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HYDRAULIC CHARACTERISTICS OF HOLLOW CONE VALVE WITH HOOD

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I. INTRODUCTION

The hollow cone valve is widely used as a by-path discharge valve in hydraulic power plants for multi-purpose dams used for power generation, irrigation, flood control and etc. With the topographical conditions of the downstream, the hoods are required to be provided on those hollow cone valves in order to restrict the diffusion of water jet discharged through the valve.

The effect of hood was confirmed by the hydraulic characteristic tests using model of hollow cone valve with hood in FUJI Hydraulic Laboratory. Those model test results are reported hereunder.

II. HYDRAULIC CHARACTERISTICS OF DISCHARGE VALVE

A model of hollow cone valve with hood was prepared and tested in the hydraulic laboratory. The model dimensions and test head are shown below:

Valve diameter	D :	170mm
Stroke	S :	0 ~ 86mm
Hood diameter	D_h:	400mm
Effective head tested	H :	4 ~ 5m
Maximum discharge tested	Q :	approx. 155ℓ/s

The effective head with the valve, H, was calculated from the following equation:

$$H = H_u + \frac{V_1^{\,2}}{2g} + \Delta EL$$

where H_u : static pressure head at valve inlet (m)
V_1 : mean velocity at valve inlet (m/s)
g : acceleration due to gravity (m/s^2)
ΔEL : altitude difference between valve inlet and outlet (m)

A water column manometer with a minimum scale of 1mm was used to measure the static pressure head. The measurement accuracy for static pressure at the maximum test discharge was 0.04%. The discharge measurement was made using inlet nozzle and its differential pressure was measured by means of a water column monometer with a minimum scale of 1mm. The measurement accuracy for the maximum test discharge was 0.09%.

1. Discharge Characteristics

Fig. 1 shows the discharge characteristics obtained from model tests. The abscissa shows the dimensionless stroke defined as valve stroke S divided by valve diameter D and the ordinate shows the discharge Q_{11} $(=Q/\sqrt{H}{\cdot}D^2)$ per unit valve diameter and unit head. The slope of unit discharge versus stroke becomes somewhat small at $S/D \geq 0.4$. In the range of large stroke (S/D=0.4~0.5), there was no breaking point at which vibrations start. However, noise occurred at small stroke (S/D=0.02~0.05). At small stroke, natural air supply was confirmed to be impossible and noise reduction could not be expected by natural aeration.

2. Discharge Coefficient

The discharge can be expressed in the from of a discharge coefficient as follows:

