CHAPTER 168

SUPERTANK LABORATORY DATA COLLECTION PROJECT

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ABSTRACT: In the summer of 1991, a multi-institutional cooperative laboratory data collection project called SUPERTANK was conducted to investigate cross-shore hydrodynamic and sediment transport processes using the large wave channel located at Oregon State University, Corvallis, Oregon. The channel is 104 m long, 3.7 m wide, and 4.6 m deep, into which a 76-m long sandy beach was emplaced. SUPERTANK is believed to be the most densely and comprehensively instrumented nearshore processes data collection project performed in the laboratory or the field. At the peak of data collection, the channel was instrumented with 16 resistance wave gages, 10 capacitance wave gages, 18 two-component electromagnetic current meters, 34 optical backscatter sensors (OBS), 10 pore-pressure gages, 3 acoustic sediment concentration profilers, 1 acoustic-Doppler current profiler, 1 four-ring acoustic benthic stress gage, 1 laser Doppler velocimeter, 5 video cameras, and 2 underwater video cameras. Broad- and narrow-band random waves and monochromatic waves were run with zero-moment wave heights in the range of 0.2 to 1.0 m and with peak spectral periods in the range of 3 to 10 sec. The wave generator absorbed waves at the peak spectral frequency that were reflected from the beach and structures such as dunes and seawalls. Twenty major data collection runs were made, most defined as starting from a new beach profile, and approximately 350 profile surveys were taken to record beach response during the 129 hr of wave action. This paper gives an overview of the SUPERTANK project and presents example results.

INTRODUCTION

The design of beaches to protect against storm erosion, flooding, and wave attack requires quantitative prediction of cross-shore hydrodynamics, sediment transport, and beach profile change. Large wave tanks (LWT) capable of producing waves and beach profile change without scale effects provide an inexpensive means, as compared with field data collection, to obtain data for developing mathematical models of cross-shore processes and to investigate fundamental hydrodynamic and sediment-transport processes under controlled conditions.

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A limited number of LWT experiments on beach change have been performed (e.g., Kajima et al. 1982, Vellinga 1986, Dette and Uliczka 1987) since the pioneering study of Saville (1956) and related U.S. Army Corps of Engineers tests (Kraus and Larson 1988), but none has taken advantage of the full range of modern instrumentation to capture the breadth of processes acting across the profile.

In support of numerical model development activities for predicting storm-induced beach erosion (Larson and Kraus 1989), in May 1987 the Coastal Engineering Research Center (CERC) at the U.S. Army Engineer Waterways Experiment Station began planning of a LWT data collection project that was called SUPERTANK. As planning progressed, it was realized that the offshore region would provide an ideal environment for hydrodynamics (waves and currents) and sediment transport measurements by researchers concerned with movement of dredged sediment placed seaward of the surf zone. Thus, one unique characteristic of SUPERTANK was utilization of the entire length of the beach in the LWT channel, extending from near the wave generator through the surf zone to the limit of runup.

This paper presents an overview of the SUPERTANK Laboratory Data Collection Project. Project planning and the major test series are described, and example results are given from the hydrodynamics and beach profile measurements.

PROJECT PLANNING

SUPERTANK was conducted as a multi-institutional effort similar to cooperative field data collection projects first performed in the 1970s, for example, the Nearshore Sediment Transport Study (NSTS) in the United States (Seymour and Duane 1978), the Nearshore Environment Research Center (NERC) project in Japan (Horikawa and Hattori 1987), and U.S. Army Corps of Engineers-sponsored projects such as DUCK85 (Mason, Birkemeier, and Howd 1987) and SUPERDUCK (Birkemeier et al. 1989). Cooperative efforts that pool expertise, instrumentation, and a wide range of research interests have led to advances unattainable by a single or small group of investigators. The advantages of cooperative research were readily carried over to the LWT environment of SUPERTANK.

