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Shaping the outflow jet of tainter gates and hollow cone valves directed into water tunnels

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Design of bottom outlets ousting into water tunnels requires careful choice of closing elements. Atypical measures are often necessary to maintain safe outlet operation. Special attention must be paid to the protection of tunnel bottom/walls from erosion. Sizes of discharge chambers may be critical - especially in cases of bottom outlet reconstruction. The article describes the design and hydraulic model tests of flow deflecting elements and discharge chamber configurations applied on some Czech dams.

Keywords: Bottom outlet, tainter gate, cone valve, hydraulic model tests.

1 Introduction

The tainter gate has been used as a classic instrument to close/regulate the outflow from bottom outlets for centuries. In the last half of the past century started the more general use of hollow cone valves - mainly for regulation. Both types are in vogue for good regulation properties, high capacity, low space requirements and favourable cavitation characteristics when used at the end of pressure ducts ousting into atmosphere. They were mostly installed on the downstream faces of dams sufficiently high above the water surface to keep the cavitation low and the flow stable. In the last decades the need for good aeration properties of gates/valves has been stressed due to environmental considerations, especially in cases of outlet intakes placed near to the upstream bottom where the oxygen levels are low.

The bottom outlets on some Czech dams had to be overhauled. A thorough reconstruction of the whole system was decided upon to increase the outlet capacity. On the other hand the basic dimensions of the reinforced concrete structures (chambers, tunnels) could not be changed to keep the reconstruction cost in reasonable limits.

The article describes the non-traditional solutions applied on two dam outlets using hollow cone valves (Mostiste, Moravka), and one outlet using the tainter gate (Sous).

2 Shaping the flow in the chambers of hollow cone valves and the ensuing tunnels

The cone-shaped outflow jet of a cone valve maintains the angle of the cone in the outflow space. In the Czech Republic the angle of 90 deg is customary.

Hydraulic research [Jaroš (1970)] proved that no significant increase of outlet capacity is gained by using relative valve opening values s/D greater than .85 . Here s means the valve travel and D the nominal diameter of the valve at outlet. The Czech designers and manufacturers generally use the maximum s/D value of .5 .

The high energy water jet causes fluctuating stress on the walls of the downstream chambers. Fortunately the high air content inside the jet usually prevents cavitation. When the chamber is small, the outlet tunnel may be clogged by the spray. Then pressure pulses and decrease of outflow capacity occur.

When the valve is ousting from the downstream face of the dam directly into the atmosphere, the spray travels a long distance and in harsh winters it may cover the adjoining structures by ice.

An effort to change the shape of the jet may ease the problems cited above. This may be accomplished by:

- reinforced concrete walls of a chamber in-built in the dam downstream face or built at the exit from the pressure duct,
- fixed steel structure placed downstream of the valve, mostly ax-symmetrical structures with an axis following the axis of the valve are used,
- moving steel structure which is usually attached to the moving outer ring of the valve.

The jet leaving a tainter gate and entering an outlet tunnel which is designed for free water surface flow spreads wide and climbs up on the vertical side walls. When the outflow rate reaches a certain level, most of the tunnel profile is filled by spray. Clogging of the tunnel and the dangerous accompanying phenomena mentioned in the case of cone valves result.

A favorable shape of the jet may be attained by using longitudinal inserts anchored in the tunnel walls.

2.1 Shaping the outflow into the tainter gates' chamber of the Sous dam

As a part of the reconstruction two regulating tainter gates have been added at the ends of two separate but parallel bottom outlets ousting into a common tunnel. The gates were 1.2 meters wide (i.e. $b = 1.2$), with maximum opening. 6 meter ($a_o = .6$). The axes of the gates were 2.2 meters apart.

The jet entered an 8.2 meters long narrowing section forming the entry into the tunnel. Then followed a 63.4 meters long section of constant width (3 meters) and constant height (maximum 2.5 meters with ceiling radius equal to 1.5 meters) sloping at a supercritical angle.

