TRITON®
COASTAL AND WATERWAY SYSTEMS

SAVANNAH RIVERBANK PROTECTION PROJECT

Observations on Cost, Constructibility and Performance

PROJECT INFORMATION: The project site is located along the north bank of the lower Savannah River, downstream from The Port of Savannah and the City of Savannah and between five and ten miles upstream from Tybee Island where the River empties into the Atlantic Ocean. The Georgia Department of Transportation and the U. S. Army Corps of Engineers have worked to maintain a 42 foot depth for shipping traffic on this portion of the river. Dikes immediately adjacent to the north riverbank provide containment for dredge material and have been threatened as evidenced by actively eroding bluffs along the riverbank. (See Figure 1)

Review of aerial photography indicated erosion rates had been as high as 23 feet / year. This riverbank protection project provided an excellent opportunity for learning about the construction and performance of heavy armoring systems in these challenging conditions. The severe bank erosion is attributable to the combined effects of several factors, including:

- Highly erodible soils (loose and unconsolidated sand and layers of soft inorganic / organic clays);
- Tidal fluctuations and groundwater weepage (mean tidal range of about 7.5 feet; storm surge of about 11 feet for 100 year storm event);
- Riverine and tidal currents and large debris (maximum of 4 – 5 ft / sec in the channel, less along the riverbank);
- Shipping traffic and the associated drawdown, waves, and turbulent current velocity (most ships at least 500 feet long, some ships up to 961 feet long, passing as close as 350 feet from the riverbank).

The preliminary design report by Olsen Associates, Inc. stated "Field observations have clearly indicated that turbulent currents generated by the transversal stern wave are the primary cause of erosion along the riverbank." For design purposes, the report estimated the transversal stern wave height to be 3.2 fet and the velocity of the associated turbulent current to be 10.2 ft / sec (for a toe depth of less than 3.2 feet).

Fig. 1: Bluff eroding into containment dike along north bank immediately upstream from test sites. Geotextile was previously placed within embankment.

During 1997, protection was installed at seven sites along this portion of the River. The project was funded by the Georgia Department of transportation and the construction was administered by Chatham County, Georgia. EMC Engineers, Inc. completed the plans and specifications.

THE OBJECTIVE: The overall objective of this project was to protect selected sections of the north riverbank and to observe cost, constructibility and performance considerations for selected types of protection, specifically:

- Riprap
- Cabled block mats
- Tetrapods
- Marine mattresses

OVERVIEW OF RESULTS: All systems were successfully installed on 2H:1V slopes with a buried toe. After approximately two years, various degrees and types of failures are evident due to the severity of the conditions. Every system experienced at least minor damage, and three of four experienced major failures. In the following, the results are discussed for each system.

One important observation was common to all sites. For these soil and water conditions, it may be impractical to achieve compaction of soils near water level. Also in this zone, soil anchors appear to have a very limited ability to develop pullout resistance; some two to three foot long soil anchors could be pulled out by hand. The limited degree of compaction also created considerations with respect to settlement.

For the purposes of this paper, the sites are lettered from A (upstream) through G (downstream).

RIPRAP SECTIONS: Sections B, E, and G were constructed of Georgia DOT Type 1 riprap. All three suffered at least one failed area. The failures appeared to be attributable not only to stone size / hydraulic stability, but also to settlement or loss of toe support. Settlement and loss of toe support may prove to cause continual degradation of the riprap installations, even in areas where the stone size is adequate.

Due in part to the hauling distance from a source of suitable stone, the cost of the riprap installation was higher than the cost of the cabled block mats or the marine mattresses. The sites were constructed from land access on moderate slopes, and the constructibility of the riprap sections was good.

In one area of Section B the riprap appeared to suffer a loss of toe support and subsequent settling or slumping. Additional riprap material has been placed as a repair and the settling or slumping appears to continue. (See Figure 2)

Figure 2: Riprap installation at Section B. In the vicinity of the vegetation in the center of the photo, slumping continues despite repairs by adding riprap.

Section E sustained loss of riprap material, shredding of the underlying geotextile, and loss of embankment material near its upstream end. Due to the extent of damage it is difficult to ascertain the mode of failure with certainty. Given its nature and location, the failure appears to have the potential to propagate along the riverbank. (See Figures 3 & 4)

Figure 3: Upstream portion of riprap installation at Section E. This area experienced major washouts.

Figure 4: Close-up view of riprap failure at Section E.

Section G sustained similar damage over three distinct stretches of riverbank which appear to be actively spreading. See Figures 5, 6, 7, 8.

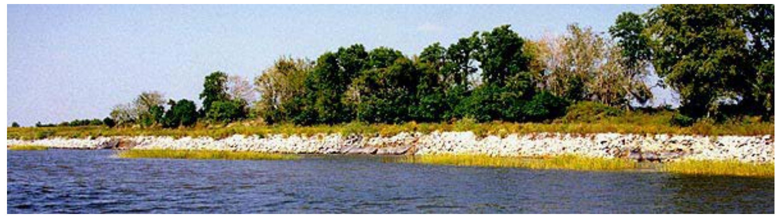

Figure 5: Downstream portion of riprap Section G. This section experienced three distinct failed areas. Left is upstream, right is downstream.