Pre-project planning was led by a 6-person steering committee formed of CERC and non-CERC members initially divided in the three basic subject areas of (1) hydrodynamics, (2) sediment transport, and (3) beach profile change, including beach and structure interaction. During the course of periodic planning meetings, steering committee members and principal investigators formed into three operational groups as (1) total-channel hydrodynamics and sediment transport, (2) foreshore and beach profile change, including swash zone hydrodynamics, and (3) instrument tests and measurements made offshore that centered around acoustic instruments and a laser-Doppler velocimeter.

Participants joining CERC at SUPERTANK came from the Florida Institute of Technology, Naval Postgraduate School, North Carolina State University, Ohio State University, Oregon State University, QUEST Integrated, Inc., RD Flow, Inc., Seatech, Inc., U.S. Naval Academy, University of California at Santa Cruz, University of Delaware, University of Florida, and University of Washington. Observers came from the Danish Hydraulics Institute (Denmark), Delft Hydraulics Laboratory (The Netherlands), and one investigator from Nihon University (Japan) actively participated. U.S. Army Corps of Engineers field office personnel and undergraduate and graduate students from various institutions around the U.S. assisted SUPERTANK investigators in data collection.

PROCEDURE

Planning

SUPERTANK was conducted using the LWT located at the O.H. Hinsdale Wave Research Laboratory (WRL), Oregon State University. This LWT has the largest wave channel in the United States in which a sandy beach can be emplaced. SUPERTANK subsequently ran for the 8-week period from July 29 to September 19, 1991. With the first and last weeks dedicated to mobilization and demobilization, data were collected over the six weeks from August 5 through September 13. Two 1-week tests of instruments were conducted six months and 1 month before the start of SUPERTANK. These valuable shakedown exercises were one reason that full-scale data collection proceeded without major problems and virtually no instrument down time.

The daily work schedule was 12 hours of wave action and associated activities from Monday through Thursday and 8 hours on Friday, starting from a daily meeting of principal investigators at 7 am. Plans for the day were reviewed and optimized at the morning meetings and in the evenings, for which data taken that day, particularly the beach profile change data, were inspected. Evenings and weekends were spent in major mechanical operations of beach profile reconstruction, emplacement and removal of dunes and seawalls, and inspection and moving of instruments, for which the tank was drained. For example, changes in wave conditions from higher to lower waves required shoreward translation of large numbers of instruments to optimize measurement coverage in the vicinity of the breaker zone and in the surf zone.

Previous LWT projects (and most small-scale laboratory experiments) on beach profile change typically initiated all tests from the same uniform slope in a test series, which required substantial sand transfer and profile regrading with heavy equipment. In the case of SUPERTANK, where a large number of researchers were on site and an even larger number of instruments were mounted in the tank, extensive regrading of the profile, with the associated delays, was not economically feasible or compatible with investigators' schedules. Execution of the pre-planned test series was modified and redirected as necessary through observation of the data (almost all data sets could be inspected during collection or shortly thereafter) and discussion by investigators participating in the particular test.

Channel, Equipment, and Operating Procedures

The channel of the LWT at the WRL is 104 m long, 3.7 m wide, and 4.6 m deep, into which a 76-m-long beach was constructed for the SUPERTANK project. Fig. 1 shows the interior of the WRL enclosure, and Fig. 2 is a view of the LWT during an instrument change. The beach was composed of approximately 600 cu m of uniform-size quartz sand of 0.22-mm median diameter. The direct, digital controlled servo-hydraulic wave generator was equipped to absorb waves at the peak spectral frequency that were reflected from the beach and structures, such as dunes and seawalls. Broad- and narrow-band random waves and monochromatic waves were run with zero-moment wave heights in the range of 0.2 to 1.0 m and with peak spectral periods in the range of 3 to 10 sec. Waves were run in "bursts" of typically 10, 20, 40, and 70-min duration to enable profile surveys to be made in calm conditions, to adjust instruments and measure elevation changes at the Optical Backscatter (OBS) sensors, and to suppress tank seiching.

