CHARACTERISTICS OF STILLING POOL WITH SIDE NOTCH

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Constructing river waterworks at mountain stretches is often aggravated due to narrow sites where it is difficult to locate stilling structures.

In such occasions stilling pools is the main type of stilling structures especially if soil foundation is insufficiently sound, as energy damping with ski-jet is ineffective at small and medium water head waterworks. But stilling pool needs much space to locate downstream apron and to arrange tailrace channel being capable to provide transition from stream with high pulse characteristics to natural stream state in the river channel. But at mountain regions as a rule this space is insufficient or is absent at all. So, in this case it is necessary to do large excavation.

Further spillway construction development, cost decrease and decrease of running costs lead to appreciable economy of material and financial funds, that's why problem of energy dissipation in the downstream pool of medium and high head waterworks is still actual.

Additionally, actuality of the research in the sphere is stipulated due to multiple dangerous river-bed erosion and emergency downstream scour, large quantities of repair-and-renewal operations do prove that it is necessary to refine upon used methods of upstream-downstream transition analysis in slowly splayed channels. Known constructions for excessive energy dissipation have merits and disadvantages so they are not universal ones and may be used only for certain characteristics of transition sections. Problem of stream outlet into the river channel may be significantly simplified by arrangement of stilling pool with notch in the side wall being symbiosis of stilling pool and side weir.

Due to complexity of the hydraulic phenomena in such structures, it is difficult to develop theoretically design method for them. Meanwhile our calculations by method including some propositions have shown principle possibility to use such structures with high robustness.

For lack of the laboratory research simulated experiment and hydraulic tests of the stilling pool with the side weir were required to obtain reliable equations describing the above structure operation.

On the base of the simulated hydraulic tests the new engineering solution for the stilling pool with the side weir providing conjugation structure parameters optimization was suggested for the conduit spillways using such type of stilling pools, recommendations on hydraulic calculations having been recommended too.

The suggested new design of the stilling pool has been applied for the dams Keynah and Shakra in Syria by “Sovintervod closed corporation”, the author of this article having taken part in that works.

Considering the lack of the laboratory research concerning spatial banked-up hydraulic hammer which occurs in the stilling pool with the side weir engineering solution was considered (Figure 1), where 1 – is the drained tunnel; 2 – hole shoulder; 3- stilling pool; 4 – end wall of the stilling pool; 5- side walls of the stilling pool; 6- notch in the side wall; 7-weir; 8- tail-race.

