A survey of passive wave absorbers

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Abstract

One of the most common laboratory effects that plague physical model experiment is reflection of wave energy from boundaries or from model structures, and dealing with wave reflection tanks right behind wave generation in importance to high quality laboratory experiments. A through survey of passive wave absorbers by authors indicate that parabolic longitude profile decrease reflection and combined with progressively wire mesh screens of progressively decreasing porosity spells a minimum reflection which its length can be constructed less than one-wave length. The efficiency can be increased by utilizing gravel and stones.

Keywords: Wave absorber, Wave reflection, Porosity, Screen

Introduction

A wave tank is one of the most important professional and educational tools applied in coastal and offshore engineering. It is usually a long channel with a wavemaker at one end, and a wave absorbing unit at the other. Water wave generated by wavemaker propagate along the tank and are utilized in the physical modeling of various wave-related phenomenon.

In reality, water wave propagating in the tank are exposed at the end of the tank to a physical wave-absorbing unit, usually an impermeable or a porous wave absorber (Sulisz, 2003).

One of the most common laboratory effects that plague physical model experiment is reflection of wave energy from boundaries or from model structure, and high quality and reliable laboratory experiments can be achieved when wave reflection is confined properly.

Unwanted reflections can alter significantly the incident wave field, which in turn may impact test results. Well conducted model studies attempt to minimize wave reflections by placing wave absorbers at reflective boundaries.

Wave absorbers are broadly classed into *passive absorbers* that damp incident wave motion by a variety of techniques, and *active absorbers* that move in response to incident waves. An effective wave absorber is one can reduce the reflection below 10%, while efficient one may has a length less than one wave length and… . Active wave absorbers are efficient if moving absorber board is in just right motion at just right time so that the absorber velocity matches the wave velocity, however absorber paddle velocities will not exactly match those of wave resulting in some reflection, and precise synchronization of the wave and absorber phases may be very difficult and sometimes impossible because of either technology or exact numerical data analysis or both. Although in passive wave absorbers this is not the case but they often require a substantial length to reduce reflection efficiently and can use up valuable space in wave flume or basin. So deciding on wave absorber class is a challenging task which is affected from required effectiveness and efficiency.

In this article passive wave absorbers are summarized after some instructive discussion about wave reflection which is most important phenomenon in wave absorber surveying.

- If there is a change in water depth as a wave propagates forward, a portion of the wave's energy will be reflected. When a wave hits a vertical, impermeable, rigid surface-piercing wall, essentially all of the wave energy will reflect from the wall. On the other hand, when a wave propagates over a small bottom slope,

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only a very small portion of the energy will be reflected. The degree of wave reflection is defined by the reflection coefficient:

$$C_r = H_r / H_i \tag{1}$$

where *Hr* and *Hi* are the reflected and incident wave heights, respectively.

- Wave energy that enters a harbor or end of a wave tank must eventually be dissipated. This dissipation primarily occurs at the harbor or wave tank interior boundaries. Thus, it is necessary to know the reflection coefficients of the interior boundaries to fully define wave conditions inside a harbor or wave tank. It is also necessary to decrease the reflection of certain boundaries in order to keep interior wave agitation at acceptable levels.
- The reflection coefficient for a surface-piercing sloped plane will depend on the slope angle, surface roughness, and porosity. It will also depend on the incident wave steepness Hi/L. Consequently, for a given slope roughness and porosity, Battjes(1974) indicated that wave reflection will depend on a parameter known as the surf similarity number or Iribarren number (Pope, Lockhart, & Morang, 2002)

$$I_r = \frac{\tan \alpha}{\sqrt{H_i / L_0}} \tag{2}$$

where α is the angle the slope forms with the horizontal and L_0 is the wave length.

- Most of the interior boundaries of many harbors are lined with structures such as bulkheads or reveted slopes. Recent laboratory investigations of Seelig & Ahrens(1981), Seelig 1983and Allsop & Hettiarachchi (1988) indicate that the reflection coefficients for most structure forms (which can be utilized in tank wave absorber)can be given by the following:

$$C_r = \frac{a.I_r^2}{b + I_r^2} \tag{3}$$

where the values of coefficients *a* and *b* depend primarily on the structure geometry and to a smaller extent on whether waves are monochromatic or irregular. The Iribarren number employs the structure slope and the wave height at the toe of the structure. Table 1 presents values for the coefficients *a* and *b* collected from the above references (Pope, Lockhart, & Morang, 2002).