Fig. 1. Wide-area view of LWT channel and control room during SUPERTANK

SUPERTANK is believed to be the most densely and comprehensively instrumented nearshore processes data collection project conducted in the laboratory or field. At the peak of data collection activities, the LWT channel was instrumented with 16 resistance wave gages, 10 capacitance wave gages, 18 two-component electromagnetic current meters, 34 OBS sensors, 10 pore-pressure gages, 3 acoustic sediment concentration profilers, 1 acoustic-Doppler current profiler, 1 four-ring acoustic benthic stress gage, 1 laser-Doppler velocimeter, 5 video cameras, and 2 underwater video cameras. The resistance wave gages, capacitance wave gages, and electromagnetic current meters formed the core of SUPERTANK data collection and were maintained throughout the project. Synchronous sampling by separate data acquisitions systems was accomplished by digital input of WWV time code to all computer clocks.

CORE MEASUREMENTS

Core measurements constitute data collection fundamental to all investigators. The core measurements consist of wave and current data collection and beach profile surveys. CERC investigators were responsible for these measurements.

Hydrodynamics

Wave transformation was measured with 16 resistance wave gages mounted on the west channel wall (right side of LWT in Fig. 2), spaced 3.7 m apart. The array of resistance gages extended from near the wave generator to a water depth of approximately 0.5 m. An array of 10 capacitance wave gages extended from the most shoreward resistance gage to the maximum runup limit. These gages were also mounted from the west channel wall, but they were mobile with spacing that varied from 0.6 to 1.8 m. In addition to measuring wave

Fig. 2. Close-up view of LWT with SUPERTANK instrumentation

transformation, the capacitance gages also measured runup and the elevation of the sand surface at gages that were intermittently submerged (Fig. 3). Fourteen Marsh-McBirney electromagnetic current meters were mounted on the east channel wall together with arrays of OBS (Fig. 4). The current meters were deployed in vertical arrays of 1 to 4 sensors with vertical spacing of approximately 0.3 m, designed to quantify the undertow profile. Each array was configured to share a timing pulse (close-proximity option) to reduce electronic interference. The meters were deployed in depths of 0.3 to 1.8 m, with selection of sensor position based on the wave conditions, water level, and bottom profile. An additional 4 electromagnetic current meters, 5 OBS, and 1 capacitance wave gage were deployed on a roving carriage (Fig. 5). The current meters were arranged in a vertical array (0.3-m spacing) off an adjustable wing extending beneath the carriage. The carriage was positioned prior to each test to locate the wave gage, current meters, and OBS sensors in the incipient breaking zone, adjacent to a wall-mounted current meter array (for finer vertical resolution), or some other point of interest. Three video cameras, mounted on a scaffold overlooking the surf zone, recorded a continuous image of surf-zone wave transformation, swash, and runup. Ten pressure gages were buried in the sand beach to measure pore pressure.

Portions of the hydrodynamic data were analyzed (spectra and time series) during or immediately after the tests for quality control and planning of subsequent tests. The instrumentation performed extremely well during the project. Instrument noise and cross-talk problems were identified and eliminated prior to the main project in shakedown tests. The wave gages were calibrated once a week during the project by raising and lowering the water level. Wave gage offsets were recorded at the beginning of each test. The current meters were calibrated before and after the project.

Fig. 3. Capacitance bed surface and water surface gages on the foreshore

Fig. 4. Vertical arrays of current meters and optical backscatter sensors

Fig. 5. Roving instrument carriage fully configured at SUPERTANK

The SUPERTANK wave conditions were designed to balance the need for repetition of wave conditions to move the beach profile toward equilibrium and development of a variety of conditions for hydrodynamics studies. The TMA spectral shape, applicable to finite water depths (Bouws et al. 1985), was used to design all random-wave tests, with spectral width parameter γ between 1 (broad-banded) and 100 (narrow-banded). Other parameters that controlled the hydrodynamics, such as water level, bottom profile shape, and shoreward boundary (seawall, dune, and terrace), also varied between tests, changing the nearshore hydrodynamics for the same imposed offshore wave conditions. Low-frequency wave energy (frequencies lying below that of the incident band) did not increase with increasing run length as might be expected due to build-up of channel seiching.

