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Branchbox Breakwater Design at Pickleweed Trail, Martinez, CA, Section 227 Demonstration Project

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PURPOSE: The objective of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to provide a preliminary design of the branchbox breakwater for the Martinez project site in the National Shoreline Erosion Control Development and Demonstration Program (Section 227) using existing design guidance and lessons learned from previous branchbox breakwater projects. The branchbox breakwater system proposed herein derives stability from both the breakwater and wetland plants between the breakwater and the shoreline. Selection of the type of wetland plants to use behind breakwaters is a critical part of bioengineering bank protection. While this technical note provides some information on plants used at specific projects, the focus of this report is on the design of the breakwater part of the system.

BACKGROUND: The city of Martinez is located in northern California's Contra Costa County, between San Pablo Bay and Suisun Bay. Pickleweed Trail is located within the Martinez Regional Shoreline Park in Martinez (Figure 1). The project area extends approximately 1,000 m along the southern shore of Carquinez Strait, adjacent to the Union Pacific Railroad right-of-way. Sandwiched between the strait and the main line of the railroad, this recreational hiking trail is maintained by the East Bay Regional Park District. The site, which is within the U.S. Army Engineer District, San Francisco, includes a coastal wetland habitat for a variety of species.

Pickleweed Trail is experiencing erosion due to what appears to be some combination of tidal currents, vessel wake, and wind wave action. As the erosion process continues, the land available for potential relocation of the trail diminishes and is limited by its proximity to the railroad. This erosion is adding sediment to a Federal navigation channel, is encroaching on the recreational hiking trail, and is also destroying potentially critical habitat for the California clapper rail, the California least tern, and the salt marsh harvest mouse, all of which are classified as threatened or endangered species. Attempts to control erosion with riprap armoring have brought limited success in adjacent areas. According to trail users familiar with the area, erosion is claiming approximately 1.5 m of shoreline per year in the unprotected areas.

Pickleweed Trail has been chosen as a site for the implementation of a bioengineered structure under the Section 227 Program. The demonstration project goal is to test the effectiveness of a bio-engineered branchbox structure at reducing wave-induced erosion in an estuarine environment. This project will also result in the reestablishment of previously lost critical habitat. The use of bioengineering techniques in engineering projects has typically been limited to streambank and lakeshore restoration-type projects as a means of controlling bank erosion. Although bioengineering techniques have seldom been used to reduce coastal erosion, there exists the potential to apply the techniques to engineering designs for low to moderate wave energy environments, such as in back bay salt marsh environments and along inland portions of navigation channels. The preliminary

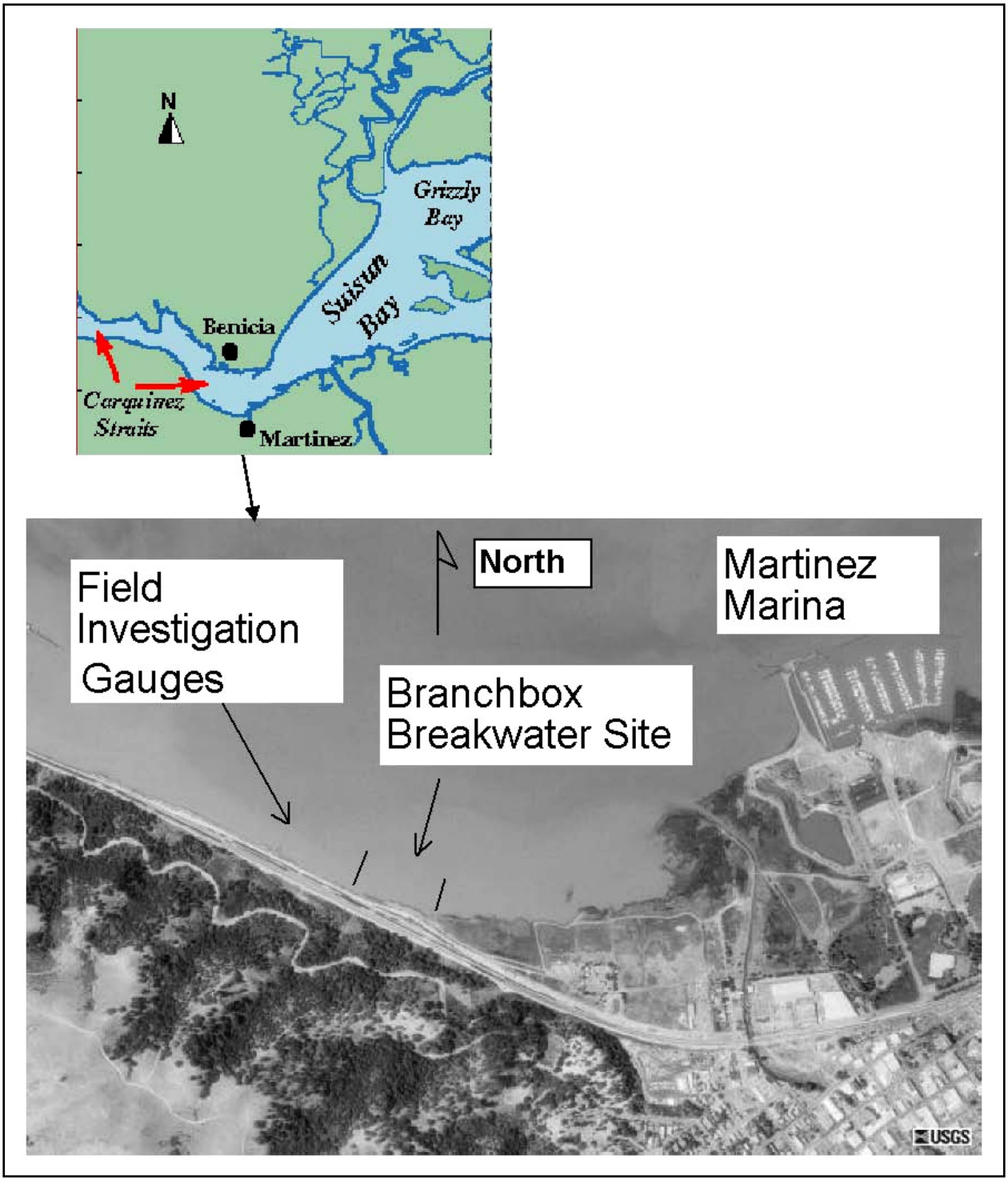

Figure 1. Section 227 project site at Martinez, CA

design proposed herein can be constructed in a possible extension of the Section 227 Program or some other funding source. Development of this preliminary design is a collaborative effort between the San Francisco District and the U.S. Army Engineer Research and Development Center (ERDC).

SITE CONDITIONS AND DOMINANT LOAD ON MARTINEZ SHORELINE: Wind waves, tidal currents, and ship/boat effects are present at the proposed demonstration site. The magnitude of each of these must be determined, and the critical question that must be answered is whether the bioengineering treatment proposed for Martinez has a reasonable probability of withstanding the various forces.

Tidal Conditions. Martinez has a semidiurnal mixed tide having two highs and two lows, but the two highs and two lows have different amplitude. Tidal characteristics relative to mean lower low water (mllw) at the closest gauge at Port Chicago are shown in Table 1. The top of bank elevation along the portion of Pickleweed Trail that is not protected by riprap is about el 2.1 mllw.

Table 1
Tide Data for Port Chicago

Characteristic Water Level	Elevation m, mllw	% Exceeded 2000-2005
Highest observed water level	2.415	0.0
Mean higher high water (mhhw)	1.498	4.7
Mean high water (mhw)	1.343	11.3
Top of proposed protection	0.900	43.3
Mean tide level	0.785	51.2
Mean sea level	0.781	51.5
Mean low water	0.226	84.8
Mean lower low water	0.000	95.5
Lowest observed water level	-0.447	100

During the field study, tidal currents were measured along the eroding shoreline during the flood tide on 8/25/04. The measurements were made at 1030 between a low of 0.0 m at 0437 and a high of 1.22 m at 1153. Measured surface velocities 10 m from the eroding shoreline were less than 0.22 m/sec. Tidal records were examined to find the maximum difference between a low tide and the following high tide. The maximum difference was about 1.4 to 1.5 m, which compares to the 1.22 m on the day the velocities were measured. At the higher differential of 1.4 to 1.5 m, it is unlikely that flood tide velocities along the shoreline will be a significant source of bank attack. Ebb tide velocities were not measured during the study. During ebb tides, the shoreline configuration and the presence of the marina at Martinez will likely result in an eddy zone caused by flow separation at the marina dike. The eddy zone may result in upstream velocities along the trail during an ebb tide. In any case, velocities along the trail shoreline during an ebb tide should be low. While both ebb and flood velocities appear unlikely to cause significant attack of the shoreline, both velocities will be capable of moving fine material eroded or resuspended by wave activity along and away from the trail.

