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Coastal Engineering

The competent coastal engineer must develop a basic understanding of the characteristics and physical behavior of the coastal environment, as well as be able to apply engineering principles and concepts to developing opportunities and solving problems in this environment. Consequently, this book provides an introduction to those physical processes that are important in the coastal zone. It also introduces the analytical basis for and application of those methods required to support coastal engineering and design.

1.1 The Coastal Environment

We define the shoreline as the boundary between the land surface and the surface of a water body such as an ocean, sea, or lake. The coastal zone is that area of land and water that borders the shoreline and extends sufficiently landward and seaward to encompass the areas where processes important to the shore area are active.

The land portion of most of the world's coastal zone consists of sandy beaches. In some places the beach is covered with coarser stones known as shingle. Where wave and current action is relatively mild and a river provides large deposits of sediment a delta may form and extend seaward of the general trend of the shoreline. In some places there is a break in the shoreline to produce an estuary or inlet to a back bay area—the estuary or inlet being maintained by river and/or tide-induced flow. Also, some coasts may be fronted by steep cliffs that may or may not have a small beach at their toe. Since sandy beaches predominate and have very dynamic and interesting characteristics, this type of coastline will receive the greatest emphasis herein.

Waves are the dominant active phenomenon in the coastal zone. Most apparent and significant are the waves generated by the wind. Second in importance is the astronomical tide, which is a wave generated by the gravitational attraction of the sun and moon. Other waves, which on the whole are less important but

that may have important consequences in some places, are seismically generated surface waves (tsunamis) and waves generated by moving vessels.

The wind and related atmospheric pressure gradient will generate a storm surge—the piling up of water along the coast when the wind blows in an onshore direction. This raised water level can cause damage by flooding and it allows waves to attack the coast further inland. The wind will generate currents that move along the coast. Coastal currents are also generated by the tide as it propagates along the coast and alternately floods and ebbs through an inlet or into an estuary. Further, the wind has direct consequences on the shore by moving sand and causing structural damage.

Wind wave action causes the most significant changes to a beach. The shore-normal beach profile changes as sand is carried offshore and back onshore over a period of time. In many locations large volumes of sand are also carried along the shore by the action of waves that obliquely approach the shore. Current effects often dominate at the entrances to bays and estuaries where higher flow velocities develop.

When structures are built along the coast their design must anticipate the effects of this dynamic wave and beach environment. This is important insofar as the structures must remain stable and must not cause undesirable sand accumulation or erosion by interfering with on/offshore and alongshore sediment transport processes.

Understanding and being able to manage the coastal environment is of critical importance. About two-thirds of the world's population lives on or near the coast, and many others visit the coast periodically. This creates strong pressure for shore development for housing and recreation and for shore protection from storm-induced damage. Shore protection and stabilization problems often require regional solutions rather than a response by a single or small number of property owners. Much of our commerce is carried by ships that must cross the coastline to enter and exit ports. This requires the stabilization, maintenance, and protection of coastal navigation channels. Coastal waters are also used for power plant cooling water and as a receptacle for treated and untreated liquid wastes.

The importance of the coastal environment is demonstrated by events at Miami Beach, Florida. In the early 1970s the beach at Miami Beach was in poor shape—a narrow beach that was not very useful for recreation or effective for storm surge protection. In the late 1970s about 15 million cubic yards of sand were placed on the beach. Estimated annual beach attendance increased from 8 million in 1978 to 21 million in 1983 (Wiegel, 1992). This was twice the annual number of tourists who visited Yellowstone Park, the Grand Canyon, and Yosemite Park combined (Houston, 1995). Foreign visitors alone now spend more than 2 billion dollars a year at Miami Beach, largely because of the improved beach conditions. The expanded beach also has value because of the protection provided from potential storm surge and wave damage to the coast. The capitalized cost of the project is just 3 million dollars per year (Houston, 1995).