A three-day series of tests conducted during the third week was dedicated to hydrodynamics. These tests included time-varying wave conditions, varying spectral width, and bimodal spectra. The hydrodynamic data will be used to develop and verify advanced hydrodynamic models (vertical current structure, wave breaking, transformation of bimodal spectra, wave setup, and nonlinear wave transformation), as well as support modeling of beach profile change and sediment transport.

Beach Profile Change

Approximately 350 full-length surveys were performed to record the response of the beach profile to wave action and to changes in shoreward boundary conditions, such as emplacement of a seawall. Surveys were made with an auto-tracking infra-red geodimeter, which targeted a prism attached to a survey rod mounted on a carriage that was pushed along the channel by two persons. The survey rod, which could move freely in a sleeve with guide rollers, made contact with the bed via a pair of wide-tread wheels. Typically, 15 minutes were required to set up equipment and survey the profile with a nominal spacing of 0.3 m, but with much finer resolution over features such as dunes, steps, and bars which had large across-shore gradients in elevation. At the start and end of a major test, the profile was surveyed along the center line of the channel and on lines located 0.9 m from each of the channel walls to assess uniformity of the profile across the channel width. Three-line surveys also were occasionally made when cross-tank flow was observed or suspected. In between wave bursts, surveys were made only along the center line.

Observation of the profile rod wheels indicated a nominal penetration depth of a few millimeters, depending on sediment compaction; this depth would tend to cancel in quantitative comparison of differences between profile surveys. Survey measurements were recorded to the nearest 3 mm in horizontal distance and elevation. Performance of the profiling system was evaluated by conducting 10 consecutive profile surveys in which the four survey crew members rotated in and out of the operation. The 10 unedited profile surveys and the standard deviation in profile elevation are plotted in Fig. 6. The standard deviation is typically less than 0.5 cm. The large deviation in one area offshore was caused by rod operator error in one survey and is easily detected in the data file and corrected.

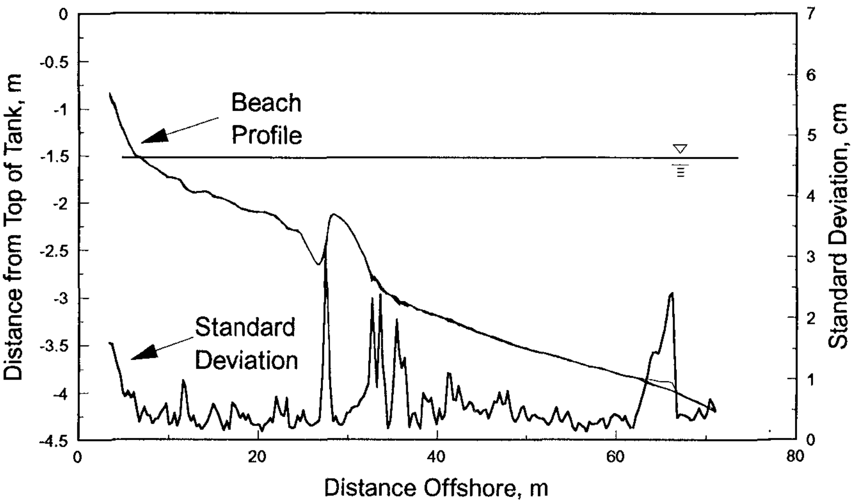

Fig. 6. Plots and standard deviation of ten consecutive beach profile surveys

Although not strictly part of the core measurements, OBS and fluorescent sand tracer measurements were supported by CERC and conducted by Drs. Reginald Beach and Paul Komar of Oregon State University. The fluorescent sand tracer experiments required sampling by SCUBA-equipped divers, and divers also measured and adjusted, as necessary, the bed-referenced elevations of OBS and other sensors at the end of each wave burst. The tracer experiments measured dispersion of sand in the offshore, as a comparison to transport rates obtained with the OBS, and recorded macro-scale movement and layering of sand in regions of rapid morphologic change, such as in areas of bar formation and dune erosion.

