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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

REVIEW OF RECENT GEOTEXTILE COASTAL EROSION CONTROL TECHNOLOGY

1. Purpose

The purpose of this engineer technical letter (ETL) is to describe a coastal geotextile container and its potential use for coastal erosion control. The discussion includes summary results of monitoring such an installation on the gulf coast of Florida over a 4 year period.

2. Applicability

This ETL applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and separate field operating activities investigating design alternatives for coastal erosion control and/or storm damage prevention projects.

3. References

References can be found in Appendix A.

4. Introduction

a. The discussions of coastal erosion control structures in the *Shore Protection Manual* (U.S. Army Corps of Engineers 1984) and other USACE technical literature tend to emphasize conventional designs using traditional engineering materials. This is not altogether unexpected, nor undesirable. The many years of performance experience with materials such as concrete, stone, or sand fill in conventional geometries provide the basis for consistent. reliable design approaches to erosion control and storm damage prevention. However, it is worth noting that *even reinforced concrete was considered an innovative and somewhat controversial construction material* early in its history. Modern coastal engineering practice requires demonstration and testing of today's innovative materials and approaches in order to continue a positive evolution in the profession.

b. Geotextile fabrics and similar materials represent one area in which there is already some experience history. In the last 20 to 25 years, the use of geotextiles has become relatively standard as an underlayer and filter media for revetments and other armoring structures (see, for example, USACE 1980). A number of prototype designs for large sand bags and other fabric sand containers have been developed and tested to some degree as reviewed in subsequent sections of this ETL. However, just as there were continuous and often dramatic improvements in the strength, workability, and quality control of concrete over the years, geotextiles also have changed to the extent that the prototype fabrics and designs of 25 years ago have only a passing resemblance to today's materials. Improvements in the fabric materials and lessons learned from early installations have resulted in second and third generation designs.

c. The ProTecTube II shown in Figure 1 is a patented device consisting of a hollow, flexible geotextile tube with a three-cell cross section. It is principally intended to be filled with sand and placed shore- parallel along a dune face, eroding escarpment, or the toe of a fill section in order to retain the upland sediment and reduce the effects of erosion during relatively low energy events. Other applications or configurations are possible with proper engineering judgment. The technology is discussed in greater detail below.

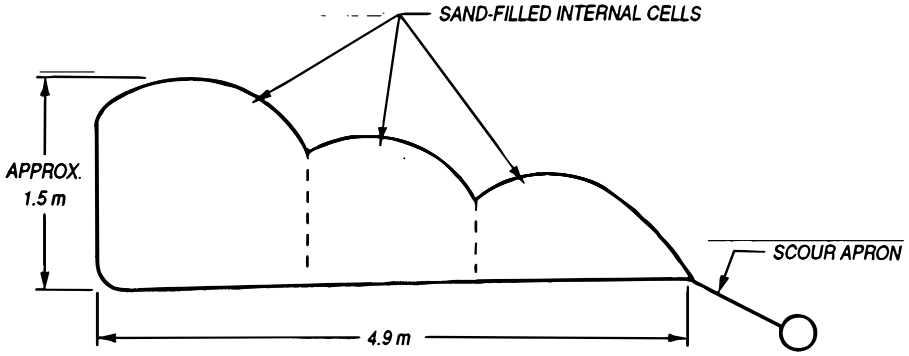

Figure 1. ProTecTube II cross section

5. **Background and Previous Experience**

a. Planning and evaluating alternatives for erosion control or shoreline protection involves considering a number of general and site-specific factors leading to successful design and performance. Considerations such as the design intent, local shoreline and profile characteristics, water levels, and wave conditions are certainly critical. At the same time, these parameters are also essentially common, or at least similarly treated, among most alternatives considered. By their nature, however, geotextile structures have certain additional design challenges. This brief background summary is intended to specifically raise those issues for later comparison to present design.

b. There have been a number of projects over the years that used sand-filled geotextile containers in a variety of configurations. *Several early installations incorporated Longard tubes, one of the first patented products, or similar "sausage casing" designs, with circular cross sections and diameters in the range of 61 to 178 cm (24 to 70 in.).* Interest in the technology in the United States gained momentum after large projects were constructed and monitored on shorelines of the North Sea. The scope of this ETL does not permit an exhaustive literature review, but the interested reader can easily find such references. For example, Armstrong and Kureth (1979) describe two projects, one in Belgium constructed in 1978, and one in the East Frisian Islands on the German coast dating to 1972. The Dutch and others extensively used a “beach grid” formed by geotextile tubes to hold sand as toe protection for polder dikes.

