Wave spectrum filtration by navigation channel

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ABSTRACT

The article presents a theoretical model of filtering the wave spectrum by an approach channel, based on the refractive reflection of waves. Was performed an analytical, experimental, and numerical study of waves in the channel. When the waves pass through the channel, some frequency components of the wave spectrum are reflected from the channel. This trend was reflected in numerical and analytical studies, and the calculation results showed good convergence.

KEY WORDS: Numerical simulation, refraction, navigation channel, wave spectrum, critical angle, experimental studies, wave basin, interference.

INTRODUCTION

Innovations in marine technology have led to an increase in maritime traffic worldwide, which has led to a significant increase in the average size of ships. This trend has led to the need to expand port facilities and increase the size of approach channels. Modern practice in the construction of navigation channels shows that they can have a significant length, width, and depth. They can have a significant impact on the propagation of waves in the channel zone and require special research, the development of appropriate models and calculation methods. Correct estimates of the wave parameters in the area of the navigation channel affect the loads acting on the port’s protective structures, and on the waves penetrating the port’s water area, affecting the conditions for mooring ships at the berths.

The parameters of waves suitable for coastal hydraulic structures are determined based on field observations, laboratory modeling, computational methods, and numerical studies. The problem of the impact of the underwater channel on the waves is a specific problem in which the waves can be amplified on the channel and can be weakened. This problem has been investigated by several scientists [Beltrami et al., 2003; Dusseljee et al., 2012; Dusseljee et al., 2014; Gruwez at el., 2011; Gruwez, Bolle, Verwaest, 2012], but most of the research relates to regular waves. At the same time, the problem of wave propagation over an underwater channel requires considering the irregular nature of wind waves.

In the studies [Kantardgi, Dreizis 1986; Kantardgi et al.,1993], a model for filtering the wave spectrum by shear current was proposed. Gravitational waves propagating on a flow that is inhomogeneous in the direction perpendicular to the velocity are considered. The OX axis is directed along the flow velocity \( \mathbf{u} = (u, 0) \), and always \( u > 0 \) (Fig. 1).

From the dispersion relation for waves on the current in deep water:

\[
\omega - k_x U = g \frac{1}{2} \left( k_x^2 + k_y^2 \right)^{1/4} \left[ U \frac{d}{k_y} \right]^{1/2} \left( k_x^2 + k_y^2 \right)^{1/2}
\]

where:
- \( \omega \) – wave frequency;
- \( d \) – water depth;
- \( U \) – flow velocity;
- \( \mathbf{k} = (k_x, k_y) \) – wave vector.

Eq. 1 describes the refraction of waves by a shear flow with varying depth and velocity. In this case, the condition \( k_y = 0 \) corresponds to the reflection of the wave from the current:

\[
U_m \geq U_{cr} = \frac{\omega}{k_x} \left[ \frac{g}{k_y} \frac{d}{\text{th} k_y} \right]^{1/2}
\]

where:
- \( U_m \) – maximal current velocity.
- \( U_{cr} \) – current velocity of wave reflection.

At \( U_m > U_{cr} \), the wave is reflected from the flow; at \( U_m < U_{cr} \), the waves pass through the flow region. No reflection of the waves occurs in the oncoming current. For the frequency spectrum of waves, Eq. 1 is applied to each component of the spectrum. Then, from Eq. 2, we can obtain an expression for the critical frequency in the form: