Water Sigh in the Buildings Research Results for Different Energy Absorbers

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Abstract. The research focuses on how a local scour develops and evolves underneath hydraulic structures with conical gates subjected to varying operational levels and energy absorbers. Laboratory investigations were conducted to analyse how operating gate opening and flow kinematics affected scour depth and energy absorbing effectiveness. Three dampers were modelled: triangular, rectangular, and polygonal to evaluate their influences on stabilization time and cumulative movements of washouts. The findings concluded that scour depth increased in a nonlinear relationship with gate opening to a maximum of 7 cm being reached with full opening, while the triangular damper showed the highest energy absorption efficacy (16 %) through cumulative movement. The Froude number in the reinforced section did not exceed 2, while scouring intensified once flow underwent hydraulic jumps above a height of 4 m. Turbulent stresses developed in the quenching chamber, where efficiency improved with energy dissipation from the flow. The system operated most efficiently at 80% gate opening and was found to provide stable flow with lower levels of scour. The results also provide valuable information in the hydraulic design and protection of structures discharging water with conical gates.

1 Introduction

Hydraulic structures incorporating conical gates frequently deal with local scour, which can be defined as the erosive and removal of sediment near structural elements as a result of high-velocity water flows and turbulent vortices [1]. In these cases, a failure to dissipate the excess kinetic flow energy increases sediment transport and scour depth, which threatens the stability of the foundation and embankment [2]. Local scour is further exacerbated in water-discharge structures as a result of flow jets impinging directly on the bed or by hydraulic jumps downstream at outlets [3].

Earlier studies have indicated that scour patterns are strongly affected by structural shape, material properties of bed material and hydrodynamic measures such as specific discharge, Froude number and downstream depth [4]. For example, studies investigating

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bridge piers and marine structures reported that conical or semi-conical shapes, alone, can reduce scour depth by reducing the strength of vortex motion and downflow [5]. Additionally, numerical studies recently reported that while empirical formulae are common, they rarely account for complex interactions in hydraulic systems, highlighting the importance for detailed laboratory work and validated modelling [6].

In the case of conical gates, the relationship between the gate jet and its influence on scour hole formation is greatly dependent on the amount of gate opening, flow axis orientation relative to binder direction, and type of energy absorber placed downstream [7]. Designing effective energy dissipation chambers (quenching chambers) and dampers is essential for limiting scour depth and lateral sediment transportation. The effect of shape of absorbers, specifically triangular, rectangular and polygonal on modifying flow trajectories and reductions in scour has been under-explored in the literature so far.

As a result, this study will experimentally investigate the cumulative movement of local washout beneath conical gates with different opening angles and different energy absorbers using a laboratory-controlled model. We will specifically examine the time to stabilize scour depth, the influence of energy absorber geometry on scour reduction and the relationship to relevant field scale parameters (e.g., Froude number, specific energy ratio and hydraulic jump values). These results are intended to help improve hydraulic design practices of discharge structures with conical gates and provide empirically-derived relationships for predicting scour depth and efficiency of energy absorbers.

2 Research methodology

Localized erosion, or local scour, often develops in hydraulic structures (water discharge) because not all excess kinetic energy has dissipated and velocity has not been even. Local scour formation is very closely related to the kinetic structure of the flow (in terms of traditional kinematic structure, vertical velocities are small in relation to the velocities that are occurring near the bed). The velocity of the flow near the bed, especially in the upper slope area and associated maximum scouring area are substantially different than the flow approaching the flow out of the scour area. As flow velocity decreases, due to the interactions of the mean components of flow and pulsation components of flow, sediment is transported, and the bed is disturbed. Thus, an accurate assessment of scour depth should consider pulsation velocity components [8].

For non-cohesive homogenous soil types, there are hydraulic and geometric parameters that influence the extent of washout from the hydraulic jumps occurring deep to the bridge ends. The specific discharge, downstream depth, Froude number, length of the berm, soil size, and time scour all influence the total extent of scour. Observations made from experiments showed two different phases [9]. First, rapid erosion took place at the ends of the embankment leading to the suspension of sediment and deepening of the scour hole. In the second phase, energy dissipation caused a slowing of the flow, as well as, creation of weak reverse flows promoting mixing and part of the sediment to redeposit.

Local scour development typically occurs upstream of conical gates when the inflow velocity is relatively high and the flow is not yet sediment saturated. Scour depth, diameter, and distance from the weir ridge are impacted by the structure design, type of energy absorbers, hydraulic regime, and soil parameters [1]. Through experimentation and numerical methods, three general flow regimes have been highlighted for their influence on velocity distribution and the depth of scour:

1. Flat connection - weak vortex and limited washout;
2. Surface connection - strong vortex generation;
3. Bed connection - deep erosion and extended scour zones [10].

Accurate prediction of local scour is essential for the design of hydraulic structures and ensuring long-term stability. The characteristics of the scour will differ with outlet geometry, energy dissipator type, soil properties, and depth downstream. In the case of conical gates, the fan-shaped jet causes transverse eddies that increase local velocity, which increases potential erosion. Obtaining field data can be difficult, so experimental modeling can be utilized wherever possible.

Equations for Scour Calculation:

The depth of local scour, designated as h_{scor}, can be located at the connection of the bypasses and adjusted below the conical dam by Murshulava's semi-empirical formula [11]. For viscous soils, iterative approximation provides reasonably reliable estimates.

$$h_{scor} = \left(\frac{3{,}3v_{inlet}t_0}{v_{base}} - 7{,}5t_0\right)\frac{sin\beta_1}{1-1{,}75ctg\beta_1} + 0{,}25h_{bypass} \quad (1)$$

where h_{scor} – scour depth (m), v_{inlet} – average inlet velocity (m/s), v_{base} – base velocity of unwashed flow (m/s), t_0 – flow layer thickness at outlet (m), β_1 – slope angle of the flow at inlet (°), h_{bypass} – flow depth in lower bypass (m).

The base flow velocity is calculated as follows [8]:

$$v_{base} = 1{,}61\sqrt{\frac{g[\rho_{soil}-\rho_{water}(1-s)d+(0{,}015c^n+p_{flow}+p_{stream})]}{\rho_{water}(1-s)}} \quad (2)$$

where: g – gravitational acceleration (9.81 m/s^2), ρ_{soil}, ρ_{water} – densities of soil and water (kg/m^3), s – mean air concentration (dimensionless, typically 0.5), d – mean particle diameter (m) $d = 0{,}004\ m$, c^n – soil viscosity coefficient, p_{flow} – dynamic pressure on the bed (Pa), p_{stream} – stream pressure on the soil layer (Pa).

The inlet velocity is obtained from Bernoulli's energy balance:

$$v_{inlet} = \sqrt{v^2{}_{outlet} + 2g\left(l_t - h_{bypass} - \frac{D_{base}}{2}\right)} \quad (3)$$

where, v_{outlet} – outlet velocity from the conical shutter, l_t-the distance from the conical bolt axis to the bottom of the outlet hole, D_{base}-diameter of the conical bolt base.

The depth of the flow leaving the conical trap t_0 can be determined using the following formula:

$$t_0 = \frac{t_1 D_{base}}{2l_t - 2h_{bypass} - D_{base}} \quad (4)$$

$$h_{bypass} = \frac{Q}{Bv_{outlet}} \quad (5)$$

where, Q - the flow rate discharged into the lower bye, B -flow rate outside the washing circuit, v_{outlet} - is the unwashed velocity of the moving stream outlet the washout loop and depends on the soil properties.

If the ground at the construction site consists of very small, non-cohesive aggregates, the depth of the washout zone behind the conical dam should be determined according to the following formula:

$$h_{scor} = \left(2{,}74 + 0{,}18\frac{v_{vx}^2}{gt_1\sqrt[3]{Fr_1}}\right)\left(\frac{v_{vx}}{t_0\sqrt{g}\sqrt[4]{d_{50}}}\right)^{0{,}8} \quad (6)$$

b is Fr the Froude number; d_{50} - the diameter of 50% of the soil particles, determined using granulometric curvature;

$$h_{scor} = 4{,}8t_0(sin\,\beta_1 + cos\,\beta_1)\left(\frac{\sqrt[3]{(Fr_v)^2}}{k\sqrt[3]{\left(\frac{h_{p.b.}}{d_{95}}\right)}}\right)^{0{,}8} \qquad (7)$$

then,

$$Fr_v = \frac{v_{inlet}^2}{gd_{95}}$$

k- the coefficient $\frac{h_{scor.}}{d_{95}}$ is determined depending on the relationship.

