The Economic Analysis of "Soft" Versus "Hard" Solutions for Shore Protection: An Example

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Abstract

This paper presents the design and economic analysis for two alternatives (soft-versus-hard) for shore protection of facilities at the US Navy's Fleet Combat Training Center, Dam Neck, Virginia, USA. Three key factors are discussed that resulted in the selection of the soft alternative (dune construction and beach nourishment) which also included a buried seawall/revetment structure beneath the dune to provide a unique solution for shore protection. Construction was completed in the fall of 1996 and the results of the first year's monitoring effort are presented. The advantages of the soft alternative are many (environmental, recreational, etc.) and may even include the economic advantage as demonstrated in this paper for one site on the Atlantic Ocean.

Introduction

The perception exists that renourished beaches (i.e., the "soft" alternative) for shore protection costs more than seawalls and revetments ("hard" alternative) over the design life of the project (Smyth, 1996). Beach nourishment is perceived as an endless expense whereas massive concrete seawalls and stone revetments require little maintenance. Economic analysis of the total, life-cycle costs of "soft" versus "hard" shore protection alternatives are needed to provide some real evidence in this debate.

The design and economic analysis for two alternatives (soft-vs-hard) for shore protection of facilities at the US Navy's Fleet Combat Training Center, Dam Neck, Virginia on the Atlantic Ocean below Virginia Beach, Virginia USA (Fig. 1) are described below. Approximately $95 million of structures including the gunnery range were threatened by historic erosion averaging 0.7 m/yr and recent years of severe storm activity that damaged the existing dune-beach system. Fig. 2 shows the Bachelor Officers

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Quarters (BOQ) protected by the dune-beach system (top, aerial photo[2]) and by an artificial, stone armour layer revetment (bottom, graphic artist schematic[3])

The soft alternative (Fig. 2, top) also included a rebuilt dune system with buried seawall/revetment structure that together provided a unique solution for shore protection in the US. The retreat alternative was far too expensive and unacceptable because the gunnery range must be located adjacent to the coastline for effectiveness and safety reasons.

Design Criteria

The design criteria was for storm damage mitigation against the one percent chance, annual storm surge event (2.65m, NGVD, 1972 adj.) and related wave conditions (H_{mo} = 4.82 m, T_p = 13.7 s) in a nearshore water depth of about 9 m. Design life selected was 25 years with an interest rate of 9.5 percent that was two points above the prime lending rate (1994) for the economic study of life cycle costs. The beach was to be restored whenever conditions returned to 1995 beach widths which were less than 12 m (MHW) at some locations.

Composite average, median grain size was 0.29mm for the native beach.

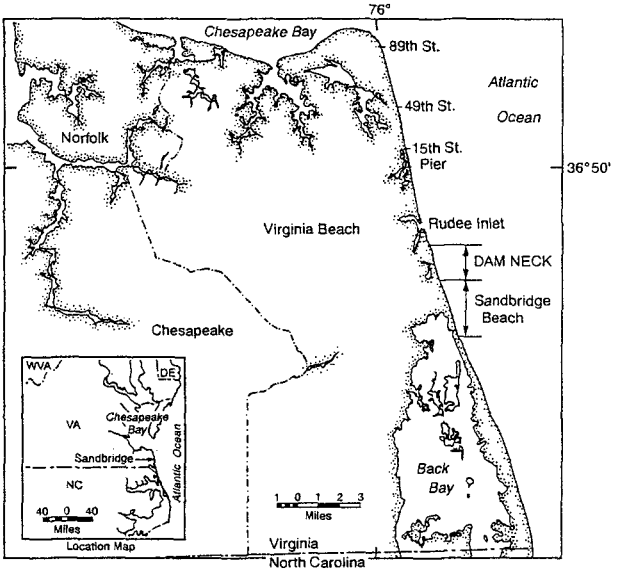

Figure 1 Location Map, Dam Neck, Virginia

[2] Steve MacGregor, MacGregor Enterprises, Norfolk, VA, USA
[3] Mariusz Mijal, Glenn and Sadler Consultants, Norfolk, VA, USA

Figure 2 Protection alternatives for Bachelor Officer's quarters showing dune/beach/ buried seawall as constructed (top) and concrete armour units as artists conception (bottom)

Key Factors in Design Alternatives

Hard Revetment

Fig. 3 displays a plan view of the BOQ, the Enlisted Man's (EM) Club and the gunnery range to be protected by over 1100 meters of revetment including tapered ends. Offshore contours are relatively straight and parallel to the shoreline to permit the use of one nearshore profile (August, 1994 at the EM Club) as representative for all sections.