Table 1- Wave reflection equation's (3) coefficients

Structure	Wave	a	b
Plane slope	Monochromatic waves	1.0	5.5
Plane Slope	Irregular waves	1.1	5.7
Rubble	….	0.6	6.6
Dolos-Armored breakwaters	Monochromatic waves	0.56	10.0
Tetrapod-Armored breakwaters	Irregular waves	0.48	9.6

As mentioned wave reflection leads to problems in full scale conditions, shipping near seawalls and inside harbors, and for experiments in basins or channels, as well. Consequently, many studies were carried out to define wave absorbers with best efficiency. In this paper, the two main working principles of wave absorbers, viscous dissipation and their combinations are discussed to enhance the efficiency. These principles can be utilized by different mechanisms which are surveyed in following.

Gentle Slope

As mentioned a very small portion of wave energy will be reflected from a gentle slope (less than 1:10) but while plane slope approaches to vertical position as expected from eq. (3), the reflection coefficient approaches to unity.

Incident wave will break on the slope, causing an increase in energy dissipation and consequently decrease in the reflection coefficient. Thus beaches and gentle slopes are generally very efficient wave absorbers, particularly for shorter period wind-generated waves. An experimental dissipative beach model is illustrated in fig. 1.

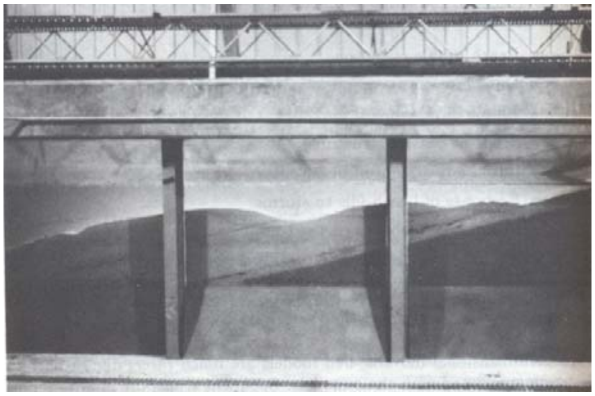

Figure 1- Dissipative beach model (Hughes, 1993)

Straub, Bowers, & Herbich (1957)briefly reviewed earlier studies on wave reflection and absorption . They presented experimental results plotting reflection coefficient versus slope angle for different values of wave steepness. Their experiments include impermeable slopes, crushed rock slopes, wire mesh slopes, and several composite slopes. Their results indicate that for an efficient wave absorber crushed rock absorber must be used which will be discussed later in mixed type wave absorbers (Hughes, 1993).

Dissipative beaches or gentle slopes are systems where most wave energy is dissipated through the process of breaking. Guza (1974) was apparently the first to use term dissipative beach and because gentle laboratory slopes have a similar hydrodynamic performance we can apply dissipative beach concepts and formulas for that kind of wave absorbers. He indicated that the wave-energy status of a nearshore system (therefore a gentle slope) could be determined using surf-scaling parameter, ε :

$$\varepsilon = \frac{a\omega^2}{g\tan^2\alpha} \qquad (4)$$

where a is the wave amplitude at breaking, ω is the wave radian frequency ($\omega = 2\pi/L$, where L is wave length), g is the gravity constant, and α is the beach slope in degrees. The proportion of incident wave energy that is dissipated by breaking increases as ε increases. When ε is less than about 2.5, most wave energy is reflected off the foreshore. For beaches where ε is larger than 20, most energy is dissipated by the turbulence associated with wave breaking. Guza (1974) designated these latter beaches as dissipative. Thus, the relative degree of dissipation or reflection of incident wave energy in a nearshore system may be used as a criterion for the classification of beaches. This is usually accomplished under the rubric of nearshore morphodynamics (Sherman, 2005).

San *et al.*(1982) have shown that the efficiency is better when the absorbing beaches are made of parabolic profile surfaces, the concavity of which is turned upwards, than when they are made of simple planes (Lebey & Rivoalen, 2002).

