Coastal Engineering Technical Note

RECOMMENDED BASE-LEVEL PHYSICAL MONITORING OF BEACH FILLS

PURPOSE: To present a base-level physical monitoring plan recommended for beach-fill projects; to outline components of the monitoring plan, discuss the practicality of each component, and provide a recommended schedule for data collection.

BACKGROUND: Beach nourishment has become a preferred method for controlling shoreline erosion and reducing coastal storm damage. Coastal communities favor beach nourishment because, in addition to providing erosion and storm protection, beach fills offer a widened beach for enhanced recreation. Increased recreational activity, in turn, benefits the local and, in many cases, the national economy. Beach nourishment is also favored from a cost standpoint, as it is often the least expensive and least impactive among shore-protection alternatives. Frequently, beach nourishment is a preferred method of shore protection for environmental and aesthetic reasons as well.

Beach fills are "soft" structures comprised of sediment placed on an existing beach to form a designed beach configuration. Beach fills are physically similar to "natural" beaches and likewise respond dynamically to waves and water levels characterizing the littoral environment. The dynamic nature of a beach fill is observed in post-construction adjustment of the placed material, seasonal variation and storm-induced change of the beach profile, and seasonal and long-term change of the planform (see Stauble et al. (1993)). Such response demonstrates the manner in which beach fills function by replicating the behavior and protective characteristics of natural beaches. Understanding and quantifying the short-term change and long-term evolution of beach fills is essential for effective engineering design.

Similar to all engineered structures, a beach-fill project has a certain assigned longevity and must undergo periodic inspection, maintenance, and renourishment in order to preserve project functionality over the designed lifetime. Maintenance refers to actions taken to maintain a design beach configuration (short of adding new sediment) such as redistribution of sand on the beach after a storm. Renourishment refers to placement of additional sediment on the beach to replace material lost from the project. The required time interval of renourishment varies from project to project, and depends primarily on the rate of long-term shoreline erosion, the wave energy at the site, the project length, and the frequency and intensity of storm-induced beach erosion. Periodic renourishment is an integral part of beach-fill technology and is included, along with initial fill placement, in the engineering design and economic evaluation of a project. Renourishment needs must be assessed regularly throughout the life of the project.

Critical engineering steps in beach-fill design include selecting a design beach and dune configuration that will provide protection against storm-induced erosion, wave impact, and inundation; determining the volume of fill material required to construct the selected design template; and developing an advance fill and renourishment schedule to replenish long-term losses of material from the project. These parameters-- design profile configuration, required volume of fill, and renourishment schedule-- are determined through analysis of coastal processes and observation of historical beach behavior at the project site. Several design alternatives are evaluated using numerical simulation models and empirical design concepts to predict with- and without-project beach and shoreline response to the littoral environment. Design optimization and selection are conducted through economic and planning analyses that incorporate physical beach response predictions with relevant economic and environmental data. Engineering design and evaluation continues throughout the life of the project as part of periodic-renourishment activities.

Although state-of-the-art engineering tools are used in the design process, critics have questioned the ability of these tools to provide realistic estimates of the primary design parameters. Further, critics have claimed that, historically, beach fills have performed poorly and that beach nourishment is highly ineffective as a means of shore protection. Despite the fact that many of these criticisms are largely unsubstantiated, such opinions have influenced public perception and shore protection policy (Houston 1991). Often, little or no information on project performance is available to counter the criticisms.

The dynamic behavior of beach fills, requirements of periodic and emergency maintenance and renourishment to preserve project functionality, and criticisms of engineering design tool accuracy and project effectiveness all establish the need for systematic and effective monitoring of beach-fill projects.

