

LABORATORY MEASUREMENTS OF WAVES AND WAVE-INDUCED CURRENTS AT A JETTIED INLET

William C. Seabergh¹, Lihwa Lin¹, and Zeki Demirbilek¹,

Abstract: This paper presents results from a comprehensive laboratory experiment measuring waves and wave-induced currents at an inlet protected by dual jetties. Densely spaced wave gauges and current meters were used to collect data on the up-wave side of a jetty and in the inlet area. Both impermeable (reflective) and permeable (absorbing) jetties were examined. Measurements were made with different incident wave conditions. Current and wave measurements were made along the up-wave face of the jetty and at shore-perpendicular transects at fixed distances from the jetty. Results show different wave and current patterns on the up-wave side of the impermeable and the absorbing jetties. Higher wave heights were measured along the impermeable jetty compared to the absorbing jetty. Comparatively weaker currents were measured on the up-wave side of the impermeable jetty, and these created an eddy near the jetty shore end. These wave and current measurements around the absorbing and the reflective jetties will serve to test and validate numerical models.

INTRODUCTION

Jetties are built at most inlets to improve navigability and minimize sedimentation in the navigation channel. These structures provide protection from waves, align tidal currents, and reduce sedimentation of the navigation channel. Waves approaching inlets may break, generating currents that flow along the shore and divert seaward by a shore-normal structure, such as a groin or jetty. These longshore currents and tidal currents can carry sediment towards the navigation channel and create a strong cross-current that can reduce channel reliability.

Figure 1 illustrates the encounter of a longshore current with a jetty at Grays Harbor, WA. Larger waves are expected to induce stronger currents, which can alter the inlet environment and activities therein.

¹ U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS, 39180-6133, William.C.Seabergh@erdc.usace.army.mil; Lihwa.lin@erdc.usace.army.mil; Zeki.Demirbilek@erdc.usace.army.mil



Fig. 1. Wave-generated longshore currents at Grays Harbor, WA, during flood tide

Advanced numerical models are frequently used in the modeling of flow, wave, and morphodynamics of coastal inlets. The U.S. Army Corps of Engineers' Inlet Modeling System (IMS) (Zundel et al. 2002) has been developed under the Coastal Inlets Research Program (CIRP). The IMS is a state-of-the-art modeling suite developed for coastal inlets (<http://cirp.wes.army.mil/cirp/cirp.html>) that consists of several hydrodynamics, waves, and sediment transport models. The physical modeling experiments described here were conducted in support of the CIRP's numerical model testing, validation, and enhancement. The focus of these experiments was on the measurement of waves and wave-induced currents at an idealized inlet that was protected by either absorbing or reflecting jetties. In the field, jetty structure composition may vary from porous rock rubble to strongly reflecting vertical sheet piles. Waves breaking along the shore create a longshore current that is deflected seaward by a jetty. The circulation created by such currents can interact with waves that propagate from the sea and reflect off the jetty.

In the past, data collection in the beach-jetty region has been limited because of the energetic wave environment. Data collection in previous physical model studies was often limited to injecting dye to measure the current field because the inertia of mechanical current meters precluded making accurate measurements. With the advent of acoustic-Doppler type current meters in the laboratory (Kraus et al. 1994), the accuracy of current measurements has been enhanced (Seabergh and Smith 2001). This is also true for field measurements. For instances, Osbourne (2003) collected significant data sets in the high-energy environment, and Sherwood et al. (2001) measured tidal currents on the ebb shoal and adjacent regions at Grays Harbor. Pollock (1995) deployed instruments from a helicopter into a hostile (extreme) nearshore environment near jetties at Siuslaw River, OR.

FACILITY FOR EXPERIMENTS

The idealized inlet model was 46 m wide and 99 m long, and set up in a concrete basin with 0.6-m high walls (Fig. 2). The inlet bathymetry was simplified so that its seaward depth contours could be represented by an equilibrium profile (Dean 1977):

$$d = Ax^{0.67}$$

where, d = still-water depth, x = distance offshore from the shoreline, and A is determined by sediment characteristics. The contoured beach slope (Fig. 3) extends to the 18.3-cm mean low water (MLW) depth.

