the pocket by submerged pressure transducers. Due to logistical problems with collecting data during periods of high wave energy at the Lake Michigan sites and lack of directional incident wave data at all sites, results are

Figure 6. Aerial view of Pentwater Harbor entrance

Table 2
Strengths and Limitations, Field Data (Carpenter 2001)

Strengths	Limitations
Quantitative data on actual performance of prototype pockets in presence of real waves	Limited length of record and range of conditions
Includes time series data and spectral analysis	No measurements of incident waves or directionality Gauges adjacent to jetty walls

considered preliminary. Data from three events at each site are summarized in Figure 7. Incident wave directions are rough approximations. The results indicated that about 20-50 percent of the wave energy passed the pocket at the Lake Michigan sites and about 60-80 percent at Ontonagon. No strong dependence on incident wave direction is evident.

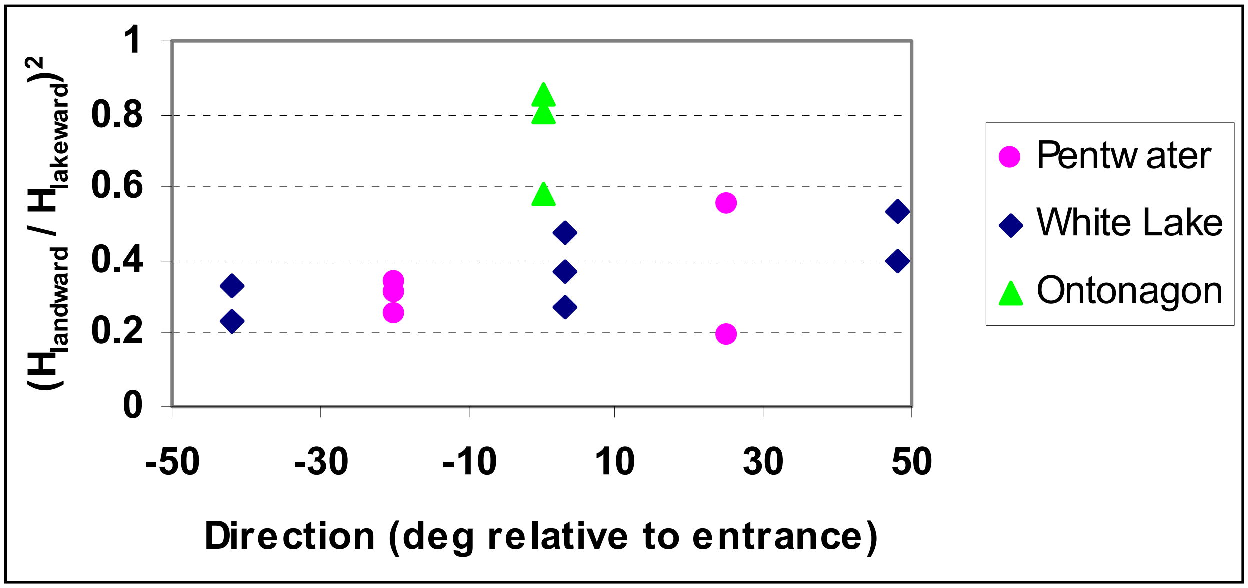

Figure 7. Wave energy fraction passing pocket for three field sites; relative direction is wave approach direction minus direction aligned with entrance channel (Carpenter 2001)

These field results provide some information about the effectiveness of a double versus single pocket absorber. The Lake Michigan results compare reasonably well with corresponding physical model data for configuration C in Figure 5. However, the pocket effect on waves does not appear to vary with incident wave direction as much as in the physical model studies (Figure 4). This difference in behavior can be attributed to the unidirectional, monochromatic waves used in the physical model. Distance between the pockets and the jetty entrance may also affect comparability of field and physical model data, though this effect cannot be evaluated with existing data. The Ontonagon results, which were selected to represent waves coming straight into the entrance, compare reasonably well with corresponding physical model data for configurations A and B, 0-deg direction, in Figure 4. It was noted, however, that these were single-point field measurements in a system with potentially significant cross-channel variation.