3 Research results

In our research, the cumulative movement of the washout in structures equipped with a conical gate was observed at different opening angles of the conical gate. The layout of the measuring rods is shown in Fig. 1.

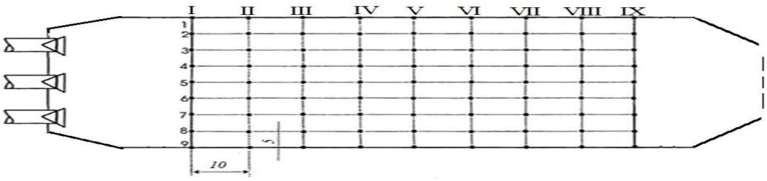

Fig. 1. Scheme of the location of the measuring rods.

In every case of the experiment the study was taken until the depth of the washout in the physical model became constant over time. The variability of the washout intensity should be noted as being extremely dependent on the opening angle at the conical gates. The stabilization time during the experiments was approximately t=32 minutes for 100% opening, t=48 minutes for 80%, t=62 minutes for 60%, and t=88 minutes for a 20% opening. In general the washout observations were recorded for as long as three hours to ensure that the scouring depth and flow conditions stabilized in full.

The time it takes for the maximum scour depth to stabilize is affected by changes in the Froude number, in addition to the kinematic flow structure in the flushing chamber. A methodology was developed using three types of energy absorbers to analyze local flushing in structures with conical gates in this study. During testing, the conical gate axis was not submerged when all three gates were operating [12]. When completely open, the critical depth in the model did not exceed 3 cm (0.77 m in field conditions). The relative specific energy was determined using the proposed methodology thereafter.

$$E_0 = h_3 + H_0 = h_3 + H + a_0V_0^2/2g \qquad (8)$$

where, $h_3 = 0{,}45\ m$, H is the pressure in the shutter, $a_0V_0^2/2g$ is the speed coefficient, in the model $E_0 = 0{,}8\ m$.

A model experiment was performed at a 1.8 m long berm of the lower bypass in order to examine the impact of hydraulic flow characteristics on local scour. In the course of hydraulic investigation, the scour depth factors of alternative energy absorbers on secondary scour depth indexes were tested with a single cone gate configuration. Upon discharge stabilization, the velocity path adjusted to the outlet of the branch, measured water depth downstream equal to the secondary connection, and then again took the measurement using a Spitzencircle.

In model testing, a berm was initially filled with sandy material as the silting material, and all the conical gates were initially in the closed position. Water was added to the previously calculated elevation and the conical valves were manually opened in a sequential manner. The subsequent discharge in each pipe was then measured to quantify flow distribution and scouring behavior.

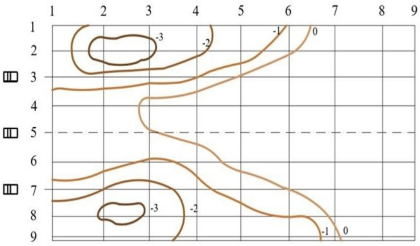

Fig. 2. View of the stack in the washdown position with the conical shutters operating at 20% opening and the multi-angle damper installed.

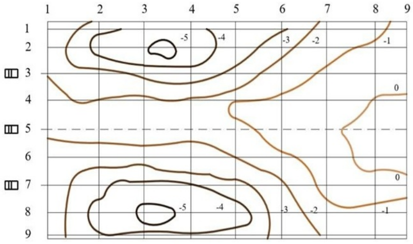

Fig. 3. View of the washout stack with the cone valves operating at 40% opening and the multi-angle damper installed.

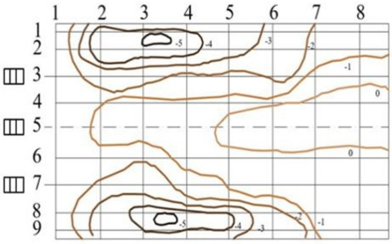

Fig.4. View of the stack in the washdown position with the conical shutters operating at 60% opening and the multi-angle damper installed.

