# CHAPTER 1 INTRODUCTION

## 1.1 PURPOSE

This thesis considers the feasibility of using inflatable, submerged, moored structures as breakwaters. These structures can be used to protect the shoreline from erosion, and near-shore and offshore structures from damaging waves caused by severe storms. They can be used continuously or, when not in use, deflated and out of the way.

Although most existing breakwaters are rigid structures that are fixed to the ocean floor and project above the water surface, the shift has been towards more temporary, transportable breakwaters. Inflatable breakwaters have numerous advantages. They are easy to install, cost-efficient, and can be filled with air, water, or some combination of the two.

## 1.2 PROPOSED BREAKWATER

The structural configuration and components of the proposed breakwater are defined in Chapter 3. Nevertheless, it is necessary to briefly describe the subject of this thesis here to make the literature review of Chapter 2 more relevant.

Ideally, the structure will be a cylindrical breakwater tied to the ocean floor with six symmetrically attached mooring lines. The structure is completely submerged and it is assumed that the structure is under sufficient internal pressure to act as a rigid body. It is filled with air.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 FLOATING BREAKWATERS

A floating breakwater is one of several types of structures that can be used for wave control. The first floating breakwater appeared in 1811 at Plymouth Port in England. During World War II, Bombardon floating breakwaters were used along the Normandy coast (Sawaragi 1995). The structures were designed, tested, and readied for use in a relatively short period of time. Until a severe storm reached the area, the breakwaters performed as intended (Naval Facilities 1971). In 1930, Japan placed the first floating breakwater in Aomori Port to test the structure's resistance to waves and the wave dissipation function (Sawaragi 1995).

There are several types of floating breakwaters, which include box, pontoon, mat, and tethered float. Box-type breakwaters are usually constructed of reinforced concrete. They generally act as barges, which dissipate energy at the wave surface. Advantages of this type of breakwater are numerous and include a fifty-year design life, simple construction, proven performance, and effectiveness under "moderate" wave conditions. The only major disadvantage of the box-type breakwater is its relatively high cost in comparison to the other types of floating breakwaters (McCartney 1985).

The pontoon breakwater, which is often referred to as the Alaska or ladder type (for its ladder-like appearance on the water surface), is smaller, less effective, and generally less expensive than most types of floating breakwaters. Tests on these structures caution the designer to avoid certain length-to-width ratios, which could yield a very inefficient structure.

The Maze, Goodyear, and Wave-Guard tire mat breakwaters have been constructed and tested. As the name implies, the interlocked tire layout looks like a mat on the ocean surface. These structures have a relatively low cost, are easily removable for maintenance, and only require unskilled labor for their construction. On the other hand, they have a short design life, frequently lose buoyancy due to the loss of air in the tire crown, and are only effective under mild wave conditions. In addition, litter entrapment is a major drawback with this type of breakwater (McCartney 1985).

The final type of breakwater, and subject of this thesis, is the tethered (moored) floating breakwater, which McCartney claims lacks sufficient prototype experience for a detailed analysis. For reference, McCartney's paper concludes with costs and designs for prototype installation of the aforementioned types of breakwaters. This includes the most effective layout pattern in a bay or basin (McCartney 1985).

The preceding breakwater classifications primarily concern rigid structures. However, Sawaragi (1995) includes inflatable (flexible) structures and further categorizes them by their functions, which include wave reflection, wave breaking, friction, jet mixing, and establishing resonance.

The aim of this section was to familiarize the reader with the numerous portable devices used as breakwaters. However, the list of structures described in the literature is quite exhaustive and rather than focus on these structures, it is more beneficial to examine certain configurations more similar to the submerged, cylindrical breakwater investigated in this thesis.

## 2.2 MOORED STRUCTURES USED AS BREAKWATERS

There are several papers dealing with moored structures used for dissipating wave energy. However, most consider structures that are floating on the surface and are only partially submerged in water. Also, many of the structures described do not have a circular cross-section. Nevertheless, given their applicability to the material discussed herein, two such models are considered in detail.