$$C = Q/\pi d b\sqrt{2gH}$$

where: C : discharge coefficient

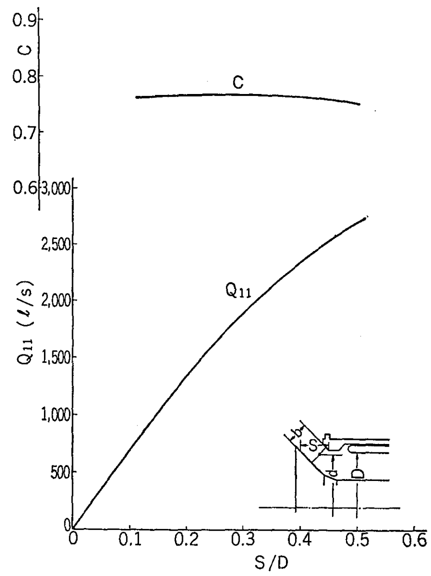


Fig. 1. Discharge characteristic curves

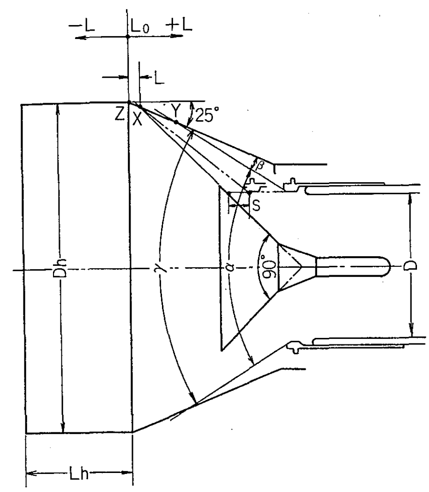
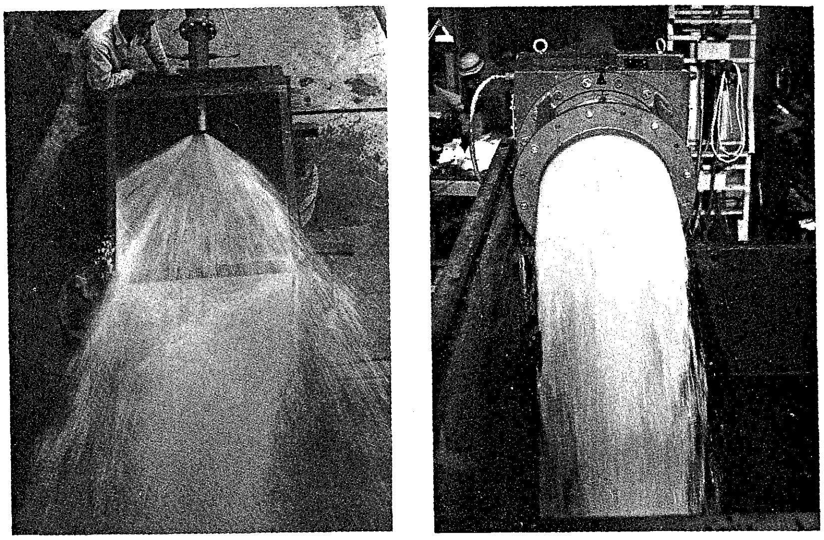


Fig. 2. Layout of valve and hood



(a) Without hood (b) With hood

Fig. 3. Comparison of water jets from discharge valves

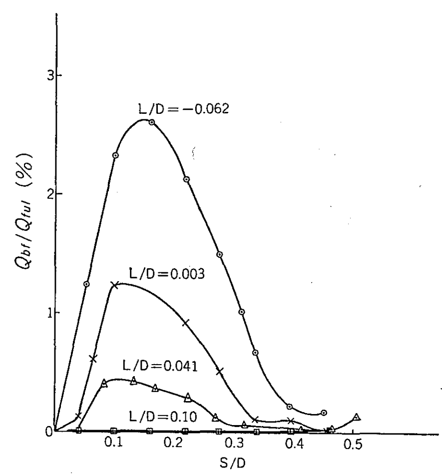


Fig. 4. Characteristics of back flow

d : average diameter of valve throat (m). Refer to *Fig. 1*.

b : channel width at throat (m). Refer to *Fig. 1*.

Fig. 1 shows the relationship between discharge coefficient C and dimensionless stroke S/D. From the figure, C was almost constant with respect to S/D but as the stroke increased, C tended to drop slightly.

3. Effect of Hood

When it is necessary to suppress diffusion of water jet discharged from valve because of dimensional restrictions of downstream structure, it is effective to attach a hood consisting of cone and cylinder to valve outlet as shown in Fig. 2. Fig. 3 shows a comparison of water jet diffusion between the valve without and with hood. The diffusion of water jet was suppressed effectively when hood was used. According to the model test, the maximum diameter of water jet was only about 1.4 times the hood diameter at a distance of about four times the hood diameter from hood tip.

4. Back Flow Phenomenon in Valve with Hood

When a hood is attached to the valve in order to suppress diffusion of discahrge from valve, part of water jet coming into contact with inner wall of hood is to flow upstream in the form of back flow. The back flow would leak into valve chamber from space between hood and valve and give unfavourable effect to valve operating mechanism.

The layout of valve and hood shown in *Fig. 2* is extremely inportant to the back flow characteristics. The parameters which control hydraulic functions of hood are hood diameter D_h, hood cylinder length L_h, hood cone angle γ and relative location of hood to valve L. The relative location between hood and valve, L, can be defined as distance from the juction point Z of hood cone and cylinder to the intersection point X of hood cone and extended line of valve cone. Of these parameters, L and γ are directly related to the back flow phenomenon. The contact angle β of water jet with respect to hood inner wall is 1/2 of the angle obtained by subtracting hood cone angle γ from water jet outlet angle α. To clarify and solve the back flow phenomenon, following experiments were performed.