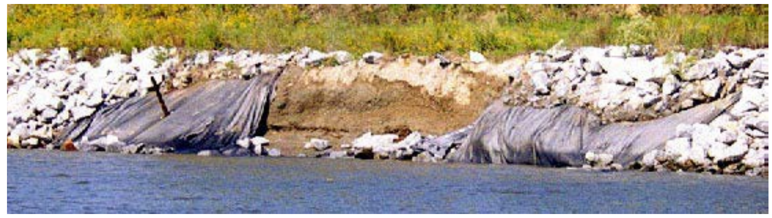

Figure 6: First (upstream) failed area at riprap Section G

Figure 7: Second failed area at riprap Section G.

Figure 8: Third failed area at riprap Section G.

CABLED BLOCK MATS: Sections A and D were constructed using a proprietary form of cabled block mat. The river has been accreting at Section D such that much of the block mat is now covered with sand deposits. Overall this site looks good and does not appear to have been seriously challenged by the river. (See Figure 9)

Figure 9: Cabled block mat Section D looking downstream. This site has been depositional, as evidenced by the sand deposits covering the armor layer.

Figure 10: Cabled block mat Section A looking upstream. This site has been erosional. Differential settlement and loss of intimate contact areprevalent.

Figure 11: Cabled block mat washout at the flanking transition on the upstream end of Section A.

Section A has experienced multiple types of failures. Much of the installation shifts underfoot as there is widespread loss of intimate contact with the subgrade. In some areas, particularly near the water line, wide voids several inches in depth have developed beneath the blocks. The inherent tendency of the cables to restrict flexibility is evident in the many suspended, rocking blocks. The irregularities in the subgrade appear to be caused by differential settlement or erosion of the subgrade. For such challenging hydraulic conditions, this loss of contact between the blocks and the filter / subgrade is typically defined as a failure in itself, signaling the onset of more dramatic failure.

In other areas the mats have heaved or flipped due to inadequate hydraulic stability. The hydraulic stability appears to be least where settlements have led to protruding blocks and where there are wide gaps between the mats. This observation is consistent with the theory of increased drag and uplift forces on protruding blocks. Early attempts to stem the problems by grouting between the blocks were largely unsuccessful. On the upstream end of the section, the mats and embankment have washed away, and failure appears likely to propagate downstream. (See Figures 10 - 13)

Figure 12: Heaving of cabled block mat on the upstream portion of SectionA.

Figure 13: Flipping of cabled block mat on the upstream portion of SectionA.

Although the cabled block mats were the least expensive of the four options installed, it is reportedly now a general consensus that the system used is not suitable for this type of application in these conditions.

TETRAPODS: A proprietary form of tetrapod was used as flanking for both ends of Sections C and E, for a total of four locations. The tetrapods were considered to be the most costly and difficult to construct of all the options tested, but were evaluated for use in special cases such as flanking. Major failure resulted at both tetrapod installations on Section E. The upstream flanking appeared to be failing progressively from the upstream end toward the downstream end, as would be expected in the case of undermining and hydraulic instability; the upstream end is arching fairly rigidly over a void created by undermining. Fragments of broken tetrapod units were seen scattered downstream. The downstream flanking appeared to be failing progressively from the toe upward, as would be characteristic of a loss of toe support and subsequent separation and loss of interlock. The results observed on this project raised questions regarding their suitability for use in conditions such as these. (See Figures 14 - 16)

Figure 14: Washout of tetrapod units at upstream flanking of Section E. Upstream edge is undermined and generally not flexing with the subgrade.

Figure 15: Washout of tetrapod units at downstream flanking of Section E. Failure appears to have developed from the toe.

Figure 16: Tetrapod flanking of Section Cperformed better and remained intact.

MARINE MATTRESSES: Marine mattresses were used to construct Sections C and F. The performance of the marine mattresses surpassed that of the other alternatives used. The preliminary design report by Olsen Associates, Inc. states that "The most important performance criteria for an erosion control structure is its inherent stability." On this project, only the marine mattress consistently demonstrated stability. (See Figures 17 & 18)

Fig. 17: Marine mattress Section C looking downstream. Each unit is anchored at top of slope by burying an extending tail of geogrid. Pairs of units are spliced together end to end. Stability has been maintained throughout.

Fig. 18: Marine Mattress Section F looking downstream. Stability has been maintained throughout.

The following includes a discussion of key attributes observed plus observations on damage to the units and lessons learned regarding avoidable construction deficiencies.

The marine mattress configuration used was a special adaptation of gabion mat, consisting of high density polyethylene (HDPE) uniaxial geogrids, HDPE bodkin connector rods, HDPE braid, and stone fill. The system was provided by Tensar Earth Technologies, Inc., Atlanta, GA. Special procedures were used for fabrication and filling to create 28 foot long by 5 ft wide by 12 inch thick units with tightly filled compartments. The units were fabricated about 50 miles from the site, then pre-filled on the site and lifted and placed using a large backhoe plus a spreader beam for two-ended lifting.