While tidal velocities may not directly erode the shoreline, the rise and fall of tides causes an alternating positive and negative pore pressures in the shoreline region that alternately reduce and increase the ability of bottom and bank materials to resist erosion. Superimposed on this cyclic loading of the bank by tides is the more rapid cyclic loading by wind waves. The most dominant effect of tides on the demonstration project is the difficulty of placing a branchbox breakwater high enough to reduce wave effects at high tides.

Wind Waves. The site is located on Carquinez Strait and has significant fetch distance to the northwest (7 km) and northeast (18 km). Wave conditions at the shoreline will be affected by the shallow bench at the site that extends about 350 m from the shoreline. At low and moderate tides, water depth on this bench will limit wave height.

Two National Oceanic and Atmospheric Administration (NOAA) stations are in the vicinity of the Martinez site. The Port Chicago NOAA station is 14 km east of the site and the Richmond NOAA station is 22 km southwest of the site. Another source of wind data is Buchanan Field Airport near Concord, CA that is about 11 km southeast of the Martinez site. The Richmond data was not used because of its greater distance from Martinez. The applicability of the Port Chicago and Buchanan Field wind data to Martinez must be determined because ground features may funnel winds along the channel axis. The USGS has a wind map for the entire bay area that is "real-time" on the web (*http://sfports.wr.usgs.gov/cgi-bin/wind/windbin.cgi*) and also contains archives of both observed and modeled wind speed and direction. The web site states that the grid used in the wind model was based on a 1 km grid that should be adequate to resolve the effects of ground features in the vicinity of Martinez, Buchanan Field, and Port Chicago. The web site was used to compare wind magnitude and direction at Martinez, Buchanan Field, and Port Chicago. The first day of every month in 2004 was compared to obtain a range of both magnitude and direction. Wind magnitude varied from 2.1-6.2 m/sec and magnitude and direction were similar for all twelve comparisons. Based on this comparison, the wind data at Port Chicago and Buchanan Field Airport are accepted as being adequate for the wind wave analysis at Martinez.

The NOAA site for Port Chicago has hourly winds available from 1994-2001 and provided 63,671 records that were used to develop the wind rose shown in Figure 2. Each leg of the wind rose represents a 10-deg window. Average hourly wind speed at Port Chicago is 4.76 m/sec. The Air Force Combat Climatology Center in North Carolina has hourly wind data for Buchanan Field Airport from 1973-2005. Data from 1984-2003 were used and provided 124,838 records used in the analysis. Average hourly wind speed at Buchanan Field was 3.9 m/sec. Table 2 provides the fetch distance and percentage of winds versus wind direction for Port Chicago and Buchanan Field based on the hourly wind observations. The more extensive data at Buchanan Field show a greater portion of winds from the North and Northwest directions that are important to wave generation at Martinez. Percentage of winds from the longest fetch to the Northeast is slightly less at Buchanan Field.

The CEDAS model (USACE, 2005) was used to determine wind wave height using fetch from Table 2, and wind speed and direction from the Port Chicago and Buchanan Field hourly wind data. The data from each station was analyzed separately. The computed wave heights were used to determine the probability of exceedance as shown in Table 3. Based on Table 3 and the more extensive data at Buchanan Field, wave height at Martinez will exceed 0.6 m only about 2 hours per year.

The state of Wisconsin defines standards for shoreline erosion control and distinguishes between low energy sites having wave height of less than 0.30 m, moderate energy sites having wave height of 0.30 to 0.70 m, and high energy sites having wave energy of greater than 0.70 m. Based on Table 3, Martinez classifies as a moderate energy level. Wind waves will likely provide a severe test of bioengineering at Martinez but the likelihood of success is great enough to proceed with a robust bioengineering technique.

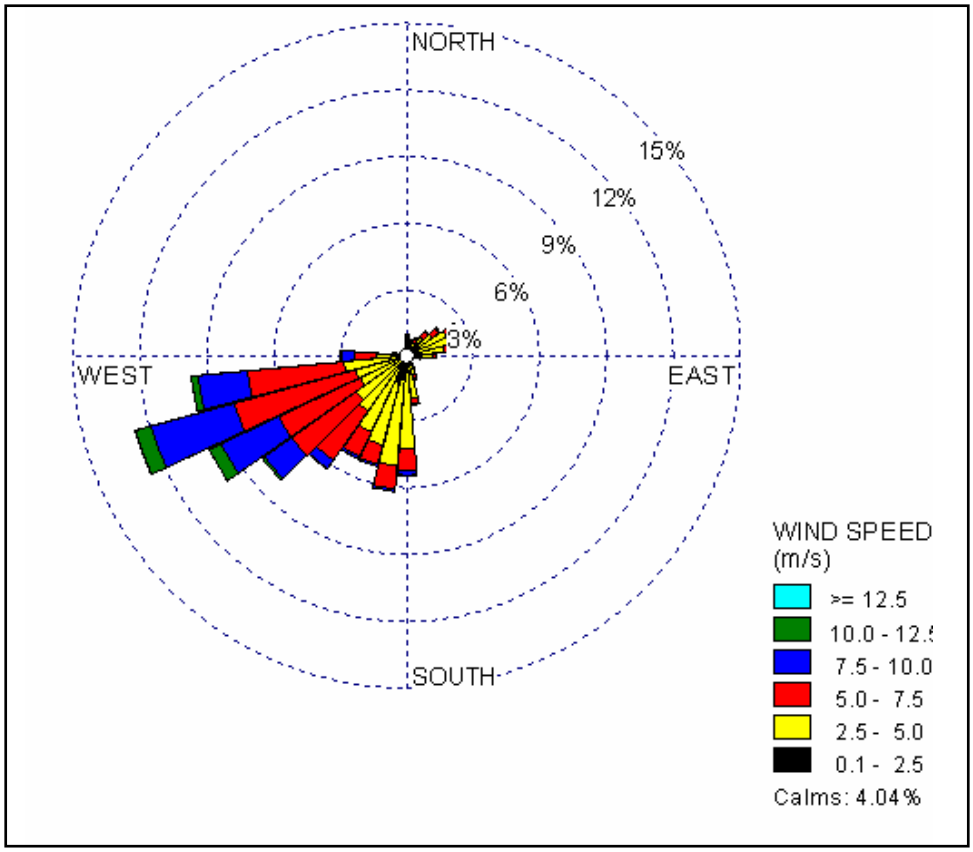

Figure 2. Wind rose for Port Chicago based on hourly winds from 1994-2001

Table 2
Fetch Distance and Percent of Winds Versus Wind Direction

Wind Direction, deg	Fetch, km	Percent of Hourly Wind Observations (number of observations)	
		Port Chicago	Buchanan Field
275-285	1	0.6 (389)	3.2 (3950)
285-295	3	0.3 (200)	3.1 (3827)
295-345	7	1.6 (991)	15.2 (18969)
345-25	3	3.0 (1916)	6.9 (8577)
25-65	18	7.1 (4526)	5.7 (7122)
65-75	7	2.5 (1601)	0.8 (961)
75-85	1	2.1 (1322)	0.5 (596)
85-275	0	78.8 (50152)	50.1 (62505)
Not applicable	Calm[1]	4.0 (2574)	14.7 (18331)

[1] Calm at Port Chicago was less than 0.1 m/sec whereas calm at Buchanan Field was less than about 1 m/sec.