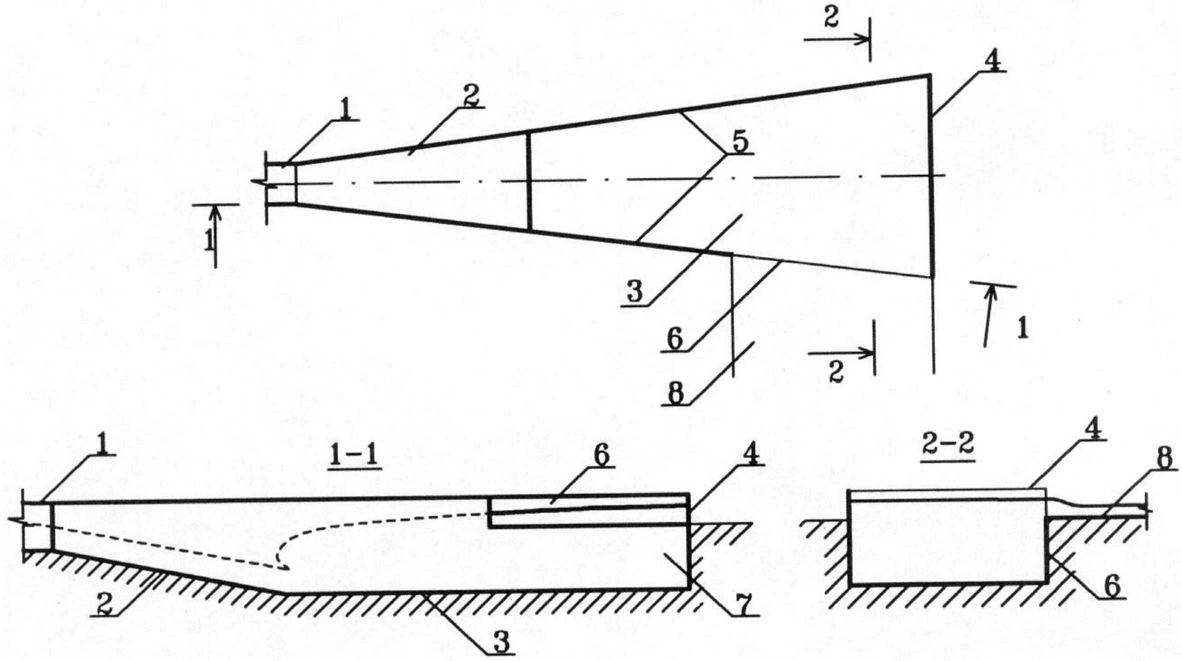

Fig.1. Construction arrangement of the stilling pool with the side notch

Energy dissipation begins in the end part of the relief tunnel junction to the stilling pool where water roll having horizontal axis is formed. This water roll is similar to that one being formed in the traditional stilling pool with straight notch.

Then flow expansion occurs alongside the lateral walls in the direction of the closed-type wall of the stilling pool. Having reached the side notch water discharges into the tail-race.

Experimental data having been obtained showed that free water surface level was minimal within the side notch for the cross-section of the stilling pool alongside its right wall and we had maximum water depth alongside the left wall of the stilling pool.

Surf was farmed near the end wall of the stilling pool as the result of upward flow stream of the hydraulic jump, which generates rising of water level according to the stream energy.

$$E = h'' + \left(\alpha v^2\right)/2g, \qquad (1)$$

where v_t - is the via (transit) water flux velocity.

Streamwise section (Fig 2) shows water jump plane in the form of dimensionless chart

$\frac{h-h_1}{h_2-h_1} = f(\bar{x})$, where $\bar{x} = \frac{x}{h_2-h_1}$, and x – is the distance from the starting segment of water jump, which allows to state an equation of the free water surface:

$$\frac{h-h_1}{h_2-h_1} = -0.0025(\bar{x})^4 + 0.046(\bar{x})^3 - 0.31(\bar{x})^2 + 0.89(\bar{x}). \qquad (2)$$

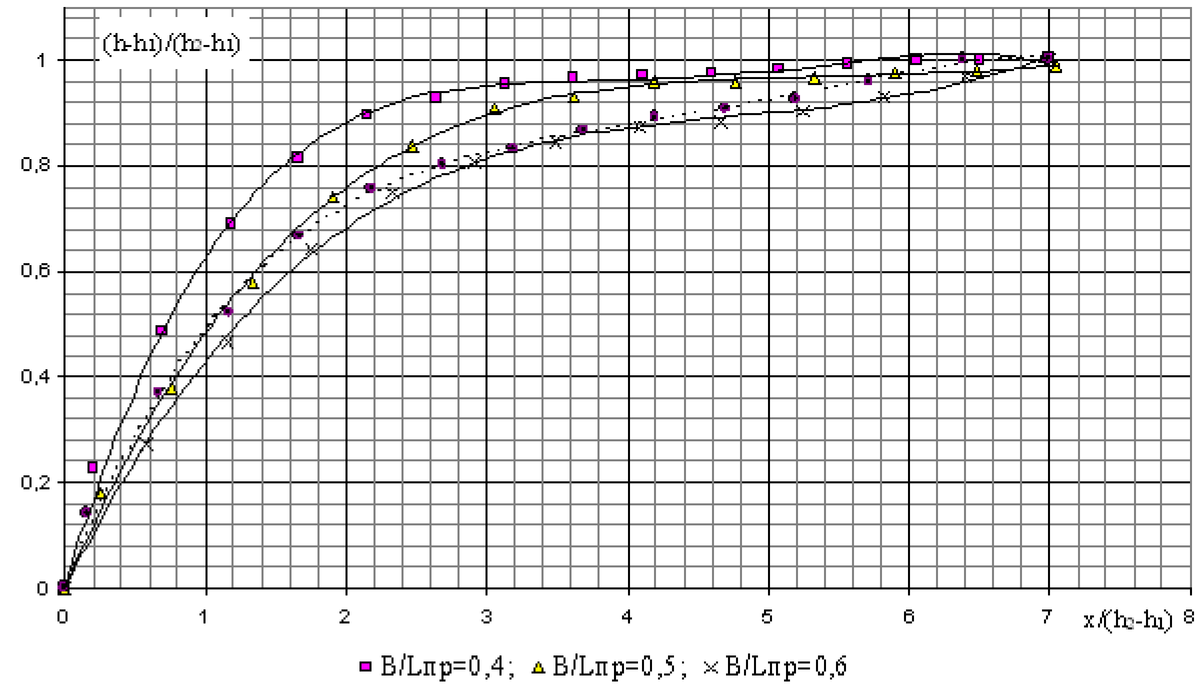

Fig.2

As the result of our research geometrics of water jump (h_2, l_{np}) has been determined, it having been compared to the known stilling pools equipped with the straight notch.

