CHAPTER 162

FLOATING BREAKWATER RESPONSE TO WAVE ACTION

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ABSTRACT

The present paper describes a study carried out to investigate floating breakwater behavior in waves. Components of the study include a field survey of floating breakwaters in British Columbia, Canada, the development of a numerical model of breakwater behavior and the experimental testing of a particular breakwater design. The numerical model has been developed to provide breakwater motions, transmission coefficients and mooring forces. The model combines linear diffraction theory for obliquely incident waves, a mooring analysis, the inclusion of viscous damping coefficients obtained from experimental or field data, and the inclusion of drag and wave drift forces for use in the static analysis of the moorings. The experiments were carried out with normally incident regular waves of different heights and periods. Preliminary results indicate that the numerical model should prove to be a useful tool in floating breakwater design.

INTRODUCTION

Floating breakwaters have found extensive application in many areas where relatively inexpensive protection from wind- and ship-generated waves is required and where open water wave conditions are not unduly severe and water depths are relatively large. The cost of traditional bottom-founded breakwaters increases significantly with water depth, so that a floating breakwater is a relatively attractive option in deeper water.

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A considerable literature on the subject has developed over the past decades, with the large variety of specific breakwater designs as well as the large number of areas of potential application having contributed to this wealth of information. Western Canada Hydraulics Laboratory (1981) carried out an extensive literature survey, covering topics ranging from analytical models of breakwater behavior to in-situ experiences with particular breakwater designs.

Numerical methods of describing breakwater response to waves have originated largely from ship hydrodynamics. Several authors have treated the two-dimensional problem of wave interaction with cylinders at or near the water surface by considering the corresponding potential flow problem and solving this to calculate the hydrodynamic coefficients necessary to determine the fluid forces on, and the motions of the cylinder. In particular, the case of oblique wave interaction with cylinders has been investigated by Bai (1975), Garrison (1969, 1984), Isaacson and Nwogu (1987) and others. Field studies involving prototype floating breakwaters are relatively uncommon. A number of authors have published field data including Nelson *et al.* (1983), Nece and Skjelbreia (1984) and Miller and Christensen (1984). Comparisons of field data with laboratory tests and numerical models have generally indicated that the response of breakwaters can be modeled quite well. However, one difficulty is that responses are lower than the inviscid theory predictions at frequencies near the resonant frequencies of the breakwater, primarily because of additional energy dissipation associated with flow separation.

The present paper describes a study carried out to investigate floating breakwater behavior in waves, with components of the study including a survey of floating breakwaters in British Columbia, Canada; the development of a numerical model of breakwater behavior which predicts transmission coefficients, breakwater motions and mooring forces for a specified breakwater/mooring system and specified incident wave conditions; and thirdly the experimental testing of a particular floating breakwater design.

FLOATING BREAKWATERS IN BRITISH COLUMBIA

British Columbia, Canada, contains relatively large areas of sheltered coastal waters, associated with protection from the open ocean provided by Vancouver Island and the presence of a large number of inlets and sounds. There is extensive use of pleasure craft in the region and a considerable number of floating breakwaters are located here. Locations of thirty more significant floating breakwaters presently in use in British Columbia are indicated in Fig. 1. In general, three categories of breakwater have been used:

