Figure I-3-12. Workers planting grass on a beach restoration project. The date and location of this image were not recorded, but the scene is likely the Outer Banks. Many dune and beach restoration efforts, sponsored by the National Park Service and other agencies during the late 1930s, also served as work relief efforts for a nation trying to recover from the Great Depression. Photograph from the Beach Erosion Board Archives

k. Evolution of shore protection and the shift from structures to beach nourishment. Prior to the 1950s, the general practice was to use hard structures to protect against beach erosion or storm damages. These structures were usually coastal armoring such as seawalls and revetments or sand-trapping structures such as groins. During the 1920s and '30s, private or local community interests protected many areas of the shore using these techniques in a rather ad hoc manner. In certain resort areas, structures had proliferated to such an extent that the protection actually impeded the recreational use of the beaches. Erosion of the sand continued, but the fixed back-beach line remained, resulting in a loss of beach area. The obtrusiveness and cost of these structures led the USACE in the late 1940s and early 1950s, to move toward a new, more dynamic, method. USACE projects no longer relied solely on hard coastal defense structures as techniques were developed which replicated the protective characteristics of natural beach and dune systems. The resultant use of artificial beaches and stabilized dunes as an engineering approach was an economically viable and more environmentally friendly means for dissipating wave energy and protecting coastal developments. Artificial beaches also had more aesthetic and recreational value then structured shores. The transition from hard structures to beach fill approaches is depicted in Figure I-3-13, which compares the percentage of Federal shore protection funds spent on beach nourishment and on coastal protection structures per decade. Since the 1970s, 90 percent of the Federal appropriation for shore protection has been for beach nourishment (Hillyer 1996).

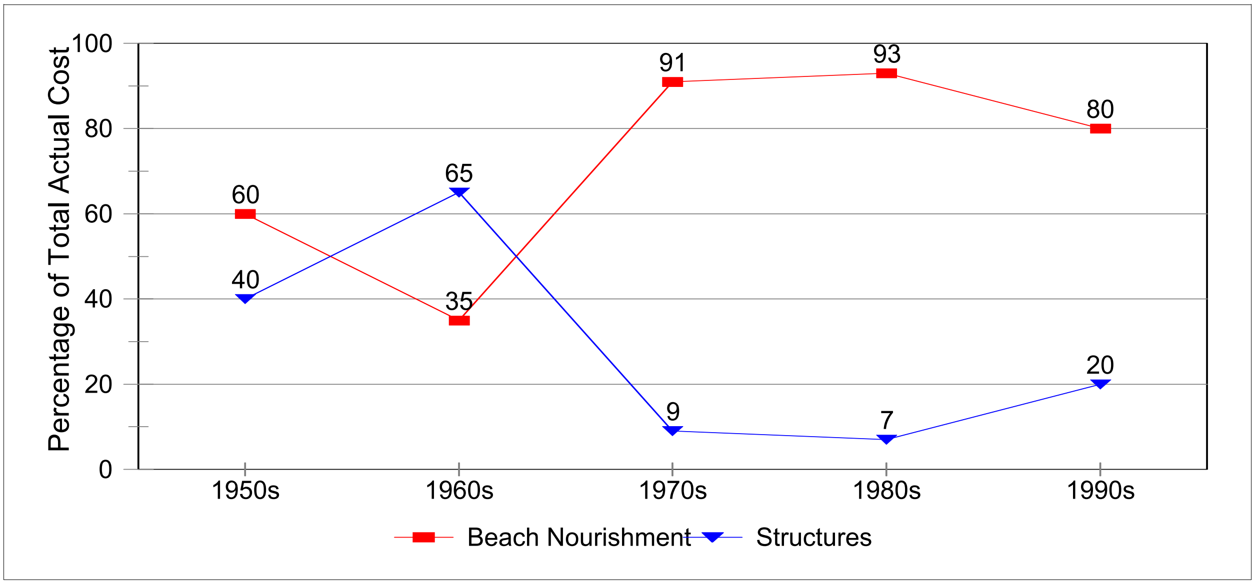

Figure I-3-13. The shift from fixed structures to beach restoration and nourishment (from Hillyer 1996)

l. The Coastal Engineering Research Center and the Coastal Engineering Research Board. In 1962, the USACE studied the merits of strengthening its coastal engineering research capabilities and the benefits from having the evaluation and reporting of coastal projects follow the same procedures as river, harbor, and flood control investigations. Responding to the recommendations of the Corps' internal study board, Congress, by approving Public Law 172 on November 7,1963, abolished the BEB and established the Coastal Engineering Research Center (CERC). CERC had the same mission as the BEB less its review function, but retained an advisory system in a "Board on Coastal Engineering Research, constituted by the Chief of Engineers in the same manner as the present Beach Erosion Board" (Moore and Moore 1991).

