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AIR VALVE SIZE FOR SUGAR LOAF DAM EMERGENCY GATE
CLOSURE TESTS
AUGUST 1979

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PAP - 392

UNITED STATES GOVERNMENT

Memorandum

TO : Memorandum
Chief, Mechanical Branch

THROUGH: Chief, Hydraulics Branch
Chief, Division of Research
Chief, Division of Design

FROM : Henry T. Falvey, Technical Specialist

Denver, Colorado
DATE: August 30, 1979

SUBJECT: Air Valve Size for Sugar Loaf Dam Emergency Gate Closure Tests

An analysis was performed to determine the required air valve size to be used for emergency closure tests of the Sugar Loaf Dam guard gate. Two flow conditions were studied. These are for total flow rates of $11.3 \text{ m}^3/\text{s}$ ($400 \text{ ft}^3/\text{s}$) and $41.9 \text{ m}^3/\text{s}$ ($1480 \text{ ft}^3/\text{s}$). The results are summarized as follows:

For the low discharge case, a 76-mm (3-in) vacuum relief valve will limit the lowest internal pipe pressure to approximately 41 KPa ($6 \text{ lb}/\text{in}^2$) below atmospheric pressure at the location of the valve. The minimum pressure in the steel pipe will be approximately 24.1 KPa ($3.5 \text{ lb}/\text{in}^2$) below atmospheric pressure. The most critical location in the steel pipe is at its most upstream point of attachment. With no air valve, the pressure at this point would be approximately 92.4 KPa ($13.4 \text{ lb}/\text{in}^2$) subatmospheric.

For the maximum discharge case, the lowest internal pressure occurs for a guard gate opening of about 30 percent. With a 152-mm (6-in) pressure relief valve the minimum pressure in the steel conduit will be approximately vapor pressure. A 203-mm (8-in) valve is required to limit the subatmospheric pressures to 44.8 KPa ($6.5 \text{ lb}/\text{in}^2$). This size exceeds the present vent dimensions. Therefore, an emergency closure should not be attempted without modifying the existing structure.

Details of the analytical procedure to determine the vacuum relief valve sizes listed above are outlined in the attached note.

Attachment



AIR VALVE DESIGN AT GUARD GATES

Introduction

Most outlet works consist of an intake structure, a guard gate, a flow regulating gate, and an energy dissipator. In many dams, the guard gate is located in a dome-shaped chamber located near the center of the dam (fig. 1). Upstream of the guard gate, the conduit is constructed of reinforced concrete with a steel liner. Downstream of the guard gate, the conduit is a steel pipe placed in a larger diameter concrete-lined tunnel. The reason for this type of design is to minimize the possibility of damaging the downstream dam embankment due to leaks which may occur in a reinforced concrete conduit operating under high heads.

The current operating criteria for an outlet works specify that the guard gate only be opened or closed under a balanced head. This requires that both the upstream and downstream conduits be filled with water and the regulating gate closed before the guard gate is actuated. The filling of the upstream conduit is accomplished either as the reservoir rises or through a valve in a bulkhead gate placed over the intake structure. The downstream conduit is filled by a bypass line which conducts water around the closed guard gate. Air trapped in the downstream conduit escapes through vents placed immediately downstream of the guard gate. These air vents are normally quite small. A gate valve is usually placed on the vents so that they are opened only during the filling process.

Criteria, which are being developed under the Safety of Dams Program, are requiring a reevaluation of the vent design downstream of the guard gate. These criteria specify that the guard gates be able to close under a full reservoir head while the control gates remain in an open position. For this type of operation, an air valve must be provided immediately downstream of the guard gate. The purpose of the valve is to limit the negative pressures in the downstream steel conduit to some prescribed value.

The purpose of this note is to describe a method of designing air valve for the case of an emergency closure of the guard gate. Two conditions must be considered. These are air flow with the downstream conduit filled and air flow with a free-water surface in the downstream conduit.