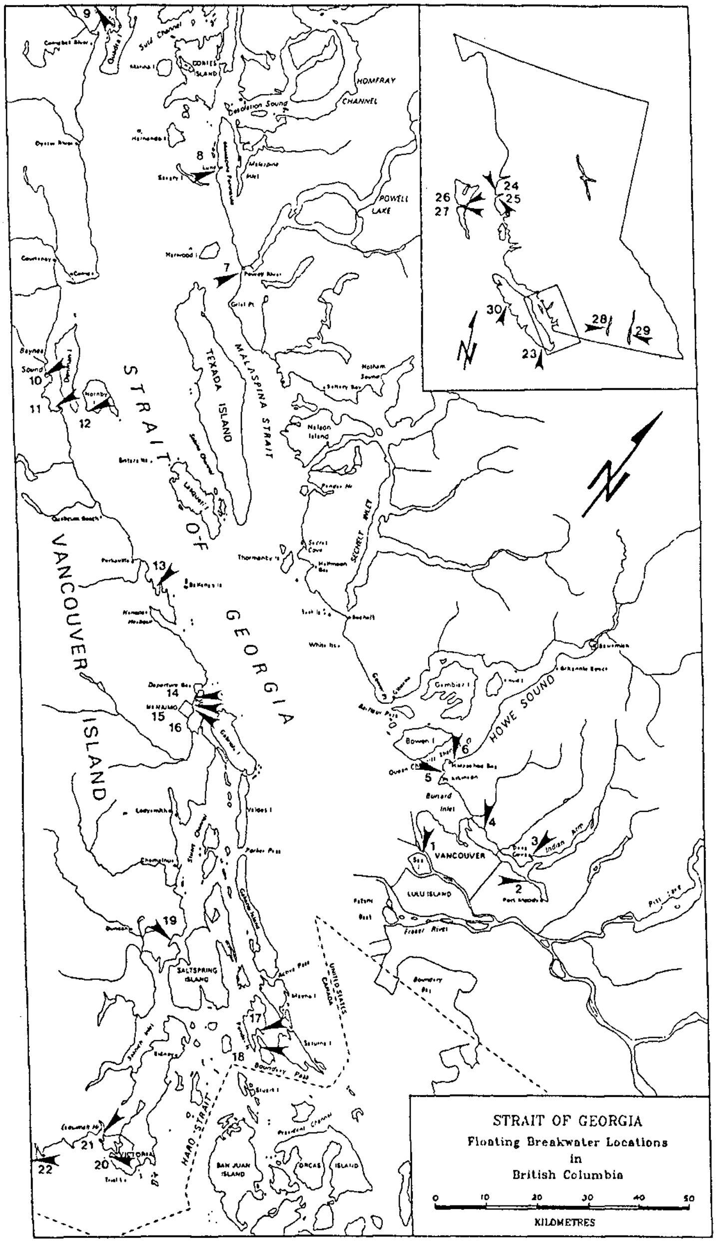

Fig. 1. Floating breakwater locations in British Columbia.

- concrete caisson breakwaters, which generally have a rectangular cross-section,
- log bundles, which generally have a circular or raft-like cross section,
- A-frame breakwaters, which generally include two pontoons and a central vertical plate.

These primarily rely on wave reflection to reduce transmitted wave heights. In addition, a scrap tire breakwater, which reduces the transmitted wave heights primarily by energy dissipation, is used at one location. Table 1 lists floating breakwaters in British Columbia corresponding to the locations shown in Fig. 1 and includes summary information on the fetch and principal wind direction for each location. Of the thirty breakwaters listed, eleven are caisson, fifteen are log and two are A-frame. Typical design wave conditions correspond to a wave period of about 4 sec and significant wave height of about 0.5 m. In addition, there is generally a large tidal range of up to about 5 m. The majority of breakwaters have generally provided quite satisfactory service. This is particularly true of the concrete caissons which tend to be more durable than the other designs and which are more amenable to secondary usage. Although they have an initially higher capital cost, the concrete breakwater systems have a lower incidence of structural damage and provide a greater degree of wave attenuation than either scrap tire breakwaters or log bundles.

As one example of a concrete caisson breakwater, a new three-module caisson breakwater was installed at Lund in May, 1987, replacing an earlier A-frame which had served at that location for 22 years. A photograph of the new breakwater during installation is shown in Fig. 2. Lund is perhaps exposed to the most severe wave climate of any caisson breakwater in the Strait of Georgia. The site is exposed primarily to waves from the southwest and northwest, with fetches of about 30 km and 12 km respectively. The layout of the breakwater is somewhat unusual in that the caisson sections are not inter-connected, but rather are staggered in the horizontal plane in an effort to avoid problems arising with inter-connections or collisions between units. The disadvantages of this arrangement include a reduction in the potential area of protection (because of the overlap of the sections), a reduction in the potential degree of protection because of wave diffraction through the gaps, and a relatively complicated mooring line arrangement.

Floating log bundles are used extensively throughout British Columbia, although in their simplest application - a mere boom of single logs - they are not particularly effective against any but the shortest period waves. An example at Reed Point Marina is shown in Fig. 3, and indicates wave reflection and diffraction around the end of the log bundle breakwater. In this case, the waves were caused by the passage of a tug and are estimated to have a height of 0. 5 m and period of 3 sec.

Fig. 2. The new caisson breakwater at Lund during installation.

Fig. 3. The log bundle at Reed Point Marina, showing wave reflection and diffraction.