In the case of stilling pool with the side notch investigation water jump is characterized with the steeper raising of water level for the starting segment.

For the area between the water jump starting segment and the beginning of the side weir free water surface level depends on the side notch length. At short notch $(B/l_{np} \leq 0,5)$ it was not enough sub-stream energy within the height of hydraulic jump above notch bulkhead for water discharge into the tail-race.

In connection with the above mentioned water level was raising till the stream energy should provide water discharge into the bed through the side notch as well as through the broad-crested weir. In this range of notch length water level in the stilling pool with side notch was higher than water level in the stilling pool with straight notch.

At the notch length ratio $0.5 \leq B/l_{np} \leq 0,6$ the mean water depth in the stilling pool was similar to the mean water depth in the usual non-prismatic stilling pool, and at the notch length ratio $B/l_{np} \geq 0,6$ it became less by 5-10%.

Experiments have shown that water depth along the side weir crest has non-uniform distribution. In general free water curve shape for the side weir crest at different flow rates was correspondent to the water jump position within the stilling pool. Free water curve being formed along weir crest and side weir began to steepen that is the difference in water marks at the beginning and at the end of the weir crest was grown.

At the end of the side stilling pool water depth was formed as well as the result of jump height and water head required for water discharge but also as energy restoration of the transit part of the stream.

Maximal water depths in the straight stilling pool depending on the notch length ratio b/lпр are shown on the figure 3 in the shares of the jump height h".

Initial point of the chart b/lпр=0 is corresponded to the boxtype stilling pool operation with water overflow through the sides of the pool. Maximum water depth was observed over the end wall, the height of the end wall being conventionally equal via(transit) water flux raising at the contact with the end wall. $\frac{h\,\}\}+\{\ \{\alpha\alpha\ rSup\ \{ size\ 8\{2}{2g}$

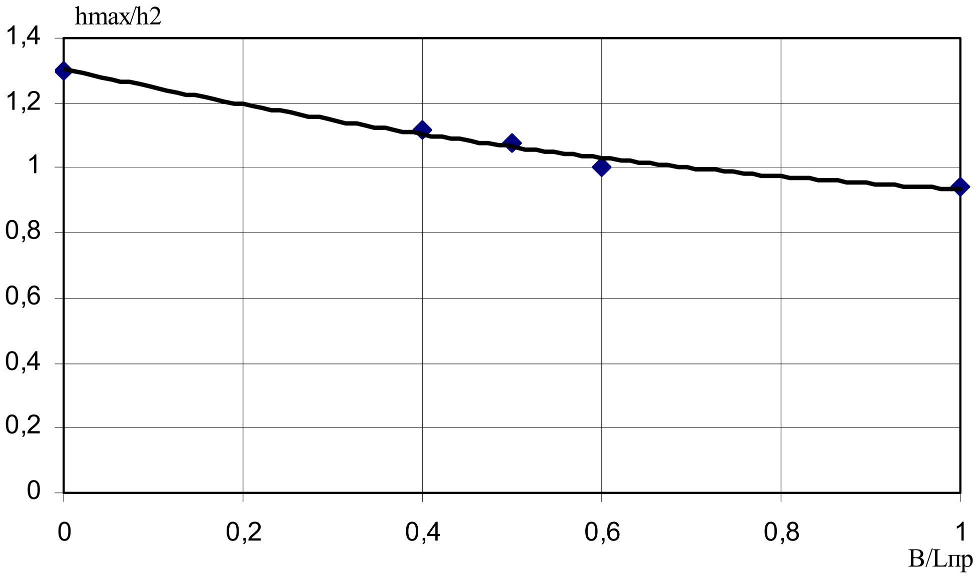

Fig.3. The chart of maximal water depth variation for the straight stilling pool in the shares of of the jump height h".