MONITORING PROGRAM: As part of the Monitoring Completed Navigation Projects (MCNP) program, pocket wave absorbers at Pentwater Harbor entrance, MI, were selected for monitoring. An aerial view of the site is shown in Figure 6. The objective of the monitoring program was to determine the effectiveness of pocket wave absorbers in reducing wave heights in entrance channels and harbor areas where they are utilized in parallel steel sheet-pile jetty configurations. Additional prototype wave data would be obtained and a physical model would be constructed. After validation of the physical model with prototype data, it was anticipated that design guidance relative to pocket wave absorber parameters would be developed.

ADDITIONAL PROTOTYPE WAVE DATA: The MCNP-supported prototype data collection effort was planned for the fall of 2002. It included an offshore directional wave gauge lakeward of the Pentwater jetties and nondirectional wave gauges along the north side of the channel lakeward and landward of the pocket absorbers (Figure 8). Gauge deployment was delayed until early April 2003. The channel gauges, designated MI002 and MI004, collected hourly data during the 7-week deployment. The offshore gauge failed to provide any incident wave data. Time series data from the channel gauges were subjected to spectral analysis and interpretation by McKinney and Sabol (2003). Long-period motions, with possible periods as long or longer than the 1,024-sec time series, were evident in some records. The long periods may be related to natural oscillations in Lake Michigan and inlet/harbor resonance at Pentwater, as described by Seelig and Sorensen (1977), but record lengths are too short to evaluate this possibility. For the long-period motion events highlighted by McKinney and Sabol (2003),[1] the NOAA/NOS 6-min water level record at Ludington, MI, 16 km (10 miles) north of Pentwater, shows prominent oscillations with approximate height and period of 30 cm (11.8 in.) and 1 hr, respectively. A recent study using water level data and numerical modeling to identify natural oscillation modes in Lake Michigan, shows several modes with periods near 1 hr and antinodes located in the coastal scallop between Big Sable Point and Little Sable Point, which includes both Ludington and Pentwater (As-Salek and Schwab 2004). Strengths and limitations of this field data collection effort are summarized in Table 3.

