

Wave dissipation performance of breakwater

Yufan Hu^{1*}

¹Department of Sino-British College, Liverpool John Moores University, Shanghai, China

Abstract. This paper conducts a comprehensive review of the wave dissipation performance of various types of breakwaters in marine engineering. Over time, breakwaters have undergone significant evolution, and modern ones are constructed using advanced materials to enhance the efficiency of wave energy dissipation. They can be categorized into vertical, sloped, floating, and permeable types, each possessing distinct wave dissipation characteristics, physical principles, advantages, and disadvantages. Vertical breakwaters primarily reflect wave energy but can potentially cause strong reflections, which may have adverse effects in certain areas. Sloped breakwaters utilize the principles of kinetic energy conversion and wave breaking to dissipate energy, making them suitable for a wide range of coastal conditions. Floating breakwaters offer flexibility and adjustability to different wave conditions, while permeable breakwaters allow for water exchange while still reducing wave energy, which is beneficial for maintaining the ecological balance of the coastal area. The choice of breakwater type depends on factors such as wave conditions, topography, and environmental impact. In the future, breakthroughs in materials, design, and technology are anticipated to improve the performance of breakwaters. The selection and combination of breakwater types should take into account local conditions and requirements to ensure the effective protection of coastlines and marine facilities.

1 Introduction

Breakwaters have played a crucial role in marine engineering throughout history. Their development can be traced back to ancient times when simple structures were built to protect coastal areas from the force of waves. Over the years, with advancements in engineering techniques, the design and materials used for breakwaters have evolved significantly. Modern breakwaters are often constructed using concrete, steel, and other advanced materials, and their structures are designed to be more efficient in dissipating wave energy.

The basic concept of a breakwater is to act as a barrier that reduces the energy of waves, thereby protecting coastlines, harbours and marine facilities from damage. Different breakwaters, such as vertical, sloped, floating, and permeable ones, have distinct wave dissipation performances based on their characteristics and the conditions in which they are used.

For instance, vertical breakwaters are suitable for deep water and areas with good foundation conditions. They are designed to reflect most of the wave energy, reducing the

* Corresponding author: 631501010829@mails.cqjtu.edu.cn

intensity of waves that reach the protected area. However, they can also cause strong wave reflections, which may need to be managed carefully to avoid adverse effects on nearby areas. Sloped breakwaters suit areas with poor foundations and abundant stone sources. They utilize the principles of kinetic energy conversion and wave breaking to dissipate wave energy. When a wave approaches a sloped breakwater, its energy is partially absorbed as the wave climbs up the slope, and the wave may also break on the slope, further reducing its energy. Floating breakwaters are used in deep water with small wave heights and large wave slopes. They are usually made of buoyant materials and are anchored to the seabed. These breakwaters work by absorbing and dissipating the energy of waves through the movement and deformation of the floating structure. Permeable breakwaters allow some wave energy to pass through while still providing some degree of wave dissipation. They can reduce the wave height and energy by causing turbulence and friction within the structure [1].

Disasters, such as the 1993 Hokkaido earthquake and tsunami in Japan and Hurricane Katrina's impact on New Orleans in 2005, highlight the importance of effective breakwaters in protecting coastlines and marine facilities [2]. The performance of breakwaters can be challenged by extreme events, and their design and construction need to consider a range of factors to ensure their effectiveness. In this paper, the wave dissipation performance of these different types of breakwaters and their effects in practical applications will be reviewed. By understanding the characteristics and performance of each type, more informed decisions can be made in the design and construction of breakwaters to better protect the coastlines and marine facilities.

2 Wave dissipation characteristics of different types of breakwaters

Breakwaters can be classified into several types based on their structure and function, including vertical, sloped, floating, and permeable types. Each type has its unique wave dissipation characteristics and physical principles[3].

2.1 Vertical breakwaters

Vertical breakwaters are designed to mainly reflect the wave energy. When a wave approaches a vertical breakwater, part of the wave is reflected, and the remaining energy is transferred to the breakwater. The wave force acting on a vertical breakwater can be analyzed using the following formulas:

- Horizontal wave force:

$$F_H = \frac{1}{2} \rho C_p H^2 L \quad (1)$$

where (F_H) is the horizontal wave force, (ρ) is the density of water, (C_p) is the pressure coefficient, (H) is the wave height, and (L) is the wavelength.