c. The Corps of Engineers evaluated sand- filled containers in several more conventional revetment-type installations as part of the Shoreline Erosion Control Demonstration Program (Section 54) authorized in 1974 by Public Law 93-251, Section 54 (USACE 1981). Many demonstration sites were revisited by staff 5 years after the original program, and product performances are further documented in USACE (1989).

d. These sources and others report very similar general problems with early fabric containers, similar modes of failure where failure occurred, and similar recommended corrective actions.

e. As summarized in USACE (1981), the tubes were functionally effective only as long as they remained structurally sound and retained their sand fill. The principal source of failure noted in the original study was vandalism and the second was accidental puncture by floating debris. Both problems were noted during initial monitoring at all Section 54 demonstration sites, and the problems parallel the general experiences of other investigators and regulatory agencies with such prototype devices in Florida in the 19708 and early 19808.

f. The follow-up to the Section 54 program (USACE 1989) found that none of the original large tubes survived to the revisit and cited puncture and deterioration as the causes. Interestingly, however, the same follow-up study noted that woven geotextile filter cloth used as underlayer in conjunction with other erosion control devices at the same sites often withstood the elements, including direct exposure to sunlight, much better than expected and was still serviceable at the time of the revisit. This suggests a *strong performance dependence on the actual materials involved and on product quality control*, neither of which may have been adequate in the prefabricated container segment of the geotextile industry 15 to 20 years ago.

g. The next most *commonly observed problem with early erosion control tubes was scour of the foundation sand along the tube face, usually followed by significant differential movement. Often sections of the circular tubes rolled forward into their own scour holes, and, in the extreme, rupture of the container resulted. This general situation was also reported in all the projects mentioned above, including those on the North Sea.* One of the great advantages of geotextile container is their flexibility during placement and ability to conform to irregular contours. However, once they are completely filled, the excess water is drained, and they reach an initial equilibrium, they do not handle subsequent large differential strains as well as might be imagined. The USACE (1981) report recommended the use of a filter-cloth foundation material with small-diameter toe tubes and/or initial entrenching to reduce scour and settlement

h. A final problem area noted in previous projects was joint or overlap separations. The points where the effects of scour are especially likely to be felt are where individual containers meet, abut, or change orientation. Large tubes are not typically structually joined in the field at these intersections (and probably could not be). As a result, differential movements can open gaps between adjacent segments. The Belgian project noted that water velocities resulting from "back- rushing" waves and the large tides were very high and concentrated in these gaps, causing considerable loss of upland sand from behind the devices.

6. Recent Design and Monitoring Experience

a. General. The present design evolved over time to incorporate feedback from early project experiences and to *specifically address problems* such as those summarized above. This section describes such a structure in more detail, including performance monitoring.

b. General design features.

(1) As shown in Figure 1. the structure is roughly right-triangular or wedge-shaped in cross section with a flat bottom approximately 4.9 m (16 ft) wide and a crest height at the heel of 1.4 to 1.5 m (4.5 to 5 ft). depending on the degree of fill. This results in an effective slope on the seaward face of approximately IV on 3H to 3.5H. The outside surface of the tube is continuous, but internal partitions divide it into three vertical cells of decreasing height, creating a slightly stepped face.

(2) The tube is prefabricated in a shop environment for *maximum quality control* and to allow for custom lengths, if necessary. The geotextile used is a two-layer material consisting of an impermeable liner fused to an *extremely durable "basket-weave" exterior*. All seams are both sewn with a like yarn and heat welded. The minimum tensile strength of the external armor material is about 140 kilograms per centimeter (780 pounds per inch), and the seam welds develop that full strength.

(3) Installation consists of unrolling and positioning a prefabricated length of the tube (typically 30 to 90 m) on a roughly flat-graded or excavated section of the profile at the predetermined design elevation. The installations to date have taken advantage of the fact that the inner container is essentially impermeable and have initially "inflated" it with plain seawater. This allows for a double check on positioning, *provides a minimum immediate level of protection to the upland*, and expedites subsequent filling with sand. A sand slurry is then pumped in through successive small openings cut through the geotextile. The pumping rate is controlled to allow the slurry water and any initial fill water to slowly be displaced out the next openings and thus reduce the potential for voids or soil bridging. The pipe openings are eventually covered with patches of the same geotextile and field welded in place--the only such field work performed.