Downstream Conduit Filled

As the guard gate closes, the pressure in the downstream conduit decreases. In addition to this general decrease in pressure, an additional local pressure reduction occurs immediately downstream of the guard gate (fig. 2). If the pressure gradeline drops below the top of the conduit, then the zone of recirculating will become filled with

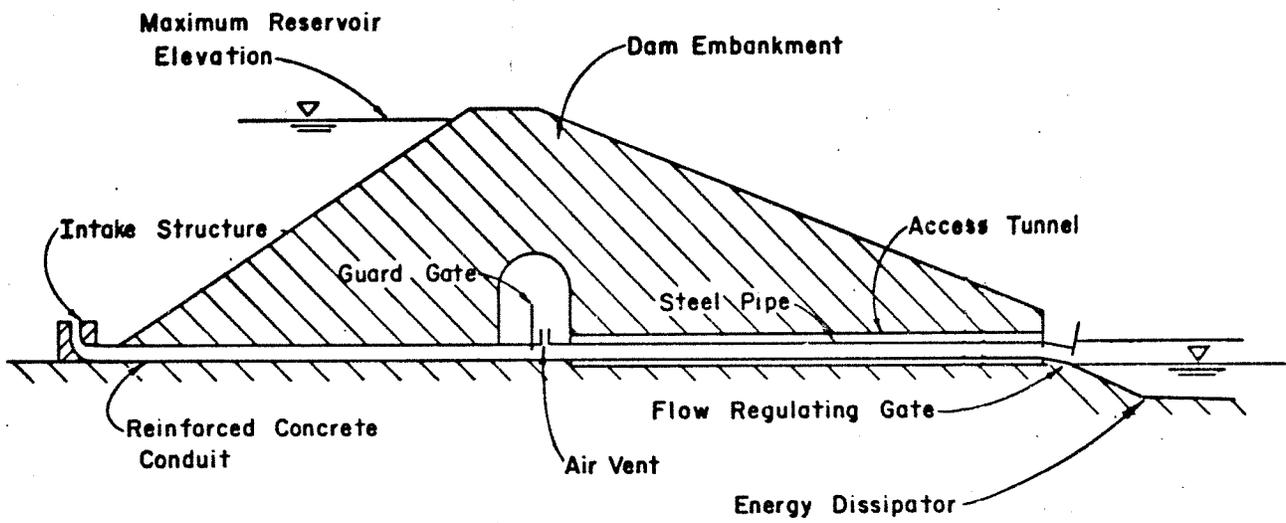


Figure 1. - Typical outlet works configuration

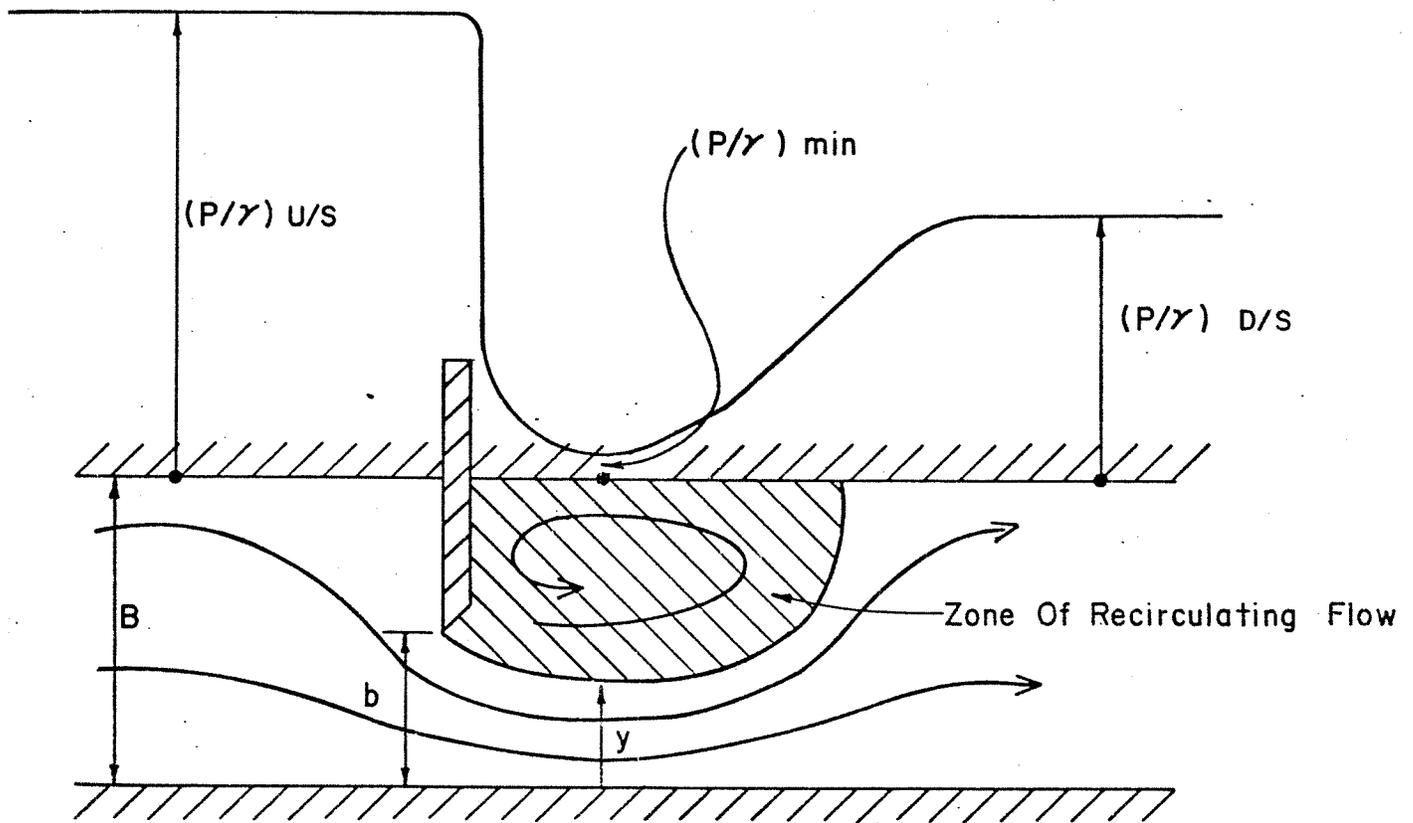


Figure 2. - Pressure distribution past a partially closed gate

air if an air valve is provided for ventilation. With no air valve, the pressure could become low enough that the recirculating flow zone would be filled with water vapor. This latter condition is very dangerous and should be avoided.

With air filling the recirculating zone, a hydraulic jump will form in the conduit. A jump tends to purge the zone of the air it contains. The quantity of air which can be removed from a conduit by a jump is given by:

$$Q_a = 0.0066 (F-1)^{1.4} (Q_w) \quad (1)$$

where:

$$F = \text{Froude number of flow at vena contracta}$$

$$= \frac{V}{\sqrt{gy}}$$

V = Velocity at vena contracta
y = Jet thickness at vena contracta
g = Acceleration of gravity

$$y_c = \frac{A}{2[y(D-y)]^{1/2}}$$

The amount of the contraction at the vena contracta is a function of the relative gate opening and the geometry of the conduit. Typical values are given in figure 3.

Free-water Surface in Downstream Conduit

At some value of the guard gate opening, the downstream conduit will flow with a free-water surface. In this case, the air flow rate can be approximated by the difference between the discharge through the guard gate and the discharge through the regulating gate.