As it is shown on the figure 3, that at the notch length $b \leq l_{\text{пр}}$ influence on the stream formation though the side wall is observed which gives the opportunity to develop stilling pool with the side notch without one of the side wall provided that the height of the side wall weir being not less than via(transit) water flux width. At side wall removal and when the height of the side wall weir is NLE than via(transit) water flux width, water discharge through the notch begins at the section line where water jump depth exceeds weir crest height.

At the beginning of the water jump the travelling fluent of the water roller has the maximal velocity that's why part of the notch discharge possesses large axial component of stream velocity which simultaneously with the low head at the weir crest reduces unit discharge to zero in this area.

When using stilling pool as an energy dissipater which sustains linear stream impact, it is necessary to know velocity field within stream discharge area from the structure. Having analyzed mean velocity profiles for the cross-section which is parallel to the side notch in the area of parallel-jet-stream current, practically uniform planned distribution of the local velocities having extremum value at the end of the notch adjoining to the end wall of the stilling pool as far as water depth and head are maximal over the notch rib.

Our research on maximal water velocity values and their directions for the weir crest have shown
that velocity field changes simultaneously with weir crest and discharge changing.

Angle β between the velocity vector and weir crest equals $\beta = 90^o$ at the end of spillway, and at the starting segment of the spillway β value is not more than 62°.

Water movement study through the side notch have shown that owing to the velocity axial component at the beginning of the notch there is significant stream contraction in a plan view.

Stream contraction in a plan view behind the crest of the side weir is variable and depends on the discharge of the stilling pool, water velocity at the weir, as well as the length of the weir crest.

In the further calculations we take into account the full length of the weir, parameters influencing its discharge capacity including stream contraction using discharge coefficient m.

To determine discharge coefficient for the side weir we accepted that:

-the head at the side weir crest is determined as a difference between the water depth in the stilling pool *Hк and the height of the weir crest p*, that is *Ho = Hк - p. Since free water surface was linearly varying within the side notch area, the mean value was taken as Ho;*

- relative deviation of the stream velocity vector *v from normal to the side wall was taken into account using experimental values of the discharge coefficient m.*

During experiments it was determined that water discharge coming through the side weir specifies water depth in the stilling pool as well as at the weir crest of the side notch depending on the notch length.

Distribution of the specified discharges for the tail water behind the notch is shown on the figures 4-6. Measurements were carried out in the cross-section characterized with practically parallel-jet-stream water movement. Specified water discharge was variable. At the relative length of the notch $B/l_{np} = 0{,}4$ maximum specified water discharges were observed at the beginning of the notch.

It can be explained that t the end of the notch adjoining to the end wall of the stilling pool, stream is feeding due to the vertical roller having been formed by the upward current of the transit jump fluent .

The initial and the central segments of the notch are fed by return fluent of the roller which brings water from the large feeding area which cover the total width of the stilling pool.

Increase in the notch length area of the maximal specified discharges remains practically at the former position but its moves to the center of the notch relative to its length (Figure 5). At the further increase in the notch length $B/l_{np} \geq 0{,}6$ feeding area of the side notch was moving to the segment being characterized with shallow jump depth which had less specified discharges and greater velocity vectors deviation from the notch normal because of the side contraction of the stream

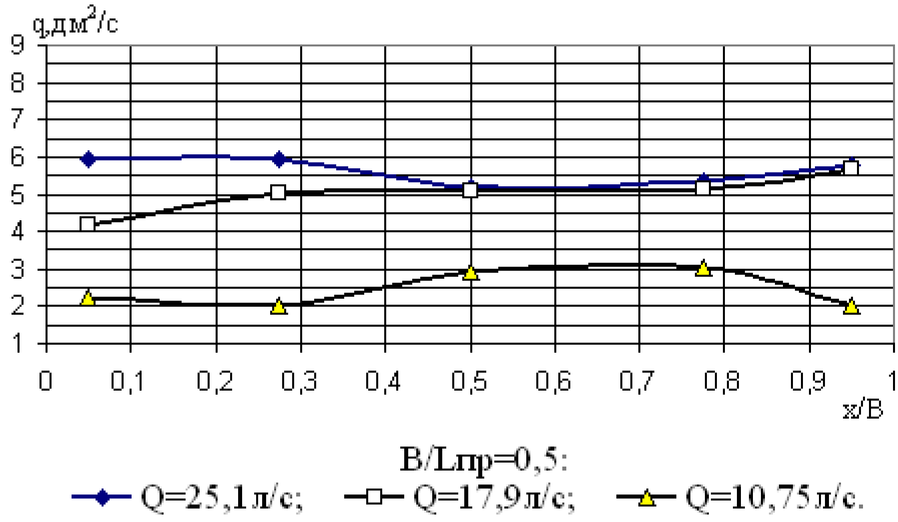

Fig.4.