OBJECTIVES OF PHYSICAL MONITORING: Primary objectives of monitoring a beach-fill project are to document and assess project performance and ensure that project functionality is maintained throughout the design lifetime. These objectives involve ongoing activities throughout the life of the project to (a) quantify short-term and long-term project evolution, (b) assess the condition of the project to determine renourishment and maintenance requirements, (c) evaluate and refine tools and procedures used in continuing design and construction of the project, and (d) develop "lessons learned" which can be translated into improved design techniques and increased performance longevity at lower cost. Effective monitoring provides information required to accomplish these tasks. Benefits of a beach-fill monitoring and analysis program include improved project performance, advancement of engineering design tools and concepts, and an objective basis for gaging level of project success and addressing criticisms concerning beach nourishment. The monitoring plan recommended herein is formulated as a practical approach to achieving these objectives.

MONITORING COMPONENTS: The recommended monitoring plan has four central physical data collection components: (a) wave and water level measurements, (b) beach profile surveys, (c) beach sediment samples, and (d) aerial shoreline photography. These four components provide the minimum base of information required to sufficiently document physical aspects of beach-fill behavior. Each component is discussed and recommendations are made regarding methods and schedules for data collection. Table 1 presents a summary of the recommended schedule for data collection. The monitoring plan presented herein focusses on physical aspects and behavior of the placed beach fill. Other considerations in monitoring a beach nourishment project may include physical monitoring of the borrow area, biological impact assessment, and economic monitoring. Stauble (1991) provides detailed discussion of additional elements of beach nourishment project monitoring.

Wave and Water Level Measurements

An essential element of a successful beach-fill monitoring program is an accurate record of waves and water levels at the project site. Waves and water levels are the principal hydrodynamic forcing parameters controlling beach-fill evolution. Storm waves and water levels erode the upper beach and redistribute sediment across the beach profile. Seasonal variations in the wave climate produce cyclical changes in beach configuration. Over the longer term, wave-driven longshore processes can transport significant volumes of sediment away from the project altering the planform and producing shoreline retreat. Establishing a cause-and-effect relationship between actual waves and water levels and measured beach response is essential for understanding project behavior.

Beach fills are designed using best estimates of wave and water level conditions that may occur during the life of the project. Actual conditions may vary from these design estimates producing unanticipated project response. For example, a beach fill is designed based on the expected frequency and intensity of storm parameters such as wave height, surge level, and duration. If in a given time period, the actual storm climate is much more severe than what is "normal" or expected, the project may erode very rapidly. In such a case, the project may be labeled a failure by critics, particularly if the period of accelerated erosion occurs early in the project life. Without wave and water level information documenting storm characteristics, no evidence exists to definitively measure project success with regards to providing protection against expected storm parameters. With wave and water level data, the storms which produce erosion can be quantified and the information can be used to determine if design storm conditions were exceeded and whether the project performed at design level. Thus, wave and water level data are critical for accurately and objectively assessing project performance in providing storm protection.

Accurate wave information is useful in assessing future renourishment needs. Renourishment schedules are determined based on estimates of loss of material from the project caused by wave-driven longshore transport processes. Measured wave data can be used to quantify coastal processes in the project area; and measured shoreline response can be related to driving wave conditions. Differences can be identified between estimated and actual longshore transport rates and resulting project losses. More accurate estimates of future project loss rates can then be developed and used to refine renourishment schedules and optimize design of continuing construction.

Wave and water level measurements also provide valuable information for evaluating project design tools. Numerical simulation models require accurate hydrodynamic data as input. With measured wave and water level data, predictions of project behavior can be generated for comparison with measured beach response. Design tools and procedures can then be evaluated on a site-specific basis and improved to provide enhanced predictive capabilities and higher confidence in model results for continuing project applications (Wise and Kraus 1993). Applications may involve reassessment of renourishment intervals and quantities, and refinement of the project design.