Table 3
Computed Wave Height Versus Percentage of Exceedance

Computed Wave Height, m[1]	Percentage of Waves Based on Hourly Wind Data Greater Than or Equal to Computed Wave Height	
	Port Chicago	Buchanan Field
0.05	11.8	26.2
0.1	5.5	21.4
0.2	1.4	7.6
0.3	0.4	0.27
0.4	0.08	0.05
0.5	0.02	0.03
0.6	0.003	0.02
0.7	0.0	0.02
0.8	0.0	0.02
0.9	0.0	0.006
1.0	0.0	0.002

[1] Using ACES model with 10-m elevation of observed wind, 0 degrees water-air temperature difference, 1 hour duration of both observation and final wind, and deep open water.

If the project is constructed, both wind magnitude and direction and wave height need to be measured at the site to develop a correlation with the winds measured at the permanent stations at Port Chicago and/or Richmond gauges. Such a correlation will permit a complete analysis of wind wave conditions experienced by the branchbox breakwater that is not possible with the present data.

Ship/Boat Effects. The Martinez site is subjected to navigation effects from vessels ranging from deep draft ships to recreational boats. A field investigation was conducted 23-27 August 2004 to measure conditions at the site, particularly ship/boat effects. During the field investigation, wind was negligible and the measurements did not provide useful wind wave data.

During the field investigation, waves from ships and wind were measured with four capacitance rods (CR) and one pressure cell. The CRs were 3 m in length and were mounted to existing piling located at the site and were 58 m from the shoreline. The measurement location is at the west end of the proposed demonstration project. The pressure gauge was mounted in a tripod with the sensor about 40 cm above the bed. The pressure gauge and the capacitance rods sampled at 5 Hz, read data for 57 min/hr and stored data for 3 min/hr. A video camera was mounted at the site to monitor ship traffic and determine ship speed. A layout of the field instruments is shown in Figure 3.

Based on the field study, ship/boat effects are broken into three groups:

a. *Recreational boat effects*. The shallow bench having width of about 250 m tends to discourage recreational boats from operating near the shoreline. Consequently, recreational boat wakes are small at the shoreline. During a field study at the site, recreational boat waves at the shoreline were infrequent and 0.15 m or less.

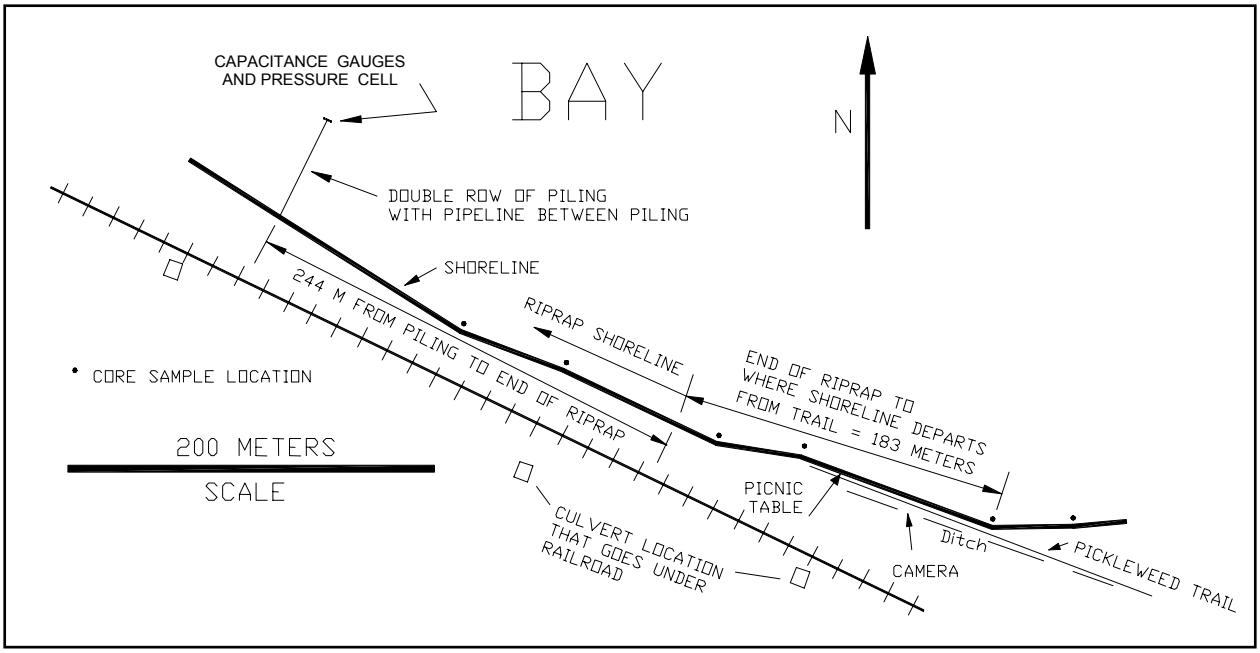

Figure 3. Layout of instrumentation and sediment borings during field study

b. *Tugboat effects*. Tugboats also pass the site to assist ships docking northeast of the site. The tugs travel at relatively high speeds when going out to meet ships or when coming back after assisting the ships away from the dock. These tugs are operating about 1,000 m or more from the eroding shoreline. While waves tend to be large near the tug, the tug-generated waves decayed to 0.15 m or less at the shoreline.

c. *Deep-draft ship effects*. Deep-draft ships pass the Martinez site and produce effects at the shoreline. During the field study, ships up to 254 m in length passed the site. The largest ships at this site are over 274 m in length, 51-m beam, and 10.4-m draft. Ships going upstream of Martinez are limited to drafts of less than or equal to 10.4 m. During the field study, up to eight ships passed the site per day. Ship logs confirm this is not a high ship traffic area. Ships at the Martinez site travel at up to about 12 knots, so the depth Froude number is about 0.5. At this Froude number, ships in channels produce both short period (secondary) waves from the bow and stern and long period (primary) waves related the drawdown around the ship. Water depth limits ship movement to no closer than 400 m from the Pickleweed Trail shoreline and ships typically travel at 600-700 m from the shoreline. Short period waves tend to decay in amplitude significantly before reaching the shoreline at these distances. During the field study, the maximum short period wave amplitude from ships was about 0.2 m. Long period or primary wave effects are a function of the blockage ratio defined as ship cross-sectional area to the channel cross-sectional area. Channels having blockage ratios of greater than 0.05 to 0.10 exhibit significant long period effects that can propagate large distances from the ship and decay far less rapidly than short period or secondary waves. At the Martinez site, the channel cross section is shown in Figure 4 along with the cross section of the largest ship passing Martinez of 51-m beam by 10.4-m draft. This ship has a blockage ratio of about 0.03, which means that long-period wave effects will