The design wave height for the stability analysis of the stone armour layer was obtained by considering all the factors that influenced the design water depth at the structure toe. The (1) beach profile is at its lowest expected position at the *end* of the 25 year design life; (2) the flattened, winter condition profile is employed and ; (3) toe scour during storms must also be included. These conditions produced a below sea level elevation (-1.8m) for the hard structure that greatly increased the initial costs for the revetment.

Two numerical models were employed to calculate the design wave height at the structure toe for varying berm elevations with results shown in Fig. 4. The SBEACH model (Larsen and Kraus, 1989) and the SZED model (Baumer, 1991 based on Thornton and Guza, 1983) both produced similar results and a design wave height of 2.5m. A 4.3 ton (US) natural stone or a 2.3 ton (US) artificial armour block unit (CORE-LOC) was required for stability. In short, the design was based on beach conditions expected during a major storm at the end of the design life (with no beach remaining, Fig. 2) and not on today's condition of the beach.

Fig. 5 is a cross-section of the armoured revetment design with crest elevation at +6.71m (+22.0) to minimize overtopping.

Soft System

The soft system alternative consisted of three components:

(1) a buried rock seawall/revetment with crest elevation at +5.49m and toe elevation of +2.7m;

(2) a rebuilt dune with crest elevation at +6.71m and crest width of 15.2m, and;

(3) a renourishment beach with design width of 23m at +2.13m berm elevation,

as depicted in Fig. 6. The buried structure was placed well back in the dune and 1.2m beneath the dune crest so that dune volume during storms was still available to feed the beach. This combination "soft" system is believed to be unique for shore protection in the US. The buried rock structure was first proposed by Headland, (1991) for Dam Neck. The buried seawall design concept has been constructed at other locations around the world (e.g. van der Graff, 1998, personal communication).

A key factor in the cost analysis for the dune design was the development of "damage" curves as shown in Fig. 7 (Basco and Shin, 1997). Again, the beach profile numerical model SBEACH (Larsen and Kraus, 1989) was utilized over a wide range of storm surge elevations, S relative to the design storm surge level, S_D = 2.77m (MSL) to estimate the volume change in dune cross-section, i.e. damage to the dune. Classical, probabilistic methods for estimating future dune damage and subsequent costs analogous to maintenance costs for rubble mound structures were then employed (Basco and Shin,

Figure 3 Plan view of armoured structure to protect Bachelor Officer's quarters (left), Enlisted Man's club (center) and gunnery range (right)

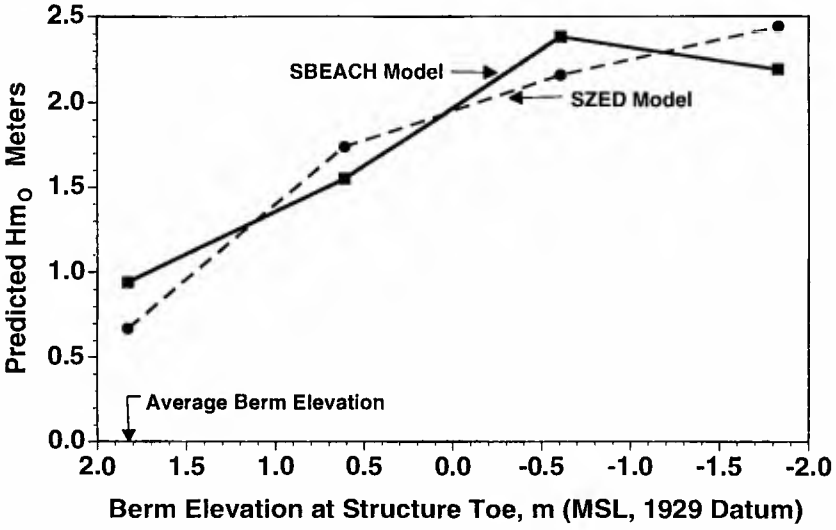

Figure 4 Spectral significant wave height -vs- elevation of beach profile at toe of structure - modeled results