Svendsen(1985), noted that the reflection from bottom depth transitions can be made negligible if

$$\frac{L\tan\alpha}{h} \le 1 \qquad (5)$$

where L is wave length, h is water depth, and α is the local beach slope. Furthermore, an absorbing beach should be designed to keep the parameter, $L\tan\alpha/h$, equally small at all depths, or

$$L\tan\alpha/h = c \qquad (6)$$

where c a constant. If we replace the local wave absorber slope, $\tan\alpha$ with dh/dx , substitute the long-wave approximation for wavelength ($L = \sqrt{gh}T$) , and integrate, eq. (6) becomes

$$h = \left(\frac{c^2}{4gT^2}\right)x^2 \qquad (4\text{-IV})$$

which is a parabola with summit at $h=0$, the still water shore line. Svendsen reported that this shape of absorber can give reflection below 5% with $c=1$and absorber length between 10 to 15 times the depth of the constant depth portion of the wave tank (Hughes, 1993).

(Ouellet & Datta, 1986) concluded for impervious plane-sloped wave absorbers the reflection coefficient decreases as wave steepness increases for a constant slope and reflection coefficient decreases as slope decreases for constant wave steepness. Also concluded parabolically-shaped absorbers appear to work better (Hughes, 1993).

Screens or wire mesh plates

Scattered waves through the harbour mouth may cause reflections leading to the generation of a partial standing waves, which may result in damage to ships and unsafe navigation conditions. Furthermore, one of the major problems associated with laboratory wave basins is the presence of unwanted reflections. This requires the installation of wave absorbers adequate to provide energy dissipation and to avoid the wave reflecting off the absorber and propagating back to test location. One of methods involves using a number of thin perforated vertical screens in which the porosity decreases towards the rear of the absorber. Fig. 2 depicts one of these wave absorbers.

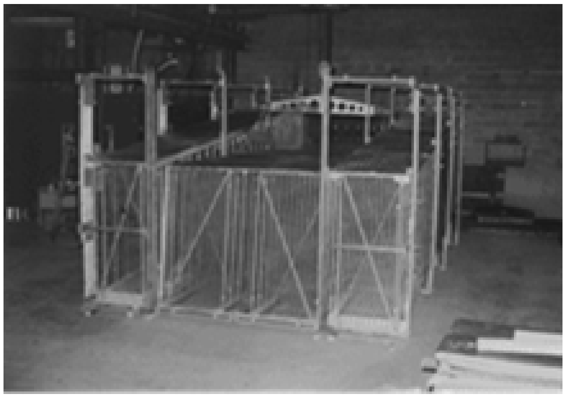

Figure 2- Multiple screen wave absorbers for a Malaysian testing facility (DRAMEX, 2004)

The functional efficiency of these wave absorbers is evaluated by calculating the reflection and transmission of wave, which depends on the characteristics of the incident wave (wave height, H, wave period, T, and angle of incidence, θ) and of the absorber, such as its geometry and its composition.

Goda & Ippen (1963) theoretically analyzed and tested different wave absorbers composed of vertical mesh screens aligned normal to the direction of wave propagation. Reflection was shown to be dependent upon screen spacing, but not so dependent on the number of screens "*provided the number is fairly large*". They also concluded that the efficient screen absorber must be at least as long as the wavelength of incident wave (Hughes, 1993).

Keulegan(1972) derived expressions for the damping of waves by screens from high porosity (≈95%-97%) aluminum wool, rubberized "horse-hair" and polyurethane foam. Model test results were provided for specific wave condition in tabular form (Hughes, 1993).

Le Mehaute(1972) introduced the progressive wave absorber as one in which porosity decreases in direction of wave propagation (Losada, Losada, & Baquerizo, 1993).

Kondo (1979) derived a theoretical solution for a breakwater with two porous walls. Chwang and Dong (1984) investigated the reflection and transmission of small-amplitude surface waves from a vertical porous plate fixed in an infinitely long channel of constant depth and wave trapping by a thin porous plate fixed near the end of a semi-infinitely long open channel of constant depth. Minimum reflection coefficients were obtained for plates with a separation of $mL/4$ (where $m=1,3,5,\ldots$ and L=wavelength) from the wall (Twu & Lin, 1991).

Jamieson & Mansard(1987) through an extensive experimental programme, evaluated the efficiency of upright wave absorbers made by multiple rows of perforated vertical metal sheets aligned normal to direction of wave propagation (Losada, Losada, & Baquerizo, 1993).