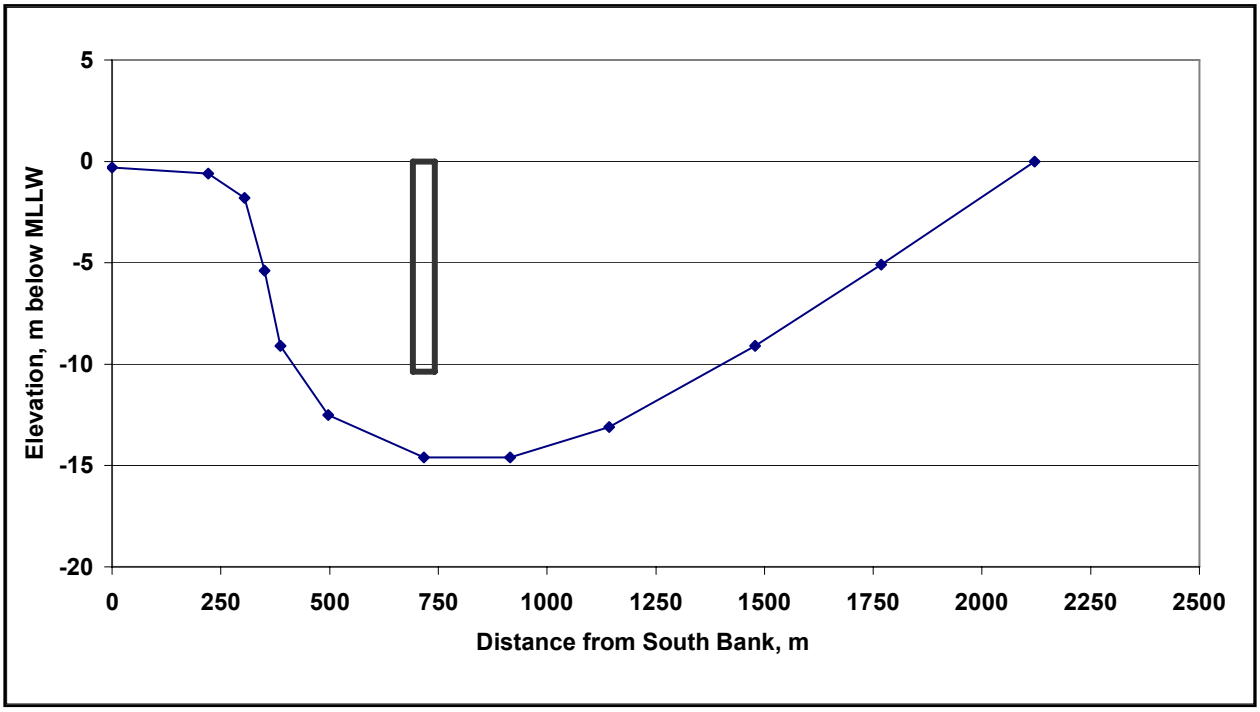

Figure 4. Channel cross section at Pickleweed Trail with 51-m beam by 10.4-m draft ship

generally be small. The limited magnitude of long-period ship effects is important because drawdown and drawdown induced waves are the two mechanisms that distinguish deep-draft ship effects from either smaller boats/ships or from wind waves. The most significant ship effects measured in the field trip occurred during passage of the inbound cargo ship *General Villa*, which passed close to the south shore of Carquinez Strait, had ship dimensions of 175-m length by 27.5-m beam by 8.4-m draft, and traveled at 10.6 knots. During the passage, another inbound ship was heading toward the dock northeast of the site that caused the *General Villa* to pass on the south side of the channel. The passage occurred at a low tide of about 0.2 to 0.3 m relative to mllw. Figure 5 shows the time-history of water level at one of the capacitance gauges. The water-level drop between 300 and 400 sec is the water-level drawdown. The water-level rise following the drawdown and subsequent undulations are the result of the drawdown and are typical of ship movement past shallow areas adjacent to navigation channels. The short period waves superimposed on the undulations had a maximum amplitude of about 0.2 m. Deep-draft ship effects at the Martinez shoreline are infrequent and small compared to wind wave conditions.

Dominant Load on Shoreline. Based on comparison of the various loads on the Martinez shoreline, wind waves are the most significant loading on the shoreline at Martinez and pose the greatest threat to the proposed branchbox breakwater. The large tidal range at Martinez will require that breakwaters be placed high enough to significantly reduce wave height at high tides.

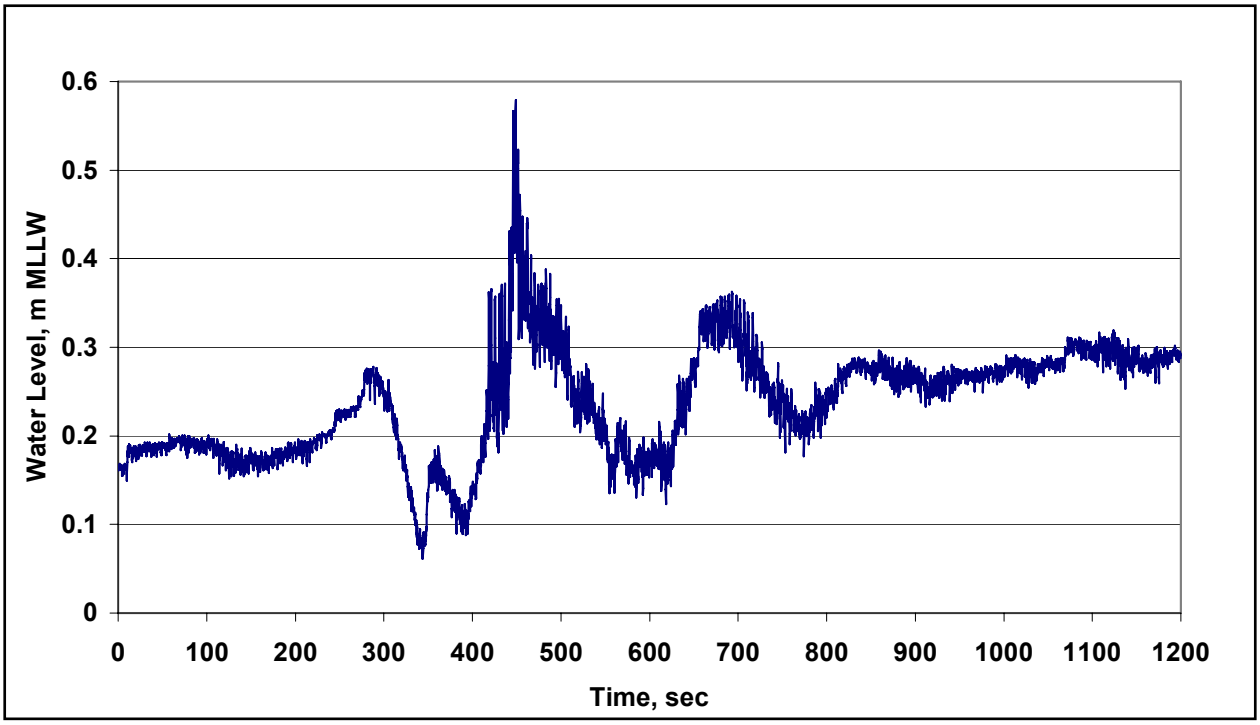

Figure 5. Time-history of water level from capacitance gauge during passage of deep-draft ship General Villa, time zero = 0748 on 26 August 2004

Sediment Borings. During the field study, six sediment borings were taken about 10 m channelward of the Pickleweed Trail shoreline at the locations shown in Figure 3. These borings were taken with 0.91-m-long acrylic tubes, 3.8 cm inside diameter, 0.48-cm wall thickness, and having a square edge where pushed into the sediment. The tubes were pushed in by hand and length of sample ranged from 48 to 64 cm. Medium to coarse sands and gravel were found in the top 5 cm of four of the samples. Wet bulk-density tests were conducted on each sample using the lower 5 cm and the middle 5 cm of the sample. Wet bulk density ranged from 1.46 to 1.60 g/cu cm. No consistent variation of wet bulk density with depth or along the site was found.

PREVIOUS APPLICATIONS OF BREAKWATERS USING WOODY MATERIAL: Woody material has been used in various ways to construct wave breakwaters. This CHETN focuses on two of these previous uses. First is the branchbox breakwater in which branches are placed between two rows of piling to produce the breakwater. Second is the slab bundle concept in which anchored woody material is used rather than two rows of piling to confine the woody material. Details of both methods are presented in the following paragraphs.

Branchbox Breakwaters. The origin of the branchbox breakwater concept traces to Holland and Germany where brushwood dikes and fences were used to create salt marsh on tidal flats. Square areas up to 400 m on a side were enclosed with brushwood fences and planted with various salt marsh plants to encourage deposition. According to Wagret (1968), the process was slow and took 30 to 40 years when successful. Allen (1992) documents the use of branchbox breakwaters for reservoir shoreline erosion control in Germany. Allen states "…the technique is a combination of a

breakwater and planted wetlands shoreward of the breakwater." Based on the German experience, the technique is constructed as follows:

a. Construct in about 1-m-deep water.

b. Place 2 to 3-m-long poles vertically in the lake substrate about 1 m apart. The poles are not inserted all the way into the substrate but deep enough to be secure.

c. Place a 25-cm-thick layer of 1.5-m-long dead branches perpendicular to the piles. These branches serve as a filter and retard scour at the bottom of the breakwater.

d. Wedge brush bundles between the rows of poles and secure the bundles to the poles with wire rope.

e. Drive the poles down firmly to tighten the entire breakwater system.

f. Cut off the tops of the poles to about 30 to 60 cm above the tops of the brush bundles.