Test Series

The 20 major data collection tests performed are listed in Table 1. Wave conditions designed to produce erosion or accretion were selected through use of predictive criteria described by Kraus, Larson, and Kriebel (1991). Several tests had objectives separate from monitoring evolution of the beach profile, such as dedicated hydrodynamic, suspended sediment, and instrument tests that examined local fluid and sediment transport conditions. Representative wave conditions are listed in Table 1. For tests involving random waves, the wave height is the significant (zero-moment) height, and the period is the peak spectral period. Sixty-six different wave conditions were run for a total of 129 hr of wave excitation; 70 percent of the wave conditions involved random waves.

Table 1. Summary of SUPERTANK Tests

Test Number	Description	Date	Representative Significant Wave	
			Height m	Period sec
ST_10	Erosion toward equilibrium, random waves	8/05 – 8/09	0.8	3.0
ST_20	Acoustic profiler tests (random; monochromatic)	8/11 – 8/13	0.2-0.8	8.0-3.0
ST_30	Accration toward equilibrium, random waves	8/14 – 8/16	0.4	8.0
ST_40	Dedicated hydrodynamics	8/19 – 8/21	0.2-0.8	8.0-3.0
ST_50	Dune erosion, Test 1 of 2	8/22 – 8/22	0.5-0.8	6.0-3.0
ST_60	Dune erosion, Test 2 of 2	8/23 - 8/23	0.5-0.7	6.0-3.0
ST_70	Seawall, Test 1 of 3	8/26 - 8/26	0.7-1.0	4.5
ST_80	Seawall, Test 2 of 3	8/27 – 8/27	0.7	4.5
ST_90	Berm flooding, Tast 1 of 2	8/28 am	0.7	3.0
ST_A0	Foredune arosion	8/28 pm	0.7	3.0
ST_B0	Dadicated suspended sediment	8/29 – 8/30	0.3-1.0	10.-3.0
ST_C0	Seawall, Test 3 of 3	9/02	0.4-0.8	8.0-3.0
ST_D0	Berm flooding, Test 2 of 2	9/03 am	0.7	3.0
ST_E0	Lasar Doppler velocimeter, Test 1 of 2	9/03 pm	0.2-0.8	3.0
ST_F0	Laser Doppler velocimeter, Test 2 of 2	9/04 am	0.2-0.7	8.0
ST_G0	Erosion toward equilibrium, mono. waves	9/04 pm	0.8	3.0
ST_H0	Erosion, transition toward accretion, mono. waves	9/05 am	0.5-0.8	4.5-3.0
ST_I0	Accretion toward equilibrium, mono. waves	9/05 – 9/06	0.5	8.0
ST_J0	Narrow-crested offshore mound	9/09 – 9/11	0.5-0.7	8.0-3.0
ST_K0	Broad-crested offshore mound	9/12 – 9/13	0.5-0.7	8.0-3.0

EXAMPLE RESULTS

In this section we present example results from Test ST_10 (Table 1), the first and longest test (21 hr of wave action) of SUPERTANK. This test was conducted to observe beach response to erosive random waves together with the associated hydrodynamics and sediment transport. Selected results illustrate beach profile response to random and monochromatic waves, and wave transformation and vertical structure of the mean cross-shore current.

Profile Change

The beach was configured as a planar foreshore joining to the subaqueous portion formed in a concave shape as $h = Ax^{2/3}$, where h is still-water depth and x is horizontal distance from the shoreline. Several wave conditions were imposed, starting from an 8-sec, 0.8-m zero-moment wave for the first 400 min of wave action ($\gamma = 20$ for first 270 min, followed by runs with $\gamma = 3.3$ or 20), 70 min of monochromatic 3-sec, 0.8-m waves, and 80 min of 3-sec, 0.8-m waves, after which the period was increased to 4.5 sec and water level lowered by 0.15 m to move the bar and to increase runup for promoting change in the foreshore.

