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1.5 Classification and calculation of discharge capacity of broad-crested weirs

Broad-crested weirs (BCW) — are simple hydraulic structures that implement an important role in hydraulic engineering, especially in water resources management and aquatic environment protection. They are important hydro-technical structures designed to regulate water levels in rivers, reservoirs, and other water bodies, ensure public safety, and ensure water regimes for water supply, energy, shipping, and other sectors of the economy. For example, rain grates inlet. Their discharge capacity in the non-pressurized mode is calculated as broad-crested weirs in the work of Leandro [112], Lopes [113], Rubinato [115].

Spillways are structures that block the flow but allow a liquid with a free surface through its upper face and are designed to drain the liquid. Spillways also include large openings, if the flowing liquid does not wet the upper edge, and many other engineering structures, for example, small bridges, spillway dams, non-pressure culverts in road embankments, canal intake structures, and some types of spillways (spills with a thin wall) are widely used as accurate devices for measuring flow in hydraulic and hydro-technical laboratories and in a number of other cases.

The advantages of using broad-crested weirs include simplicity of design and cost-effective installation, high strength, and long service life. In some cases, broad-crested weirs is a convenient tool for measuring volumetric water flow velocity in open channels as in the work of Badr & Mowla [105], Zhuk et al.,[118].

The study of wide weir spillways is important in hydraulic engineering because such spillways are used to reduce excess water, conserve water resources, and prevent floods. Studying the flooded mode of operation of spillways with a wide threshold makes it possible to understand how the system behaves in different conditions and increases the effectiveness of such systems in practice.

The study of the dynamics of fluid movement through a flooded spillway, including the calculation of flow, pressures and velocity of fluid movement, is important to ensure the safety and efficiency of hydraulic structures such as dams, canals and culverts.

In addition, research on wide-bed spillways is important for developing new technologies and improving existing systems to conserve water resources and reduce the negative impact of floods on human life and property.

The spillway separates the flow into two parts: the upstream - the flow before the spillway and the downstream - the flow behind the spillway (figure 1).

The upper end of the broad-crested weir wall is called the crest of the spillway.