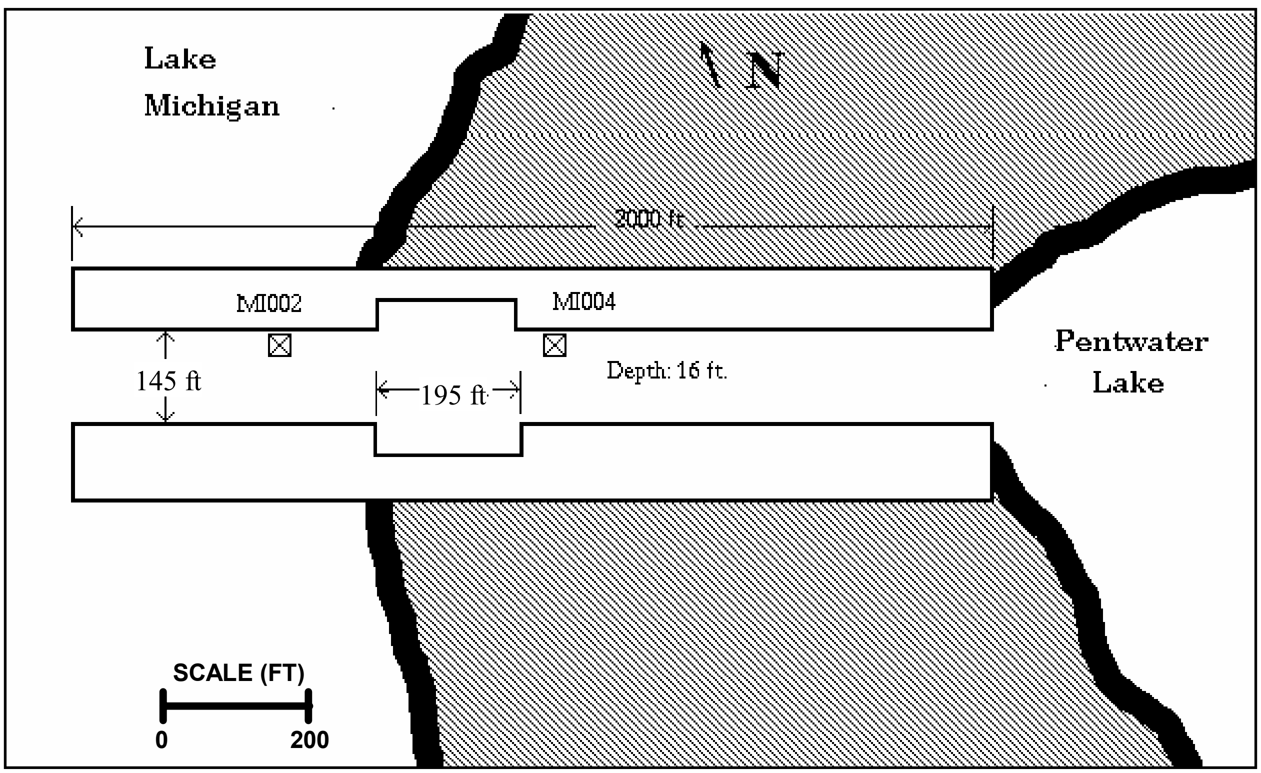

Figure 8. Location of MCNP wave gauges, Pentwater, MI

[1] McKinney, James P., and Sabol, Margaret A. (2003). "Evaluation of the Wave Absorber at Pentwater, Michigan," Unpublished report, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Table 3
Strengths and Limitations, Field Data (McKinney and Sabol 2003)[1]

Strengths	Limitations
Quantitative data on actual performance of prototype pockets in presence of real waves	Limited length of record and range of conditions (no fall or winter storms)
Hourly data over a 7-week time period	No measurements of incident waves
Includes time series data and spectral analysis	Gauges adjacent to jetty walls

Based on cases with significant height from Gauge MI002, $H_{m0MI002}$, greater than 0.1 m (0.33 ft), the average ratio of significant wave height from the landside of the absorber, $H_{m0MI004}$, to that on the lakeside of the absorber is 0.621 m (2.0 ft). The corresponding energy ratio is 0.39 m (1.3 ft), indicating that wave energy after the pocket absorbers was 39 percent of the energy level before the absorbers. The percent energy passing the pocket exhibits a mild tendency to increase with significant height, reaching 45 percent for cases with $H_{m0MI002}$ greater than 0.5 m (1.6 ft) (McKinney and Sabol 2003). This field data set suggests that the Pentwater absorbers are slightly less effective than indicated by the University of Michigan field data (Figure 7) and physical model data (configuration C, Figure 5).

Although the MCNP field study has limitations, it provides a much more extensive suite of field data than was previously available for pocket absorbers. Pocket absorber effectiveness as a function of various wave parameters can be examined. As before, absorber effectiveness is expressed with a parameter indicative of relative transmitted wave energy, $(H_{m0MI004}/H_{m0MI002})^2$. An indication of incident wave direction can be obtained from National Data Buoy Center (NDBC) buoy 45007, which operated through the time period of the MCNP study. The NDBC buoy is located in the middle of the southern lobe of Lake Michigan, about 144.8 km (90 miles) south-southwest of Pentwater.

The dependence of absorber effectiveness on significant wave height lakeward of the pocket is shown in Figure 9. Only cases with dominant deepwater waves traveling toward the entrance are included (cases for which wave direction from the NDBC buoy fell within the range 225-360 deg). Similar plots for dependence of absorber effectiveness on peak wave period, T_{pMI002} , and incident wave direction, as represented by the NDBC buoy, D_{NDBC} , are given in Figures 10 and 11. The fraction of wave energy passing the absorber appears to be independent of wave height, period, and direction.

SUMMARY OF INTERIM RESULTS AND FUTURE PLANS: Preliminary results from the generic physical model and the prototype data presented herein indicate that pocket wave absorbers are effective in reducing wave heights in vertical-wall entrance channels. However, both the physical model and prototype data collected are limited in their applicability, as summarized in Tables 1-3. The prototype data obtained were at single points adjacent to the jetty walls and do not depict variation across the channel. Also, prototype data were obtained for limited wave conditions and only one pocket configuration. Physical model and prototype data give an incomplete, and somewhat inconsistent, portrayal of the dependence of absorber effectiveness on incident wave parameters.

[1] McKinney and Sabol, op cit., p. 9.