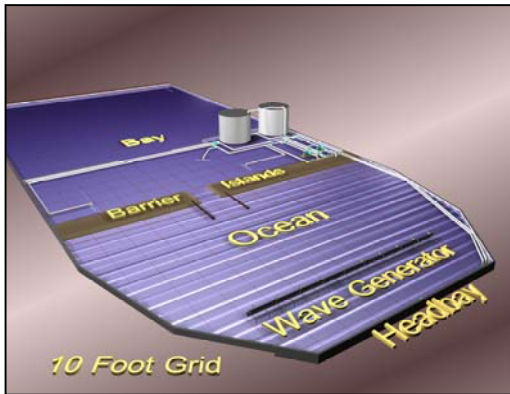


Fig. 2. Idealized Inlet model research facility

The inlet throat region converges to a depth of 15.2 cm relative to a MLW datum. The minimum width is 267 cm across the inlet between MLW contours. Figure 4 shows the inlet with dual jetties. See Seabergh (1999) for more information. A 24-m-long unidirectional-wave generator, capable of producing irregular and regular waves, was used in the study (Fig. 2).

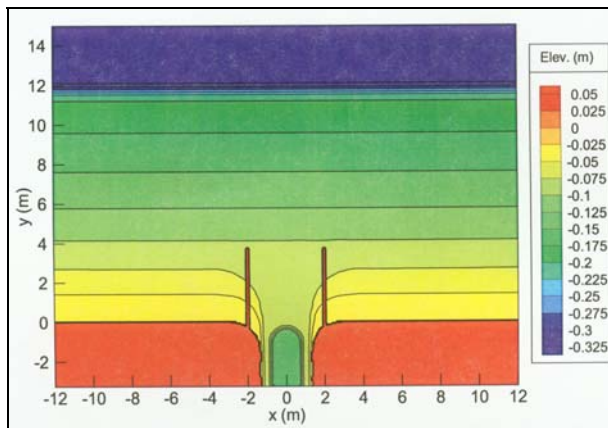


Fig. 3. Contours in idealized inlet



Fig. 4. Idealized inlet channel

Electrical capacitance gauges measured wave height, with a sampling rate at 20-Hz. Velocity data were collected with SonTek 2D Acoustic Doppler Velocimeters (ADV) at 20 Hz, though the instrument makes 250 pings/sec and averages for each output sample. The velocity data were analyzed to determine wave direction.

EXPERIMENT SETUP

The first set of experiments concerned a nonreflecting structure. It was achieved by lining the up-shore face of an impermeable rock jetty with a fibrous material to increase its wave absorption capacity. Wire mesh held the absorber in place (Fig. 5). For the reflecting jetty, a plywood face (Fig. 6) was placed outside at the edge of the fibrous material so that the gauge locations could be maintained for both jetty types. Wave gauges and current meter locations were fixed for both the absorbing and reflecting jetty cases. A spur jetty experiment was also performed, but is not presented here. Figure 7 shows a sample sketch of gauge locations for wave height.