1) Relation between stroke and maximum back flow

Measured back flow (Q_{bf}) divided by the maximum discharge (Q_{ful}) are shown against dimensionless stroke S/D in *Fig. 4* with relative location of hood to valve, L/D as parameter. In visual observations using a model with hood made by transparent acryl resin, the position Y in which outer cone of water jet touches hood cone almost coincide with X when stroke was small (*Fig. 2*). The contact point Y shifted to upstream side as stroke S increased but the distance shifted was less than the stroke moved. Therefore, as stroke increased, contact angle β tended to become smaller as can be seen in curve ② (*Fig. 5*). As will be explained in 4.2), there is less back flow when $L > 0$. When stroke is small, back flow leaks easily into valve chamber guided by extended cylindrical gate. When stroke is large, there is less guiding action of extracted cylindrical gate and back flow tends to be hard to leak into valve chamber. For these reasons, back flow leakage in the range of large S/D decreases as S/D increases (curve ③). However, in the small stroke range, the amount of back flow increase in proportion to the discharge characteristics (*Fig. 1*) of main flow jetting from valve (*Fig. 5* ①). Therefore, the resultant back flow characteristics are of convex shape against stroke.

2) Relations between back flow and contact position/angle of water jet to hood

The model test were performed by inserting liners between valve and hood to change relative location L. The test results are shown in *Fig. 4*. The stroke at which back flow becomes the maximum was around $S/D = 0.12 \sim 0.14$ irrespective of L/D. A curve of solid line in *Fig. 6* shows the relation between the maximum amount of back flow and relative location L/D. When $L/D < 0$, water jet comes into contact with hood cylinder so that contact angle β is large and back flow increases. On the other hand, when $L/D > 0$, water jet comes into contact with hood cone so that contact angle β becomes small and back flow rapidly decreases.

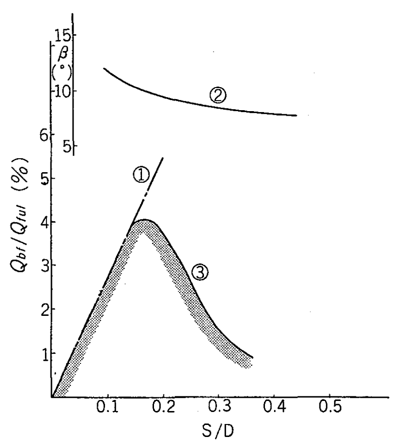


Fig. 5. Relation between stroke and back flow

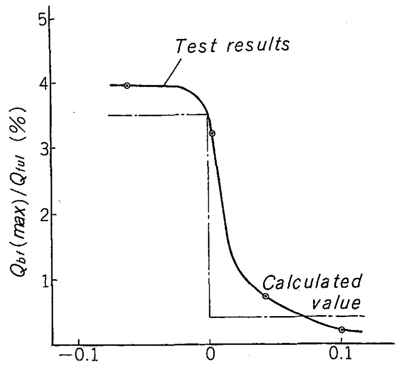


Fig. 6. Effect of relative location between hood and valve

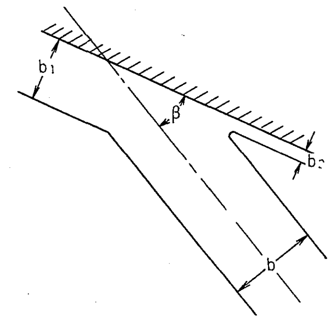


Fig. 7. Water jet against inclined wall

3) Comparisons with calculated results

When water jet flows against an inclined flat plate at contact angle β, back flow can be calculated by the following equation (refer to *Fig. 7*);

$$b_2 = \frac{b}{2}(1 - \cos\beta)$$

When is assumed that $\dfrac{b}{b_{ful}} \propto \dfrac{S}{S_{ful}}$

$$Q_{bf}/Q_{ful} = \frac{1}{2} \cdot \frac{S}{S_{ful}} (1 - \cos\beta) \times 100$$

where: b_2 : width of back flow at stroke S
b : width of water jet at stroke S
b_{ful} : width of water jet at full stroke S_{ful}
β : angle between wall and water jet b

The outlet angle α of water jet discharged from hollow cone valve without hood was taken from test result which previously performed in FUJI hydraulic laboratory, and the contact angle β ($= \frac{1}{2}(\alpha - \gamma)$) was calculated (*Fig. 5*, curve ②). Substituting β in the above equation, the calculated back flows are shown by the chain line in *Fig. 6*. The experimental and calculated results showed good agreement and the relation between back flow and contact angle was confirmed quantitatively.

5. Methods of Reducing Back Flow

As is shown in *Fig. 6*, back flow can be minimized by making relative location of valve and hood, L/D, sufficiently large (layout so that extended line of valve cone makes contact with hood cone).

On the other hand, it is also possible to reduce back flow leakage without L/D becoming too large by inserting cut-off rings between valve gate and hood. *Fig. 8* shows the attachment position of cut-off rings tested.