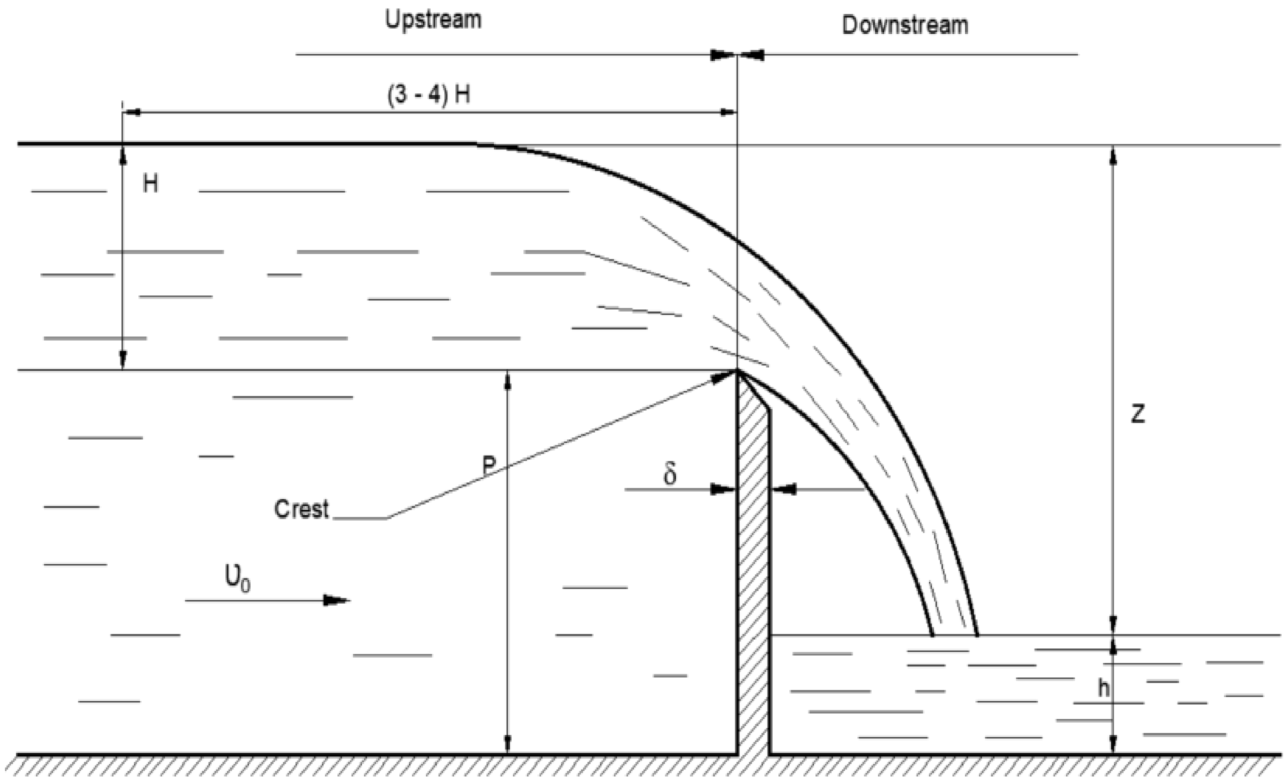

Fig. 1. Spillway.

The depth of the liquid above the crest of the broad-crested weir, measured where the level has not yet decreased, is called the static pressure on the spillway and is denoted by *H*. The drop in the liquid level in front of the spillway begins at a distance of 3 - 4 *H* from its crest. The excess of the crest of the spillway above the bottom of the stream upstream is called the height of the weir threshold and is denoted by *P*. The difference in liquid levels upstream and downstream is denoted by *Z*. $\boldsymbol{v_0}$ — is the approach speed, i.e. the average speed before the spillway; δ — is the thickness of the spillway wall.

Spillways are classified according to the following main features:

- *according to the outline of the wall profile*:

a) **with a thin wall** (or weirs with a sharp edge) (figure 1), when the liquid overflows through a thin (sharp) transverse obstacle. When the wall thickness is $\delta \leq 0.67\ N$, it is believed that the wall thickness does not affect the nature of the flowing weir;

b) **broad-crested weir** (figure 2), when the wall blocking the flow has a thickness of $8H \geq \delta > 2H$, at which a parallel jet flow is observed at the threshold;

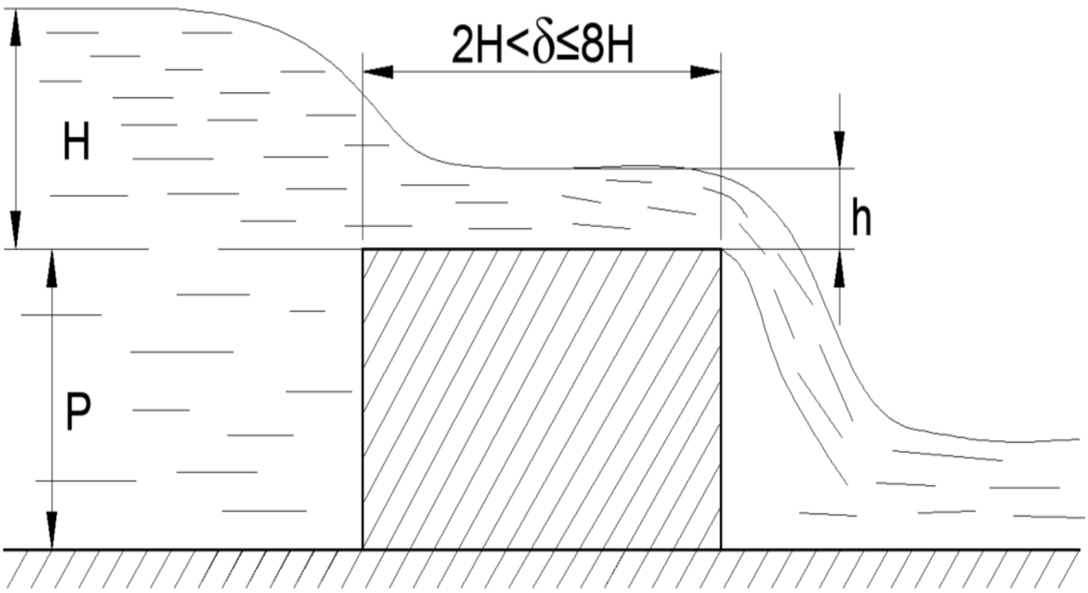

Fig. 2. Broad-crested weir.