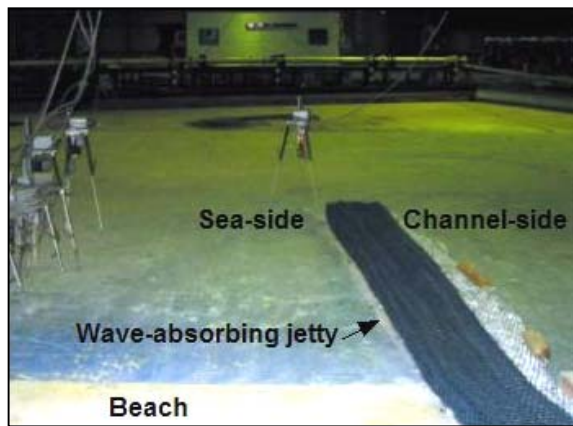


Fig. 5. Wave-absorbing jetty

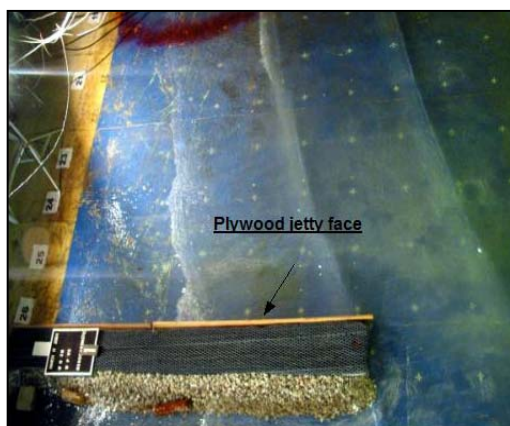


Fig. 6. Wave-reflecting jetty

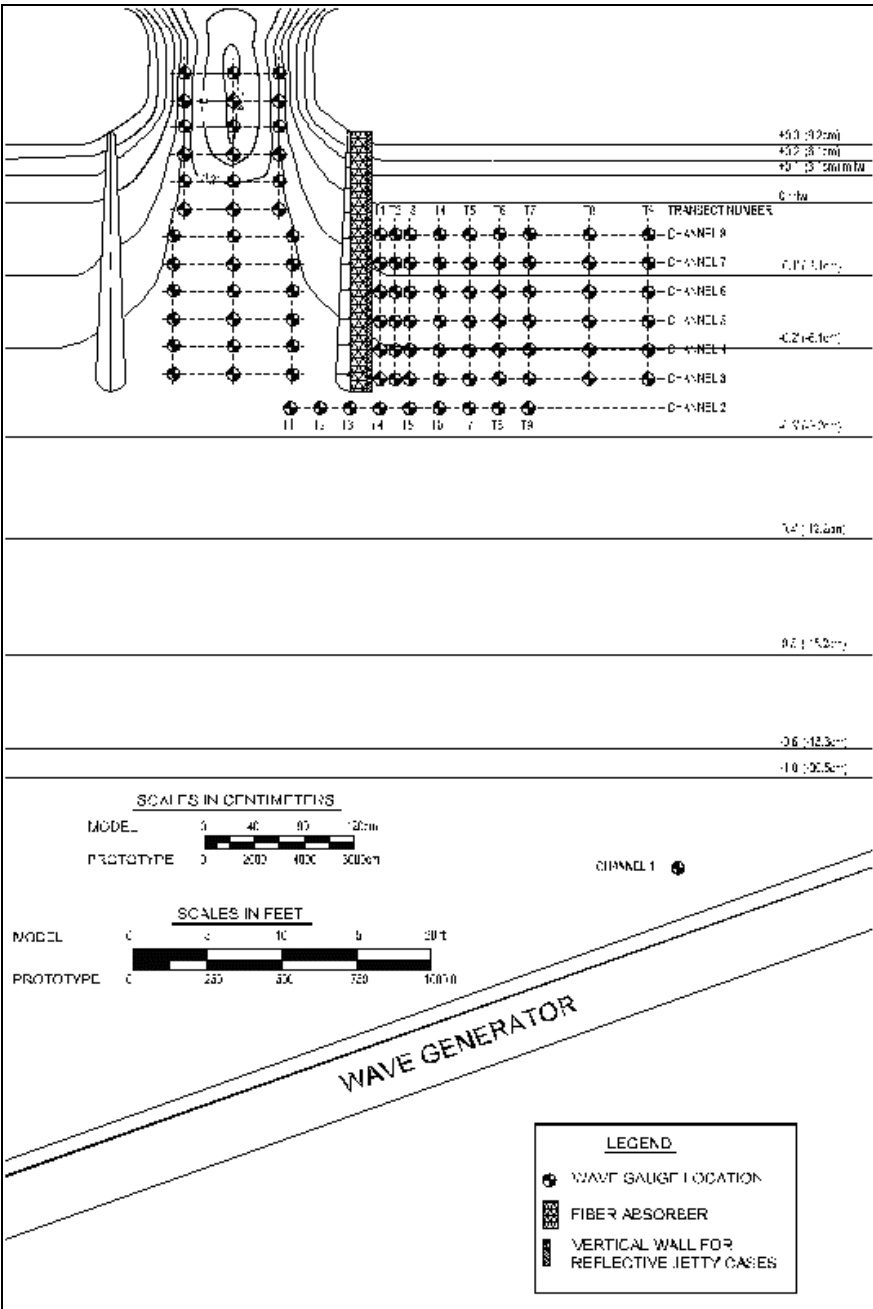


Fig. 7. Wave gauge locations

EXPERIMENT CONDITIONS

The laboratory experiments were conducted for measuring waves and wave-induced currents at an idealized inlet with dual jetties. Incident waves in these experiments were monochromatic waves that were generated at the seaward channel boundary at a 20-deg angle with the shore (see Fig. 7). Table 1 lists the height and period of the offshore wave conditions, together with jetty type. Both laboratory and assumed, illustrative prototype values (in parentheses, 1:50 Froude scale) are listed.