(1) Early years. The Coastal Engineering Research Board (CERB) and CERC followed the lead of their predecessor, the BEB, in pursuing field measurements and basic coastal processes research. The argument was that more research would produce more data, provide for more sound coastal engineering approaches, and lead to greater savings. Spurred by both increasing development and environmental awareness, CERC planned programs to quantify phenomena that previously had been only understood qualitatively. The Marine Science Council, created by the Marine Resources and Engineering Development Act of 1966, appointed the USACE as coordinating agency in a multidisciplinary, interagency effort to identify the effects of construction on the coastal zone. That same year, USACE Headquarters (HQUSACE) asked CERC to draft a program covering the Corps' long range needs in coastal engineering. This triggered a reevaluation and a program increase between 1964 and 1969 (Moore and Moore 1991).

(2) Fort Belvoir. As CERC assumed new missions, its most critical needs were office space and a shelter for the Shore Processes Test Basin (SPTB). Weather conditions limited the open-air SPTB use to the period April through October. A HQUSACE command inspection of CERC in December, 1967, concluded that there was not enough space at the Dalecarlia site for the future CERC. A plan was developed to build a research and development complex in the northwest corner of Fort Belvoir on 182 hectares (450 acres). Several USACE and Department of Army agencies would be located at the complex. CERC, the Board of Engineers for Rivers and Harbors, and the Institute for Water Resources would be located in the Kingman Building. CERC was allocated 40.5 hectares (100 acres) for the replacement of existing test facilities and future expansion.

(3) Field Research Facility. Prior to its move to Fort Belvoir, CERC had planned and budgeted to construct a Field Research Facility (FRF) to evaluate and examine coastal phenomena on prototype (full-size) scale. CERC learned that the U.S. Navy was preparing to surplus a bombing range at Duck, North Carolina, and acquired the property in 1973. On 29 August 1980, the 50^{th} Anniversary of the creation of the Beach Erosion Board, the FRF was officially opened. The 73.7-hectare (182-acre) FRF stretches from ocean to sound, contains a 589-m (1800-foot) pier and laboratory facilities and is used for physical and biological studies (Mason 1979). Meteorological, topographical and oceanographic data are continuously recorded, and the staff conduct research projects at the site and frequently host large field experiments involving other Federal, state and local agencies, plus U.S. and foreign universities. The FRF's advantages of ocean location, research pier, sophisticated infrastructure, synoptic and continuing hydrodynamic and process database, and experienced staff are unique in the United States. Data are accessible on the Internet at the FRF's Web page: http://www.frf.usace.army.mil/frf.html

(4) Shore Protection Manual. When first established, CERC was the only Federal agency with a mission in coastal engineering and almost alone in funding studies of waves and their effects. The research programs at CERC, with their field and laboratory testing and data collection, had an immense practical value. CERC's first combined volume containing guidance on coastal science and engineering was *Shore Protection, Planning, and Design*, Technical Report No. 4 (TR-4), first issued in 1954. The USACE District and Division staffs had a need to apply the data and research results reported by CERC into useful design tools, and they often relied on TR-4 and some related Engineering Manuals published by HQUSACE for design guidance. The *Shore Protection Manual* (SPM) was first published by CERC in 1973 as the updated replacement for TR-4. CERC used the SPM as its primary technology transfer mechanism for many years, with a second edition printed in 1975, a third in 1977, and a fourth and final edition in 1984.

(5) Waterways Experiment Station. A number of events and policy changes in the early 1980's shifted CERC's emphasis into more applied research and moved the laboratory to the Waterways Experiment Station (WES) in Vicksburg, Mississippi. Despite disruptions caused by the 1983 relocation and declining research budgets, CERC prospered in Vicksburg. Reimbursable project work more than compensated for the decline. Mathematical modeling, sophisticated wave tanks and basins (part of the reason for the move), and a closer, more responsive relation with the USACE District and Division staffs all contributed to increased workload.

(6) The Coastal and Hydraulics Laboratory. In the early 1990s, due to political and policy changes, Federal funding for the beach erosion control and flood control projects was severely curtailed and closely regulated. This resulted in reduced research funding and a decrease in the number of new beach erosion control and flood control studies at CERC and the Hydraulics Laboratory. During 1996, both laboratories were combined into one new entity, the Coastal and Hydraulics Laboratory (CHL). CERC's traditional functions such as coastal engineering research, design guidance development such as this manual, and design assistance are still provided by the CHL with the advice of the CERB and a field review group of Division and District staff engineers.