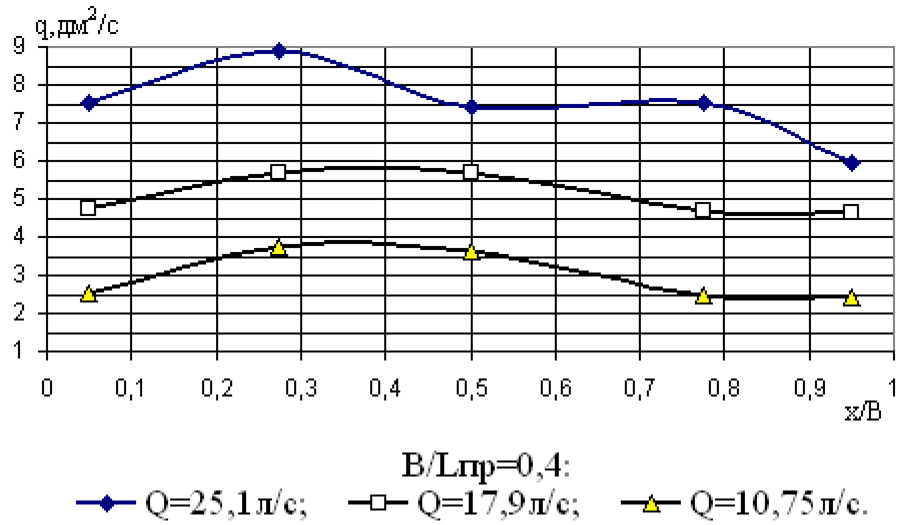

Fig.5.

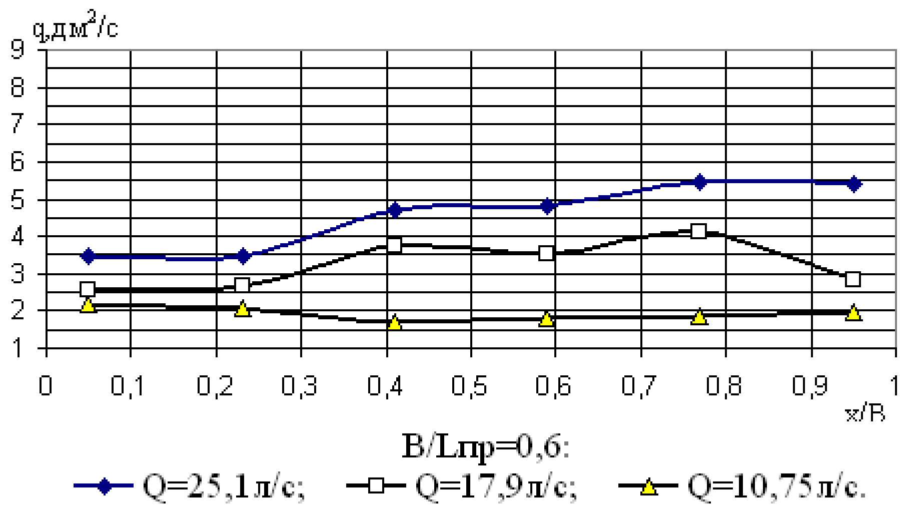

Fig. 6.

Observable quantity of the coefficient of discharge for the side weir we determined using the following equation:

$$m = \frac{Q}{B\sqrt{2g}H_{o}^{32}}. \quad (3)$$

On the base of the calculations the charts showed on the figure 7 were developed $m = f(H_o h_{\max})$ and $m = f(Bl_{np})$, which approximation provides to obtain the relationship for coefficient of discharge culculation $m = f(H_o h_{\max}, Bl_{np})$ (4)

$$m = 0,97 \cdot \left(\frac{B}{l_{np}}\right)^{-0,998} \cdot \left(\frac{H_o}{h_{\max}}\right)^{-0,46\frac{B}{l_{np}}-0,12}$$

where B – is the length of the side notch, l_{np}– is the effective length of water jump, H_o – is the mean head at the weir, h_{max} – maximal effective depth in the straight stilling pool with the crest height corresponding to stream discharge to the tail race which equals