c) **ogee-crested spillway** (figure 3), when the liquid overflows through a thick curvilinear wall $2H \geq \delta > 0.67H$, and the outline of the bottom boundary of such a spillway is close to the shape of a stream;

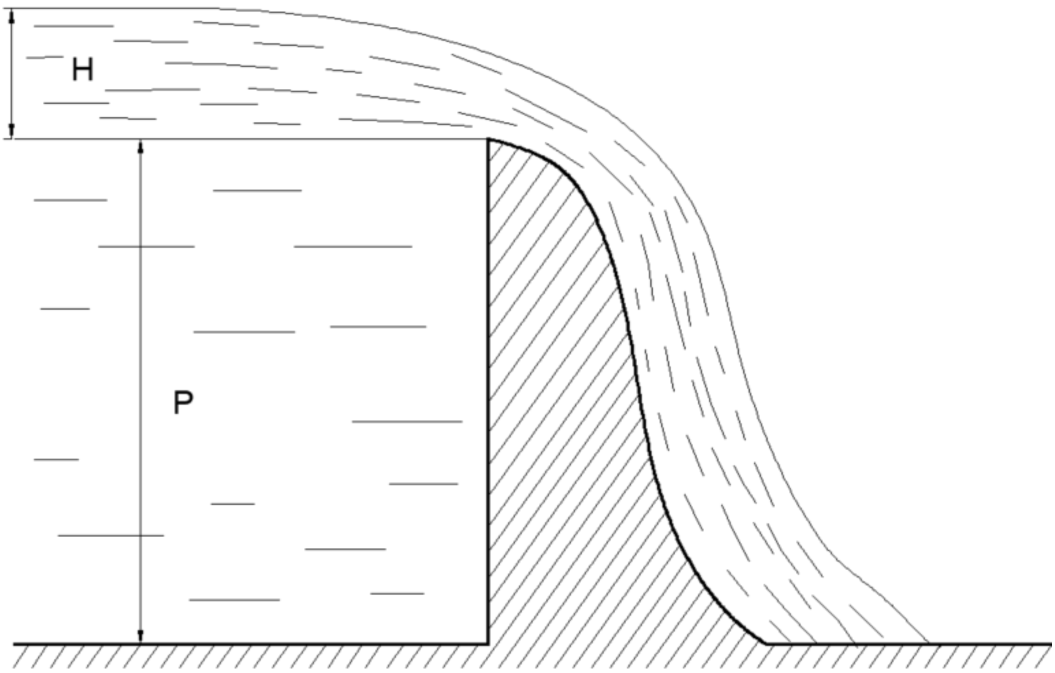

Fig. 3. Ogee-crested spillway

It is the overflow type spillway which has a controlled weir and is ogee-shaped(S-shaped) in profile. It is shaped such that it follows the lower surface of a horizontal jet emerging from a sharp crested weir. The pressure at the ogee crest remains atmospheric at the design head. At lower head, the pressure on the ogee crest becomes positive which results into the backwater effect and this backwater effect reduces the discharge while at the higher head pressure on the crest becomes negative causing backwater effect to increase the discharge.

- *according to the shape of the drain opening*: trapezoidal, triangular and rectangular holes are made in the spillway wall (figure 4).

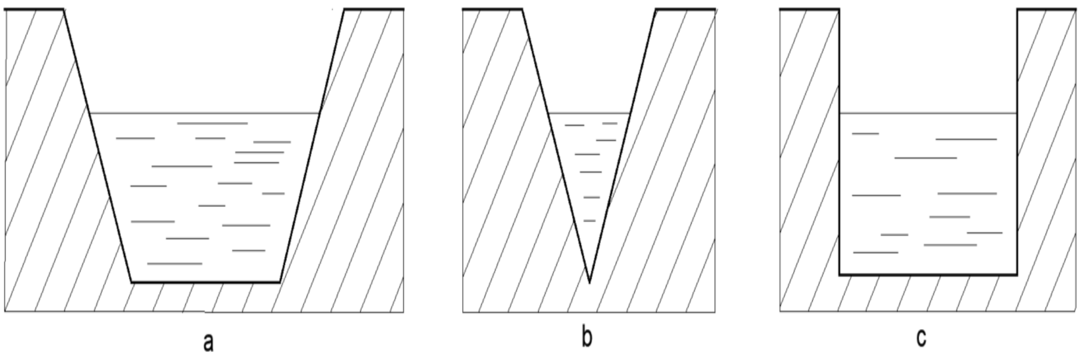

Fig. 4. The shape of the cutout of the drain hole.