Recommendations: Wave and water level data should be collected using a directional wave gage. The gage should provide a continuous record of information from which values of significant wave height, peak wave period, peak direction, and mean water level can be determined. Water level measurements from the gage should be compared with any available information from area tide gages to establish vertical datum control for the water level measurements. The wave gage should be placed offshore of the center of the project outside the zone of broken waves. A depth of approximately 10 m is typically sufficient for gage placement. Hemsley, McGehee, and Kucharski (1991) provide further guidelines for consideration in collecting wave and water level data.

Wave data collection should begin during project construction and continue for at least 3 years from the time of initial fill placement. After 3 years, a decision should be made whether to continue wave data collection based on sufficiency of information already obtained in characterizing the wave climate and beach-fill response. At a minimum, wave collection should continue long enough to document beach-fill response to several storm events and to accurately assess seasonal and longer-term trends in project behavior in order to refine estimates of renourishment needs.

Beach Profile Surveys

Systematic measurement of the beach profile shape is a key element of monitoring beach-fill projects. Profile surveys provide data which are used to calculate fill volumes and document changes in beach cross section. Accurate estimates of fill volume are essential during construction to ensure that contractors fulfill obligations in placing the required volume of material in the construction template. Throughout the project lifetime, estimates of total volume remaining in the project area and volume remaining on the subaerial beach are needed to assess maintenance and renourishment requirements. Profile surveys document post-construction adjustment of the beach fill, seasonal variation in profile shape, and storm-induced change in beach cross section (see Larson and Kraus (1994)), all of which are important for determining project condition.

Recommendations: Profile surveys should be conducted using a sea-sled system. Because of its accuracy, simplicity of design, and wide availability of system components, the sea sled is considered to be the best method for profiling beach nourishment projects (Grosskopf and Kraus 1993). In areas where sea sled surveys are not practical (e.g., in environments with extensive reefs, rock outcrops, submarine canyons, etc.) offshore surveys should be taken by boat with a properly calibrated fathometer.

Survey locations should be selected to include profiles within the project limits as well as control profiles some distance up and downdrift of the project boundaries. The number and location of profile surveys within the fill area is site specific and depends on length of the fill and complexity of the beach morphology. On an essentially straight open-coast beach, longshore profile spacing of approximately 300 m (1,000 ft) should provide adequate resolution.[1] In areas where the shoreline orientation changes sharply and small-scale features need to be resolved, such as near structures or local bottom features, spacing of profiles should be smaller at 150 m (500 ft) or less. Two profiles spaced at approximately 600 m (2,000 ft) both updrift and downdrift of the project should be surveyed to compare behavior of the fill with natural beach profile changes and assess the impact on adjacent shorelines of longshore movement of the fill.

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[1] Pre- and post-construction profile surveys are routinely collected at higher resolution, with spacing of 60 m (200 ft) or less, in order to accurately determine placement volumes for paying purposes.

Beach profile surveys should be taken along a reference baseline from known benchmarks that are documented and recoverable in future years. A project baseline should be established at the beginning of a project study, and all subsequent surveys should be referenced to this baseline. The surveys should extend across the entire zone of active profile change. The subaerial portion of the survey should begin landward of the primary dune at a point not expected to erode and extend seaward in a direction normal to the local shoreline orientation. The offshore portion of the survey should extend seaward beyond the depth of closure. Depth of closure is defined as the depth beyond which sediment transport of engineering significance does not occur (Stauble et al. 1993, Hallermeier 1981, Birkemeier 1985). Additional guidelines and procedures for surveying beach-fill projects are given by Grosskopf and Kraus (1993).

In practice, exact timing of beach profile surveys will depend on the construction sequence and climatic conditions; but, in general, surveys should be conducted as follows:

a. Within 30 days prior to each construction (initial placement and each renourishment).
b. Within 10 days following each construction.
c. Quarterly in March, June, September, and December during the year following construction.
d. Semiannually in March and September during other non-construction years.