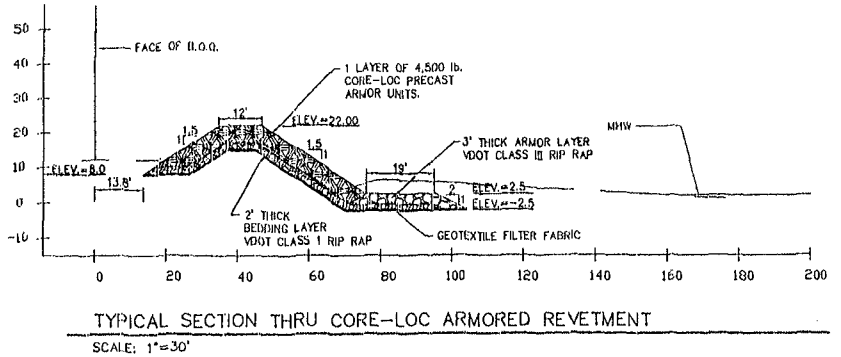

Figure 5 Cross-section of armoured revetment design (hard alternative)

1997). Dune damage curves were estimated at the end of a beach renourishment cycle (8 - 9 yrs) when the beach profile approximates before nourishment conditions. As a safety margin, the secondary, buried structures traps some sand (Fig. 7, with seawall) but serves as shore protection in case two severe storms should be encountered in one hurricane season.

Another key factor in the economics of the soft alternative was identification (Kimball and Dame, 1989) and utilization of a suitable, long term borrow site for sand required for periodic beach nourishment. The offshore borrow area is in Federal government water (beyond the 3 mile limit) about 5 km from Dam Neck. Over 30 million cubic meters of excellent beach material (d_{50} = 0.34 mm) is available for the design life so that the unit costs estimated at $\$6.67/m^3$ ($5/cy) will be reasonable.

Finally, the relatively low annual erosion rate at the site (0.7 m/yr) also contributed to an 8 - 9 year estimate for the renourishment cycle and the relatively lower costs for the soft alternative.

Comparison of Alternatives

Costs

Table 1 summarizes the cost comparison for the hard and soft alternative designs. The new CORE-LOC, artificial, armour unit (Melby and Turk, 1997) was slightly less expensive than natural stone and resulted in a unit cost of slightly over $7200/m for a 1103m revetment.

Table 1 Cost of Alternatives, millions $

Type	Initial Cost, $	Maint. Costs, $	Total Unit Costs, $
Hard	7.746 M	0.204 M	7200
Soft	3.657 M	2.979 M	6016

The soft alternative costs per unit meter were also based upon this length for shore protection (Fig. 3) but the design beach was longer (1600 m) to increase its life. As shown in Table 1, the life-cycle costs favor the soft alternative, in this example. The life-cycle unit costs were $6016 per meter and included almost $3 million in maintenance costs for two nourishment events. These are "present worth" maintenance expenses.

Decision Criteria

Costs are only one criteria in the decision matrix for choosing the soft or hard alternative. Table 2 summarizes all the criteria used to evaluate the alternatives. The sole advantage of the armoured revetment is lower annual maintenance costs. All others favored the dune-beach buried seawall system.

The soft alternative provides a recreational and environmentally useful (turtle nesting habitat) beach at the end of the design life. The permitting agencies, public perceptions, and public relations (image) of the US Navy also favored the soft alternative. Both alternatives provide the same level of shore protection.