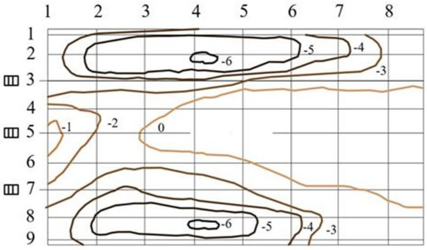

Fig.5. View of the stack in the washdown with the conical shutters operating at 80% opening and the multi - angle damper installed.

The findings suggest that the specific energy was almost unchanged when all valves were fully open. The scour depth during the washing process was significantly smaller in the triangular damper when compared to an increase in flow length and lateral deflection. For both the polygonal and rectangular dampers, the scour depth was in the range of 1–5 cm at 20% shutter opening, whilst in the conical damper case, scour depth was in the range of 5–7 cm at 100% opening.

It was observed experimentally that sediment displacement varied with damper type; specifically, sediment was visibly moved toward both the ridge and the damper's end in the triangular dampers. Therefore, damper geometry and minimizing areas of reinforced will be crucial in the design of structures with conical locks.

Overall results indicate that dampers noticeably impact flow kinetic energy and scouring behaviour in the conical gate structures studied. Even with turbidity, the embankment erosion was still significant. The experimental and field studies in the present work indicated that adding dampers was successful in reducing washout depth and sediment movement in water discharge structures.

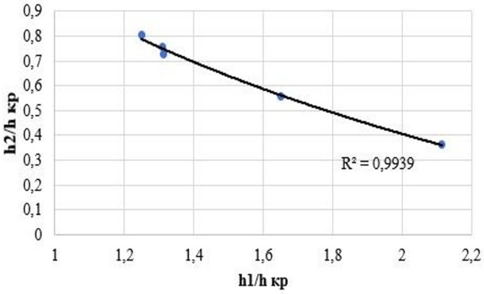

Fig.6. Graph of the depth of the lower by - pass when water flows through the cone gates.

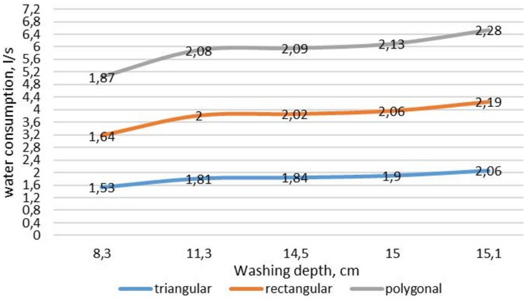

Fig. 7. Flushing depths in the lower by-pass at different water rates in cone dams.

In this study, field measurements are compared to laboratory measurements for predicting the size of the cumulatively disturbed area in washouts to prevent erosion downstream by controlling conical gate opening benefits. In model tests on structures that incorporated the use of conical gates to alleviate potential activity, all damper types showed a bidirectional cumulative effect, however, they were mainly different in their absolute and relative a. However, with gate manipulations, the flow characteristics changed, yielding more complicated washout characteristics.

The relative energy (E_0) results showed that triangular dampers decreased the most. At 80% of total gate opening, cumulative movement in the washout was reduced by 8% for polygonal dampers, 11% for rectangular dampers, and 16% for triangular dampers.

Hydraulic calculations were also conducted to define parameters for the quenching chamber, which meant experiencing stresses from flow impact and turbulent pulsations.

Therefore, the experiments defined the geometric dimensions at this location based on flow energy attenuation.

$$\eta = \frac{E_A - E_c}{E_A} \qquad (9)$$

where E $_A$ -total specific energy of the flow

$$E_A = \varphi^2 H_0 + z_0 \qquad (10)$$

where φ- velocity coefficient determined as a result of experimental studies, Z_0- distance from the bottom of the water intake channel to the axis of the gate, E_C is the total specific energy of the flow in the compressed cross section of the water discharge channel.

$$E_c = h_c + \frac{aV_c^2}{2g} \qquad (11)$$

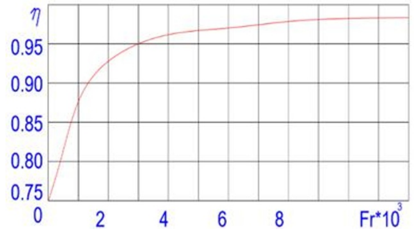

Fig.8. Graph of the relationship between the quenching rate of the quenching chamber and *the Fr* number.