Allen (1992) shows one example of a branchbox breakwater in which the area between the breakwater and the shoreline has been backfilled to a desired elevation relative to the water level to facilitate wetland plant growth. Filter fabric is placed adjacent to the breakwater to prevent movement of the backfill material through the breakwater. The branchbox technique is also referred to as "Double Stake Row with Planting" and is used to provide protection from wind and short-period boat waves. Design of the double stake technique is limited to determining the depth that the stakes or piling must be imbedded to withstand the wave forces. Schiereck (2004) refers to these structures as "load reductors" because they are used to reduce loads to the point at which vegetation can survive and further enhance the stability of the region behind the breakwater. Schiereck notes that "…to facilitate the exchange of water and animals, apertures (openings) at regular intervals are necessary."

In the United States, the branchbox breakwaters have been used primarily for bank protection but land or marsh reclamation is also a desired goal. Branchbox breakwaters have been used at various sites in the United States. Four sites are described herein.

Rice Reservoir. The Wisconsin Valley Improvement Company (WVIC) performed a case study and held a Shoreline Stabilization Workshop on Rice Reservoir in 1999. In this study, four different types of shoreline stabilization techniques were used including a branchbox breakwater. All the bioengineering treatments tested encompassed varying uses of wetland plants and local materials to protect an archeological site on an eroded reservoir shoreline and to stabilize the shoreline from further erosion. The branchbox breakwater built at Rice was 15 m long and approximately 0.61 m wide and 0.91 m tall. Two rows of 2.4-m-long cedar poles were placed vertically in the lake bottom and spaced 0.61 m apart. The rows were also spaced 0.61 m from each other. The poles used were recycled from local farmers and were approximately 0.20-m diam. The branches were primarily live alder and willow brush from the surrounding area. The material was well graded with diameters varying from fine tips to a maximum of 5.0-cm diam. The branches were placed in the breakwater with alternating butt ends to allow maximum compaction (Wendt and Allen 2001). Stainless steel

cable (1.6 mm) was laced between the rows of poles and over the branches. The cable was fastened to the poles with galvanized fence staples. After the cable and brush were completely in place, the poles were slowly driven into the ground using a vibratory compactor until the branches were adequately compacted. The final structure was about 0.9 m tall. Once the branchbox breakwater was completed, vegetation was planted in front of the structure and behind the structure. Emergent aquatic vegetation purchased from a local nursery (*Iris versicolor*, *Acorus calamus*, *Scirpus fluviatilis*, *Scirpus cyperinus*, and *Juncus effuses*) was planted behind the breakwater. Transplants from a nearby wetland were planted in front of the breakwater. A branchbox breakwater system comprises not only piles and branches, but also aquatic vegetation to aid in accretion. (Personal communication, 2005, Cathy Wendt, WVIC, Wausau, WI.)

The branchbox breakwater on the Rice Reservoir is subject to wind waves and ice. The primary westerly wind direction has a fetch of about 2.0 km and the average depth over the fetch is 4.9 m. The second force that acts on the branchbox breakwater is ice. During the winter, the entire reservoir freezes and ice floes are produced. The ice floes are destructive to structures in the reservoir. Since the forces the branchbox breakwater would encounter from ice floes were unknown, larger diameter poles were used to help ensure success of the structure.

The overall performance of the branchbox breakwater is affected by several factors. The first factor is that the Wisconsin Department of Natural Resources (WDNR) restricted the placement of the structure in the permit to a distance of 4.5 m outward from the bank line. WDNR has since revised this and now allows a branchbox breakwater to be placed up to 9.0 m from an existing bank line. Though approximately 0.03 m of sediment has been deposited since 1999, Rice Reservoir contains very little suspended sediment, and it was expected that minimal accretion would occur landward of the breakwater. Vegetation was placed in front and behind the breakwater after construction. The vegetation in front of the breakwater was destroyed by wave action within the first year. Because the area behind the breakwater is shaded by shoreline vegetation, some of the vegetation landward of the breakwater was lost. Plant survival and possibly sediment accretion would have improved if the breakwater had been allowed to move further from the bank line. Smaller poles might be possible, but the effects of the ice heave were not known at the time of installation. Overall the branchbox breakwater has lasted over 10 years and has stabilized the bank line. Of all the shoreline stabilization methods tested by WVIC, the branchbox breakwater has proven to be the least expensive. Figures 6 and 7 show the branchbox breakwater in April 2005.

Georgiana Slough. The Sacramento-San Joaquin Delta is located in north central California, northeast of San Francisco Bay. Lying in the confluence of the Sacramento and San Joaquin rivers, it is the largest inland delta and the largest estuary on the west coast of North America (Hart and Hunter 2004). Georgiana Slough is located in the northern part of the Sacramento San Joaquin Delta. The slough is about 20 km long, varies from 50 to 100 m wide with an average bed slope of 0.01 percent (Hart and Hunter 2004). Currently, approximately 30 percent of the flow from the Sacramento River is being diverted into Georgina Slough. The shorelines of the slough are also subject to waves from local recreation boat traffic. Wind waves are minor because of limited fetch. The shoreline of the slough is experiencing erosion that can first be detected by the development of semicircular scallops along the shoreline. Figure 8 is a picture of one of the bank scallops.

Figure 6. Branchbox breakwater at Rice Reservoir, front view

Several branchbox breakwaters have been constructed to provide bank protection along the slough. The company constructing the breakwaters, Hart Restoration, Inc, uses 7.6-cm-diam by 2.4-m-long wooden poles arranged in two parallel rows approximately 0.71 m apart. A post is driven approximately every 0.84 m and driven to a depth where about 1.2 m of the post remains exposed above the waterline. Between the two rows of posts, dried cuttings from peach, pear, Lombardy poplar, or Christmas trees were placed. Native willows were also used to fill the branchbox when available. It was necessary that the cuttings be thoroughly dried to prevent any future sprouting from the branch used. Caution should be exercised to prevent the introduction of nonlocal plants into the area being protected. The branches were compacted and secured with stainless steel wire fastened together with a Gripple brand[1] connector. The Gripple connector holds tension on the wire in one direction and will allow the wire to be released to add more branches at a later time.

[1] Use of vendor's names, products, and affiliations does not constitute an endorsement by the U.S. Army Corps of Engineers.

Figure 7. Branchbox breakwater at Rice Reservoir, behind breakwater

Figure 8. Scalloped bankline along Georgiana Slough

At Georgiana Slough, additional materials were placed landward of the branchbox breakwater to further reduce wave and current effects at the shoreline. These additional materials included rooted material in blast buckets, brush bundles, and fiber roles in a scallop repair. Hart Restoration also states that a branchbox breakwater is a system where the branchbox breakwater works in conjunction with the aquatic plants. (Personal Communication, 2005, Cathy Wendt, WVIC, Wausau, WI.) The breakwater is the first line of defense and the vegetation acts as a second line of defense to further reduce wave energy and promote sediment deposition. Figure 9 is the same site in Figure 8 site 1 year later after brush bundles and aquatic vegetation had been placed landward of the branchbox breakwater.

Figure 9. Branchbox breakwater at bank scallop on Georgiana Slough (1 year later from Figure 8)

On Georgiana Slough, the branchbox breakwaters accumulated significant sediment behind the breakwaters. This accumulation along a river environment may be much greater than along lakes and estuaries because a river can deliver significant amounts of sediment during high flows. The size of the poles and the construction techniques appeared adequate to prevent damage from waves and currents. After construction of a branchbox breakwater, maintenance will be continued for 1 to 3 years or until the scalloped shoreline is determined to be stable.