Frederiksen (1971), Williams, et al. (1997), Harms (1979), Thompson, et al. (1992), Murakami, et al. (1996), Atzeni, et al. (1996), Williams (1996), Ren, et al. (1994), Lau, et al. (1990), Triantafyllou, et al. (1994), Isaacson, et al. (1996), Kato, et al. (1969), Saito, et al. (1996), Murali, et al. (1997), Lipsett, et al. (1991), Nagata, et al. (1983), Idris, et al. (1996), Vethamony (1995), and Valioulis (1990) deal primarily with the performance and effectiveness of various moored structures used for wave attenuation. Other papers that deal with moored structures, but are primarily concerned with the effect of various mooring systems, include Wilson, et al. (1971), Gottlieb, et al. (1992), Gottlieb, et al. (1993), Gottlieb, et al. (1997), Chung (1997), Szelangiewicz (1991), Masuda, et al. (1995), and Headland, et al. (1991).

### 2.2.1 WILLIAMS AND McDOUGAL BREAKWATER

Williams and McDougal (1996) consider a long, tethered breakwater that has a rectangular cross section and can be either submerged or surface-piercing (partially floating). Only surge, heave, and pitch motions of the structure in two dimensions are considered. Small-scale tests are used to verify the theory and “reasonable” agreement is found.

The prismatic breakwater is located some distance from the ocean surface. In addition, the breakwater is attached to the ocean floor by linear springs. The major assumption made by the authors deals with the structure’s degrees of freedom. It is assumed that the structure will respond linearly only in surge, heave, and pitch. The structure is excited by a series of small amplitude waves.

The main conclusions found in this paper deal with the surge response of the structure. The lowest transmission coefficient (ratio of incident wave amplitude to wave amplitude behind the structure), around 0.5, is found when the structure is excited near the surge natural frequency of the structure. However, this nominal effectiveness is concluded to only exist for a narrow band of wave periods. As a result, this structure is deemed effective only if the stiffness of the structure (mooring lines) could be altered readily for various incident wave frequencies.

### 2.2.2 YAMAMOTO AND YOSHIDA

Yamamoto and Yoshida (1979) experimentally consider two specific cases and examine the wave attenuation characteristics of each structure. Neither of the two structures considered is completely submerged. The first case is a three-circle cylinder (three different circular cross-sections along its length) with various mooring configurations. In contrast to the cylindrical structures that will be discussed in the following section, and the breakwater of this thesis, the longitudinal axis of the cylinder is in the direction of wave propagation. Springs are used to attach the structure to the floor. Various mooring line configurations are considered and even cross-mooring is used in one instance. The second structure is a rectangular cylinder, which is moored to the floor as well.

For the circular breakwater, the large “sway and roll” motion of the structure contributes to its effectiveness. Zero transmission coefficients occur at low frequencies. However, the bandwidth is once again very small. The rectangular breakwater is very effective at the frequencies corresponding to heave and to combined sway and roll. The system is effective for waves shorter than five times the length of the breakwater.

## 2.3 MOORED CYLINDRICAL BREAKWATERS

Several authors have considered the feasibility of using both rigid and flexible cylinders as breakwaters and have commented on their eminent wave-dissipating characteristics. Some studies are concerned with surface-piercing cylinders, while others deal with breakwaters completely submerged some distance below the ocean surface. However, most of the research done in these areas is either primarily experimental or considers two-dimensional motions analytically for an infinitely long cylinder. Three-dimensional effects are neglected and only heave, sway, and sometimes surge are considered as displacement modes. These two assumptions are readily questioned for oblique seas. In addition, in order to use submerged cylinders as breakwaters, they must be short enough to be effectively tied to the ocean floor and they must be placed in series with one another to provide enough protection to a given area. Nevertheless, the following papers serve well as an introduction to these breakwaters and manifest the possibilities such structures bring to the rapidly-growing breakwater industry.

### 2.3.1 EVANS' CYLINDER

Using a two-dimensional analysis, Evans (1979) considers a long, submerged, cylindrical breakwater that is constrained by springs and dampers so that only small oscillations are possible. Linear water wave theory is used, along with the assumption that the structure only exhibits heave and sway. Experimental results are included in the paper, which verify most conclusions.

It is effectively shown that a submerged cylinder can, under a broad bandwidth, be very efficient in absorbing wave energy. In fact, a maximum efficiency of 100% is found for an infinitely long cylinder, which corresponds to a transmission coefficient of zero. The paper also focuses on the fact that the structure is most effective at the "tuning frequency" (when the wave frequency is equal to a natural frequency of the cylinder in water).

Although this paper makes various rudimentary assumptions, it still serves well as a validation for the work included in this thesis. In fact, Section 4.4 deals primarily with this procedure.