The mesh screens made in progressively decreasing porosity. They found that the frontal area of the supporting framework should be minimal. High porosity mesh screens work best for absorbing energy from high steepness waves. Low porosity screens work best for absorbing energy from low steepness waves. Mesh screen porosity should decrease toward the rear of the wave absorber. Screen locations should be selected approximately at node locations of the partial standing waves. Wider screen spacing is required for steeper waves and longer wave period, with sheet spacing progressively decreasing toward the rear of the wave absorber. Optimum wave absorber length varies between *0.35L*to*1.0L* where *L* is the maximum wavelength to be efficiently attenuated. The number of mesh screens in the absorber increases as the range of wave heights and periods to be absorbed increases (Hughes, 1993).

Jamieson *et al.* (1989) applied a similar configuration of mesh screens to absorb lateral wave energy at the side walls of a large wave tank (Hughes, 1993).

Losada *et al.*(1993) theoretically confirms and set bounds to the experimental results, which state that the performance of upright absorbers with constant porosity can be improved by decreasing the porosity of porous screens towards the rear of the absorber. This occurs for $\omega^2 h/g \succ 0.4$, where ω is angular frequency and h is depth. However, for $\omega^2 h/g \prec 0.3$, constant porosity absorbers produce the minimum reflection coefficient for the case studied. (Losada, Losada, & Baquerizo, 1993).

Porous or Permeable material

Impermeable wave absorbers built in wave tanks decrease wave reflection by causing wave breaking, however, an efficient impermeable wave absorber (often a very mild slope) occupies a significant part of a wave tank and wave breaking generates a strong current. For these reasons porous wave absorbers are more often applied in wave tanks to minimize wave reflection. Popularity of wave absorbers is expected to further increase with the growing variety of porous material available on the market and significant progress in recent years in the numerical modeling of wave interaction with porous media. New porous materials and numerical models make it possible to reduce the size and to optimize wave absorbing properties of porous wave-tank absorbers and one of them is illustrated in fig. 3.

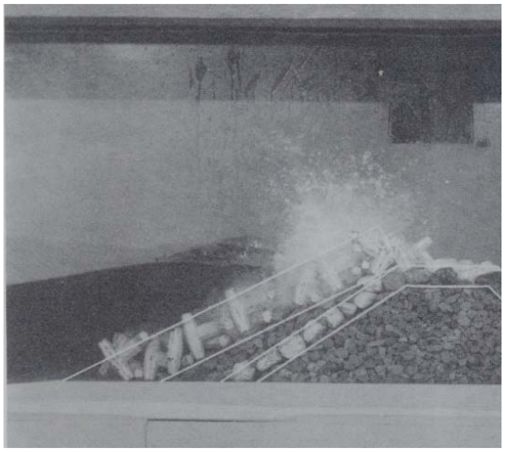

Figure 3- A porous rubble mound wave absorber in wave tank (Hughes, 1993)

Le Mehaute (1972) proposed a passive wave absorber in which the incident waves progressively encounter regions of increased energy dissipation (less porosity). In each section a portion of the energy is dissipated while the remainder is either transmitted or reflected. He tried to optimize the progressive wave absorber by minimizing reflection while gradually dissipating the energy. This allowed the overall length of the absorber to be shorter than one wavelength (Hughes, 1993).

Efforts done by (Madsen, 1983) to predicted the wave reflection from vertical permeable wave absorbers which indicated that reflection coefficient is function of the width of the absorber relative to the wave length. It appeared that on order to be efficient, rectangular wave absorbers width should be at least ¼ of the wave length. For higher waves a porosity of 0.95 is much more efficient than a porosity of 0.5. On the other hand the porosity 0.5 is optimal for absorbing very low waves, in which case the high porosity results in almost full reflection and it is seen that the surface slopes of these absorbers (1:3 to 1:4) have increased the efficiency (Madsen, 1983).

Results of (Sulisz, 2003) show that the geometry of wave absorbers has a complex effect on wave reflection and length of wave absorber has a limited, often nonintuitive effect on wave reflection and extension of wave absorber beyond a certain limit does not change wave reflection. Physical and hydraulic properties of the material used to build an absorber have a significant effect on wave reflection. The results show that wave reflection usually decreases with increasing porosity and decreases with increasing damping coefficient; this applies to a wide range of wave frequencies. A further reduction of wave reflection can usually be achieved by increasing absorber width. Experimental data show that the porous wave absorber made from plastic material dissipates incoming wave energy very well (Sulisz, 2003).

Mixed Types

In several reports it is indicated that unique absorbing mechanism usually is not efficient and effective as the only means of damping, so they are often used in combination with each other as will be discussed in the following.