Lake Wister. Lake Wister is located southeast of Tulsa, OK, near the Arkansas-Oklahoma border. USACE (2003) discusses application of several bioengineering treatments at Lake Wister. This document states that "…vegetative treatments alone are applicable to areas with small escarpments with a fetch of 1 mile or less, or if the shoreline has a large bench (mudflat) to attenuate wave height." The report also states "When fetches in combination with wind produce waves greater than 1 ft in height, it is advisable to consider the use of some type of breakwater system, either floating or fixed/attached to the lake bottom." It should be noted that there has been limited success with floating breakwaters. The USACE (2003) report concluded that most open-water situations in Lake Wister warrant use of a breakwater. Lake Wister, like Martinez, is a challenging environment because of lake water level variation of up to 5 m. Branchbox breakwaters were considered for portions of eroding shorelines at Lake Wister. If branchbox breakwaters are used, the shore must be treated at intervals up and down the slope covered by the 5-m stage variation. In April 2000, a branchbox breakwater demonstration project was constructed as part of a USACE workshop along a

small portion of the eroding shoreline. Eighteen months after construction, the breakwater had accumulated sediment and had vegetation growing behind the breakwater.

Christmas Tree Program. One of the largest applications of a breakwater made of woody material is the Louisiana Department of Natural Resources program to use Christmas trees to protect and restore coastal wetlands. As of 2001, over 12.9 km of brush fences have been built utilizing over 1,140,000 Christmas trees. Some of the fences have been in-place for up to 15 years. Present construction of the fences uses two rows of treated pine posts having actual dimensions of 8.9 cm × 8.9 cm × 2.44 m long. The rows are about 1.2 m apart and the posts are spaced on about 1.8-m centers. In some cases, a few boards having actual dimensions of 2 cm × 14 cm are attached to the outside of the posts to better contain the trees. Ropes or wire cable are placed over the top of the trees for containment. The system is often constructed in 0.6-m water depth and extends about 0.6 m above the water level. About 1.2 m of the post is embedded in the substrate, but soft substrate requires longer posts. Maintenance is a must, every 3-4 years trees must be added to the fence. The system has worked well in low to medium energy environments. Boumans et al. (1997) conducted measurements of wave energy dissipation and sedimentation response at two Christmas tree sites over the first 3 years following construction. Boumans et al. (1997) measured near-bed pressures close to and on each side of the brush fence and used the variance of the bed pressures to conclude that wave energy at the bed decreased 50 percent across the monitored fences. Wave transmission coefficients were not determined. The use of treated posts and the addition of trees every 3-4 years means these systems can have a long life compared to the use of untreated wood.

Slab Bundle Breakwaters. On the Kanawha River in West Virginia, rather than using branches typically used in branchbox breakwaters, the U.S. Army Engineer District, Huntington, developed a technique using bundles of slabs from a lumber operation. Slabs are the waste from a lumber operation and consist of the unusable outer rounded edge of the tree. Slabs are actually only waste at small lumber operations. Large lumber operations generally have chippers and use the slabs to make wood chips that are sold for a variety of purposes. Slab bundles were placed at three sites within the Huntington District, two on the Kanawha River and one on the Ohio River. The two sites on the Kanawha River were at St. Albans and at Quincy; both were originally designed as habitat structures and part of the Marmet Pool mitigation project. The third site was located on the Ohio River at Bat Grape Island.

The slabs varying in width from 20 to 30 cm based on the diameter of the log from which they were cut, were loaded and trucked to a construction site from the lumber mill. They varied in thickness from 2 to 10 cm and were approximately 2.5 m long. A jig was constructed to form the bundles. The bundles were constructed by placing a layer of slabs parallel to the long axis of the bundle and then a layer of slabs perpendicular to the bundle axis. The perpendicular layer made the bundle porous as opposed to an almost solid bundle of wood. The slabs were nailed together with galvanized nails, and this process was repeated until the slab was approximately 0.9 m in height. The jig formed the slab into an elliptical shape with the bundle widest at a height of 0.45 m. Completed slab bundles are shown in Figure 10.

Figure 10. Slab bundle in jig used for building bundle

After the bundles were finished, but still in the jig, they were then bound together with stainless steel strapping. After strapping, they were transported and placed along a predetermined alignment to form a breakwater. The bundles were placed with the top of the bundle just below the normal pool elevation at St. Albans and Quincy. At this vertical position, the bundles were constantly in the water. The bundles were then anchored to the ground using Duckbill No. 88 anchors and 5-mm-diam stainless steel cable (Figure 11). The anchors were driven to about 1.8 m or refusal.

The spaces in the bundle allowed for waves to pass through as wave energy was dissipated. As with the branchboxes, the slab bundles were a first line of defense. Local plants were selected and planted landward of the slab bundles to absorb the remaining wave energy and allow deposition of suspended sediments. Figure 12 shows slab bundles at Bat Grape Island with plantings shoreward of the bundles.

Figure 11. Duckbill anchor used to secure bundles

Figure 12. Slab bundles at Bat Grape Island. Notice second bundle placed landward of riverward bundle in left photograph and plantings in right photograph

At all three sites, the slab bundles experienced the largest force from boat-generated waves and commercial tow induced drawdown. Boat waves at the shoreline are generally 0.4 m or less. All of the slab bundles that were constructed are still in place after 9 years. One possible failure mode is when the slab bundle rotates toward the channel as a result of scour at the channelward edge of the bundle. As the bundle rotates, there is less of an opening for the wave to pass through. Two of the three sites were inspected and 0.45 to 0.9 m of sediment had been deposited landward of the bundles. The bundles are now firmly entrenched into the shoreline where there is a gentle sloping bench until the riverward edge of the slab bundle is reached. At the riverward edge of the bundle there is a sharp drop-off channelward. The slab bundles are routinely inspected but have not required any additional maintenance.

Branchbox Versus Slab Bundle Breakwaters. By design, slab bundles are more robust than branchbox breakwaters. One of the disadvantages of slab bundles compared to branchbox breakwaters is that slab bundles are fixed and difficult to repair or add material. Branchbox breakwaters can have material easily added as done by the Christmas tree program in Louisiana. Another concern of the slab bundles is the problems that could occur if the bundle were to come loose intact and float away from the site. It should be noted that this has not been a problem with slab bundles on the Kanawha River and that the anchoring cables can be attached to the straps forming the bundle to reduce the possibility of the bundle coming loose. The bundle could float with little visible material above the waterline and pose a threat to all but the largest boats. Slab bundles have the advantage of not requiring piling, which has been found to be expensive on some projects. After the woody material has decomposed and no longer provide protection, the only thing left to remove are the cables. Branchbox breakwaters have piling remaining that will have to be removed.

WAVE TRANSMISSION THROUGH BREAKWATERS: One of the key elements in design of any breakwater is the transmission of the wave past the structure. The transmission coefficient K_T is the ratio of transmitted wave height to incident wave height:

$$K_T = \frac{H_T}{H_I} \tag{1}$$

where H_T is the transmitted wave height and H_I is the incident wave height. The ratio of energy transmitted/energy incident at a breakwater is equal to the square of the transmission coefficient. For example, transmission coefficients of 0.3, 0.5, and 0.7 mean 9, 25, and 49 percent of the wave energy is transmitted past the breakwater, respectively. Two characteristics of branchbox and slab bundle breakwaters proposed for Martinez significantly affect the transmission coefficient. Overtopping and porosity significantly increase K_T compared to solid, nonovertopped breakwaters. Based on results for solid breakwaters in Headquarters, U.S. Army Corps of Engineers (2002), Schiereck (2004), and Clauss and Habel (2000) a solid breakwater with top elevation equal to the still water level has a transmission coefficient of about 0.2 to 0.4. For a lower structure with top elevation at one-half H_I below the still-water level, the transmission coefficient would be about 0.6. Based on Kriebel (1992) and Clauss and Habel (2000), porosity further increases K_T. For a structure that is not overtopped, a porosity of 10 and 20 percent result in K_T of 0.5 and 0.7, respectively. Clauss and Habel (2000) provide results applicable to both overtopping and porosity. For a structure with top elevation at one-half H_I below the still-water level and a porosity of 11 percent results in K_T of about 0.8.