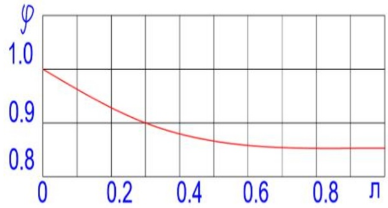

Fig. 9. Flow rate coefficient and turbulence coefficient in the quenching chamber.

The velocity and thickness of the stream impinging on the side walls in the quench chamber are determined as follows.

$$V = \varphi\sqrt{2gH_0} \qquad (12)$$

The total discharge of the water discharge channel, taking into account the rate of flow energy dissipation of the quenching chamber, is calculated as follows:

$$T_0 = (1 - \eta)(\varphi^2 H_0 + z_0) \qquad (13)$$

Following the evaluation of flow energy attenuation in a quenching chamber, the leaching processes in a lower bypass and the respective hydraulic parameters were investigated. The experiment was carried out under quasi-natural-flow conditions (depths in the lower bypass varied from h_{bypass} = 3.6 m to 4.2 m and hydraulic jump values were 3.26 m and 4.08 m). The experimental tests were conducted with one conical gate functioning and depth values (h_1, h_2) only started to change after 80% of gate opening.

At the test site, the accumulation depth in the lower bypass increased to 4.10 m when the discharge value was 90 m³/s. The results indicated that the accumulation depth varies with increased flow pattern. For the relationship between discharge and Froude number, the maximum discharge in the center support zone was Fr = 2, where adverse dynamic changes occur beyond a hydraulic jump greater than 4 m.

Additionally, a pressure-discharge relationship was determined for the conical traps, which allowed for defining the variations of the discharge coefficient observed under different pressures by experimental means. The final definitions of discharge coefficients were obtained based on these experimental results.

$$\mu = \frac{Q}{\omega_1 \sqrt{2gH_0}} \tag{14}$$

The results indicate that flow characteristics vary with the valve opening degree and cone geometry, independent of pressure magnitude (n=S/S_{max}). When the cone was opened to 80%, the flow remained stable, while a reduction in the central angle decreased water permeability. Nonetheless, cones with smaller central axes demonstrated several functional advantages despite this limitation.

4 Conclusion

This research analyzed the hydraulic performance and local scouring in water discharge systems that contain conical gates, examining the influence of flow energy reduction, degree of valve opening, and cone geometry on hydraulic stability. The experimental and analytical results showed that the Froude number values in the middle of the reinforced part of the lower bypass conducted the water remained below 2 in high discharge scenarios, indicating a stable flow regime. Nevertheless, the process produced fluctuations when the height of the hydraulic jump exceeded 4 m, suggesting increased turbulence and local scour.

The quenching chamber was designed to dissipate excess kinetic energy of the flow. It introduced high stresses from both ambiance impact and turbulent pulsation; therefore, its geometric dimensions were designed experimentally based on the phase of sustainable energy reduction. Optimizing the quenching chamber is an important component of maintaining hydraulic stability and reducing further erosion downstream.

Analysis of the experiments yielded evidence that both flow characteristics and scouring depths fluctuated in accordance with the combined effects of the conical gate opening. The data collected from the experiments, conducted at a near-natural flow condition, had bypass water depths of approximately 3.6 to 4.2 m, and were achieved by measuring free surface flow depths where the hydraulic jumps had values of 3.26 m and 4.08 m, respectively. The results showed that all depths (h_1, h_2) ranged considerably for about 80% gate opening, as the flow was perceived to run on normal hydraulic performance, indicating energy dissipation and sediment transport were being controlled.

In addition, there was an indication that even for a smaller central cone angle, the water permeability was drastically diminished. However, cones that had a smaller central cone exhibited better stability of flow as well as reduction in scour depth in the downstream section. In conclusion, results of this study demonstrate that a forward cone open to an approximate depth of around 80% is preferred as an optimal performance based on flow characteristics, energy dissipation efficiency, and erosion control at the lower bypass system.

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