Table 1
Experiment Conditions (Wave Direction, 20 deg; Type-Monochromatic)

| Jetty Type | Incident Wave Height, m (prototype scale, 1:50, m) | Wave Period, sec (prototype scale, 1:7.07, sec) |
|-------------------|---|--|
| Absorbing | 0.02 (1.0) | 1.56 (11) |
| Absorbing | 0.04 (2.0) | 1.56 (11) |
| Absorbing | 0.07 (3.4) | 1.13 (8) |
| Absorbing | 0.02 (1.0) | 1.13 (8) |
| Absorbing | 0.033 (1.65) | 1.56 (11) |
| Reflecting | 0.02 (1.0) | 1.56 (11) |
| Reflecting | 0.04 (2.0) | 1.56 (11) |
| Reflecting | 0.02 (1.0) | 1.13 (8) |
| Reflecting | 0.07 (3.4) | 1.13 (8) |
| Reflecting | 0.015 (0.75) | 1.13 (8) |
| Spur | 0.02 (1.0) | 1.56 (11) |
| Spur | 0.04 (2.0) | 1.56 (11) |
| Spur | 0.07 (3.4) | 1.13 (8) |

Only the first three experiments were run with data collection in the channel. The in-channel data should be similar for both absorbing and reflective jetties as the only change was at the outside part of the jetty boundary. Inside the channel, both jetties consisted of rock rubble (roughly 2 to 5-cm diameter) and had an impermeable core. These experiments were conducted with a constant water level. The water surface elevation was at 0.33 m above the MLW datum.

The absorbing jetty (Figure 5) was composed of fibrous rubberized hair filter material. Keulegan (1972) examined this material in a laboratory study and found that its reflection coefficient ranged between 0.10 and 0.25. The reflective jetty was constructed of smooth, $\frac{3}{4}$ -in. marine plywood. The spur jetty was constructed of rock (2 to 5-cm diameter). The contoured floor of the experimental facility was molded to templates with concrete mortar. The surface had a smooth, troweled finish, and was painted. An estimated Manning's n for this surface is 0.015.

EXPERIMENT RESULTS

Samples of data collected in these experiments are given in Figs. 8 and 9. Figure 8 shows water level measurements for incident wave height of 0.04 m and wave period of 1.56 sec at the wave generator (Gauge 1 in Fig. 7) and at locations along the up-wave side of the reflective jetty (Gauges 3 and 8). Figure 9 shows a 10-sec segment of the

600-sec current data at a location near the absorbing jetty. This sample of current data clearly illustrates the presence of both orbital and translational velocities that occur near the jetty.