The dune/beach/buried seawall, i.e. "soft" alternative was selected for final design and construction.

Table 2 Decision Criteria - Advantages

Criteria	Alternatives	
	Soft	Hard
Shore Protection	✓	✓
Economics		
- Initial Costs	✓	
- Maintenance Costs		✓
- Total Costs	✓	
Environment	✓	
Recreation	✓	
Permits	✓	
Public Perceptions	✓	
Navy Image	✓	
Combined	✓	

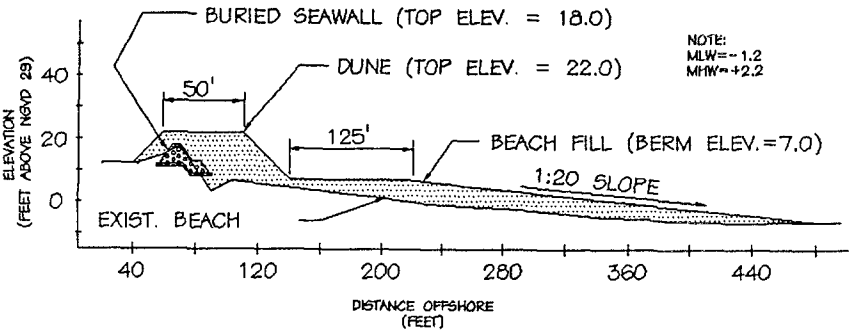

Figure 6 Cross-section of dune/beach/buried seawall design (soft alternative)

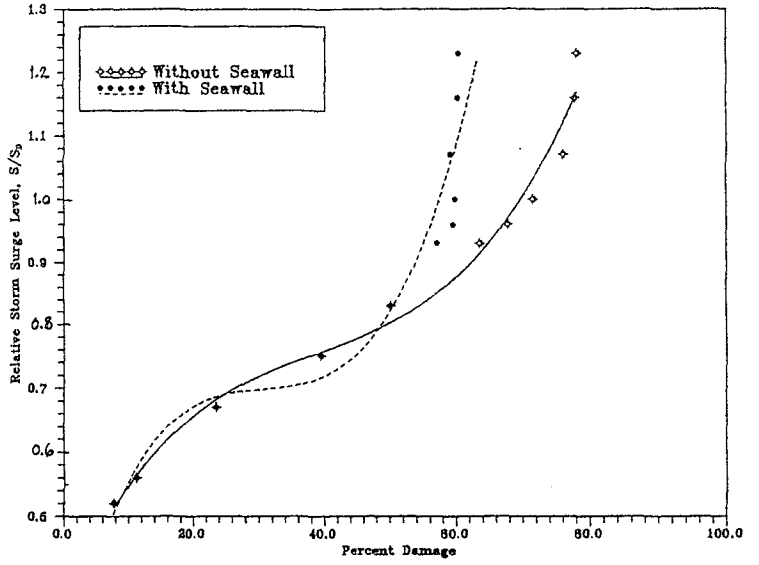

Figure 7 Dune damage curves (from Basco and Shin, 1997)

Final Design, Construction, Monitoring

Final Design

At the Navy's request, the final design was to extend the useful life of the initial beach fill to 12-13 years so that only one renourishment event was expected over the 25 year design life. This required an increase in the beach length (2804 m) including 150 m tapers at both ends for an average length of 2679 m. The design width was also increased to about 38 m to give an average section design fill of 34.4 m^3/m (85.9 cy/ft). The Corps of Engineers' Technical Note, CETNII-32 (CETN, 1994 revised) was employed to estimate the dry beach design width for intersecting profiles since the borrow material was coarser than the native beach material.

End losses for a finite beach fill were estimated using the analytical solution for a one line model of beach fill following Dean, (1992) as discussed further below.

Construction

The major portion of the dune with buried seawall/revetment was constructed in the fall of 1995. Fig. 8 is a photo showing dune/seawall construction and Fig. 9 pictures the final dune before beach nourishment which began in the summer of 1996. The initial placement volume as measured by nearshore sled survey in November, 1996 was about 520,000 m^3 or about 9.4 percent less than the design placement volume. The difference was due to (1) the lack of a true, pre-placement survey (June 1995 survey employed); (2) early erosion occurring between the end of beach fill construction and the initial survey in November 1996; and (3) the dredging contractor not filling the design template. All three factors combined probably contributed to the difference.