Surveys taken immediately prior to and following construction document fill volumes and cross-sections. Quarterly surveys taken during the year following initial construction document post-construction adjustment of the placed material. Semiannual surveys document profile seasonality and yearly condition of the project. March, June, and December surveys can be dropped from (c) following renourishment construction, if the renourishment material has grain-size characteristics similar to the originally placed material and it is determined that post-construction adjustment has been sufficiently documented. After the first 3 years of the project, March surveys can be dropped from *d.* above, if it is determined that seasonal behavior of the project is sufficiently documented.

The above surveying schedule should be supplemented with contingency plans to collect post-storm sled surveys for major storms occurring during the first 3 years of the project (and wading depth surveys for storms occurring thereafter) in order to document storm-induced beach change and determine post-storm condition of the project. Post-storm surveys should be performed as soon as possible following the storm, preferably within a day or two, to document the beach configuration before recovery occurs.

Site inspections should be performed concurrently with all beach profile surveys. Inspections should document any information relevant to characterizing the condition of the subaerial beach (e.g., level of dune vegetation, evidence of modification or addition of fill material by locals, effects of storms such as scarping and overwash, presence of post-storm recovery berm, longshore variability in subaerial beach features). Site inspections should include photographs of the subaerial beach (taken looking alongshore) at each beach profile survey location.

Aerial Shoreline Photography

Aerial photography is an essential monitoring component for documenting long-term performance of a beach-fill project. Aerial photographs provide a visual record of shoreline position, variations in beach planform, condition of the dune and berm, and subaerial beach width-- and do so with a total-project perspective that cannot be obtained by ground photographs and beach profile surveys alone. Such information is useful for documenting project planform evolution, evaluating project end effects, and identifying erosional "hot spots." Aerial photographs, together with beach profile surveys, provide information on the 3-D characteristics of fill behavior which can be used to better assess project storm protection and renourishment requirements.

Recommendations: Aerial photography should be taken along a single flightline with 60-percent overlap stereo coverage of the entire project area shoreline, including updrift and downdrift control areas.
Color film with a 9- x 9-in. film format should be used. The scale of the photographs should be sufficient to identify shoreline features. An approximate scale of 1 cm = 50 m is recommended. All photography should be taken near mid-day and around low tide to reduce shadows and reflections and to provide the maximum area of exposed intertidal beach.

Aerial photography should be performed within 30 days prior to initial placement of the fill to document the without-project shoreline, and within 10 days following each construction to document the post-nourishment shoreline. During the first 3 years of the project, aerial photographs should be taken annually in September to document shoreline response to measured wave conditions. After the first 3 years, aerial photographs should be taken in September of the year following each renourishment and every other year thereafter up to the next renourishment. Aerial photographs are recommended for collection in September, because it is at this time, prior to the storm season, that the beach is typically in its most-accreted condition. During this time, effects of storms on the observed shoreline are minimized making it easier to assess fill condition from year to year and providing a more consistent measure of long-term project performance.

Beach Sediment Samples

Beach sediment sampling is needed to document sediment characteristics such as median grain size and grain-size distribution. Sediment sampling is particularly important to project evaluation when fill material and native material have different sediment characteristics. Sediment grain size affects the beach profile shape and fill volume requirements. For example, equilibrium profile theory indicates that sediments which are finer than the native material will result in a beach profile slope milder than the original profile, and will require a larger fill volume to produce a specified dry beach width (Dean 1991, Houston 1994). Sampling of beach sediment provides data that can be used to relate fill performance to characteristics of the fill material. This information can then be used to evaluate future borrow-material suitability and determine required fill volumes for renourishment.

Recommendations: Sediment samples should be collected at selected locations within the project area to account for longshore and cross-shore variability in sediment characteristics. The longshore spacing of sediment sampling locations should be approximately 900 m (3,000 ft) with sampling locations corresponding with nearest profile survey locations. Sediment samples should also be collected at the locations of the updrift and downdrift control profile surveys to document natural variability of the native beach sediment and introduction of fill material to adjacent beaches.