The A-frame breakwater at Lund which was in use until 1987 is shown in Fig. 4. The breakwater has steel pontoons of diameter 0.76 m, a beam of 7.6 m, and a draft of 3.7 m. The timber centerboard is connected to the pontoon with a steel space-frame, and extends upwards from the still water level approximately 2 m. The identical design has been used for the A-frame breakwater at Queen Charlotte City.

Only one breakwater in British Columbia involves scrap tires and is located at Eagle Harbor. The breakwater consists of two rows of cylindrical steel pontoons between which scrap tires are strung on conveyor belting.

A unique floating breakwater at Powell River comprises of ten old concrete-hulled ships and is shown in Fig. 5. This has been in use since about 1930, having been gradually expanded to the present configuration by the use of additional ships. The ships range in length from 102 m to 128 m and are anchored with eight to ten concrete anchors, each weighing up to 14.5 tonnes.

Although the breakwaters indicated in Table 1 have generally provided satisfactory service, possible difficulties which have been reported to arise with floating breakwaters have involved their inability to provide adequate wave protection, and possible damage or failure most often associated with connections between individual units of a breakwater or with its moorings.

NUMERICAL MODEL

A numerical model of floating breakwater behavior due to wave action has been developed. Linear diffraction theory is used for a two-dimensional breakwater section to provide the breakwater motions and transmission and reflection characteristics for a regular, obliquely incident wave train. The method has been described by Isaacson and Nwogu (1987) and is based on a boundary integral equation approach deriving from Green's theorem. The breakwater is treated as an infinitely long horizontal cylinder and the fluid is assumed incompressible and inviscid and the flow irrotational so that potential flow theory is used. The velocity potential Φ of the flow is considered to be made up of components associated with the incident waves ϕ_o, the diffracted waves which would arise if the cylinder were fixed, ϕ_4, both of these components being proportional to the incident wave height H, and forced waves associated with each of three modes of motions of the cylinder, ϕ_1, ϕ_2 and ϕ_3, corresponding to sway, heave and roll respectively. The latter potentials are proportional to the amplitude of the motion ξ_j of each mode. Thus the total velocity potential is expressed as:

Fig. 4. The A-frame breakwater at Lund (removed in 1987).

Fig. 5. The floating breakwater at Powell River, comprised of ship hulls.

$$\Phi = \left[\frac{-i\omega H}{2} (\phi_o + \phi_4) + \sum_{j=1}^{3} -i\omega \xi_j \phi_j \right] \exp[i(ky\sin\beta - \omega t)] \quad (1)$$

where $i = \sqrt{-1}$, ω is the wave angular frequency, y is the distance along the cylinder axis, β is the angle the incident wave crests make with the cylinder axis, k is the wave number, and t is time.

The equation of motion of the breakwater can be expressed in the usual way as:

$$\sum_{j=1}^{3} [-\omega^2(m_{ij} + a_{ij}) - i\omega(b_{ij} + b'_{ij}) + c_{ij}]\, \xi_j = F_i \quad \text{for } i = 1, 2, 3 \quad (2)$$

where m_{ij} and c_{ij} are the mass and hydrostatic stiffness coefficients; and a_{ij} and b_{ij} are the added mass and damping coefficients associated with the hydrodynamic forces, and F_i are the exciting force amplitudes. b'_{ij} represents an empirical damping coefficient accounting for viscous effects which is used to modify motion predictions from those based solely on potential theory. The hydrodynamic coefficients a_{ij}, b_{ij} and F_i may be obtained in terms of the potentials $\phi_o, ..., \phi_4$. The transmission and reflection coefficients, defined as the ratio of transmitted or reflected wave heights to the incident wave height, are also of interest and are obtained by computing wave conditions on control surfaces upstream and downstream of the structure.

A suitable extension of this program provides the response to a random incident wave train, which may be obliquely incident, and which may be short-crested (see Isaacson and Nwogu, 1987). In particular, the program provides spectra of the transmitted wave train and of the component breakwater motions. These may be used to estimate the maximum transmitted wave heights and breakwater motions for a storm of specified duration.

The program may be used in conjunction with a three-dimensional mooring analysis program, which utilizes the predicted breakwater motions to provide maximum mooring line tensions.

