Chapter 1

Introduction

1.1 Waves in the Sea

Engineers build various types of maritime structures. Breakwaters and quaywalls for ports and harbors, seawalls and jetties for shore protection, and platforms and rigs for the exploitation of oil beneath the seabed are some examples. These structures must perform their functions in the natural environment, being subjected to the hostile effects of winds, waves, tidal currents, earthquakes, etc. To ensure their designated performance, we must carry out comprehensive investigations in order to understand the environmental conditions. The investigations must be as accurate as possible so that we can rationally assess the effects of the environment on our structures.

Waves are the most important phenomenon to be considered among the environmental conditions affecting maritime structures, because they exercise the greatest influence. The presence of waves makes the design procedure for maritime structures quite different from that of structures on land. Since waves are one of the most complex and changeable phenomena in nature, it is not easy to achieve a full understanding of their fundamental character and behavior.

Waves have many aspects. They appear as the wind starts to blow, grow into mountainous waves amid storms and completely disappear after the wind ceases blowing. Such changeability is one aspect of the waves. An observer on a boat in the offshore region easily recognizes the pattern of wave forms as being made up of large and small waves moving in many directions. The irregularity of wave form is an important feature of waves in the sea. However, upon reaching the shore, an undulating swell breaks as individual waves, giving the impression of a regular repetition. Yuzo Yamamoto, in his novel *Waves*, sees an analogy between successive waves and a son's succession to the father.

The generation of waves on a water surface by wind and their resultant propagation has been observed throughout history. However, the mathematical formulation of the motion of water waves was only introduced in the 19th century.[a] In 1802, Gerstner, a mathematician in Prague, published the trochoidal wave theory for waves in deep water, and in 1844, Airy in England developed a small amplitude wave theory covering the full range of water depth from deep to shallow water. Thereafter, in 1847, Stokes gave a theory of finite amplitude waves in deep water, which was later extended to waves in intermediate-depth water. This solution is now known as the Stokes wave theory. The existence of a solitary wave which has a single crest and propagates without change of form in shallow water was reported by Russell in 1844. Its theoretical description was given by Boussinesq in 1871 and Rayleigh in 1876. Later, in 1895, Koreteweg and de Vries derived a theory of permanent periodic waves of finite amplitude in shallow water. This is now known as the cnoidal wave theory.

Thus, the fundamental theories of water waves were established by the end of the 19th century. Nevertheless, several decades had passed before civil engineers were able to make full use of these theories in engineering applications. An exception is the theory of standing wave pressure derived in 1928 by Sainflou,[2] an engineer at Marseille Port. Sainflou's work attracted the attention of harbor engineers soon after publication; his pressure formula was adopted in many countries for the design of vertical breakwaters. It should be mentioned, however, that it was during the Second World War when the mathematical theory and engineering practice was successfully combined together. This led to the formation of the discipline of coastal engineering, which can be said to have begun with the wave forecasting method introduced by Sverdrup and Munk[3]; this later evolved into the more sophisticated S-M-B method, the calculation of wave diffraction by a breakwater developed by Penney and Price,[4] and other milestone developments.

In proposing the foundation for the present S-M-B method, Sverdrup and Munk clearly understood that sea waves are composed of large and small waves. They introduced the concept of the *significant wave*, the height of which is

[a]The following historical overview of the study of water waves is based on the literature listed by Lamb.[1]

equal to the mean of the heights of the highest one-third waves in a wave group, as representative of a particular sea state. Therefore, the significant wave concept was based upon the understanding of sea waves as a random process. However, the significant wave, expressed in terms of a single wave height and wave period, is sometimes misunderstood by engineers to represent waves of constant height and period. The theory of monochromatic waves and experimental results obtained from a train of regular waves have been directly applied to prototype problems in the real sea on the belief that the regular waves correspond exactly to the significant wave.

As early as in 1952, a group of American oceanographers, headed by Pierson,[5] took the first step in recognizing the irregularity of ocean waves as a fundamental property and incorporating this fact in the design process. The so-called P-N-J method[6] of wave forecasting, often compared with the S-M-B method, introduced the concept of wave spectrum as the basic tool for describing wave irregularity. The generation and development of wind waves, the propagation of swell and wave transformation near the shore were all explained in detail via the concept of wave spectrum. Although the spectral concept became widespread among oceanographers at an early stage, coastal and harbor engineers with the exception of a few researchers considered it too complicated. Hence, the introduction of spectral computation techniques into the design process for coastal structures was much delayed.

With advances in wave studies, however, engineers have gradually become aware of the importance of wave irregularity and its relevance in engineering applications. It has been demonstrated many times that the use of regular waves with height and period equal to those of significant wave can give inconsistent or erroneous results in the analysis of wave transformation and action of waves. Therefore, in this book, the concept of randomness in waves is taken as fundamental in the design procedures concerning waves in the sea. A total system of procedures for designing maritime structures against random sea waves is presented.

1.2 Outline of Design Procedures against Random Sea Waves

1.2.1 *Wave Transformation*

A prerequisite for the reliable estimation of waves on maritime structures is a detailed understanding of how waves transform during their propagation