ANALYSIS OF THE WAVE GENERATED BY A LANDSLIDE IN RELATION TO IDEAL WAVE MODELS

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INTRODUCTION

Today, the management of water resources and ensuring the reliability and operational safety of hydraulic structures are considered among the greatest scientific and practical challenges worldwide. In particular, the extreme hydrodynamic processes that occur in reservoirs, lakes, and other natural and artificial water bodies-including shock waves generated by landslides-are regarded as a hazard in their own right [1].

The soil from a landslide entering a body of water at high speed transfers a large amount of momentum to the aquatic environment. This leads to a sudden deformation of the water surface and the formation of waves characterized by high energy and often nonlinear behavior. Such waves pose a serious threat to the stability of dams and other hydraulic structures [2].

This work provides a scientific analysis of the physical properties of waves generated by a landslide impact on water, their key parameters, and their relationship to idealized wave models.

General characteristics of waves caused by a landslide.

A landslide is a geomechanical process in which soil masses move and shift under the influence of gravity; it occurs on mountain slopes or along the banks of bodies of water. When this mass enters the aquatic environment, an exchange of momentum occurs, leading to the formation of hydrodynamic waves.

Waves generated by a landslide are characterized by the following properties:

- high energy;
- localized nature;
- high degree of nonlinearity;
- attainment of a large amplitude in a short time.

For this reason, such waves are often interpreted as impulse waves in the scientific literature.

The physical mechanism underlying the interaction between landslides and water.

When the landslide mass plunges into a body of water, a complex, multi-stage process occurs:

1. The soil mass enters the aquatic environment;
2. The water is compressed and displaced upward;
3. Potential energy is converted into kinetic energy;
4. A wave front forms and propagates as a result of the deformation of the free surface.

The most important influencing factors in this process are the mass of the soil (m) and its velocity (υ), the water depth (h), the shape and volume of the soil, and the geometry of the water body.

The landslide impulse is determined as follows:

$$I = m \cdot \upsilon$$

As a result of transmitting this impulse into the water medium, wave energy is generated [2, 3].

Main parameters of the waves generated by the landslide.

The waves generated by a landslide are characterized by the following main parameters:

1. Wave height (H) - the maximum elevation of the free surface, which is directly related to the energy of the wave [4].
2. Wavelength (L) - the distance between two consecutive wave crests.
3. Wave propagation speed (c) is determined in shallow water conditions as follows [3]:

$$c = \sqrt{gh}$$

Here g is the acceleration due to gravity, and h is the water depth.

4. Wave energy is proportional to the square of the wave height:

$$E \sim H^2$$

This relationship shows that as the wave amplitude increases, its energy also increases.

The concept of ideal water waves.

Ideal waves are a theoretical model adopted to simplify mathematical modeling, based on the following assumptions:

- the fluid is ideal (no viscosity);
- the flow is laminar and continuous;
- energy losses are not taken into account;
- the wave shape is sinusoidal.

The ideal wave equation is expressed as follows [5]:

$$\eta(x, t) = a\sin(kx - \omega t)$$

here, a is the amplitude, k is the wavenumber, and ω is the angular velocity.

Differences between waves formed by a landslide and ideal waves.

The waves generated by a landslide are a real, complex, and nonlinear process, differing from ideal waves in the following respects [2, 5]:

Indicator	Wave generated by a landslide	Ideal wave
Nature	Nonlinear	Linear
Form	Asymmetric	Sinusoidal
Energy	With losses	No losses
Formation	Impulsive	Periodic

Therefore, ideal models cannot fully reflect the real process, but they are effective for identifying important laws.

Modeling approaches based on idealization.

The following theoretical approaches are widely used in calculating waves generated by landslides:

1. Shallow water equations (Saint-Venant equations)

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} = 0$$

2. Laws of conservation of energy and momentum – Allows for the assessment of the overall energy exchange in the system.

3. Frud number

$$Fr = \frac{\upsilon}{\sqrt{gh}}$$

This dimensionless quantity is the primary criterion that determines the flow regime and the wave characteristics.

Propagation characteristics of waves.

The waves generated by a landslide decrease in amplitude, dissipate energy, and transform in shape as they propagate through the water body. In these processes, dispersion, turbulent diffusion, and boundary conditions (shore influence) play an important role.

Impact on hydraulic structures.

Waves generated by a landslide can lead to the following hazardous conditions:

- overtopping of the dam (pereliv);
- erosion of the bank and slopes;
- loss of structural stability of the facility.

High-amplitude impulse waves are particularly dangerous, generating critical loads in a short time.

Laboratory models and numerical modeling.

Waves generated by a landslide are studied using the following methods:

- physical 3D laboratory models;
- numerical modeling;
- analytical and semi-empirical formulas.

Laboratory results allow for the verification and calibration of theoretical models.

CONCLUSION

Waves generated in water bodies by a landslide are a complex, multifactorial, and strongly nonlinear hydrodynamic process.

To gain a deep understanding of them, it is necessary to apply a comprehensive combination of theoretical, experimental, and numerical approaches.

Idealized models serve to simplify and explain the process and reveal the fundamental physical laws, but they do not fully reflect real conditions.

Therefore, when assessing the safety of hydraulic structures, it is crucial to rely on nonlinear models that approximate real-world conditions and on laboratory research.

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