Ellis et al. (2002) provides field data for K_T for a nonovertopped branchbox breakwater. Based on their study, $K_T = 0.63$ for nonovertopping conditions. While $K_T = 0.63$ sounds high, it represents a 60 percent reduction in wave energy across the breakwater. Using the slot/screen configuration in the Kriebel (1992) and Clauss and Habel (2000) data, the branchbox breakwater having $K_T = 0.63$ corresponds to a nonovertopped slot/screen having a porosity of about 15 percent. Using a porosity of 15 percent, bottom elevation at structure of 0.0 m mllw, and the Clauss and Habel (2000) data, Table 4 shows the transmission coefficient and energy transmitted for various top elevations of the structure and various water levels at Martinez. Based on this analysis, a single branchbox or slab bundle breakwater will result in no more than a 60 percent reduction in wave energy at the shoreline. Multiple structures proposed subsequently should provide a higher energy reduction. Flume tests of both branchbox breakwaters and slab bundles to determine K_T are planned for the summer of 2005 at ERDC under the Section 227 Program.

Table 4
Transmission Coefficient and Energy Transmitted for Various Top Elevations and Various Water Levels for a Single Branchbox Breakwater at Martinez

Structure Top Elevation, m mllw	Water Level, m	K_T	Percent Energy Transmitted
0.9	1.0	0.72	52
“	1.343 (mean high water)	0.89	79
“	1.498 (mean higher high water)	0.93	86
1.343 (mean high water)	1.0	0.63	40
“	1.343 (mean high water)	0.72	52
“	1.498 (mean higher high water)	0.80	64
1.498 (mean higher high water)	1.0	0.63	40
“	1.343 (mean high water)	0.67	45
“	1.498 (mean higher high water)	0.72	52

PROPOSED DESIGNS FOR MARTINEZ: Figure 1 shows the location of the proposed branchbox breakwater at Martinez. This location corresponds to the 183-m-long reach shown in Figure 3 where the shoreline is not protected with riprap and Pickleweed Trail is close to the eroding shoreline. Based on Tables 1 and 4, a branchbox or slab bundle breakwater at Martinez will need to be placed at an elevation of at least mean high water (mhw) or too much energy will pass over the breakwater at high tides. At Martinez, the elevation 0.0 m mllw bottom contour is the breakpoint between the extremely flat bottom slope channelward of this elevation and the 1V:5H to 1V:10H foreshore slope adjacent to the eroding bank. Elevation 0.0 m mllw is generally 6-12 m from the eroding shoreline. The key to stopping long-term shoreline erosion is preventing scour of the foreshore slope. While protection only of the vertical scarp at Martinez will have short-term success at halting shoreline recession, such a protection may be undermined and fail when the foreshore slope is scoured. The proposed breakwater should be placed at the elevation 0.0-m mllw bottom contour to prevent scour of the foreshore slope. To ensure a minimum level of marsh reclamation, the proposed breakwater should be placed at either the 0.0-m mllw bottom contour or 9 m from the vertical bank, whichever is greater. A single structure at the 0.0-m mllw contour and extending up to mhw would have to be 1.343 m high. That height is greater than a typical slab bundle breakwater. It is not recommended that larger than typical slab bundles be built because of the large forces involved in wave environments and the difficulty of handling large slab bundles. A solution more likely to withstand the wind wave climate at Martinez is to build one typical 0.9-m-high slab bundle breakwater at the 0.0-m mllw contour (or the 9-m distance) and a second 0.9-m-high breakwater up the foreshore slope at about the 0.6-m mllw contour. The top of the second row would be between mhw and mhhw. This would reduce wave forces on each breakwater, be high enough to significantly reduce wave energy at high tides, and also provide two different types of aquatic environment behind the breakwaters. For branchbox breakwaters, the same two-row technique would be constructed. In addition, a single row branchbox breakwater is proposed with top elevation equal to somewhere between 0.9 m and 1.4 m mllw to determine the effects of top elevation. The flume tests will help determine the height of the single row scheme. The two rows of posts in the branchbox breakwater are tentatively proposed to be 0.6 m apart. The ERDC flume should help define the required spacing between rows. Post spacing along each row should be about 0.9 m based on previous applications. Figure 13 shows a proposed cross section of the branchbox or slab roll concept at the Martinez site. Contours at 0.0 and 0.6 m mllw and the location of the near-vertical bank are shown in Figure 14. Note that the 0.6-m mllw contour is located at the near-vertical bank over some of the reach. In these cases, the slab bundle or branchbox will be placed close to the bank with only enough room for construction. The breakwater will be constructed in a shingled fashion to provide openings along the length of the structure as well as tiebacks perpendicular to the bank every 15-18 m to reduce velocity behind the structure. Figure 15 shows a layout of the proposed protection schemes. A portion of the reach east of the three protection schemes will be left unprotected to provide a comparison to the protected reach.

Some of the literature on shoreline restoration suggests the branchbox breakwaters are temporary until vegetation establishes, at which point the breakwaters are no longer needed. That scenario is certainly true in some areas having low energy wave action, but it appears unlikely at Martinez where wave energy is greater. Some type of breakwater structure will likely be required at Martinez to keep the site from reverting to its present condition. A reasonable objective of this project would be to determine the life and performance of the proposed branchbox or slab bundle structures. Based on the performance of past branchbox and slab bundle breakwaters, the life should be at least 3 years

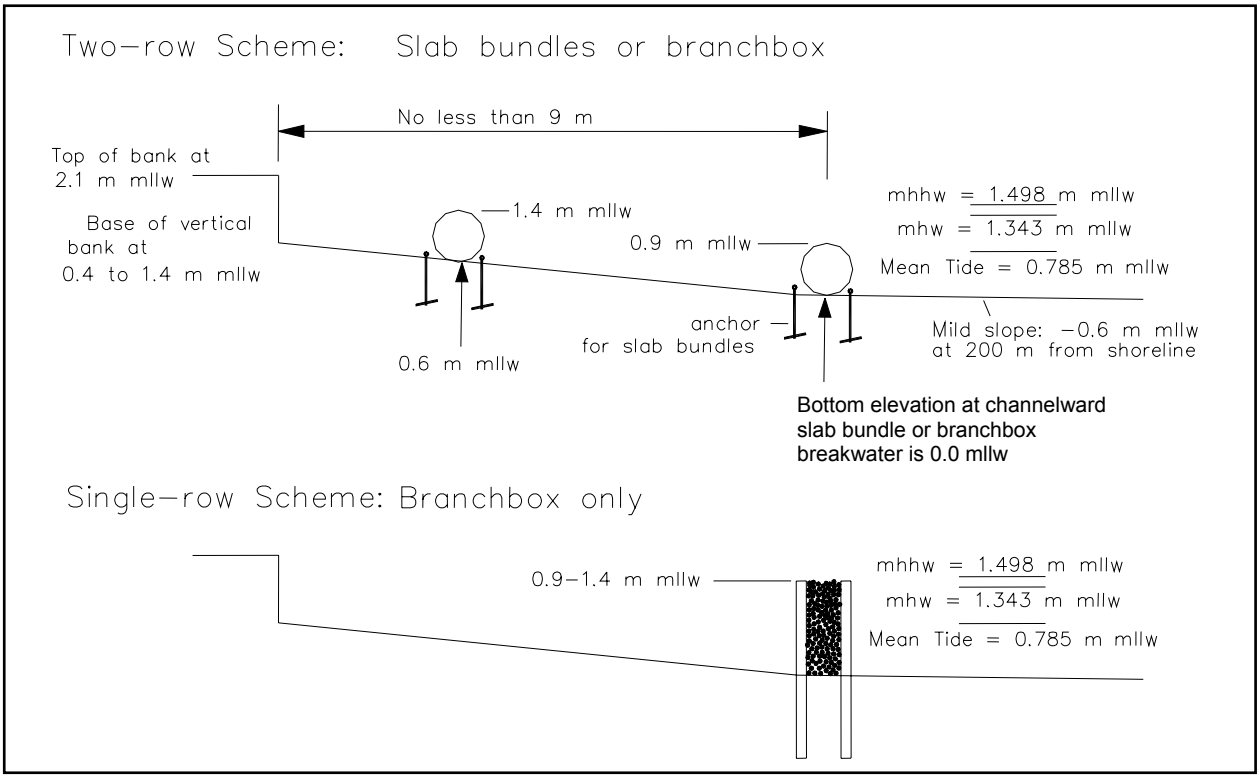

Figure 13. Cross sections of proposed branchbox or slab bundle breakwaters at Martinez