Screens on a Gentle Slopes

(Svendsen, 1985)pointed out that constant-depth screens are not very efficient as the only means of damping, but they often are used in front of wave boards to damp lateral water motions (Hughes, 1993).

(Ouellet & Datta, 1986) concluded curves of reflection versus absorber slope are similar for crushed rock and wire mesh for slope angles less than 15 degrees. Wire mesh absorbers are more efficient for slope angles greater than 15 degrees. They also indicate parabolically-shaped absorbers appear to work better (Hughes, 1993).

Porous Material on Gentle slopes

Earlier experiments of Straub*et al.* (1957), included impermeable slopes, crushed rock slopes, wire mesh slopes and several composite slopes indicated that crushed rock absorber slopes must be less than about 1:4 to keep reflection less than 10% (Hughes, 1993). A simple kind of aforementioned wave absorbers is shown in fig. 4.

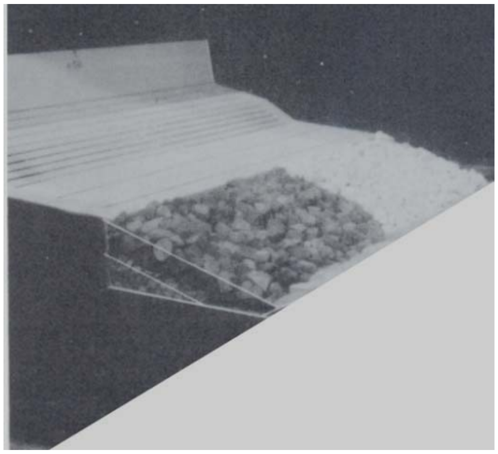

Figure 4- Porous material mounted on a slope (Hughes, 1993)

Lean(1967) developed a simplified theory for predicting wave reflection from permeable wave absorbers of simple shape made of uniformly porous material. Lean examined absorbers backed by vertical walls, uniformly-sloping bottoms, and parabolically-sloping bottoms. For a given overall wave absorber length, Lean found that lower reflection coefficients are possible when the porous absorber material is placed over plane-sloping and parabolically-sloping bottoms rather than placing absorber material over a constant depth bottom. He recommended that the absorber length should be at least 75% of the incident wavelength to achieve wave reflection coefficients below 10%, however there will always be some reflection, even for very long absorbers (Hughes, 1993).

Ouellet *et al.* (1986) indicated that the most popular passive wave absorber is a constant-slope beach constructed of gravel or stones. Although these fixed absorbers prove effective in reducing wave reflection, they are not easily moved, making them less practical for model basins where frequent boundary changes may be need.

Also Ouellet *et al.* (1986) concluded that size of stones used in permeable wave absorbers appear to have a little effect on the average reflection coefficient. Curves of reflection versus absorber slopes are similar for crushed rock and wire mesh for slope angles less than 15 degrees (Hughes, 1993).

Results of Sulisz (2003) show slope of porous absorbers have a more pronounced effect on wave reflection. The results show that wave reflection usually decreases with decreasing the slope. A reduction of wave reflection can be achieved by increasing absorber length and simultaneously decreasing its slope (Sulisz, 2003).

Concluding Remarks

The problem due to the swell reflection on sea wall remains important especially inside harbors and coast shipping. The wave reflection leads to the same difficulties in experimental channels or basins. The incident swell or wave produced by a model must be completely dissipated in experimental channels or basins because of the necessary quality of the tests. Many wave absorber types exist and some of them can be used in full scale conditions or in test basins, as well. The wave absorbers can be divided into two categories: i)wave absorbing beaches and ii) viscous phenomenon or resonance mechanism utilized structures.

Wave absorbing beaches have the advantage of simple design and being very efficient for a large scale of swells. But their required sizes make them impossible to use in harbors and also using them in laboratory sets needs large space especially in test basins. To overcome this problem of too important sizes, two main solutions are used:

1. Transform the simple wave absorbing beaches design into constructing increasing the wave breaking phenomenon or the viscous dissipation process of the swell energy.
2. Use more recent phenomenon or mechanisms which are designed to create an important dissipation of the swell energy under effect of viscous phenomena and of mechanism of resonance. Also later solution involve strong structures, they have advantage of requiring shorter sizes.

A through survey of passive wave absorbers by authors indicate that parabolic longitude profile decrease reflection and combined with progressively wire mesh screens of progressively decreasing porosity spells a minimum reflection which its length can be constructed less than one-wave length. The efficiency can be increased by utilizing gravel and stones.

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