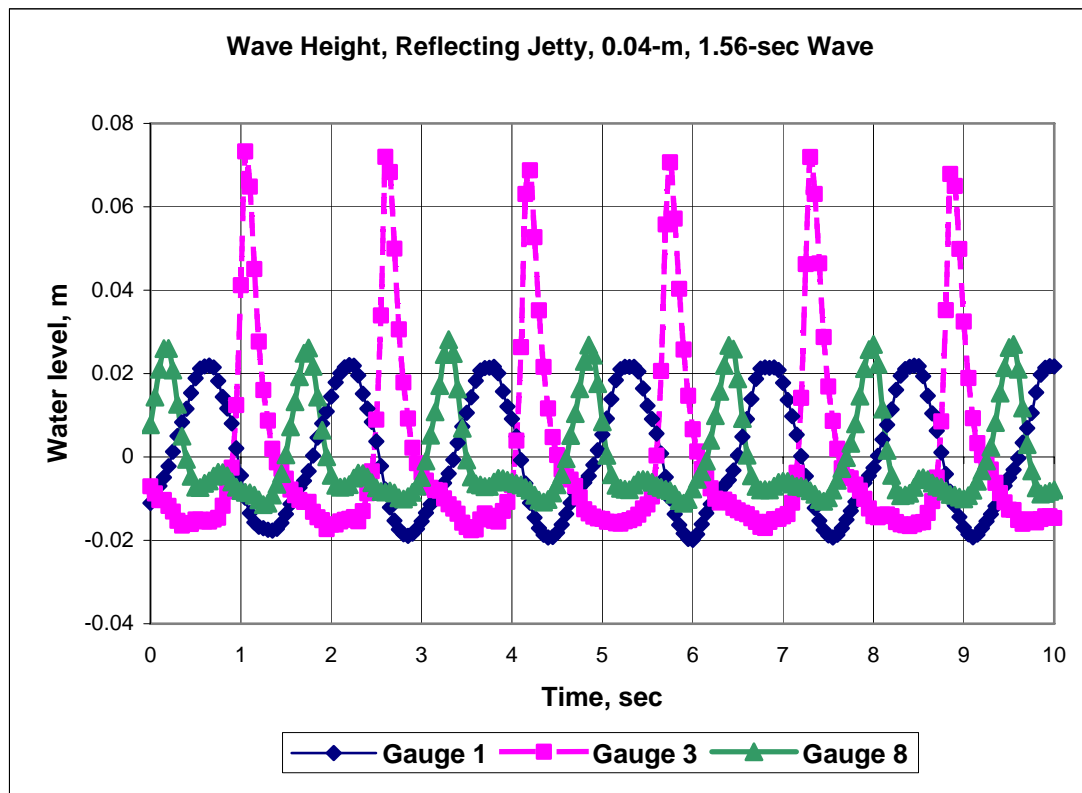


Fig. 8. Wave height measurements (in meters) showing waves at generator Gauge 1, and Gauges 2 and 3, waves near jetty

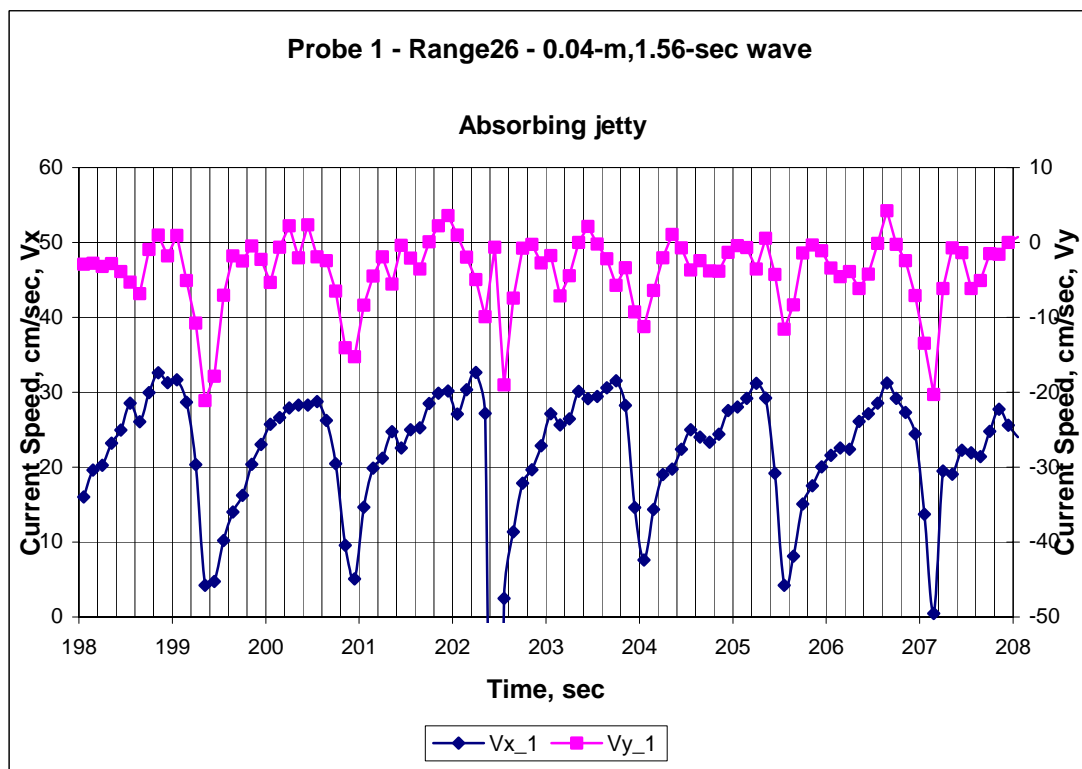


Fig. 9. 10-sec snapshot of x and y components of velocity measurements at the up-wave side of the absorbing jetty

OBSERVATIONS

Examples of data from the study are briefly discussed in this section. Figure 10 presents wave directions and scaled wave heights for the 2-m, 11-sec incident wave (scaled by 1:50 Froude scale). Figure 10a shows that wave direction approaching the jetty was unchanged as it entered the absorbing jetty. Figure 10b indicates the effect of the reflective jetty as a guide where wave direction vectors were parallel to it. Also wave height was greater along the reflective jetty. The current that flowed alongshore, then seaward, in the vicinity of the jetty, modified the wave direction and magnitude. The circulation was different for the two jetty types as discussed next.