The cut off ring Ⓒ on gate was fixed during the tests, but ring Ⓓ on gate and those cut off rings Ⓐ and Ⓑ on hood were of detachable construction. Back flow characteristics were tested in five cases by changing cut-off ring combinations.

Fig. 9 shows test results for an extremely small L/D of 0.003. From this figure (*Fig. 9*, C-4), in case that the only cut-off ring Ⓒ is attached, back flow still exists greatly even under conditions of L/D = 0.003, it is possible to reduce back flow leakage into valve chamber by attaching

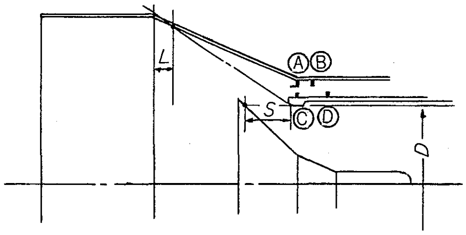


Fig. 8. Attachment position of cut-off rings

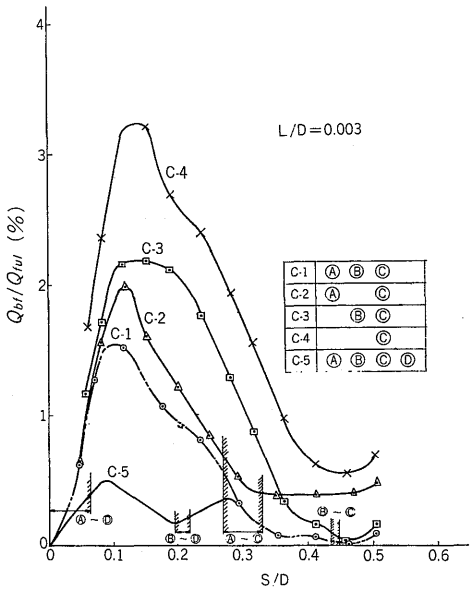


Fig. 9. Effect of cut-off rings

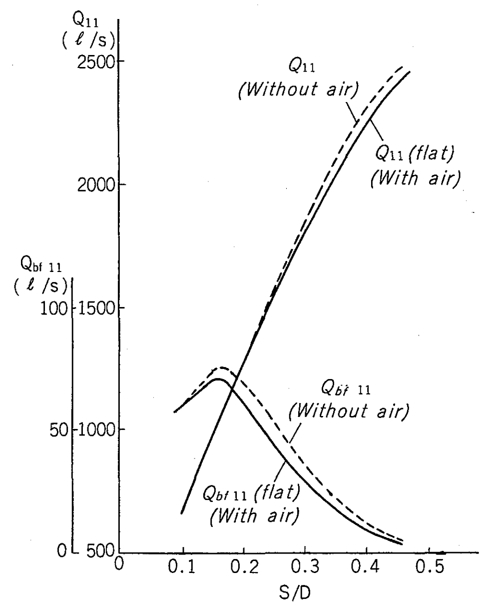


Fig. 10. Effect of air supply

cut-off rings in appropriate positions. The figure shows the range where cut-off rings on hood and valve are overlapping at which it is evident that the back flow leakage is suppressed. Cut-off ring Ⓐ is very effective in preventing back flow leaked along hood.

6. Effect of Aeration

Aeration is generally effective for dissipation of water jet energy. In this concern, model tests were performed to find the effect of aeration to unit discharge Q_{11} and unit back flow Q_{bf11}. The static pressure at outlet of valve throat was increased with air supply, so that effective head was decreased and both of discharge Q and back flow Q_{bf} were decreased. At first, with increase of air supply, discharge and back flow are decreased sharply. Then, Q and Q_{bf} become constant at the some degree of air supply even if air supply is increased more than that degree.

Those constant values of discharge and back flow are indicated by Q_{flat} and Q_{bf}(flat). *Fig. 10* shows relationship between S/D and Q_{11flat}, $Q_{bf11(flat)}$. As shown in the figure, there is no effect of air supply on the discharge at the lower stroke than $S/D = 0.22$.

It is quite apparent that the influence of air supply is large for the zone of larger S/D values.

III. CONCLUSION

Hydraulic characteristic tests of model hollow cone valve with hood were performed, and beside discharge characteristic tests, various tests related to the back flow problem caused by attaching hood were carried out changing various parameters. The back flow problem was almost clarified and the effective counter measure to prevent back flow was established.