EXPERIMENTAL STUDY

Laboratory experiments have been carried out to measure transmission coefficients and breakwater motions using two particular breakwater models subjected to normally incident, regular waves. One is a rectangular section breakwater, while the other is an A-frame breakwater. Measurements have been made of the breakwater motions and of the transmission coefficient for a range of incident wave conditions.

The experiments were carried out in the wave basin of the Hydraulics Laboratory at the University of British Columbia. This is 14 m long, 5 m wide and can accommodate water depths up to 0.45 m and wave periods ranging from about 0.5 to 1.5 sec. A variable speed electrically driven wave paddle at one end of the basin was used to provide regular long-crested waves, with the amplitude and period varied by adjusting the stroke and frequency of the paddle. A sloping beach consisting of a frame covered with artificial hair matting was located at the opposite end of the basin to reduce wave reflections. Capacitance type wave probes were used to measure the incident and transmitted wave heights. For all the tests, a vertical wall was installed in the basin to prevent waves reflecting from the model from interfering with the incident wave signal. The rectangular breakwater used was based on the concrete caisson breakwater employed in field tests reported by Nece and Skjelbreia (1984). This corresponds to a prototype beam of 4.8 m, a length of 23 m and a draft of 1.1 m, and the model was constructed to a scale of 1/15. Experiments were carried out at several different wave periods, with separate tests carried out at each wave period with waves of low and high steepnesses.

The transmission coefficient was measured by the use of wave probes, and the breakwater motions were measured by an optical system. Three reference markers were attached to the model at known positions vertically above the breakwater's center of gravity, with fixed scales located behind each target. The amplitudes of motion, but not the phases, were measured by sighting the targets and scales through a theodolite, and aligning the cross-hairs in turn on each target at its maximum horizontal or vertical excursion. Simple algebraic formulae were used to relate these motion amplitudes to those of the breakwater's center of gravity.

A preliminary comparison with numerical predictions for the case of the rectangular breakwater has been carried out and selected results are indicated in Figs. 6 and 7. In the figures, a is the half beam of the breakwater. Fig. 6 compares numerical results of the transmission coefficient with measured values, as well as with the field measurements reported by Nelson *et al.* (1983) and Nece and Skjelbreia (1984). There is considerable scatter in the measured values so that the comparison is somewhat inconclusive. The values obtained from field measurements are relatively high and relatively insensitive to wave frequency. Fig. 7 shows the heave response amplitude operator, with the numerical predictions based on various values of the viscous damping coefficient. The trend of the response to reduce with increasing wave frequency is apparent.

As expected, the numerical predictions confirm that the breakwater is most effective for higher frequency waves, corresponding approximately to $B/L > 0.3$, where B is the width of the rectangular section and L is the incident wave length. The roll and sway motions exhibit strong resonant peaks, which are quite sensitive to the value of the viscous damping

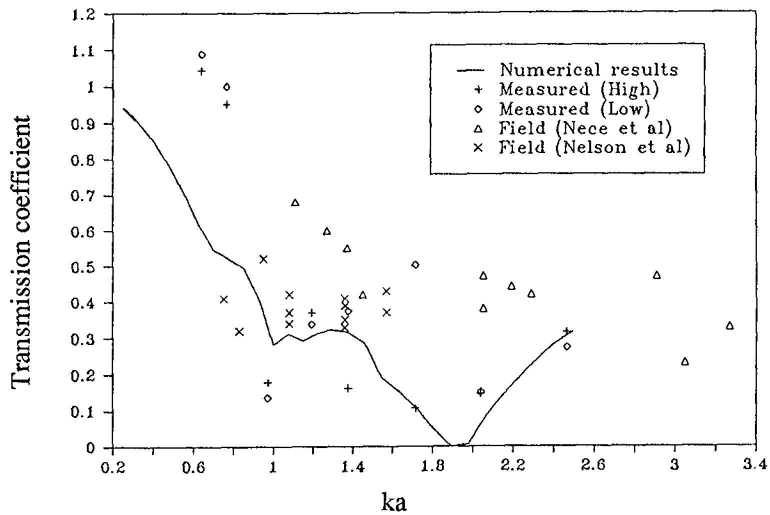

Fig. 6. Numerical, laboratory and field results of the transmission coefficient for the rectangular breakwater.