Sediment sampling should consist of collecting shallow sediment grab samples at seven locations across each sampled profile: (a) at the dune, (b) at the berm, (c) at mid-tide level, (d) at mean low water, (e) at a depth approximately one-third the depth of closure, (f) at a depth approximately two-thirds the depth of closure, and (g) at the depth of closure. This sampling scheme documents variation of sediment properties across the profile and provides for characterization of hydrodynamic zonation of the sediment grain-size distribution.

Sediment samples should be collected within 30 days before initial placement to document sediment characteristics of the native beach, and within 10 days after initial placement and each renourishment to document sediment characteristics of the placed material. Samples should be collected in September of the year following each construction to document the sediment characteristics of the adjusted fill. When sediment samples are collected, sampling should be performed concurrently with scheduled beach profile surveys.

SUMMARY OF RECOMMENDED DATA COLLECTION SCHEDULE: Table 1 presents the recommended data collection schedule for physical monitoring of beach-fill projects. The schedule is divided into two phases. The initial phase is a period of more-intensive monitoring during the first 3 years of the project. This phase includes continuous wave and water level data collection and more-frequent profile surveys and aerial photography to sufficiently document processes and responses characterizing the project. This phase provides information required to adequately assess project design and performance and to gain a good understanding of project behavior which can be translated into improved performance throughout the rest of the project life. The final phase focusses on monitoring longer term aspects of project performance and ensuring that project functionality is maintained.

MONITORING AND ANALYSIS COSTS: In order to determine the feasibility of a monitoring program, the costs of data collection and analysis must be considered in light of total project costs. The following example presents a generalized estimate of data collection and analysis costs associated with the recommended monitoring plan. Monitoring cost estimates are formulated and compared with average initial beach restoration and renourishment costs of constructed Corps shoreline protection projects as presented in the *Shoreline Protection and Beach Erosion Control Study* (1994), hereafter referred to as SPBECS.

SPBECS documents costs of Corps projects constructed in the Shore Protection Program from 1950 to 1993. The study includes 56 large constructed projects of which the average project length is approximately 6,100 m (20,000 ft). Of the 56 large projects, 40 projects involved initial beach restoration for which complete cost data were available. Initial beach restoration costs for these 40 projects totaled $657 million (adjusted to 1993 dollars). This translates to an average initial beach restoration cost of $16.4 million.

In order to compare monitoring costs to total project costs, data collection and analysis cost estimates are developed for a hypothetical beach-fill project with length of 6,100 m (20,000 ft), corresponding to the average project length determined from the SPBECS. In formulating monitoring cost estimates, the following assumptions are made regarding the monitoring scheme for the hypothetical project and data collection and processing costs for specific monitoring components:

a. Beach profile surveys (21 lines within project and 4 control lines = 25 total lines = 1 survey set): $37,500 ($1,500 per line) for collection and $2,500 for data processing = $40,000 per survey set.

b. Sediment sampling (7 samples per line on 7 lines within project and 4 control lines for 11 total lines = 77 samples = 1 set): $4,500 for collection and $3,500 ($45 per sample) for sieve analysis = $8,000 per set.

c. Aerial photography (~ 6 miles per flight = 1 photo set): $3,000 for flight/photography and $7,000 for digitization/CADD and data processing = $10,000 per photo set; plus $15,000 for base map construction (one-time cost).

d. Wave gage (3 years continuous measurement and data processing): $150,000 for first year; $50,000 per year thereafter.