I-3-8 Coastal Engineering in the Military

a. Amphibious operations. Amphibious military operations are not new. Herodotus (1992, translation) describes, in *The Histories*, how Xerxes constructed and used a floating causeway across the Hellespont (the Dardanelles) in 480 B.C. The first amphibious operation in the Americas was the 49-day siege of the French Fortress of Louisburg on Cape Breton Island, Nova Scotia, Canada, in 1745. The Chief Engineer of the operation was Richard Gridley who published that same year the first map in America, a "Plan of the City and Fortifications of Louisburg," and who later became the first Chief Engineer under Commander-in-Chief George Washington in 1775. Many amphibious operations were conducted in North Africa, Italy, France, and the Pacific during World War (W.W.) II. These exercises taught us that for a successful over-the-beach assault, details and forecasts of changes must be acquired of coastal type, beach configuration, morphodynamics, profiles, wave conditions, tides, beach material, beach trafficability, and nearshore and offshore bottom-holding capacity for moorings and anchored ships. At the start of the war, many charts were available showing areas safe for deep-draft navigation and details of land topography, but hardly any of the nearshore areas where assault troops and supplies could be landed. Much of this type of information was collected and evaluated during the war. Of prime importance to military amphibious operations are the wave conditions that can be anticipated. Correlations among wind strength, duration, fetch, and wave height and period were developed in the United States and in the United Kingdom (U.K.) for wave forecast for planning and for operations. The state-of-the-art in military coastal engineering at the end of W.W. II was documented in the *Manual on Amphibious Oceanography*, (University of California at Berkley (UCB), Institute of Engineering Research (IER) 1952) (Wiegel 1999).

b. Expedient harbors. Expedient harbor design for the invasion of Normandy also required substantial coastal engineering effort. The design of the two Mulberry harbors ("A" at St. Laurent (Omaha Beach) and "B" at Arromanches) required information on wave and tide prediction (design tide range was 7.3 meters (24 feet)), wave diffraction, wave induced forces, bottom conditions, and placement of structures and their foundations. Wave-diffraction theory (wave transmission about the tip or through a gap between breakwaters) was developed for this project. The Mulberry Harbor was designed in two parts. The portion closest to shore, in shallow water, had a breakwater of vertical reinforced-concrete caissons (code name "Phoenix") and sunken ships protecting it, while the seaward portion was protected by moored floating breakwaters ("Bombardon"). The Bombardon had a cross section similar to a Maltese cross in shape; each unit was 61 meters (200 feet) in length, 7.6 meters (25 feet) in beam and depth with 5.8 meters (19 feet) draft. They were deployed in pairs with a 15.2 meters gap between pairs. Located inside the shallow water sheltered area were pier heads and mile-long pontoon-supported flexible bridges (causeways code named "whales"). After initial construction, a storm along the Normandy coast with gale winds blowing from the northeast generated sea conditions larger than project design waves. Operations were disrupted and delayed, with great damage to the artificial harbors, craft and ships. Mulberry "A" suffered damage beyond repair. Shown in Figure I-3-14 Is Mulberry "B" after being repaired. *The Civil Engineer in War, A Symposium of Papers on Wartime Engineering Problems, Volume 2, Docks and Harbors* (Institute of Civil Engineers 1948) provides details on the design, installation, and performance of the Mulberry Harbors (Wiegel 1999).

c. Military coastal engineering studies. After W.W. II, UCB contracted with the Office of Naval Research (ONR) to review amphibious operations reports from the war. As expected, many landing-craft and amphibious-vehicle casualties were due to enemy action, but many were related to problems with waves and currents causing capsizing, swamping, broaching, getting stuck on bars and, when the ramps were down, filling with water and sand. Another major problem was beach trafficability. Vehicles were frequently stuck in the sand. A trafficability study of beach sand characteristics, beach slope, water level, and vehicle type was made. It was observed that saturated sand near the water's edge would liquefy due to vibrations produced by the vehicular traffic. Several full-scale amphibious assault-training exercises were observed in detail and reports prepared on the observations and findings.

During the 25 October, 1949, exercise across three west coast beaches at the Waianae-Pokai Bay region of Oahu, Hawaii, long-period waves surging up the steep beach face caused substantial landing craft casualties on two of the beaches. Many of the craft broached and were shoved onto the steep beach by the surging breakers (see Figure I-3-15). Of the 20 landing craft sent ashore in 3 "waves" in the first 15 minutes of the amphibious exercise, 7 retracted and 8 were lost, some filling with water and sand when the ramps were lowered. The exercise was quickly halted and five of the craft later salvaged. Because of the problems experienced moving personnel, equipment and supplies through the surf and over the beach, the Department of Defense began the development of helicopters and air cushion vehicles (Wiegel 1999).