Fig. 7 shows beach profile evolution in ST_10 starting from the initial profile for selected times of 60, 290, 470, and 820 min of wave action. For clarity, the profile was truncated seaward of the bar at a depth of 3 m. After 60 min, the foreshore had already eroded and a break-point bar had formed. By 290 min, the foreshore had eroded considerably, and a gradually sloping terrace formed that led to a trough followed by a substantial bar; this beach configuration did not change appreciably under another 110 min of similar wave action. However, 70 min of monochromatic waves produced a sharply defined and asymmetric larger bar. After that, the longer period (4.5-sec, 8-m) random waves produced a berm while maintaining the terrace that joined with a subdued trough followed by a small bar and more round and symmetric larger bar located farther offshore.

Hydrodynamics

Beach profile change is driven by such hydrodynamic processes as decay of breaking wave height, vertical profile of the cross-shore current, setup, and long-period swash energy. Figs. 8 and 9 respectively summarize selected hydrodynamic measurements of erosional random waves in the first 20 min and after 550 min of wave action in Test ST_10 (20-min and 40-min averages, respectively). The decay of the maximum wave height H_{max} and statistical significant (average of highest one-third waves) wave height H_s from the resistance wave gages are shown in the upper half of the figures. The direction and magnitude of the mean cross-shore current measured at various locations is represented with arrows. Wave breaking on the initial profile occurs primarily at the most shoreward resistance gage and further shoreward. The cross-shore current seaward of the surf zone is directed offshore and is weak. After 550 min of wave action, Fig. 9, the wave height envelope shows steep decay over the prominent bar, and the current structure has strong offshore flows in the surf zone and particularly over the bar, with weaker offshore-directed flow seaward of the bar. The bottom half of the figures show the proportioning of wave energy, plotted as wave height, between incident (high pass) and low frequencies. The energy was segregated by using a low-pass filter with a cutoff at half the peak frequency. In both Figs. 8 and 9, the high-pass or incident-band wave height decreases through breaking, whereas the low-pass wave height tends to increase.

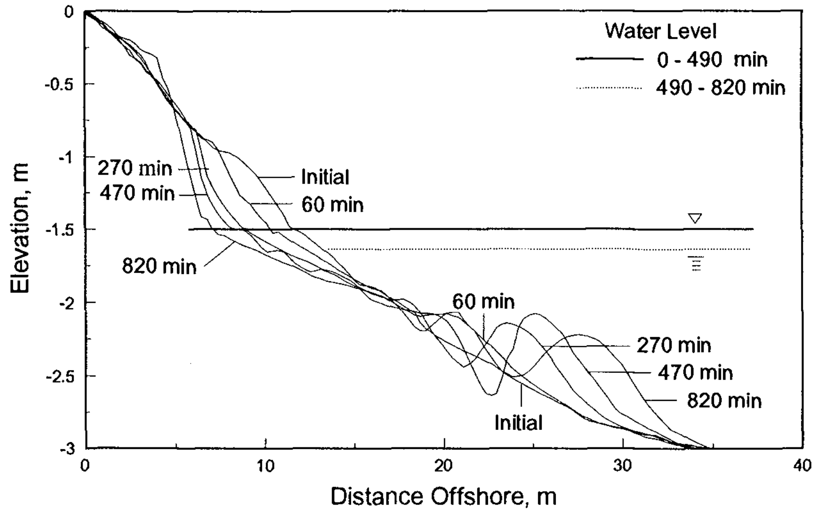

Fig. 7. Selected profile surveys for Test ST_10

Wave transformation across shore includes not only linear shoaling and wave breaking, but also nonlinear energy transfer to frequencies higher and lower than the peak frequency. Figs. 10 and 11 are measured wave spectra at three cross-shore locations (most seaward gage, a gage in the active surf zone, and the most shoreward gage) for a narrow-band (γ = 20.0) and a broad-band (γ = 3.3) incident spectrum, respectively. The narrower spectrum displays clear first and second harmonics of the peak frequency at the shallower measurement locations. The broader spectrum possesses a small peak at the first harmonic and small general increase in energy at higher frequencies. Both cases show an order of magnitude increase in low-frequency energy at shallower depths, similar to what is observed in the field.

SUMMARY AND FUTURE ACTIVITIES

SUPERTANK succeeded as a cooperative multi-institutional data collection project in which investigators shared resources and expertise toward achieving common goals. Advancements in engineering tools, such as improvement of numerical models of beach change and wave transformation through the surf zone, as well as improved understanding of basic sediment transport and bottom boundary layer processes, are already emerging from the project.