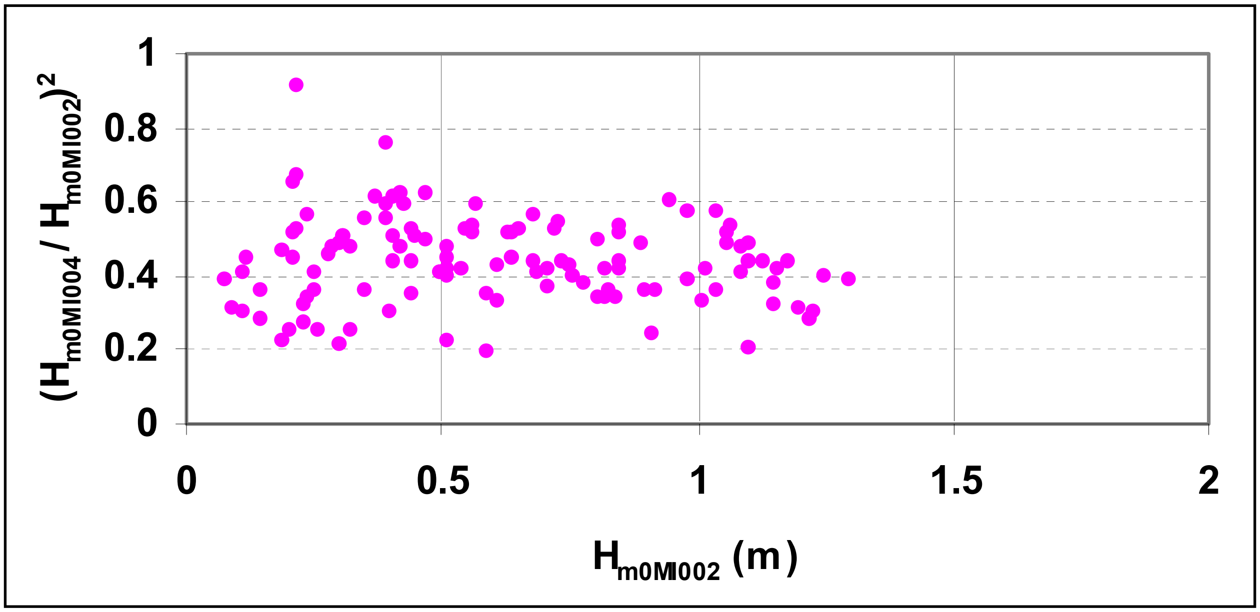

Figure 9. Wave energy fraction passing pocket versus significant height incident to pocket, Pentwater, MI

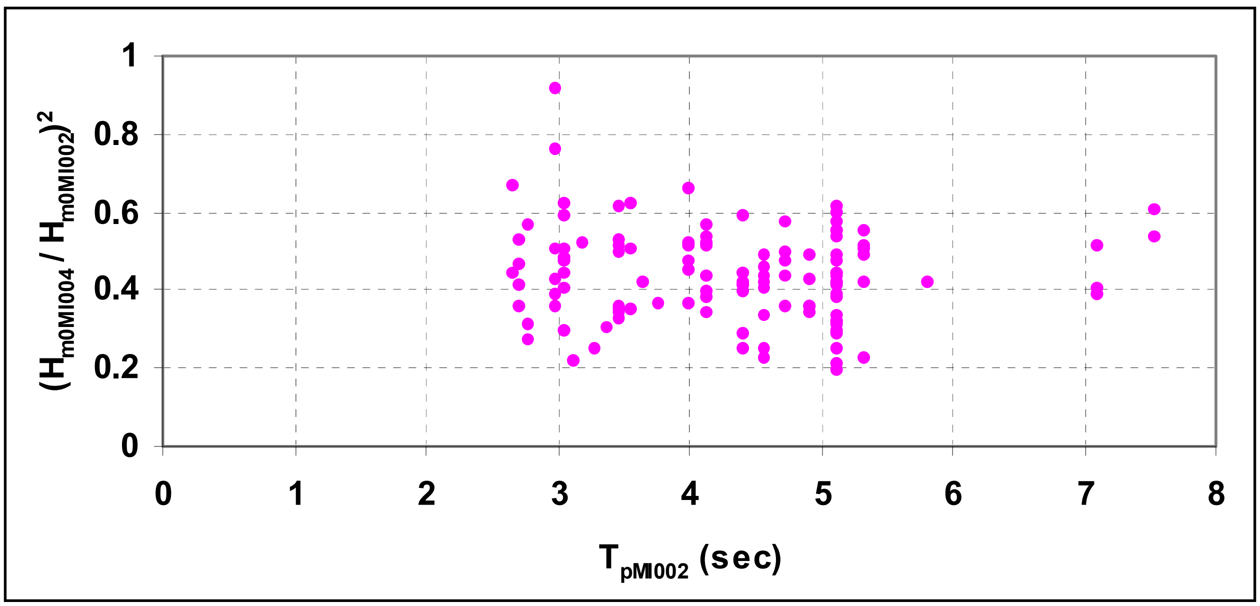

Figure 10. Wave energy fraction passing pocket versus peak wave period incident to pocket, Pentwater, MI