Recommended Computational Procedure

1. Determine pressure head in conduit downstream of guard gate. - The pressure head downstream of the guard gate can be calculated as a function of the discharge using the method outlined on page 469 of the Design of Small Dams publication. The total loss between the reservoir and the conduit downstream of the guard gate must be determined. The pressure is given by:

$$\left(\frac{P}{\gamma}\right)_{D/S} = Z_r - Z_c - \Sigma h_L - \frac{V^2}{2g} \quad (2)$$

where:

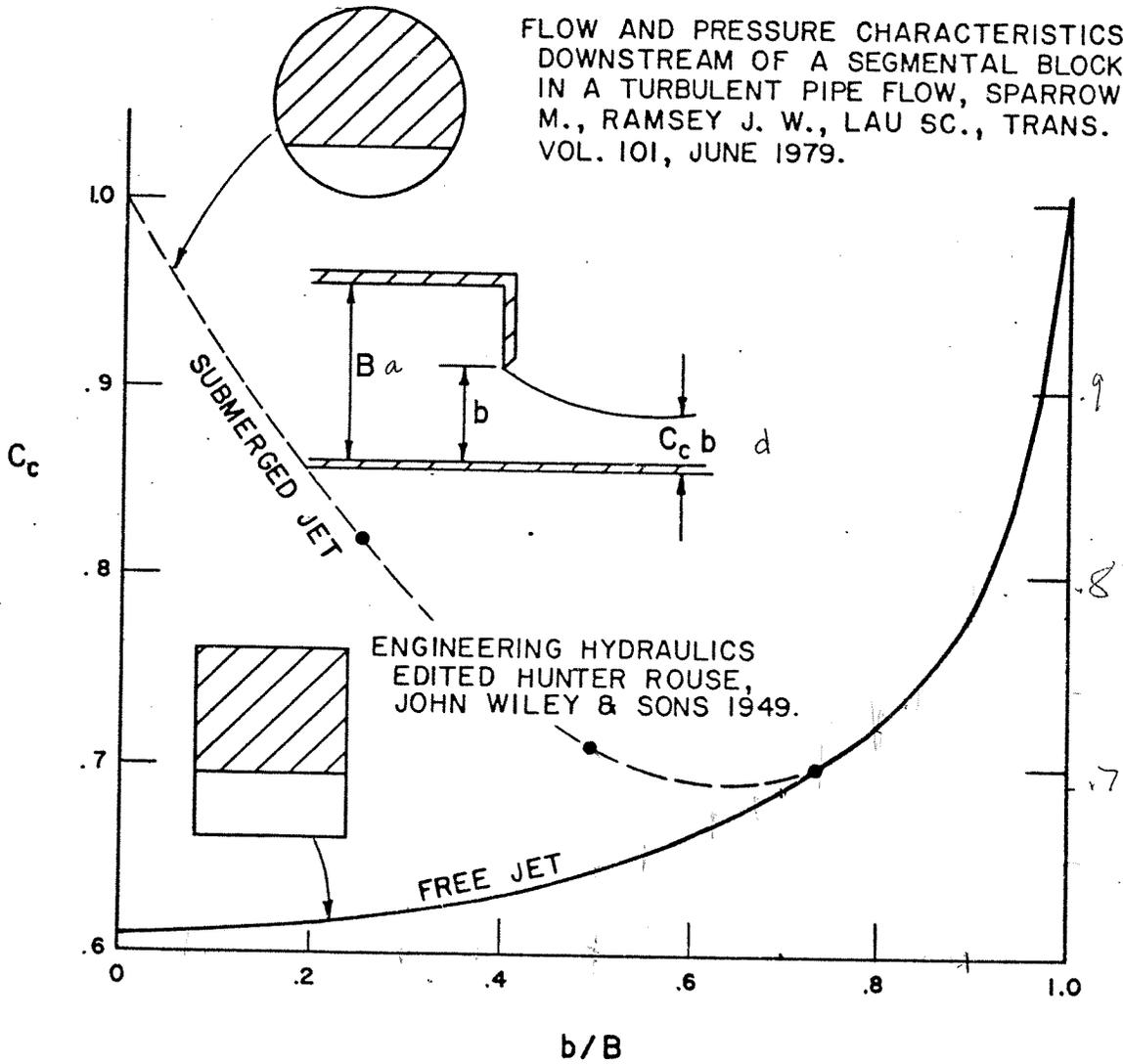


Figure 3. - Contraction coefficients

$$H_L = \left(1 - \frac{B}{C_c b}\right)^5 \frac{V_1^2}{2g} \quad K_L = \left(1 - \frac{B}{C_c b}\right)^2$$

- Z_r = Reservoir elevation
 Z_c = Conduit invert elevation at guard gate
 Σh_L = Summation of head losses between reservoir and the downstream conduit. This must include partially open gate losses and expansion losses from the gate to the downstream conduit.

The loss across the gate can be estimated from the following table or figure 4.

Table 1. - Loss coefficients for gate valves

Percent opening	Loss coefficient
	K
0	∞
10	273
20	61
30	22.5
40	10.6
50	5.2
60	2.7
70	1.4
80	0.6
90	0.2
100	0

The loss h_L , units of length, given by:

$$h_L = \frac{KV^2}{2g} \quad (3)$$

The computations do not have to be continued for negative values of $(P/\gamma)_{D/S}$ since these indicate free surface flow in the downstream conduit.

2. Determine the minimum pressure immediately downstream of the guard gate. - In terms of the contraction coefficient, the minimum pressure can be determined for rectangular sections from:

$$\left(\frac{P}{\gamma}\right)_{\min} = \left(\frac{P}{\gamma}\right)_{D/S} \left[1 + K - \frac{1}{C_c^2} \left(\frac{B}{b}\right)^2 \right] \frac{V^2}{2g} \quad (4)$$