- *according to the location of the threshold*: **spillways are straight in plan** (figure 5, a), when the weir threshold is perpendicular to the direction of the flow in the upstream, **oblique** - the threshold is located at an angle to the flow (figure 5, b), **lateral** - the threshold is located parallel to the direction of the flow (figure 5, c)

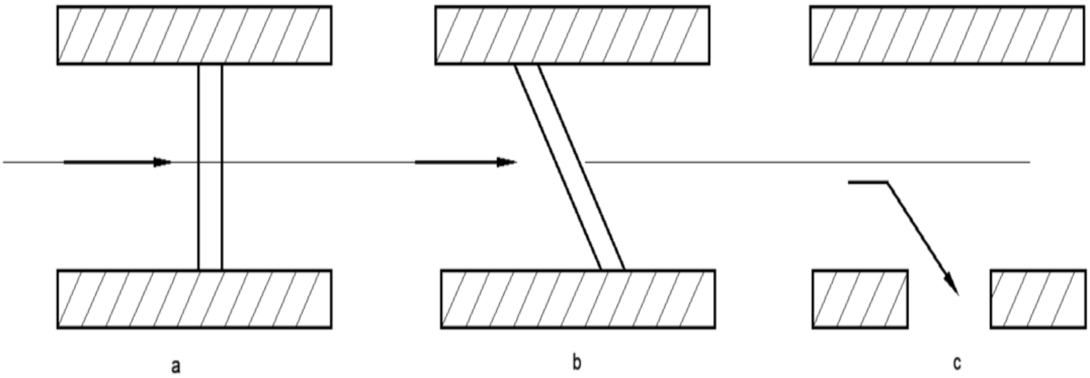

Fig. 5. The location of the threshold in spillways in plan: a - straight lines; b - oblique; c - lateral.

- *according to the conditions of lateral flow compression:* spillways are divided into spillways without lateral compression when the channel width and spillway width are equal ($b=B$) and spillways with lateral compression when the width of the spillway is less than the width of the channel on which the spillway is located, i.e. $b<B$ (figure 6).

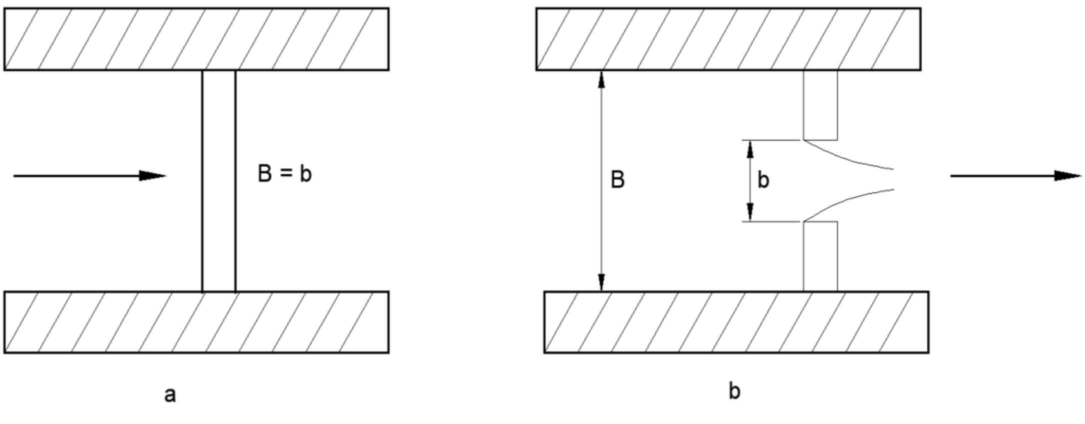

Fig. 6. Spillway a - without lateral compression; b - with lateral compression

A broad-crested weir is a spillway that has a horizontal threshold, the length of which along the stream (wall thickness δ) is within (2 / 3) H < δ < (8 / 10) H (figure 7). At the same time, the nature of the flow movement on such a spillway changes smoothly, close to a parallel jet with hydrostatic pressure distribution.