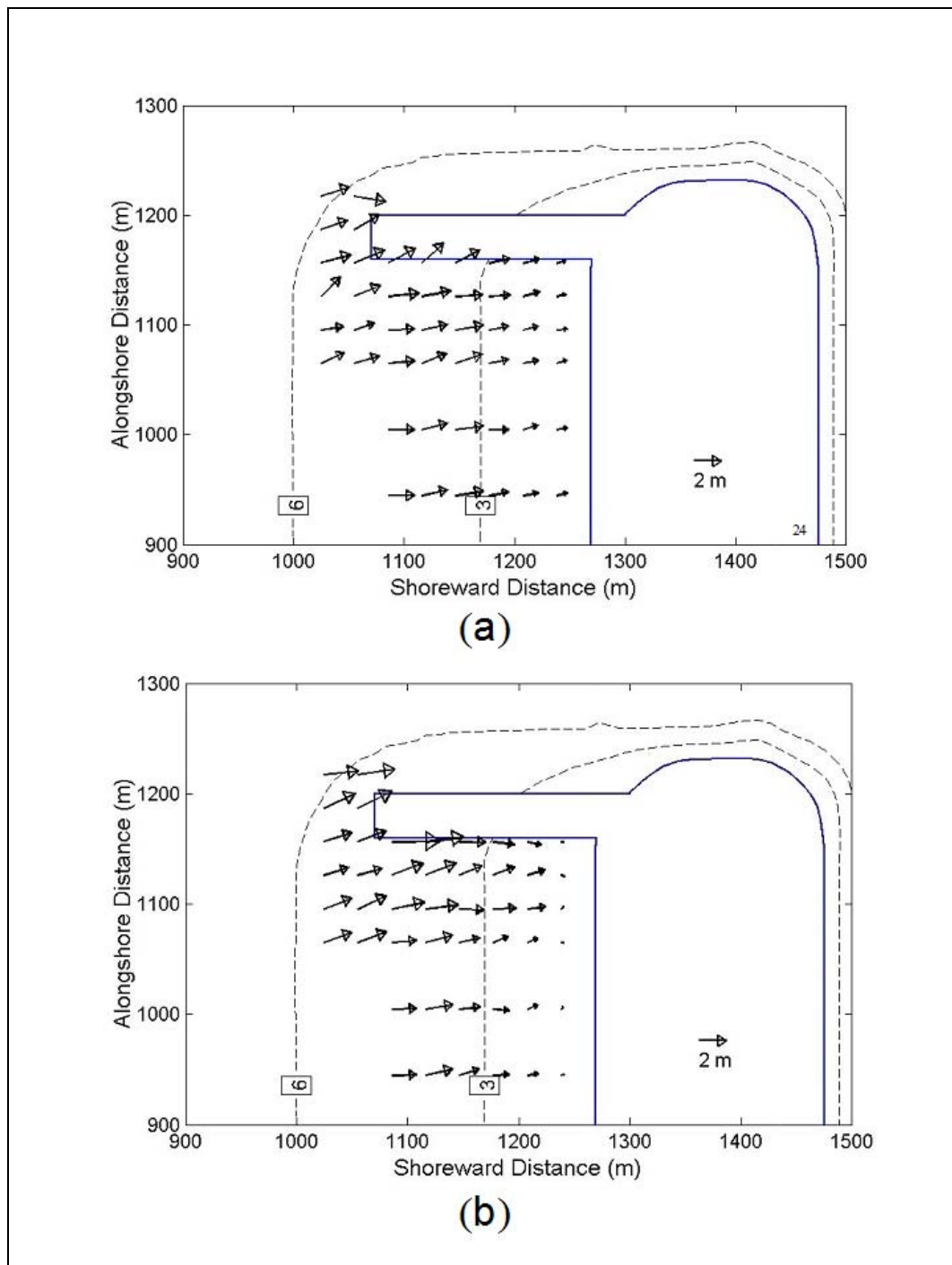


Fig. 10. Wave direction vectors and scaled wave height (2-m, 11-sec incident wave, prototype scale; 0.04-m, 1.56-sec laboratory) for (a) wave absorbing jetty, and (b) reflective jetty

Notable hydrodynamic differences were observed for the two extreme jetty structures. The reflective jetty and the absorbing jetty each created different circulation patterns (Fig. 11). The absorbing jetty permitted the longshore current to approach the structure and then deflect seaward 90 deg along and close to the jetty. The ensuing circulation cell with an absorbing jetty approached the base of the jetty before deflecting seaward. In contrast, the reflective jetty created a clockwise circulation cell, starting about at the mid-section of the jetty that reached all the way to the shoreline. This cell was large and sufficiently strong to deflect the offshore movement of the longshore current approximately one wavelength upcoast.