### 2.3.2 BRISTOL CYLINDER

Davis, et al. (1981) consider a moored horizontal breakwater normal to the incident waves as an energy-dissipating device. Two-dimensional linear wave theory is used alongside both two and three-dimensional experimental results. The efficiency of the cylinder is determined as a function of the wave period for several clearances (defined as the distance between the top of the cylinder and the ocean surface). The results show that the structure is most effective close to the surface. However, the authors openly admit that the experimental results are only a fair validation of theoretical results at best.

## 2.4 FLEXIBLE STRUCTURES USED AS BREAKWATERS

Although this thesis considers the effectiveness of rigid cylinders used as breakwaters, it is still useful to examine some of the research dealing with flexible structures. The breakwater described in Section 1.1 is inflatable and out of the way when not in use. It is assumed that the structure is under enough internal pressure that the structure's dominant modes are rigid body displacements. This is discussed in more detail later.

Lo (1981) considers a horizontal cylinder of infinite length filled with a fluid of specific gravity 0.9 and completely submerged in water. The cylinder is treated as a membrane and is pressurized. Heave and sway are considered, along with the flexible vibration modes. However, no radiation effects due to rigid body motion are included and the dissertation focuses primarily on the flexibility of the structure.

Kim and Kee (1997) consider oblique waves interacting with a tensioned, vertical flexible membrane using two-dimensional, linear water wave theory. Both submerged and surface-piercing buoys are considered. Although the authors consider effective, practical structures, a two-dimensional analysis is insufficient for such small structures.

Ergin, et al. (1992) provide a very complete examination of the dynamic characteristics of a flexible cylinder vibrating in water at some finite depth. The theoretical derivations are made using three-dimensional analysis. The paper manifests the effect that water plays in natural frequency values and mode shapes.

Dewi (1997) considers the effectiveness of a flexible semi-cylindrical bottom-mounted breakwater under certain depths of water. The structure is submerged and has a radius of 4 m and a length of 150 m. The response of the structure is considered for both normal and oblique waves using a three-dimensional analysis. The results show that this structure can be effective in dissipating energy and thus in reducing incident wave intensity. By considering a structure of finite length using three-dimensional analysis, the author shows clearly the importance that end effects have on wave dissipation for oblique and normal waves.

Liapis, et al. (1996) examine the effectiveness of a flexible mound acting as a wave attenuation device. The structure is hemicircular and a two-dimensional analysis is used. The results are compared to those obtained by using the same structure modeled as a rigid body and it is found that the flexible membrane is more effective.

## 2.5 MOORING SYSTEMS

There are numerous methods used to model mooring lines and their characteristics. For the breakwater of this thesis, the mooring lines that are part of the configuration are modeled as both massless springs and a series of lumped masses connected by springs. The effects are discussed in Chapters 3 and 4.

Several papers speak of the effectiveness of cable systems as mooring components and include Dercksen, et al. (1994), Ansari (1980), Bernitsas, et al. (1995), Szelangiewicz (1996), and Chaplin, et al. (1992). Studies dealing with modeling mooring lines with lumped masses include Berteaux (1976), Van Den Boom, et al. (1987), Driscoll, et al. (1996), Thomas, et al. (1994), Huang, et al. (1994), Kato, et al. (1986), Nakajima (1986), Ansari, et al. (1986), Chen et al. (1986), Nath, et al. (1975), McLauchlan, et al. (1973), Inoue, et al. (1991), Thresher, et al. (1975), Leonard, et al. (1981), Nuckolls, et al. (1977), Nakajima, et al. (1982), Van Den Boom (1985), Choo, et al. (1973), Migliore, et al. (1979), and Takikawa (1995).

## 2.6 NEED FOR FURTHER RESEARCH

The previously discussed papers show clearly the possibilities that abound for the use of moored cylindrical breakwaters for ocean wave control. However, most experimental results do not replicate numerical calculations. This is due primarily to the assumptions made by most researchers. For a two-dimensional analysis to be adequate for a moored cylindrical breakwater, the structure must be very long so that end effects are negligible and the structure primarily undergoes heave and sway. In addition, very little is said about oblique incidence angles, which are commonly encountered by breakwaters. In this case, end effects are quite important. Finally, the structure should be small enough so that its implementation is feasible. However, more than just one breakwater is usually required to protect a specific region. In this case they should be placed side by side where their motions are coupled and they tend to act more like one long cylinder.