Model tests [Šulc (2000)] were used to support the design of the shaping elements. With none shaping elements clogging of the tunnel was registered at the design discharge rate of 2 x 10.6 meters cube per second. Then a non-symmetrical case (15.3 + 5 meters cube per second) was tested resulting in clogging, too. Tests of a number of shaping elements using many discharge levels and combinations were then performed. Satisfactory exploitation properties have been found with two in-built longitudinal fence-like elements each 8.2 meters long and .2 meter wide placed 1 meter above the floor on the vertical walls of the tunnel. Schemes of the tunnel modifications and the resulting fields of flow are shown in Figs. 1 and 2 respectively.

The chamber is aerated by two vents in the vertical wall above the tainter gates. The air is sucked in by the water jet and spray from a vertical shaft the entry of which is in the machine room above.

2.2 Shaping the outflow into the cone valve's chamber of the Mostiste dam

A moving shaping element made of steel metal sheet connected to the sliding ring of the valve is used.

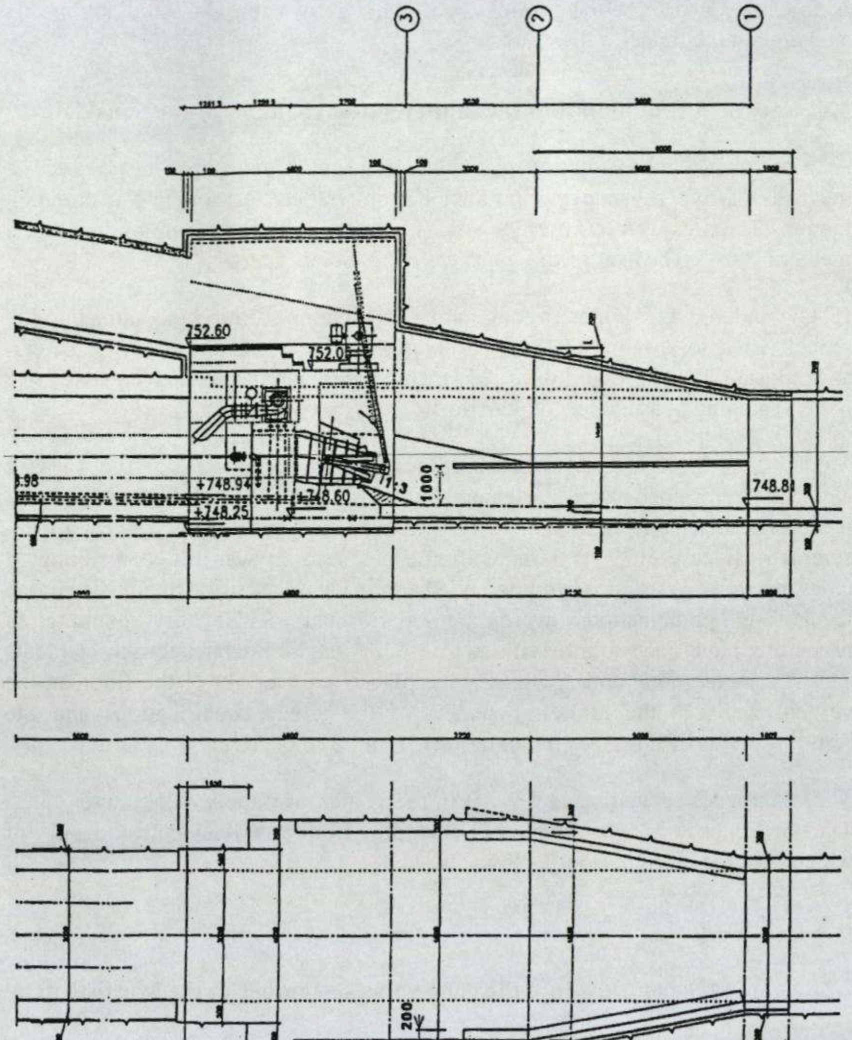


Figure 1: Shaping the outflow from a tainter gate by horizontal fence-like elements in the chamber of the bottom outlets of the Sous dam