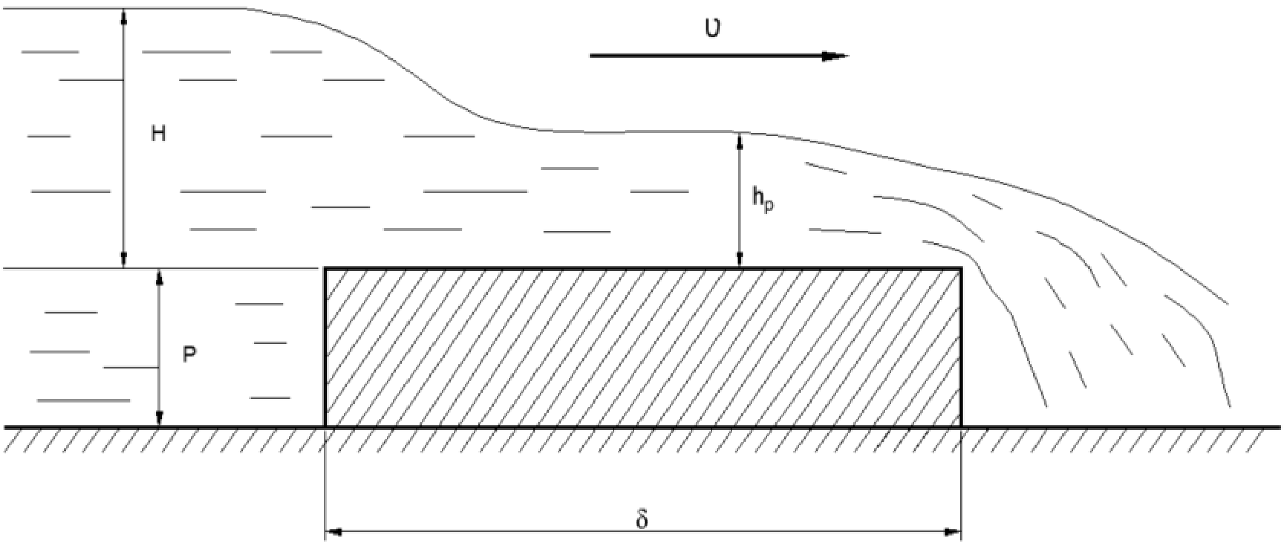

Fig. 7. Not flooded broad-crested weir.

Denoted by *H* is the depth of the liquid above the crest of the broad-crested weir, measured where the level has not yet decreased, is called the static pressure on the spillway. The drop in the liquid level in front of the spillway begins at a distance of *3 - 4 H* from its crest.

The most difficult factor affecting BCW throughput is the flow rate. A review of the literature shows that BCW flow rate estimation methods are generally based on two main approaches. When, the BCW discharge coefficient is considered only as a function of the relative height of the upstream reservoir wall (Konstantinov & Hizha [110]; Rekomendatsii [114]). On the other hand, most European countries use a different approach, which is based on the assumption that the BCW flow rate depends only on the relative length of the sill and is not a function of the wall height (Hager & Schwalt [108]; Govinda Rao & Muralidhar [106]; Jalil et al. [109]; Salmasi et al. [116]; Guven et al. [107]; Kulkarni et al. [111]; Zachoval et al. [117]).

The discharge capacity of the broad-crested weir is determined by various modifications of the flow equation through the BCW. The structure of all remains similar, it differs only in the approach to determining the parameters that affect the bandwidth.

$$Q = mb\sqrt{2gH_0^{3/2}}$$

where m – the discharge coefficient of rectangular sharp-edged BCW; b – width of the weir; H0 − total head on the weir, which is found as a sum of geometric and velocity heads:

$$H_0 = H + \frac{aV^2}{2g}$$

where H – geometric head of weir; α – kinetic energy factor; V – average velocity on the upstream side of the weir.

$$V = \frac{Q}{b(P + H)}$$

where P – the height on the upstream side of the weir.

A review of scientific works shows that there are still a number of questions regarding the reliability of the determination of the flow coefficient for BCW with different ratios of spillway length to height (Hager & Schwalt [108]; Govinda Rao & Muralidhar [106]; Jalil et al. [109]; Salmasi et al. [116]; Guven et al. [107]; Kulkarni et al. [111]; Zachoval et al. [117])

Like other types of spillways, broad-crested weirs can be not flooded or flooded. Depending on the combination of the falling jet with the water level behind the spillway, the latter can be not flooded (figure 7) or flooded (figure 8).