There is inadequate information to provide design guidance. It is unfortunate that the offshore directional wave gauge at Pentwater malfunctioned during the spring 2003 deployment. Plans are to redeploy the prototype wave gauges at Pentwater in early 2004. If adequate data is obtained, a physical model will be constructed and unidirectional spectral waves reproduced to study the pocket wave absorber design parameters. Once the wave conditions have been validated at various locations

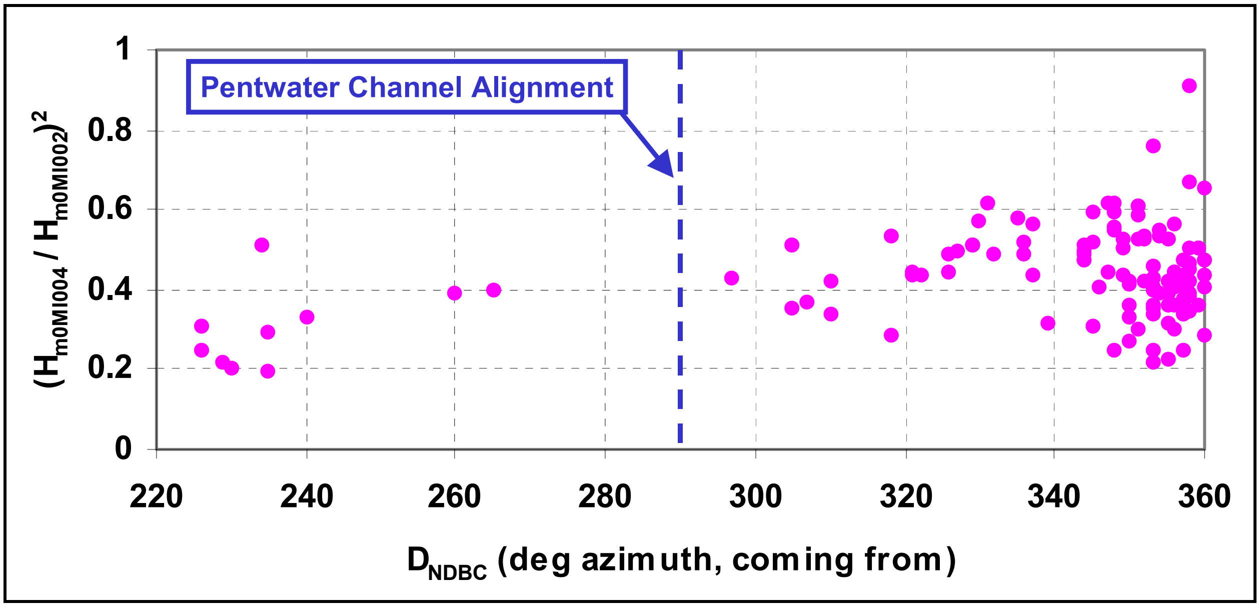

Figure 11. Wave energy fraction passing pocket versus wave direction measured at NDBC buoy 45007, Pentwater, MI

in the model with the prototype data, model wave heights throughout the region between jetties would be obtained with a high degree of confidence. Experiments would determine the impacts of pocket wave absorbers on wave conditions in the navigation channel, as opposed to only those adjacent to the vertical jetty wall. In addition, once validated, the model would be used to study a wide range of incident wave conditions (wave heights, periods, and directions). Changes in pocket wave absorber parameters (lengths, locations, stone sizes, slopes, etc.) would then be made to develop design guidance. Prototype and physical model data will be used to validate the numerical model, CGWAVE, for development of a pocket wave absorber "performance index," which is relevant to the objectives of the monitoring study. The performance of Boussinesq (BOUSS-2D) will also be evaluated using the available prototype and physical model data.

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