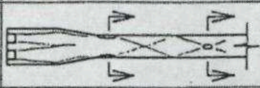
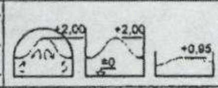
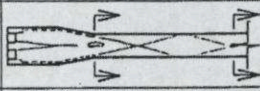
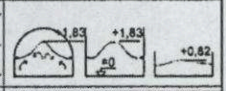
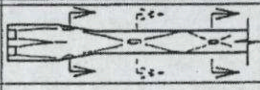
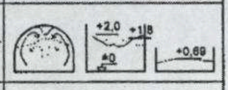
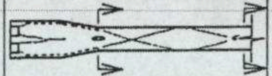
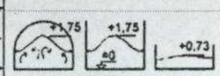
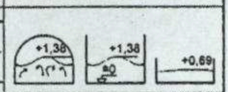
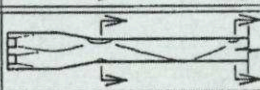
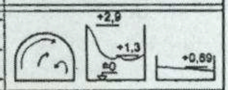
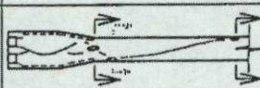
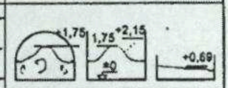
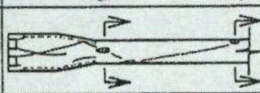
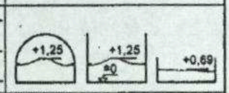
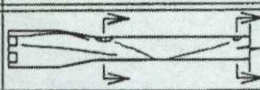
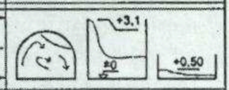
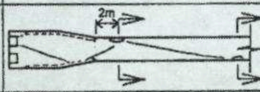
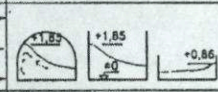
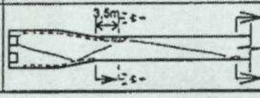
Comparison of the stream-shaping effect				
Fence height [mm]	Discharge Q [m³.s⁻¹] Q-left (downstream) Q-right (downstream)	ΣQ [m³.s⁻¹]	Plan-view of the crests of the spray	Profiles of spray upper surface in important sections
0	10,3 10,3	20,6		
125	10,3 10,3	20,6		
200	10,3 10,3	20,6		
0	7,5 7,5	15,0		
125	7,5 7,5	15,0		
200	7,5 7,5	15,0		
0	10,3 5,0	15,3		
125	10,3 5,0	15,3		
200	10,3 5,0	15,3		
0	10,5 0,0	10,5		
125	10,5 0,0	10,5		
200	10,5 0,0	10,5		

Figure 2: Influence of various horizontal fences on the stream in the characteristic profiles of the Sous bottom outlet

The jet enters a cylindrical tunnel of a diameter equal to 3 meters designed for free surface flow. The shaping element is formed by a 1.3 meters long mildly narrowing cone the weight of which is carried by guiding rails anchored in the tunnel walls.

The valve nominal diameter is D = 1.1 meter, the maximum relative opening $s_{max}/D = .527$ with maximum cone travel s_{max} equal to 580 millimeters. This is a mild "over-opening" when compared with the usual value of s/D = .5 .

Air is fed into the jet both from the outside and inside the jet. The air enters the inside of the jet through a hollow structure of one of the carrying elements.

The valve maximum capacity at maximum head of $H_{max} = 26$ meters is $Q_{max} = 16$ meters cube per second.

A low level of jet aeration was feared when reconstruction was decided upon. Therefore an additional vent was created by using the shaft designed as maintenance entry into the chamber (section dimensions .55 x 1.04 meters) the hatch of which must be opened before the valve itself is opened.

This non-traditional scheme was designed on the basis of model research results and additional corrective measures resulting from our previous experience. Final tests of the real valve proved a faultless closing/regulation function.

2.3 Hollow cone valves of the new bottom outlets of Moravka dam

During the reconstruction of the Moravka dam it was decided to build new (added) bottom outlets.

The capacity of the original outlets remained unchanged, i.e. Q = 24 meters cube per second at lake surface level of 506.73 meters a.s.l. The new bottom outlets have a capacity of Q = 36 meters cube per second.