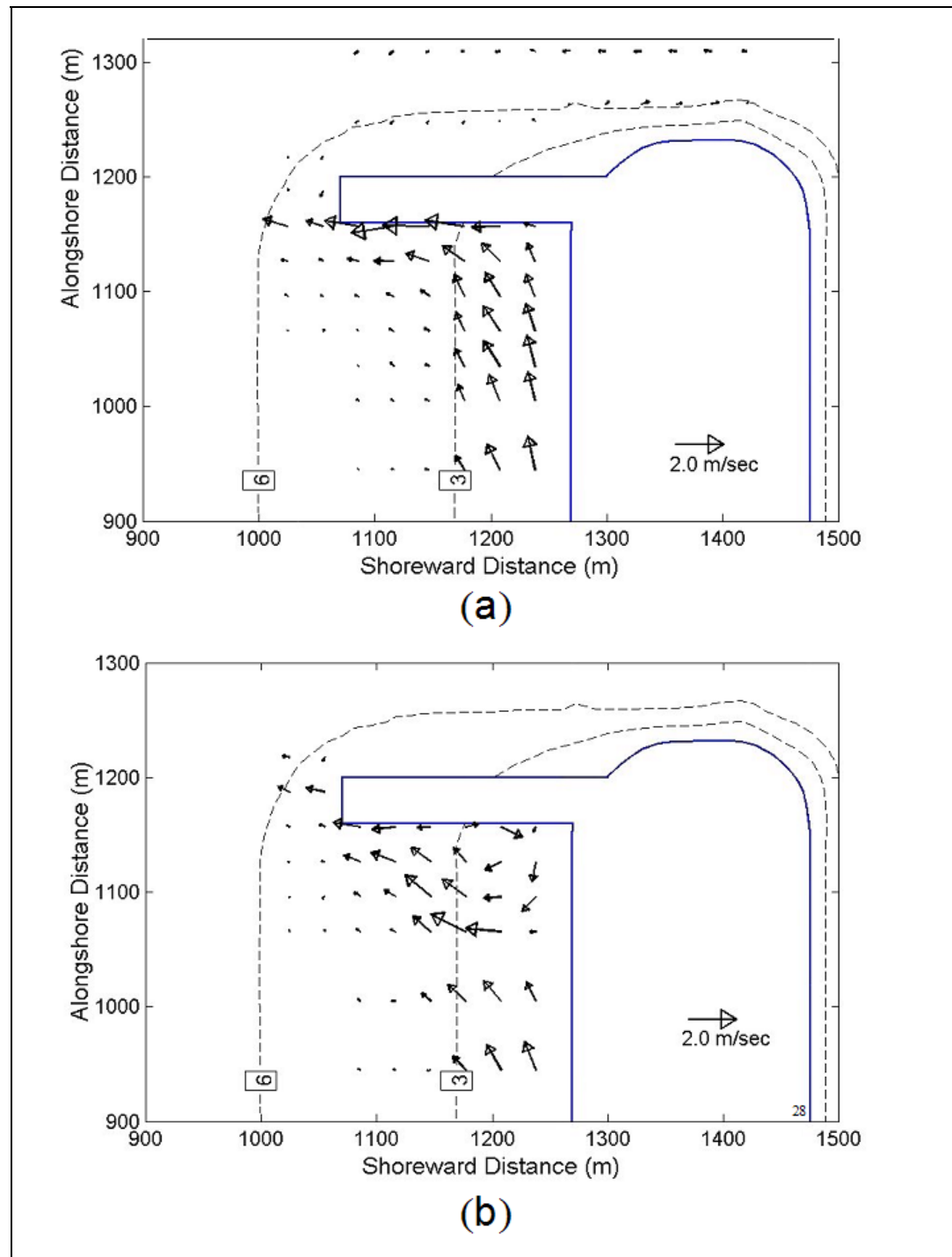


Fig. 11. Comparison of circulation velocity current patterns for (a) absorbing jetty and (b) reflecting jetty, with 2-m, 11-sec wave, prototype scale (0.04-m, 1.56-sec laboratory wave)

Figure 12 shows a time sequence of photographs with dye movement driven by the longshore current toward the absorbing jetty. The current flows to the base of the structure and then is turned seaward.