- Vertical wave force:

$$F_V = \rho g C_v \frac{H^2 L}{8} \quad (2)$$

Where (F_V) is the vertical wave force, (g) is the acceleration due to gravity, and (C_v) is the vertical force coefficient.

- Wave moment:

$$M = F_H \cdot h_c \quad (3)$$

Where (M) is the wave moment and (h_c) is the height of the centre of pressure from the base. However, vertical breakwaters can cause strong wave reflections, which may lead to increased wave energy in some areas. To reduce the reflection, measures such as adding curved surfaces or using porous materials can be taken.

Advantages of vertical breakwaters include their strong ability to reflect waves, providing good protection for the areas behind them. They are suitable for areas where strong wave reflection is acceptable or can be managed, such as in some industrial ports.

However, a major disadvantage is that they can cause strong wave reflections, which may lead to increased wave energy in some areas. This can cause erosion and instability in the surrounding areas. To reduce the reflection, measures such as adding curved surfaces or using porous materials can be taken, but these additions may increase the complexity and cost of the breakwater.

2.2 Sloped Breakwaters

Sloped breakwaters mainly utilize the principles of kinetic energy conversion to gravitational potential energy and wave breaking. When a wave approaches a sloped breakwater, its energy is partially absorbed as the wave climbs up the slope. The wave may also break on the slope, further dissipating its energy. The Goda formula [4], proposed by Yoshimi Goda, is often used to calculate the wave forces on sloped breakwaters.

- The horizontal wave force (P_s) is calculated as:

$$P_s = (\alpha_1 + \alpha_2)\gamma H \tag{4}$$

where (α_1) and (α_2) are coefficients, (γ) is the specific weight of water, and (H) is the wave height.

- The total wave force (P) is calculated as:

$$P = 0.5(P_s + P_b)d_1 + 0.5(P_s + P_m)h_c^* \tag{5}$$

where (P_b) and (P_m) are related to (P_s), (d_1) is the height from the base of the parapet wall to the still water level, and (h_c^*) is the height of the parapet wall above the still water level.

- The energy dissipation rates associated with wave breaking on slopes can be expressed using the following empirical formula (Yoshimi Goda formula)[5]:

$$\gamma = A\{1 - \exp[-1.5 \frac{\pi db}{L_0} (1 + 15 \tan^{4/3} \theta)]\} / \frac{db}{L_0} \tag{6}$$

In this formula:

- γ represents the wave energy dissipation coefficient.
- db is the water depth at the breaking point.
- L_0 is the deep water wavelength.
- θ is the slope angle.

Advantages of sloped breakwaters include their effective wave dissipation ability, reducing the energy of waves through kinetic energy conversion and wave breaking. The construction of sloped breakwaters may require more materials and space compared to vertical breakwaters. Additionally, the stability of the slope needs to be carefully considered to ensure its performance, as the slope may be subject to erosion and instability over time.

2.3 Floating Breakwaters

Floating breakwaters are usually made of buoyant materials and are anchored to the seabed. They work by absorbing and dissipating the energy of waves through the movement and deformation of the floating structure.

- The wave force acting on a floating breakwater can be analyzed using the following formula:

$$F = C_d \frac{1}{2} \rho U^2 A \tag{7}$$

Where (F) is the wave force, (C_d) is the drag coefficient, (ρ) is the density of water, (U) is the velocity of the water particles, and (A) is the projected area of the breakwater.

- The movement of the floating breakwater can be described by the equation of motion:

$$m \frac{d^2x}{dt^2} + C \frac{dx}{dt} + kx = F \quad (8)$$

Where (m) is the mass of the breakwater, (x) is the displacement, (C) is the damping coefficient, (k) is the stiffness coefficient, and (F) is the wave force.

Floating breakwaters can be easily installed and removed, making them suitable for areas with specific requirements or temporary wave protection needs.

However, they may require regular maintenance and monitoring to ensure their stability and performance. They may also be affected by extreme weather conditions and require additional measures for protection, which can increase the cost and complexity of their operation.