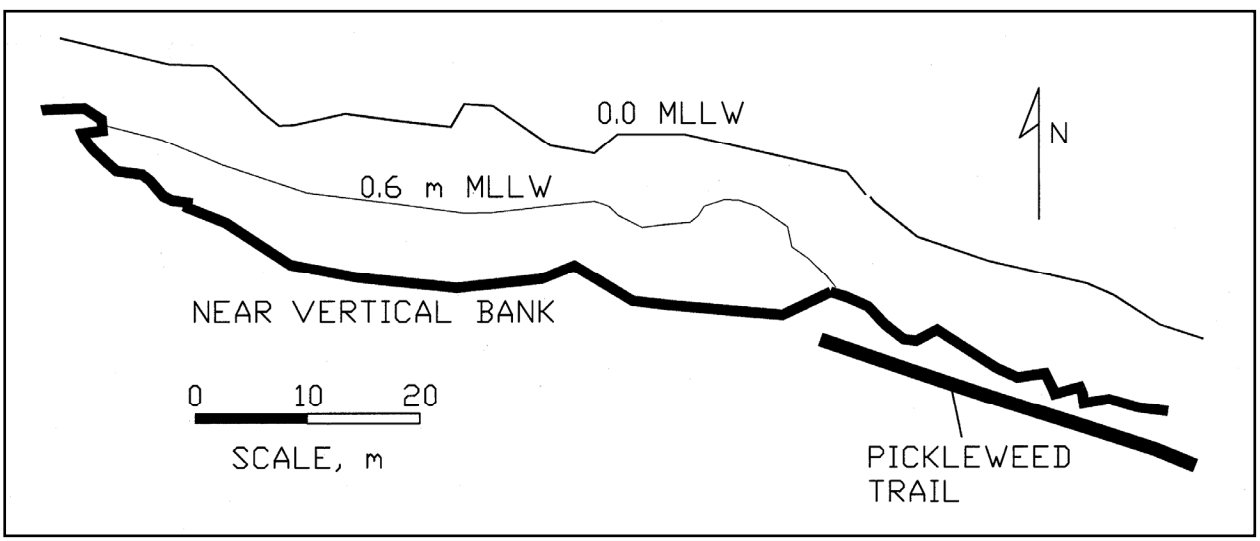

Figure 14. Location and alignment of mllw contour and 0.6-m mllw contour at Martinez

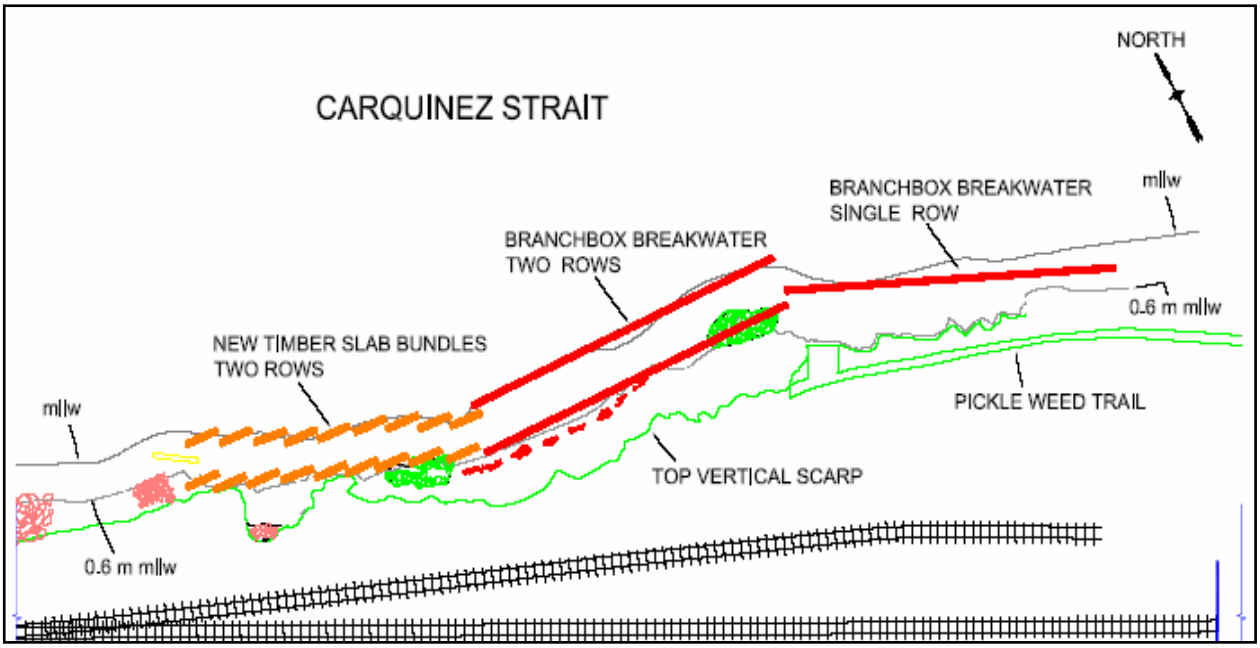

Figure 15. Layout of proposed protection at Martinez

and hopefully in the 5-10-year range unless an extreme event occurs. For the branchbox breakwater, use of some type of treated piling along with branch replacement as needed would result in greater life. Depending on funding and other priorities, when these structures begin to fail, a decision would be made regarding which one of the two structure types to rebuild. The selected structure would be built 10 m or more channelward of the initial breakwaters. The new structure would protect the failing old structures and further reclaim marsh. If at some point in the future enough marsh had been reclaimed and funding were available, a more permanent breakwater could be constructed to maintain the reclaimed marsh over a longer period.

Flume studies at ERDC will evaluate branchbox and slab bundle breakwaters. The flume test results will be part of the decision to use branchbox and/or slab bundle breakwaters. Single- and two-row breakwaters will be tested in the flume.

This technical note focuses on the design of the breakwater. Other critical components of the Martinez design not addressed herein are whether to fill the area behind the breakwater to the desired marsh elevation and planting design for the breakwater system. The present plan is to use this demonstration project to determine the rate at which the area behind the breakwater fills with sediment. If the rate of natural infilling is too low, artificial fill to promote marsh development may be desirable. Marsh plantings will be incorporated into the initial construction.

SUMMARY AND CONCLUSIONS: The Martinez Section 227 Program demonstration site is subject to significant wind wave effect that will provide a severe test of a breakwater constructed out of woody material. The large channel size at Martinez results in limited ship/boat effects at the shoreline and the modest frequency of ship passage further limits the significance of ship effects.

Branchbox and slab bundle breakwaters are two types of woody material breakwaters that have been successfully used in low to moderate wave environments. Branchbox breakwaters have an advantage of ease of repair/addition of woody material whereas slab bundles appear difficult to repair but are constructed of more robust material. Slab bundles do not require piling but raise concerns about the consequences of the bundle breaking away from the anchoring intact and posing a hazard to navigation. Flume tests to be conducted in 2005 will help determine if branchbox and/or slab bundles will be recommended for Martinez.

Because of the large tidal variation, the top of the breakwater should be at or above mhw to achieve significant energy dissipation at high tides. For slab bundles, a two-row protection scheme is proposed to address wave effects because a single-row of slab bundles cannot be built and handled that is large enough to protect from high tides. The first row will be placed with top elevation at slightly greater than the mean tide level. The second row, located on the foreshore slope between the first row and the vertical bank, will be placed with top elevation between mhw and mean higher high water (mhhw). Branchbox breakwaters will also be built in the two-row protection scheme and using a single row built to a top elevation of somewhere between the tops of the first and second rows in the two-row scheme.

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> Maynord, S. T., Winkler, M. F., and Demko, D. E. (2006). "Branchbox breakwater design at Pickleweed Trail, Martinez, CA, Section 227 Demonstration Project," ERDC/CHL CHETN-VI-42, U.S. Army Engineer Research and Development Center, Vicksburg, MS. *http://chl.erdc.usace.army.mil/chetn*

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