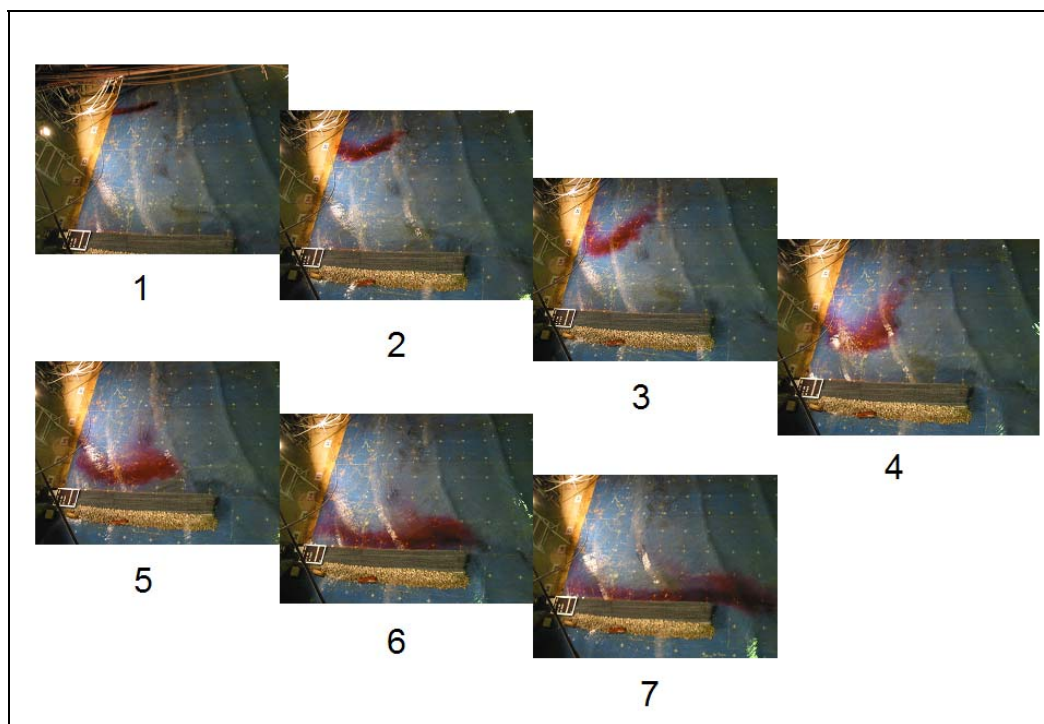


Fig. 12. Sequence of photographs (1-7) of dye patch approaching absorbing jetty (2-m, 11-sec wave)

CONCLUSIONS

Wave height and direction, and wave-induced currents were measured in a laboratory experiment at numerous locations near an inlet that was protected by dual jetties of either reflective or absorbing type. A spur jetty, with three equally spaced short spurs along the jetty length, was also tested. Experiments were typical for a coastal inlet, where waves were breaking and the longshore current deflected seaward by structures. A comprehensive laboratory data set representative of tidal inlets has been developed that contains wave height, wave direction, and wave-induced currents (Seabergh et al. 2005).

Differences in the response of the wave-generated currents for the reflected versus the wave absorbing jetties were observed. The composition of the jetty was designed to represent the extremes of an inlet jetty – a jetty that fully reflects the incident waves toward the upcoast shoreline adjacent to the jetty, and an almost fully absorbing jetty, which reflects very little energy. These two extreme jetty structures created different circulation patterns. The nearly fully wave-absorbing jetty configuration permitted the wave-generated longshore current to approach the jetty and be deflected seaward 90 deg along the jetty. The waves fully reflecting from the hard-surfaced reflective jetty created a clockwise circulation cell, starting at the mid-section of the jetty and reaching the shoreline. This cell was large enough to deflect the offshore movement of longshore current a distance of approximately one wavelength upcoast of the jetty. This difference of circulation compared to that observed with an absorbing jetty, where the longshore current approached the base of the jetty before deflecting seaward was significant. Data for these two structure configurations is expected to be useful in numerical model validation.

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