Several characteristics of the marine mattress system proved important to their successful performance in this combination of difficult conditions:

•High mass (70 to 90 lb / sq ft) and porosity to maintain hydraulic stability without soil anchors along the slope face, and in spite of irregular subgrade contours;

•Flexibility to settle differentially and yet maintain contact with underlying geotextile filter and subgrade;

•Less differential settlement due to the load-spreading characteristics of the bottom layer of geogrid and the relatively uniform contact pressure applied beneath the marine mattress units;

•Tensile strength of geogrid (top layer of marine mattress extended and buried at top of slope) to resist downslope sliding and eliminate the need for toe support;

•Tightly filled compartments to limit movement of the stone fill and thereby limit the"inside-out" abrasion which is characteristic of conventional gabion mat installations in high-energy wave or flow environments;

•Network of irregular voids to safely dissipate wave energy within the compartments, reducing scouring and reflected wave energy.

Marine mattress units can sustain many types of minor damage without compromising their performance. After placement some of the marine mattress units sustained damage, primarily mechanical damage caused by large debris such as trees. In most instances the damage has been minor and no repair is necessary to maintain functionality of the units. In some locations, the damage has been sufficient to create potential for loss of stone fill, and a patch should be installed by braiding in place a section of similar geogrid. In one location, a ± 2-inch diameter steel cable was left lying on a marine mattress, and has caused extensive damage, apparently due to abrasion from the sawing action of the cable. The repair for this one unit will require at least a large patch and may require replacement of the unit. See "Suggested Repair Guidelines for Triton™ Marine Mattress Units."

Some flaws in the marine mattress installations could have been avoided with appropriate construction technique. First, many of the end-to-end splices were never connected properly, and others have separated because the bodkin connector bars were not secured in position. (See Figure 19)

Fig. 19

Second, the side-to-side gaps between marine mattress units are excessive in some cases; in one notable case, the patch over the gap was inadequate. These types of problems are addressed in the repair document mentioned above. (See Figure 20)

Fig. 20: An excessively wide gap at the side-to-side joint between marine mattress units has been repaired by filling the gap with stone and braiding a geogrid patch in place over the stone. Lesson learned: due to the excessive width of the gap, baffles are needed to prevent movement of stone down the slope.

Last, investigation of a large void beneath two marine mattress units indicated faulty installation of the geotextile filter. It appears that in the immediate vicinity, the geotextile beneath the units was discontinued. Although the gap in the geotextile coverage was in the upper portion of the slope, the subgrade apparently eroded during a high water event and the void propagated, primarily downslope beneath the geotextile. The development of the void is considered directly attributable to the missing geotextile. Grouting should be considered to fill the void and future grouting may be required, depending on the lateral extent of the missing geotextile. (See Figure 21)

Regarding constructibility, marine mattress received high marks, similar to riprap, and the installation contractor commented after construction that the marine mattress was easier to install than the cabled block mats. It was further noted that marine mattress would likely be advantageous compared to riprap in cases of steep slopes or installation by barge.

Overall, the unit cost of the installed marine mattress sections was less than the unit cost of the installed riprap sections, even though a toe trench was used for the marine mattresses as well.

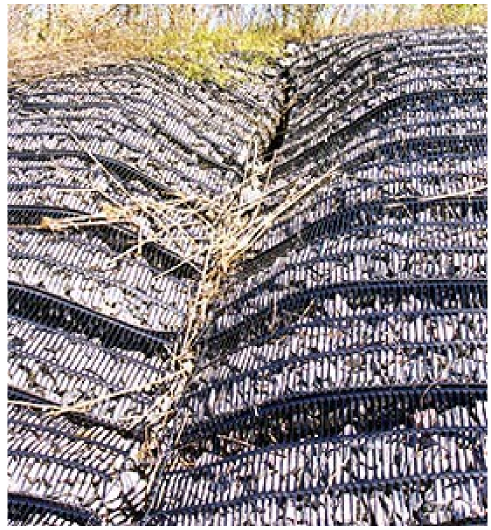

Fig. 21: A void two to three feet wide and two to three feet deep had developed beneath two units and near the top of the slope. Video inspection of the void showed that the geotextile underlayer was missing and apparently had not been placed. The upper edge of the geotextile was found at the lower end of the visible gap (the top third of this photograph). The void had propagated downslope.

CONCLUSION: Based on the results of construction and the observations of performance, the four alternatives ranked in the chart below:

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RANKING		ECONOMY	CONSTRUCTIBILITY	PERFORMANCE
1		CABLED BLOCK MAT	MARINE MATTRESS	MARINE MATTRESS
2		MARINE MATTRESS	RIPRAP	RIPRAP
3		RIPRAP	CABLED BLOCK MAT	TETRAPODS
4		TETRAPODS	TETRAPODS	CABLED BLOCK MAT

** Suitable riprap was not available within a local hauling distance.*
*** Marine mattress and riprap were comparable in terms of ease to construct; marine mattress is ranked slightly higher for its greater adaptability to soft ground, steep slopes and placement by barge.*

For more information on the Triton System or other Tensar Systems, call 800-TENSAR-1, email info@tensarcorp.com or visit www.tensarcorp.com

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