The structure submerged in the lake is equipped with two short tubes of nominal diameter 1.4 meter reduced at the end to diameter 1.2 meter where hollow cone valves have been installed.

Their outflow enters a common tunnel with free surface flow. The length of the tunnel is L = 356.6 meters and supercritical slope $J_o = 1.519$ percent. The tunnel has a transition part at the entry followed by a long constant profile section and is finished by a diffuser.

Model tests have been undertaken to check the function of the new design. The research was aimed at finding the optimum values of valve relative opening, optimizing the shape of the transition part and of a newly designed flow shaping element and determination of the air/water flow relation. The results of the two-stage research have been published [Šulc (2003)].

To achieve the originally demanded capacity of Q = 34 meters cube per second one expected a certain measure of "over-opening" of the valve at about s/D = .75. This value was confirmed by the model tests of the chosen valve version.

The tests have been performed with five versions of the valves (one without a shaping element and four with various shaping elements installed). The installation of the shaping elements resulted in negligible changes of the valve capacity ([Šulc (2003)] and Fig.3).

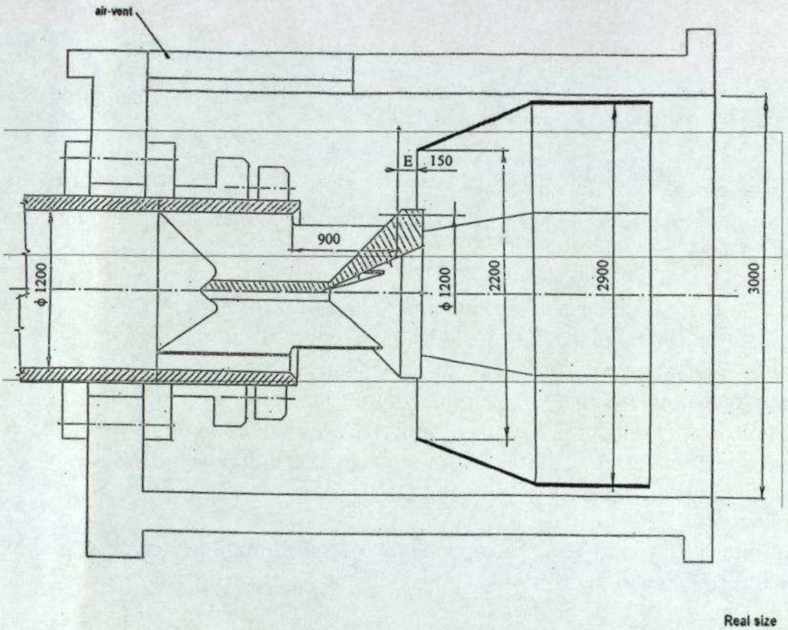


Figure 3: Mutual positions of valve and octagon

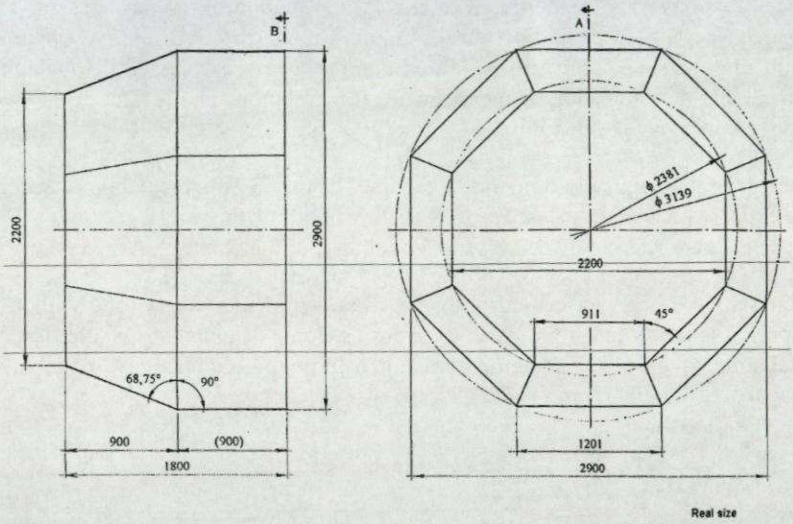


Figure 4: Final version of the octagon

Comparing the outflow structure quality, weight and cost of the versions tested led to the choice of octagon as the most suitable profile of the shaping element (Figs. 3,4).