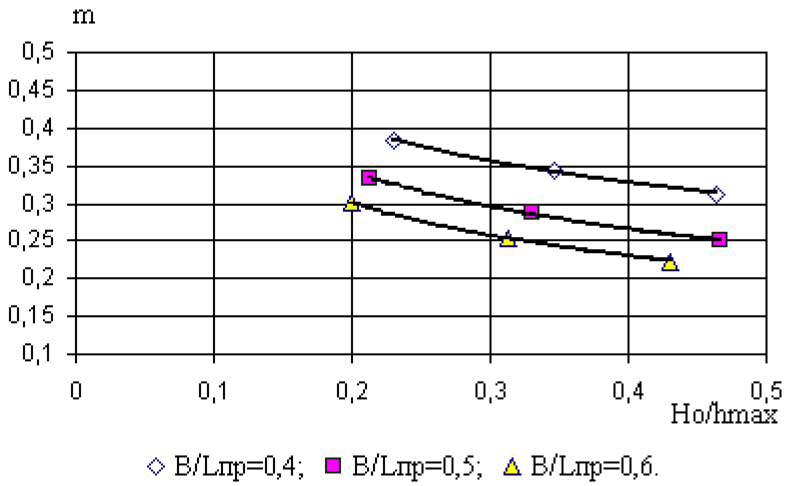

Figure. 7

Contours of coefficient of discharge are shown on the figure 8 m=f(p/p_{max},B/l_{np}) for Q=*25.1/s.*

Increase in the notch length causes coefficient of discharge m decrease, which can be explained by stronger stream constriction in the side notch as well as greater deviation from the notch normal of the local stream velocities in the section line of the notch.

However coefficient of discharge decrease should not be considered as a diseconomy parameter for the stilling pool with the side notch. The total effect of the notch length increase should be considered as less concrete consumption due to total height decrease and side wall lightening because.

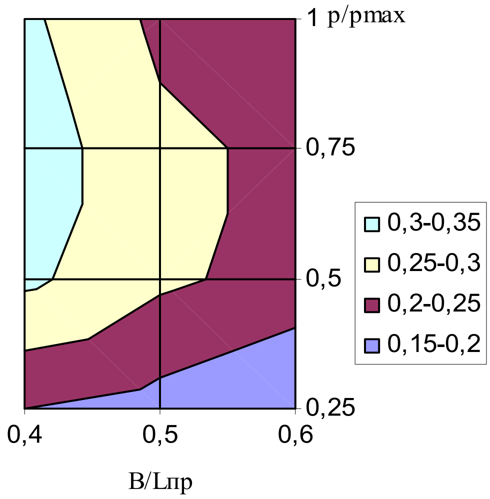

Fig. 8. Isotachs of coefficient of discharge values $m=f(p/p_{max},B/l_{np})$ for Q=25.1 *1/s*

On the base of the conducted experimental research the pattern of both stilling pool wall pressure and side notch crest pressure distribution has been determined.

The pressure profiles plotting show that this pressure is distributed according to hydrostatics law.

Fig.9. Stilling pool with the side notch operation in the case of spatial conjunction of races at Q=25,10 l/s (design discharge).

According to measurement data of the water depth in the stilling pool with the side notch the graphs of energy losses were plotted. The operation feature of this stilling pool is water withdrawal from the water jump roller.

As to generalized representation water jump roller is a dissipater of water jump energy. From this point of view water jump roller decrease should cause less efficient energy dissipation in the stilling pool. To estimate energy dissipation efficiency energy losses were calculated as the difference between energy value in the contracted section and at the end wall relatively to the bottom of the stilling pool. Energy at the end wall was estimated using the depth taking into account kinetic energy restoration. On the basis of research we can make conclusion that an spillway expanding stilling pool is the more effective structure for stream energy dissipation at Froude number $Fr>45$. At side notch presence stream energy dissipation was less effective than in the straight stilling pool. It can be explained that intensity of water jump roller is lower at side water discharge. Stream energy dissipation loss due to the roller is partially compensated with the losses for transit fluent blow against the end wall as well as fluent turn by 90^o into the side notch.

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