(4) *The wedge cross section is specifically intended to improve the structure's rotational stability compared with circular tubes or containers*. The center of the wedge is very low in the section and located toward the heel. This *significantly reduces* the potential seaward overturning moment even if the toe should settle or excessive scour occur. Since the filled weight of the cross section is on the order of 4.5 to 5.2 metric tons per meter, *sliding stability is exceptional, as is resistance to wave impact for the size waves possible in water depths up to the crest height.*

(5) In a further effort to address concern about toe scour, the device has been fabricated with an additional 0.9-m-(3-ft-) wide piece of geotextile attached to, and projecting beyond, the toe as a scour apron. A small diameter (approximately 0.3 m) tube is formed along the seaward edge of ~ "flap" and filled. The intent is that during any

severe profile lowering or liquefaction, the small tube will settle, draw the fabric apron down with it, and provide some level of *increased scour protection* to the main structure.

(6) Adjacent segments along the shoreline are not structurally joined, but are vertically overlapped to form a "keyed" joint. This is accomplished by filling the last 6 to 8 feet of a segment to only half its intended height The next section of tube is placed directly on top of the previous one and adjusted so that the three cells nest together. The overlapping section is then also filled to half height, creating the net full height and weight at the joint This approach places most of the joint "seam" in the horizontal plane and above the potentially most active scour level. *At the two terminal ends of an installation the tube alignment is turned landward to form a gentle taper.*

c. Performance

(I) This performance discussion is based principally on a demonstration installation at Longboat Key on the southwest coast of Florida. As of the date of this ETL, three similar projects have been constructed, including an earlier one using the same material, but a somewhat different geometry than discussed here. The other two projects were in Vero Beach, Florida, and Daytona Shores, Florida. All three projects were built under Florida Department of Natural Resources (DNR) permits, and the department can provide basic information about them. However, the Longboat Key project was chosen as the reference example for this review because more detailed monitoring was performed.

(2) This project initially consisted of a 182-m length of tube (two abutting 91-m prefabricated segments) placed shore-parallel landward of the high water line in 1988 (see Figure 2). The need for the project resulted from many years of continuing shoreline recession which finally reached the point where an upland swimming pool and other amenities were in danger of loss from relatively minor, high frequency seasonal weather conditions. *The threatened structures were originally constructed over a hundred feet from the waterline and landward of a dune system with elevations in the range of +2.13 to +2.74 m (+7 to +9 ft) National Geodetic Vertical Datum (NGVD).* A calculated *average annual recession rate at the site would be in the range of 1.1 to 1.4 m/year (3.5 to 4.5 ft/year) over 17 years.* However, an average annual rate is somewhat misleading because the pattern of erosion loss on the property was that a very narrow, steep foreshore remained reasonably stable during the mild conditions prevalent most of the year. *With even a moderate increase in water level and wave energy during typical winter frontal systems, the vertical dune face would be undercut, causing a permanent and disproportionate volumetric loss within a matter of hours to days.*

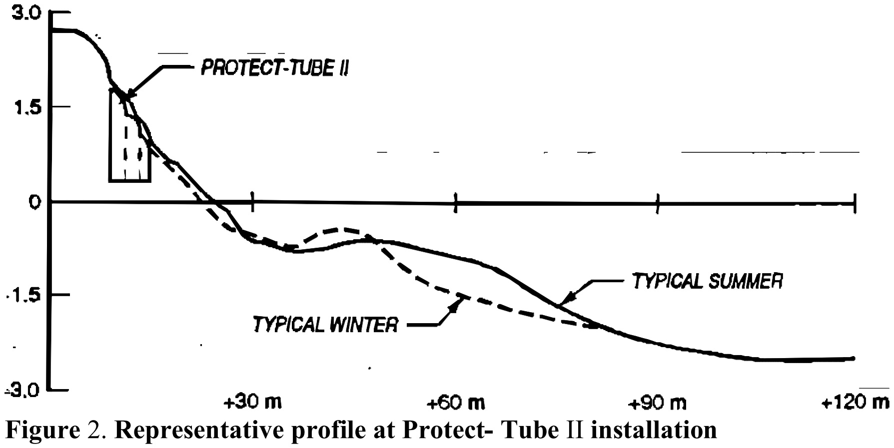

Figure 2. **Representative profile at Protect- Tube** II **installation**

(3) State regulatory policy at the time discouraged the use of rock revetments, bulkheads, and similar "hard" armoring to protect nonhabitable structures. *The property owners elected not to pursue a policy exception and selected the ProTecTube II geotextile container instead, principally because of a more rapid, less intrusive installation process and in the hope that the geotextile containers would allow for greater future access and use of their beach compared with conventional armoring.* A 38-m (125-ft) extension was added to the original length in 1990 when bank recession threatened an adjacent covered parking area. Both projects required Florida DNR permits and conditions on those permits require the property owner to place compatible upland fill on top of the tube seasonally to replace any runup-induced losses. No general fill is placed seaward of the tubes or on adjacent shoreline areas.

