Introduction

Underwater construction is indeed an ancient art embracing the manifold discipline of civil engineering.

Battered, crumbling, often submerged, but still there to see, the quays, coastal fortifications, and great harbors along the Mediterranean shoreline disclose the skill of ancient civilizations and man's toils with construction underwater. The colossal harbor of Pharos, whose layout and skillful use of the seabed's configuration would match the genius of today's engineers; the great Phoenician port of Tyre built about 2000 B.C.; Utica, the military harbor fortress near Carthage; and the formidable teeming two-harbor fortified city of Apollonia built about 600 B.C on the Libyan coast are but a few instances of challenging precedents for successful underwater construction. By the third century B.C., through the incredible genius of the Romans, hydraulic cement, watertight cofferdams, methods of construction of breakwaters, and similar underwater techniques had been developed. The details of ancient underwater techniques for soil investigation, excavation of soil and rock, and placing of foundations are not fully known, of course; nevertheless, those crude and simple techniques were sufficient for the design and construction of underwater works that have withstood the ravages of elements and man.

Today the types of underwater construction projects have not materially changed; the number of projects and their complexities, however, have greatly increased. The offshore platforms for oil extraction require pile support in depths of water greater than ever experienced in the past. Offshore docking and material handling facilities are located at distances at sea not previously contemplated. Submerged oil tank storage in the Persian Gulf is indeed an innovation of underwater construction requiring new skills and techniques. Submarine cables, pipelines, subaqueous tubes, bridge piers, pneumatic caissons, cofferdams, anchor ties, land reclamation, salvaging, and underwater archeological work are but a few examples involving sampling and testing of soil underwater and requiring divers. A challenging field is underwater construction for earth and rockfill dams. The Hugh Keenleyside (Arrow) Dam was built to a large extent by placing soil and rock below the water surface using barge dumping and other water techniques. Critical to the use of these techniques was the control of construction, most of which was performed with divers. The huge earthfills for the railroad embank-

Copyright© 1972 by ASTM International www.astm.org

ment across the Great Salt Lake, the cofferdams for Akosombo, and the rock dams of the Mississippi are cases where innovative techniques were used to place massive fills underwater without sacrificing construction control.

As with most construction, underwater construction requires investigation of soil conditions. For shallow depths of water, say 100 ft or less, soil sampling and testing can be achieved with conventional drilling equipment mounted on suitable floating platforms. However, the time consuming operations of pulling a long string of drill pipe and sampling tubes have necessitated new methods for exploring sediments in deep water. Operations in open water emphasize the importance of rapid and simple procedures for soil drilling, sampling, and *in situ* testing.

The morning session of the symposium was given to review of the state-of-the-art techniques of soil sampling and testing in shallow and deep water. Shallow penetration samplers, having penetration depths of a few to nearly 100 ft, and deep penetration sampling and drilling operations used for greater penetrations into the sea floor, normally of tens of feet and in special cases up to several thousand feet, were reviewed. Tools requiring vibratory, rotary, and jetting action with operation from the water surface as well as from submersible tethered platforms or bottom crawler equipment are presented. The remote sampler, currently used mostly as a research tool, is fast becoming a commercially available tool. Several papers are devoted to a discussion of remote sampling and testing of soil. The significance of the test data obtained by these techniques in relation to soil classification and properties—especally shear strength—is described.

The afternoon session of the symposium dealt with underwater construction and techniques to control construction. Types of construction equipment and underwater problems associated with dredging, land reclamation, pile foundations, tremie concrete construction, offshore platforms, subaqueous tunnels, and similar foundation works are described. As already mentioned, underwater construction techniques are not new, but their application to facilities located in deep water demands logistics that are innovative and the use of equipment whose size and capability were developed practically all within the last decade. These aspects are considered in the state-of-the-art paper on construction control.

Inspection, testing, and control of underwater construction are still carried out by divers. Development of new diving equipment has permitted divers freedom of movement and better control of underwater construction and, with these advancements, new approaches in underwater technology are evolving. However, submersible and surface pressure chambers for construction in deep water are still in their infancy, and much of the operation of this type of equipment is still experimental. Saturation diving for construction operations and remotely controlled systems for soil testing are alluded to in several of the papers. The potential of these methods appears unlimited; indeed, they are the fields for new, rapidly evolving techniques for underwater work.

This ASTM special technical publication, with its two state-of-the-art reports and accompanying papers, summarizes techniques for soil sampling and testing in deep water and describes the procedures that have been used to control underwater construction. Emphasis has been placed on investigation and control aspects of civil engineering works. The publication should be of interest to those planning offshore facilities such as platforms for oil and mineral extraction, nuclear power plants, breakwaters, docks, and other facilities placed on, buried within, or anchored to sediments of the sea floor. Of significance is the summary of the soil sampling and *in situ* testing methods, in particular as they relate to an evaluation of the compressibility and stability of sediments and the potential for liquefaction of granular soils during an earthquake. Anchoring of mooring ties; constructing foundations for bridges, subaqueous tubes, water intake structures, and mining equipment; excavating for offshore pipelines; installing piles for platforms; placing massive materials for breakwaters; providing lateral resistance against wave forces; etc., all require sampling and testing of sediments in depths of water and on a scale not previously considered. Because of the exacting demands of these operations, complete and reliable soil data are essential. Thus, new and innovative construction techniques are being developed, as is equipment operated by remote control from surface vessels or by divers trained in techniques of saturation diving.

E. D'Appolonia

President
D'Appolonia Consulting Engineers, Inc.
Pittsburgh, Pa. 15235