2.4 Permeable Breakwaters

Permeable breakwaters allow some wave energy to pass through while still providing some degree of wave dissipation. They can reduce the wave height and energy by causing turbulence and friction within the structure. The wave dissipation effect of permeable breakwaters can be analysed using the concept of transmission coefficient, which is defined as the ratio of the transmitted wave height to the incident wave height. The transmission coefficient can be calculated using empirical formulas or numerical models.

3 Advantages and Disadvantages of Different Types of Breakwaters

Compared to other types, vertical breakwaters are suitable for areas where strong wave reflection needs to be managed, such as some industrial ports, but they may not be suitable for areas where wave reflection could cause problems due to increased wave energy. Sloped breakwaters are commonly used in areas where wave dissipation is the main goal, as they are more effective in reducing wave energy through kinetic energy conversion and wave breaking, and they are suitable for a wide range of coastal conditions. Floating breakwaters are more flexible and can be adjusted to different wave conditions, making them suitable for areas with specific or temporary needs. Permeable breakwaters are a good choice in areas where water exchange is desirable while still reducing wave energy, which is beneficial for the ecological balance of the coastal area. The choice of breakwater type depends on factors like local wave conditions, coastal topography, protection purpose, and environmental impact. Engineers need to carefully consider these factors to select the most appropriate type for a specific location to ensure effective wave dissipation and coastal protection.

4 Conclusion

In conclusion, to ensure effective wave dissipation and protection of the coastal area, a rational combination of different types of breakwaters should be adopted based on specific conditions.

For instance, in areas where strong wave reflection is manageable, such as some industrial ports, vertical breakwaters can be utilized. The horizontal wave force acting on a vertical breakwater is calculated by the formula $F_H = \frac{1}{2} \rho C_p H^2 L$. However, their strong wave reflections may cause problems in areas where it is undesirable, so careful consideration is needed.

Sloped breakwaters, which utilize the principles of kinetic energy conversion and wave breaking, are often a good choice in areas where wave dissipation is the primary goal. The

Goda formula for calculating the wave forces on sloped breakwaters, such as $P_s = (\alpha_1 + \alpha_2)\gamma H$ and $P = 0.5(P_s + P_b)d_1 + 0.5(P_s + P_m)h_c^*$, demonstrates their ability to reduce wave energy. They are suitable for a wide range of coastal conditions and are commonly used in many ports and harbours.

Floating breakwaters, with their flexibility and adjustability to different wave conditions, are suitable for areas with specific or temporary wave protection needs. The formula $F = C_d \frac{1}{2} \rho U^2 A$ shows how they work to absorb and dissipate wave energy.

Permeable breakwaters are a suitable option in areas where allowing some water exchange while reducing wave energy is desirable to maintain the ecological balance of the coastal area.

In the future, there may be several potential breakthroughs in the performance of breakwaters. Advances in materials science could lead to the development of more durable and efficient materials for breakwater construction. Their resistance will be enhanced. Further research and innovation in the design and layout of breakwaters, based on the understanding of the physical principles represented by these formulas, could improve their wave dissipation capabilities and reduce the impact of wave reflections. The integration of smart technologies and monitoring systems may enable real-time monitoring of breakwater performance and early detection of potential issues, which can improve maintenance and adjustments.

Overall, the selection and combination of breakwater types should be based on a comprehensive understanding of the local conditions and requirements, considering the characteristics and formulas associated with each type. Continued research and development in this field will contribute to the improvement of their performance and effectiveness in protecting our coastlines and marine facilities.

References

1. Li Yanbao, Wu Yongqiang, Jiang Xuedong, A Review of the Development of Research on Breakwater Failures at Home and Abroad. *China Harbour Engineering*. **6**,(2004)
2. Lei Songlin, Zheng Yonglai, Discussion on the Structural Type and Application of Breakwater. *China Water Transport*. **06**,07,(2007).
3. Industry standard of the People's Republic of China Code for design of breakwaters and revetments. People's Communications Publishing House Co., Ltd. (2018).
4. Goda Y, A performance test of nearshore wave height prediction with CLASH datasets. *Coastal Engineering*. **56**,220-229,(2009).
5. Kamphuis J W, Incipient wave breaking[J]. *Coastal Engineering*. **15**,185-203,(1991).