The finally chosen variant of the element had a diffuser shaped entry part with the diffuser (one-sided) angle of 42.5 degrees ensuring a wall-tangent-to-flow design. No backward spray due to jet impingement on the element wall nor spray formation on the free surface of the jet have been registered. The jet aeration process is smooth with no pulses. This flow-shaping is suitable at all valve openings tested. The fact that the element is composed of evolvable metal sheet cuttings allows easy manufacture.

The inner air-space of the jet is aerated by four "dragon's teeth" type hollow structures placed at the end of shaping element's walls (Fig. 5).

The operation tests of the real new bottom outlets proved their capacity and safe operation.

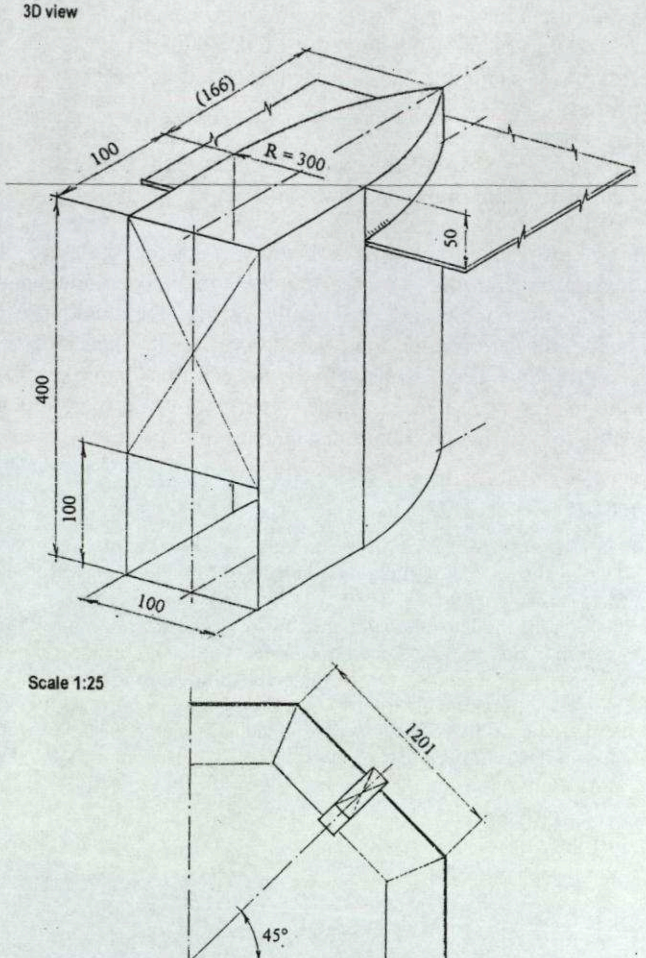


Figure 5: "Dragon's tooth" with in-built air-vent

3 Conclusion

The shaping of the jet from hollow cone valves entering the tunnels of bottom outlets shown and recommended in this contribution insured a safe and reliable function of bottom outlets.

The shaping elements whether fixed or moving guarantee a full regulation capability of the valves with no clogging of the tunnel by the water flow or spray. Successful jet shaping is possible when generous aeration of the bottom outlets is ensured.

The influence of the shaping elements used in the outlets of the given configuration on the value of the outflow coefficient is negligible.

The amount of air sucked into the valve chambers depends on the factors mentioned in the contribution. Our measurements made on models and real size dams cannot lead to reliable and sufficiently general conclusions defining the model similarity and determining the desired coefficients. The measured values of aeration coefficients differ substantially for various dams or their models even when the results were gained by the same team using the same technique. Much more attention to this problem must be paid in the future.

4 Literature

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