(4) Monitoring has consisted of profile surveys twice a year in early winter and summer. Twelve profiles are typically surveyed including three Florida DNR stations--one at the project and one each 305 m (1000 ft) north and south--for which background data exist back to 1974. The other profiles are typically spaced at 61-m (200-ft) intervals across and adjacent to the tube and extend seaward to wading depths. The data are used to generate shoreline position at the time and to calculate volumetric changes since the previous survey and cumulative since the initial installation. A careful visual inspection of the tube is also performed to assess its general condition and note any damage.

(5) The monitored *structure is normally completely covered by 15 to 30 cm (6 to 12 in.) of sand*. The milder portion of typical winter conditions will periodically remove part of this covering and expose approximately the seaward third of the tube. *Site visits have confirmed that sand often redeposits over the toe as wave conditions change.* During more energetic periods of winter conditions, the entire sand cover will be removed, exposing the full slope, and recovery at the higher elevations will be slow and incomplete. *Neither lateral nor cross-shore pedestrian access is restricted by the installation during any conditions.*

(6) As noted above, *the long-term trend in this section of Longboat Key has been persistent shoreline recession*. Over the 15 years between a Florida DNR baseline survey and installation of the first tube segment, this property eroded at an annual average rate of 2.53 cu m/m (1.01 cu yd/ft) of shoreline. The losses in a 305-m (l,000-ft) section of monitored beach beginning 61 m (200 ft) from the end of the tube have averaged about 2.28 cu m/m (0.91 cu yd/ft) of shoreline per year since the installation. The difference in these two values is minor and is probably within the accuracy of the measurements, indicating that *<u>erosion outside the protected area has continued at the historical pace.</u>* An interesting footnote to this calculation is that the erosion rate would be approximately 40 percent greater along the same section of shoreline if losses were considered only above the -O.9-m (-3-ft) NGVD contour rather than over the full profile. This comparison confirms the net transfer of sand from the dune and beach face to the offshore.

(7) During the monitoring period, a similar volumetric change calculation based on the surveys within the protected area suggests a net volumetric gain of about 2.00 cu m/m (0.8 cu yd/ft) per year. However, the tube itself occupies roughly 3.75 cu m/m (1.5 cu yd/ft) of shoreline, and there has been some minor replacement of the 15-cm sand cover following the worst of the winter conditions. Even after considering these volumes, a conservative interpretation would still conclude that *the installation has at least succeeded in offsetting the continued erosion at the site*. It is also interesting to look at changes within the protected area, as before, above, and below the -O.9-m (-3-ft) contour. Apparent volumetric gains shown on the profiles below this contour cannot re related to the volume directly occupied by the structure. Although these gains are modest, they clearly confirm *that the profiles within the limits of the tubes have not steepened during the monitoring, and if the increases result from the covering sand layer. the material seems to be retained in the immediate area.*

(8) The device is not intended as the primary shore protection approach *for low frequency, very high energy storm events*. Its behavior under such events, however, is still of interest. There have been no direct hurricane landfalls at the demonstration site during the monitoring, but there have been several other cases of relatively high water levels and moderate wave energy.

(9) For example, in October 1990, Tropical Storm Marco passed immediately offshore from south to north and entered Tampa Bay approximately 32 to 48 km (20 to 30 miles) from the installation site. A tide station at St. Petersburg/ Tampa recorded a maximum water level of elevation +1.22 m (+4 ft) NGVD, which is approximately 0.85 m (2.8 ft) above normal mean high water. No gauge measurements are available at the site, but observers reported that the mean water levels during the storm reached the crest of the larger tube, which averages +1.68 m (+5.5 ft) NGVD elevation. This water level would correspond to roughly a 10-year return period event using the data and simulations of Dean, Chiu, and Wang (1988). Breaking wave heights on the tube were estimated at 0.9 m (3 ft).