Although data collection has been completed, reduction and analysis of the enormous (multi-gigabyte) data set is still in progress. Significant effort has been dedicated to organize and clean the data sets so that they may be accessed by all researchers, including those who did not participate in SUPERTANK. The first year after SUPERTANK has been devoted to reduction of all major data sets -- converting quantities to engineering units and cleaning and organizing the data. The following two years will include data exchange among SUPERTANK investigators and data analysis. In September, 1994, three years after SUPERTANK was performed, the data will be made available to the public.

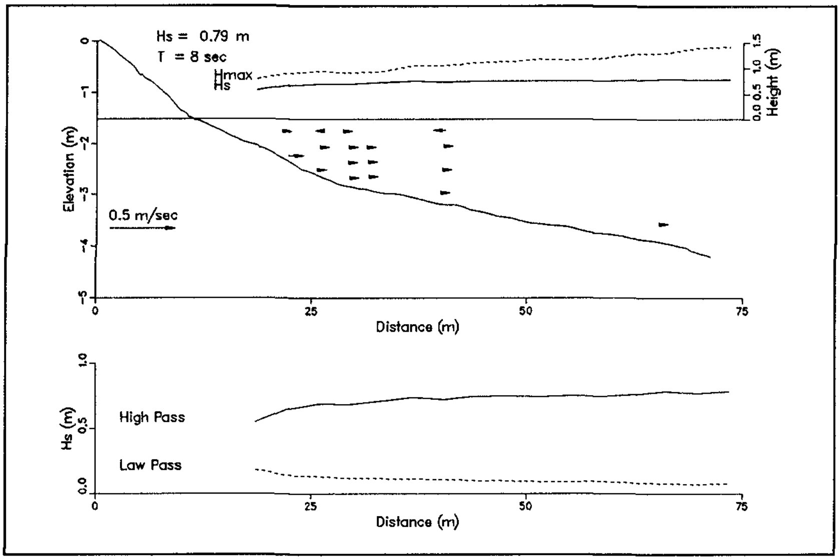

Fig. 8. Wave-height envelope and mean current on the initial beach profile, Test ST_10, after 20 min (20-min average)

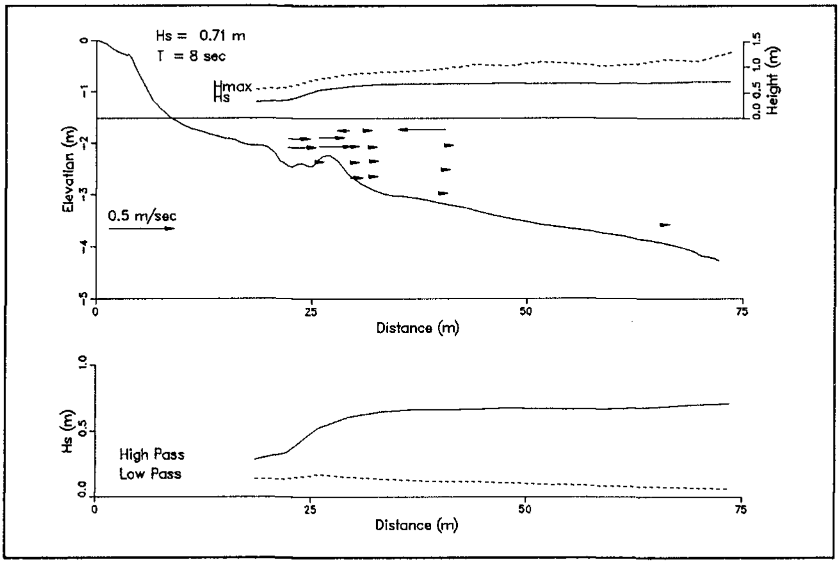

Fig. 9. Wave-height envelope and mean current on a barred beach profile, Test ST_10, after 290 min (40-min average)