Monitoring

A three year monitoring effort is underway to determine volume change of the dune and renourished beach. Sled surveys of beach profiles at 17 locations out to closure depth are being made over a 4875 m reach that extends beyond the beach nourishment project on both ends. The initial year of monitoring (completed October 1997) accounted for all the initial fill volume. The percentage of beach fill volume remaining after year one of the monitoring effort was 84.8 percent over the project length of 2679 m.

Fig. 10 displays the percent volume remaining (crosses) of the nourished beach including intermediate surveys (Mar 1997, June 1997) over the initial year. The dashed line with sediment diffusion coefficient G equal to 0.065 $miles^2$/year was employed for design. End losses are estimated from the diffusion equation

$$\frac{\partial y}{\partial t} = G \frac{\partial^2 y}{\partial x^2} \tag{1}$$

where y (x, t) is the shoreline position in the one-line model for shoreline change (Dean, 1992). The G coefficient depends upon many factors, but mainly the annual wave energy climate striking the beach. A nearshore wave gauge (VA001) is available nearby to measure the waves and is being employed in the monitoring effort. Wave year 1997 (October 96 - September 97) had higher than normal wave energy, yet the sand loss measured followed the theoretical design curves for lower wave energy. Monitored results after three full wave years will (hopefully) be presented at the ICCE `2000

Figure 8 Photograph of dune with buried seawall/revetment under construction

Figure 9 Photograph of completed dune structure before beach renourishment

conference. The actual life of the beach is a key factor in the economics of the "soft" alternative.

Conclusions

On eroding shorelines, hard structures pin the shoreline location, flatten and deepen the profile. Design of hard structures must be for conditions at the end of the design life, when no beach may exist, not for today's beach conditions. The economics of the soft alternative depend upon many factors including (1) historic erosion rate; (2) relative grain size of borrow material, location and long-term volume in borrow area; (3) cross-sectional volume and length of beach fill. The soft alternative maintains a flexible shoreline location and natural beach conditions even at the end of the design life. The advantages of the soft alternative are many (environmental, recreational, etc.) and may even include an economic advantage as demonstrated in this paper for one site on the Atlantic Ocean at Dam Neck, Virginia, USA.

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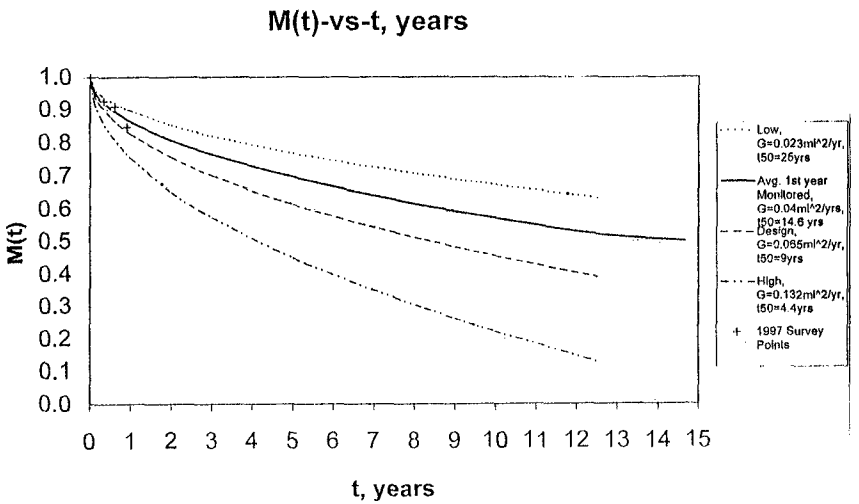

Figure 10 Percent of beach fill remaining versus time (years) for theory (Dean, 1992) and measured results of year one monitoring.