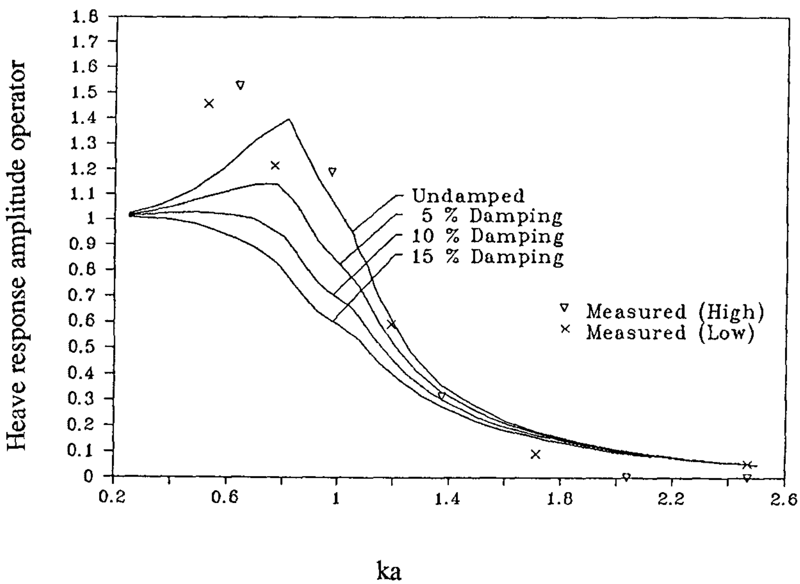

Fig. 7. Numerical and laboratory results of the heave response amplitude operator for the rectangular breakwater.

coefficient selected. With only 5% damping, these resonant peaks are all but removed, which is consistent with the observations of other studies (e.g. Miller and Christensen, 1984).

CONCLUSIONS

Floating breakwaters are a viable means of providing wave protection in areas where incident wave conditions are not too severe and water depths are relatively large. They have been widely used in British Columbia, Canada. Although experience in British Columbia has not revealed major difficulties in the use of floating breakwaters, other reported difficulties associated with their use include a possible inability to provide adequate protection from waves, and possible damage or failure most often associated with connections between individual units of a breakwater or with its moorings.

A numerical model based on linear diffraction theory and extended to include the effects of moorings, obliquely incident, random waves and additional damping has been developed. The program has been verified in part against laboratory measurements and should be quite viable for use in floating breakwater design. Laboratory tests have been carried out, but a comparison with numerical predictions is somewhat inconclusive.

APPENDIX - REFERENCES

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Table 1. Summary of Floating Breakwaters in British Columbia

No.	Location	Type	Year	Fetch (km)	Dirn.
1	Richmond	Caisson	1979	1.7	W
2	Port Moody	Log Bundle	1976	0.8	NE
3	Deep Cove	Caisson	1976	5.5	NE
4a	Burrard YC	Caisson/barge	1977	3.1	E
4b	Burrard YC (Destroyed 1983)	Scrap tire	1977	3.1	E
5	Eagle Harbour	Pontoon / tire	1977	39.1	SW
6	Horseshoe Bay	Caisson / ship		9.0	N
7	Powell River	Ship Hull	1930+	28.7	SW
8a	Lund	Caisson	1987	29.6	SW
8b	Lund (Removed 1987)	A-frame	1963	29.6	SW
9	Brown Bay	Tank Car	1983	2.8	E
10	Fanny Bay	Log Bundle		2.6	NE
11	Deep Bay	Log Bundle		2.2	W
12	Ford Cove	Log Raft		6.5	NW
13	Northwest Bay (Destroyed 1980)	Log / Styrofoam	1975	37	
14	Nanaimo			0.2	E
15	Nanaimo	Caisson	1974	5.3	SE
16	Nanaimo				
17	Pt Browning	Log		2.1	SE
18	Bedwell Hbr	Log		3.0	NW
19	Maple Bay	Caisson	1977	4.3	NE
20	Victoria Hbr	Caisson		0.5	S
21	Esquimault	Caisson		1.8	SW
22	Becher Bay	Log		1.5	SE
23	Sooke Basin	Log		1.9	SW
24	Prince Rupert	Log			
25	Prince Rupert	Log			
26	Qn Charlotte City	Log		4.4	
27	Qn Charlotte City	A-frame	1967	2.4	
28	Kelowna	Log Bundle	1978		W
29	Nakusp	Caisson	1986		
30	Tahsis	Log		2.8	SE