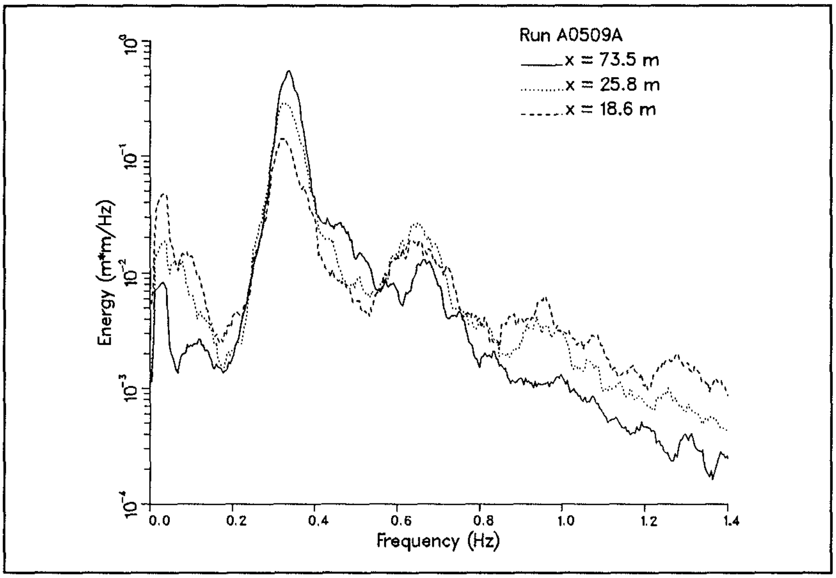

Fig. 10. Transformation of narrow-band wave spectrum across shore, Test ST_10

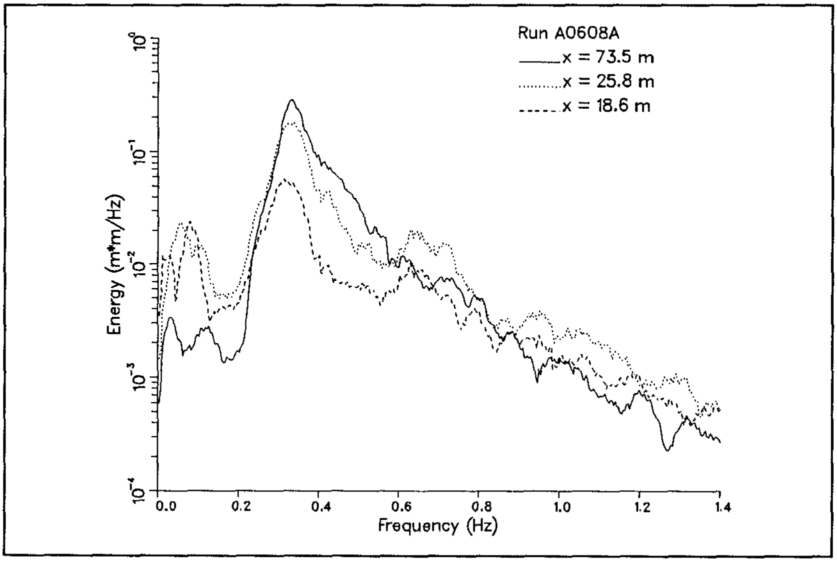

Fig. 11. Transformation of broad-band wave spectrum across shore, Test ST_10

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SUPERTANK succeeded through the efforts of numerous individuals who assisted over several years in planning, instrument testing, mobilization, execution of the project, and subsequent demobilization. The tireless efforts and professionalism of the investigators will be forever engraved in the huge, high-quality data set they created for coastal engineering. Drs. William R. Dally, David L. Kriebel, and William G. McDougal were SUPERTANK Steering Committee members together with the authors. We thank Mr. Jesse Pfeiffer, Headquarters, U.S. Army Corps of Engineers, for assisting in the difficult contracting process, and Messrs. Terry Dibble, William Hollings, and David Standley of the Wave Research Laboratory and Mr. William Grogg of the Coastal Engineering Research Center for electronic, mechanical, and computer support. Permission was granted by the Chief of Engineers to publish this information.

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