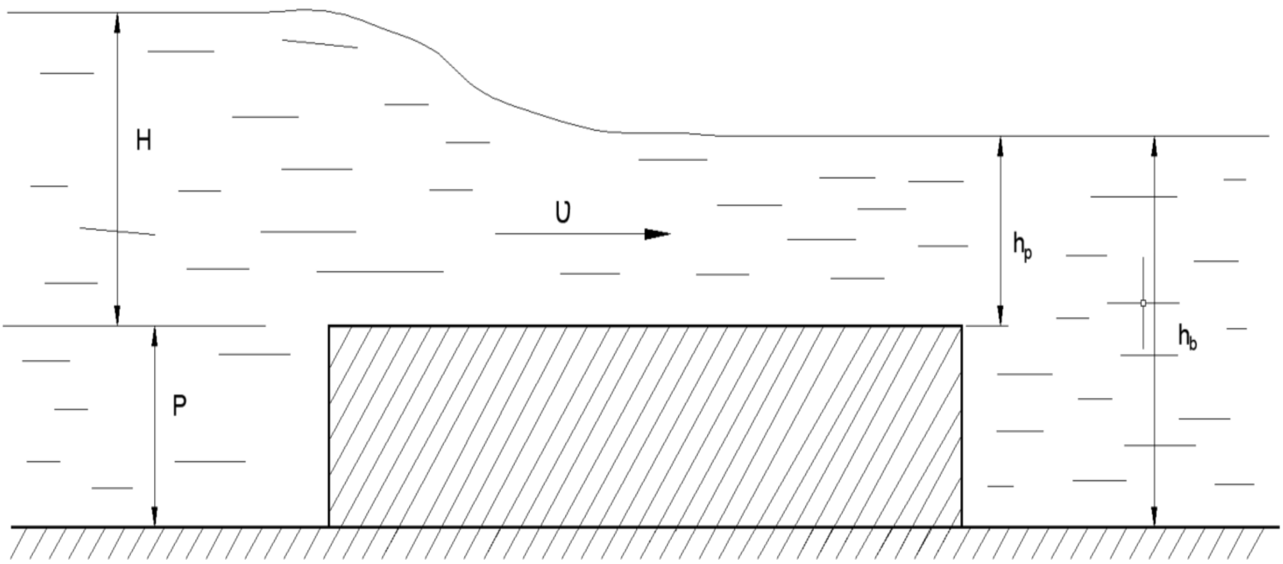

Fig. 8. Flooded broad-crested weir.

An not flooded spillway with a wide weir has two drops of the free flow surface: at the beginning and at the end of the threshold. It should be noted that an not flooded spillway with a wide threshold at the end of it sets the depth h_p, namely, while the level the downstream h_b will not exceed the water level at the end spillway. Flooding will not affect the outflow of liquid through the spillway and, accordingly, the flow rate.

With a flooded spillway, the flow rate is determined by the formula.

$$Q = \varphi \mathrm{bh_p}\sqrt{2g(H_0 - h)}$$

where φ – is the speed coefficient of the flooded spillway (for a threshold without rounding of the inlet edge); b – width of the weir; h_p – depth of flooding; h – depth of water at the threshold (approximately it can be considered constant along the length of the spillway). Water depth at the threshold of a flooded spillway $h = h_p$.

As conclusion, spillways with a wide threshold play an important role in hydraulic engineering, especially in water resources management and protection of the aquatic environment. They are important hydro-technical structures designed to regulate water levels in rivers, reservoirs and other water bodies, ensure public safety, eliminate the consequences of floods, and ensure the water regime for water supply, energy, shipping, and other sectors of the economy. One of the main possibilities of spillways with a wide threshold is to provide regulation of water levels in rivers. This allows for to reduction of the risk of floods by controlling the water regime in the river basin. Thanks to spillways with a wide threshold, it is possible to influence the distribution of water in the river, ensure appropriate water levels at different times of the year, and regulate the water regime in ensuring water supply, energy, shipping, and other sectors of the economy.

In addition, spillways with a wide threshold can be used to control the energy regime of water bodies. The use of special hydraulic units in spillways allows you to obtain electricity by using the potential energy of water when it is poured from the spillway. It can be an important source of renewable energy, helps to ensure the stability of the energy supply and reduce emissions of harmful substances in the process of electricity production.

Consequently, spillways with a wide threshold play an important role in hydraulic engineering, providing regulation of the water regime, flood protection, energy production, and development of various economic sectors. They can also have socio-economic significance, ensuring the development of regions.