(10) A detailed subsequent inspection at the site showed that wave runup above the surge had eroded sand landward of the containers at an elevation of +2.13 to 2.43 m (+7 to +8 ft) NGVD. A 30- to 45-cm- (1- to 1.5-ft-) high escarpment existed above the tube crest, but below the upland dune, which has typical elevations of +2.74 m (+9 ft). *No settlement, displacement, or damage to the containers was observed. The sand losses described, within the protected area, were minor while the adjacent dune escarpments typically receded 1.5 to 2.4 m (5 to 8 ft) landward over their entire 2.4- to 2.7-m (8- to 9-ft) height.*

(11) As Hurricane Andrew exited the Florida coast into the gulf in August 1992, it passed the monitoring area roughly 240 km (150 miles) off shore. Tides at St. Petersburg were approximately 0.6 m (2 ft) above normal high with winds at 17.9 m/sec (40 mph).

(12) In addition, at least two significant extra- tropical storms have also affected the area, on October 3-4, 1992, and March 12-13, 1993. The 1992 storm had a water level which reached elevation +1.01 m (+3.3 ft) NGVD 0.64 m (2.1 ft above normal) with *18.8-m/lsec* (42-mph) winds. The March 1993 storm produced water levels over +1.28 m (+4.2 ft) NGVD (0.91 m (3 ft) above normal high) and winds between 22.4 and 26.8 m/ sec (50 and 60 mph). During each of these events, water levels in the area remained elevated above normal high tides for over 24 hr.

(13) *All three events produced combinations of water level and wave heights which overtopped the structure for significant periods*. The effects at the site were very similar to those described for Marco: minor losses landward of the tubes at an elevation corresponding to the maximum wave runup, and *much more serious undercutting and full-height dune recession in unprotected adjacent areas.*

(14) *No net settlement or any other movement of the tube or its joints, nor any apparent seaward scour, is evident from any of the surveys. No punctures, tears, or similar damage have been noted during regular inspections or special site visits following storms*. The patches covering the filling openings are specifically checked, and there have been some cases of patch lifting following die more severe wave conditions, but no sand losses. There have not been any signs of vandalism although such abuse would not be likely at the demonstration site.

(15) *The basic conclusion which can be drawn from almost 4 years of monitoring is that the tube has been successful in stabilizing the profile land- ward of the installation while the remaining sections of the property have continued to receive sporadic erosion damage resulting in documented net retreat*. Perhaps even more important is that the shoreline within the structure limits did not achieve its apparent stability as a result of an artificial cross section protruding seaward and "fixing" the waterline. The *surveys show fluctuating shoreline positions at the structure location, typical of seasonal and other changes expected on an otherwise unaltered profile.*

(16) The project's success to date is not the result of any newly discovered “magic,” but is simply attributable to the fact that the tubes are not in contact with the waterline during average conditions and function only to reduce the effects of (moderately) elevated wave energy. When wave attack does occur, however, the very flat structure slope minimizes reflection and scour so that upland protection is not produced at the expense of a further steepened foreshore.

7. **Installation Design Considerations**

a. The position of the geotextile structure on the profile is probably the most important design consideration and requires a *careful analysis of the site and a clear definition of the project intent*. If the device is intended as toe protection for an upland dune or bluff, the existing profile provides the best evidence for horizontal positioning, and the analysis can proceed to setting the necessary crest elevation based on wave runup.

b. As noted, the structure does not provide a high void cross section, nor significant surface roughness. Runup calculations should assume no less than 95 to 100 percent of the smooth slope potential. The design should rely on the flat slope and a relatively landward position to provide the energy dissipation.

c. The cost of the installation will vary depending on the amount of initial profile preparation and grading, and on the source of sand used to fill the tubes. In some areas, such as most of Florida, sand to fill the tubes and to backfill the finished profile landward of the crest must be hauled in and may not be taken from the active beach area. Suppliers have suggested overall costs for a typical installation may be estimated at approximately $200 per linear foot (October 1992 prices) depending on pumping or hauling distances.

d. Other potential coastal uses for geotextile container structures may be tailored to specific needs using available information and life-cycle cost estimates.

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FOR THE DIRECTOR OF CIVIL WORKS:

1 **Appendix**
APP A -References

APPENDIX A: **REFERENCES**

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Note: Italics and underlining added for emphasis by A.C.T.. No other material changes have been made to this report.