The above estimates represent average costs in 1994 dollars for each monitoring component.[1] Using these estimates, the total costs of specific elements of the monitoring plan are summarized below. It is noted that the total costs presented below include costs of coastal processes analysis. Timely analysis of the collected data is essential to enable effective use of the information in project evaluation, and data analysis should be planned and budgeted for when formulating a monitoring program.

a. *Estimated Costs: Phase I - Initial Placement and Years 1-3*

Profile surveys (12 survey sets including 2 post-storm survey sets):	$ 480,000
Sediment sampling (3 sets):	$ 24,000
Aerial photography (5 photo sets):	$ 65,000
Waves and water levels (continuous):	$ 250,000
Coastal processes analysis ($75,000 per year):	$ 225,000
TOTAL	$ 1,044,000
(Average Cost per Year)	$ 348,000

[1] Monitoring costs for a given project may vary due to regional cost differences, site-specific considerations, and economies of scale.

b. *Estimated Costs: Phase II - Each Renourishment*

Profile surveys (3 survey sets):	$ 120,000
Sediment sampling (2 sets):	$ 16,000
Aerial photography (2 photo sets):	$ 20,000
Coastal processes analysis:	$ 40,000
TOTAL	$ 196,000

C. *Estimated Costs per Year: Phase II - Non-Construction Years for Project Years 5-N*

Profile surveys (1 yearly survey set, 1 post-storm survey set every 2 years):	$ 60,000
Aerial photography (1 photo set every 2 years):	$ 5,000
Coastal processes analysis:	$ 25,000
TOTAL	$ 90,000

Estimated data collection and analysis costs total approximately $1.0 million for the first 3 years of intensive Phase I monitoring. This value is approximately 6 percent of the average initial beach restoration cost ($16.4 million) determined from the SPBECS. This percentage of total costs is reasonable for the initial phase of a monitoring program. Considering that the typical project design life is 50 years, it may be practical to spend up to 10 percent of initial project costs on Phase I monitoring in order to adequately understand project behavior and assess project performance.

For this example, the average Phase I monitoring cost over the first 3 years is approximately $350,000 per year. During Phase II of the monitoring program, costs are much less, with estimated costs per year of approximately $200,000 and $90,000 for renourishment years and non-construction years, respectively. The information and understanding of project behavior obtained through Phase I monitoring can be utilized with the more-limited information from Phase II monitoring to regularly assess the project condition and optimize project performance.

A major benefit of monitoring is improved design for periodic renourishment. In the SPBECS, 33 projects involved periodic renourishment for which complete cost data were available. The total adjusted cost of periodic renourishment for these 33 projects is $385.3 million. This translates to an average renourishment cost of $11.7 million per project[1]. This figure shows that renourishment costs are significant in comparison to initial project costs. Adequate monitoring of beach-fill projects can be beneficial in lowering these long-term costs by enabling optimization and refinement of renourishment design and construction.

The above example, while not intended as an absolute guideline for establishing monitoring costs for a given project, provides a general estimate of the relative costs of the recommended monitoring plan with respect to initial project and renourishment costs. The recommended plan, with Phase I monitoring tied to initial construction and Phase II monitoring tied to continuing renourishment construction, provides a practical and economically feasible means of monitoring beach fills.

PROJECT AND SITE-SPECIFIC CONSIDERATIONS: The data collection plan presented herein is formulated as a practical approach for achieving the previously stated objectives of physical monitoring. The recommendations of monitoring components, data collection methods, and sampling schedules which comprise the base-level plan are typically applicable and appropriate for most beach-fill projects. In developing a monitoring plan for a particular project, however, it is noted that variables such as project location, size, boundary conditions, function, cost, and design lifetime together with project-specific monitoring objectives may require modification of the base-level plan to meet project and site-specific needs. Although such project and site-specific considerations ultimately determine the level of monitoring that is appropriate for a particular project, a monitoring plan that neglects any of the basic components of the recommended plan will be limited in providing information that is essential for practical evaluation and improvement of beach-fill project design and performance.

ADDITIONAL INFORMATION: For further information contact Mr. Randy Wise, Coastal Processes Branch, Coastal Engineering Research Center, at (601) 634-3085.

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[1] It is noted that many of the projects included in the study are ongoing and therefore have continuing renourishment costs. The average total renourishment cost, over the entire life of a project, is expected to be higher than $11.7 million.

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