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Attempts to solve some coastal zone problems such as beach erosion and the functional and structural design of harbors date back many centuries. Bruun (1972) discusses early coastal erosion and flooding control activities in Holland, England, and Denmark in a review of coastal defense works as they have developed since the tenth century. Inman (1974), from a study of early harbors around the Mediterranean Sea, found that harbors demonstrating a “very superior ‘lay’ understanding of waves and currents, which led to development of remarkable concepts in working with natural forces” were constructed as early as 1000–2000 B.C.

Coastal works have historically been the concern of civil and military engineers. The term “coastal engineer” seems to have come into general use as a designation for a definable engineering field in 1950, with the meeting of the First Conference on Coastal Engineering in Long Beach, California. In the preface to the proceedings of that conference M.P. O’Brien wrote, “It (coastal engineering) is not a new or separate branch of engineering and there is no implication intended that a new breed of engineer, and a new society, is in the making. Coastal Engineering is primarily a branch of Civil Engineering which leans heavily on the sciences of oceanography, meteorology, fluid mechanics, electronics, structural mechanics, and others.” Among the others one could include geology and geomorphology, numerical and statistical analysis, chemistry, and material science.

This definition is still essentially correct. However, coastal engineering has dramatically grown in the past few decades. The Proceedings of the First Conference on Coastal Engineering contained 35 papers; the Proceedings of the 28th International Conference on Coastal Engineering held in 2002 contained 322 papers selected from over 600 abstracts presented to the conference. In addition to the biannual International Conferences on Coastal Engineering there are several specialty conferences held each year dealing with such subjects as ports, dredging, coastal sediment, the coastal zone, coastal structures, wave measurement and analysis, and coastal and port engineering in developing countries. The American Society of Civil Engineers has a Waterway, Port, Coastal, and Ocean Division which, along with magazines titled *Coastal Engineering* and *Shore and Beach* publish papers on all aspects of coastal engineering. In addition, a growing number of general and specialized textbooks on coastal engineering have been published.

Areas of concern to coastal engineers are demonstrated by the following list of typical coastal engineering activities:

- Development (through measurement and hindcasts) of nearshore wave, current, and water level design conditions

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- Design of a variety of stable, effective, and economic coastal structures including breakwaters, jetties, groins, revetments, seawalls, piers, offshore towers, and marine pipelines
- Control of beach erosion by the design of coastal structures and/or by the artificial nourishment of beaches
- Stabilization of entrances for navigation and water exchange by dredging, construction of structures, and the mechanical bypassing of sediment trapped at the entrances
- Prediction of inlet and estuary currents and water levels and their effect on channel stability and water quality
- Development of works to protect coastal areas from inundation by storm surge and tsunamis
- Functional and structural design of harbors and marinas and their appurtenances including quays, bulkheads, dolphins, piers, and mooring systems
- Functional and structural design of offshore islands and dredge spoil disposal areas
- Monitoring various coastal projects through a variety of measurements in the field.

A major source of support for coastal engineers is the available literature on past coastal engineering works along with the design guidance published in textbooks; manuals from government agencies; and special studies conducted by university, government, and consulting firm personnel. Additional design tools generally fall into one of the following categories:

- Many aspects of coastal engineering analysis and design have a strong analytical foundation. This includes theories for the prediction of individual wave characteristics and the properties of wave spectra, for the calculation of wave-induced forces on structures, for the effect of structures on wave propagation, and for the prediction of tide-induced currents and water level changes.
- Many coastal engineering laboratories have two- and three-dimensional flumes in which monochromatic and spectral waves can be generated to study fundamental phenomena as well as the effects of waves in models of prototype situations. Examples of model studies include wave propagation toward the shore and into harbors, the stability of structures subjected to wave attack and the amount of wave overtopping and transmission that occurs at these structures, the response of beaches to wave attack, and the stability and morphological changes at coastal inlets owing to tidal flow and waves.

- Various computer models that numerically solve the basic wave, flow, and sediment transport equations have been developed. These include models for wind wave prediction, for the analysis of wave transformation from deep water to the nearshore zone, for the surge levels caused by hurricanes and other storms, for the resonant response of harbors and other water bodies to long period wave motion, and for the sediment transport and resulting shoreline change caused by a given set of incident wave conditions.
- An invaluable tool for coastal engineers is the collection of data in the field. This includes measurements of wave conditions, current patterns, water levels, shore plan and profile changes, and wave-induced damage to structures. There is a great need for more postconstruction monitoring of the performance of most types of coastal works. In addition, laboratory and numerical models require prototype data so that the models can be adequately calibrated and verified.

The wind wave and surge levels that most coastal works are ultimately exposed to are usually quite extreme. It is generally not economical to design for these conditions. The design often proceeds for some lesser wave and surge condition with the understanding that the structures will be repaired as needed.

Compared to most other areas of civil engineering (e.g., bridges, highways, water treatment facilities), coastal engineering design is less controlled by code requirements. This is because of the less predictable nature of the marine environment and the relative lack of an extensive experience base required to establish codes.

1.3 Recent Trends

Some of the recent important trends in coastal engineering practice should be noted.

With the explosion in the capabilities of computers there has been a parallel explosion in the types and sophistication of numerical models for analysis of coastal phenomena. In many, but not all, areas numerical models are supplementing and replacing physical models. Some areas such as storm surge prediction can be effectively handled only by a numerical model. On the other hand, some problems such as wave runup and overtopping of coastal structures or the stability of stone mound structures to wave attack are best handled in the laboratory.

There is a trend toward softer and less obtrusive coastal structures. For example, offshore breakwaters for shore protection and stabilization more commonly have their crest positioned just below the mean water level, where they still have an ability to control incident wave action but where they also have less

negative aesthetic impact. In some coastal areas coastal structures are discouraged.

There has been a significant increase in the capability and availability of instrumentation for field measurements. For example, three decades ago wave gages commonly measured only the water surface fluctuation at a point (i.e., the different directional components of the incident wave spectrum were not measured). Now directional spectral wave gages are commonly used in field studies.

Wave generation capabilities in laboratories have significantly improved. Prior to the 1960s only constant period and height (monochromatic) waves were generated. In the 1970s one-dimensional spectral wave generators became common-place. Now directional spectral wave generators are found at many laboratories.

1.4 Coastal Engineering Literature

This text presents an introduction to coastal engineering; it is not a coastal engineering design manual. For practical design guidance the reader should see, for example, the design manuals published by the U.S. Army Corps of Engineers including the Coastal Engineering Manual and the various Engineering Manuals dealing with coastal engineering topics.

A good source of detailed information on the various subjects encompassed by coastal engineering is the broad range of reports published by many government laboratories including the U.S. Army Coastal and Hydraulics Laboratory, the Delft Hydraulics Laboratory (Netherlands), Hydraulics Research Limited (Wallingford, England), the Danish Hydraulic Institute (Horsholm), and the National Research Council (Ottawa, Canada). Several universities conduct coastal engineering studies and publish reports on this work.

As mentioned previously, there are many general and specialty conferences dealing with various aspects of coastal engineering. The published proceedings of these conferences are an important source of information on the basic and applied aspects of coastal engineering.

Many senior coastal engineers were introduced to coastal engineering by two texts published in the 1960s: *Oceanographical Engineering* by R.L. Wiegel (Prentice-Hall, Englewood Cliffs, NJ, 1964) and *Estuary and Coastline Hydrodynamics* edited by A.T. Ippen (McGraw-Hill, New York, 1966). Since the 1960s a number of texts on coastal engineering or a specific facet of coastal engineering have been published. A selective list of these texts follows:

Abbott, M. B. and Price, W.A., Editors (1994), *Coastal, Estuarial and Harbor Engineers' Reference Book*, E & FN Spon, London.

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An increasing amount of field data and a number of useful publications and software packages are becoming available over the internet. Two useful sites are noaa.gov and bigfoot.wes.army.mil.

1.5 Summary

Coastal engineering is a unique branch of civil engineering that has undergone significant development in recent decades. Practitioners of this branch of engineering must be knowledgeable in a number of special subjects, one of which is the mechanics of surface gravity waves. Basic two-dimensional wave theory and the characteristics of these waves are the starting points for this text.

1.6 References

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