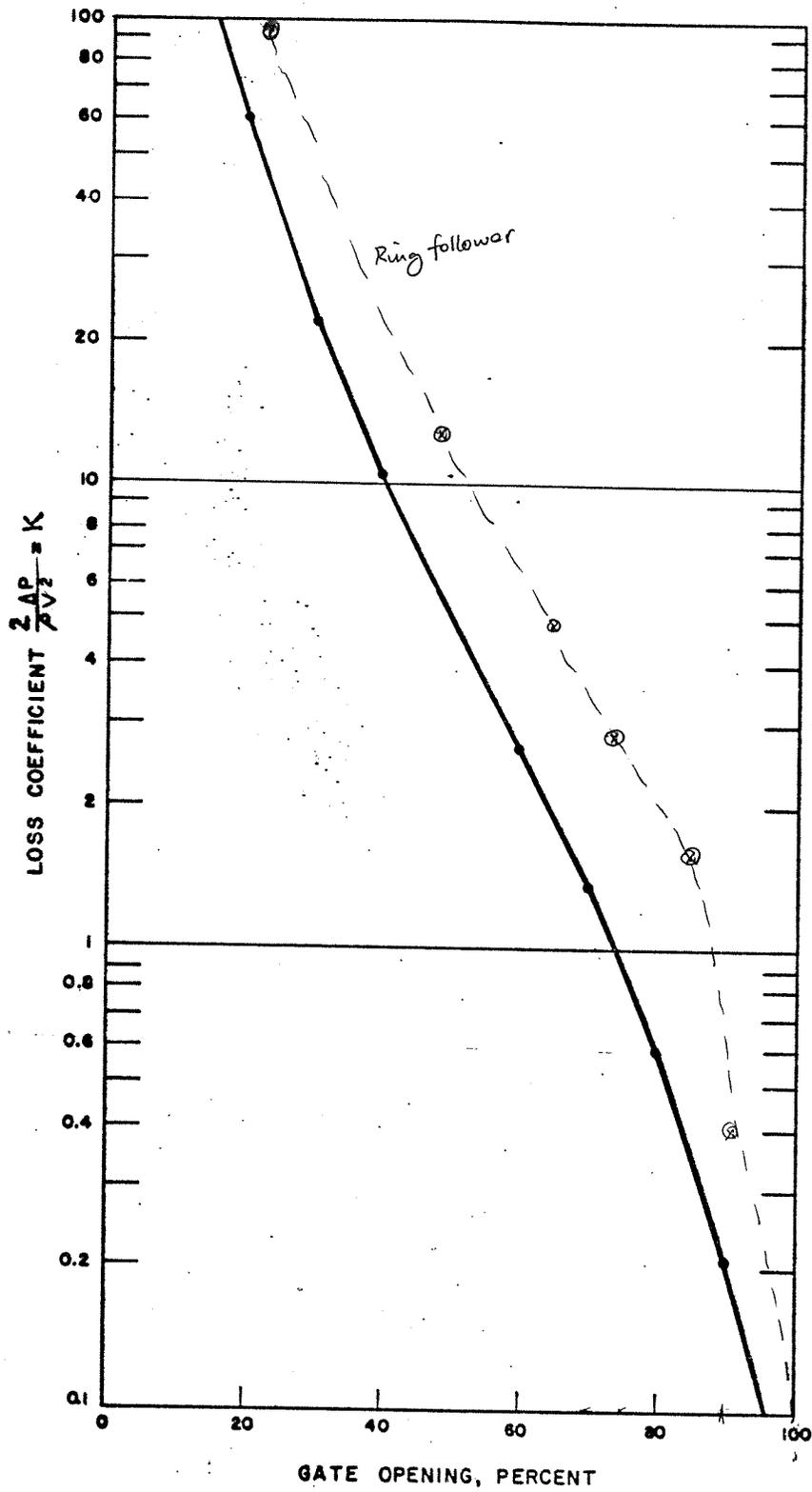


Figure 4. - Loss coefficients for partially open guard gates

where:

- b = Gate opening
- B = Height of upstream conduit
- C_c = Contraction coefficient
- P/γ = Pressure head
- V = Mean velocity in full conduit at gate

If the value of (P/γ)_{min} is less than the vapor pressure of water, the computations should be stopped since the pressure will not drop further.

3. Determine air valve size due to hydraulic jump in conduit. - The quantity of air which must enter the valve to replace the air removed by the jump is given by equation 1. If a minimum acceptable internal pressure for the conduit is given, the required size of air valve for this condition can be obtained from figure 5. This figure is based upon:

$$\frac{1}{A_o} Q_a = \frac{C_d A_o}{R_a} \left(\frac{P_d}{P_a} \right)^{1/\alpha} \sqrt{\frac{2P_a}{\rho_a} \left(\frac{\alpha}{\alpha-1} \right) \left[1 - \left(\frac{P_d}{P_a} \right)^{\frac{\alpha-1}{\alpha}} \right]} \quad (5)$$

for $P_d/P_a > 0.53$, and

$$Q_a = C_d A_o \left(\frac{2}{\alpha-1} \right)^{\frac{1}{\alpha-1}} \sqrt{\frac{2P_a}{\rho_a} \left(\frac{\alpha}{1+\alpha} \right)} \quad (6)$$

for $P_d/P_a < 0.53$

where:

- Q_a = Air flow rate
- A_o = Orifice area
- P_a = Atmospheric pressure
- P_d = Allowable internal pressure
- ρ_a = Density of air at standard temperature and pressure = 1.204 kg/m³
- C_d = Discharge coefficient for an orifice = 0.6
- α = Isentropic gas constant for air = 1.4

4. Determine air flow rate with free water surface in downstream conduit. - The air flow rate with a free water surface is equal to the difference between the water flow rate through the guard gate and the water flow rate through the regulating gate. The computation of this

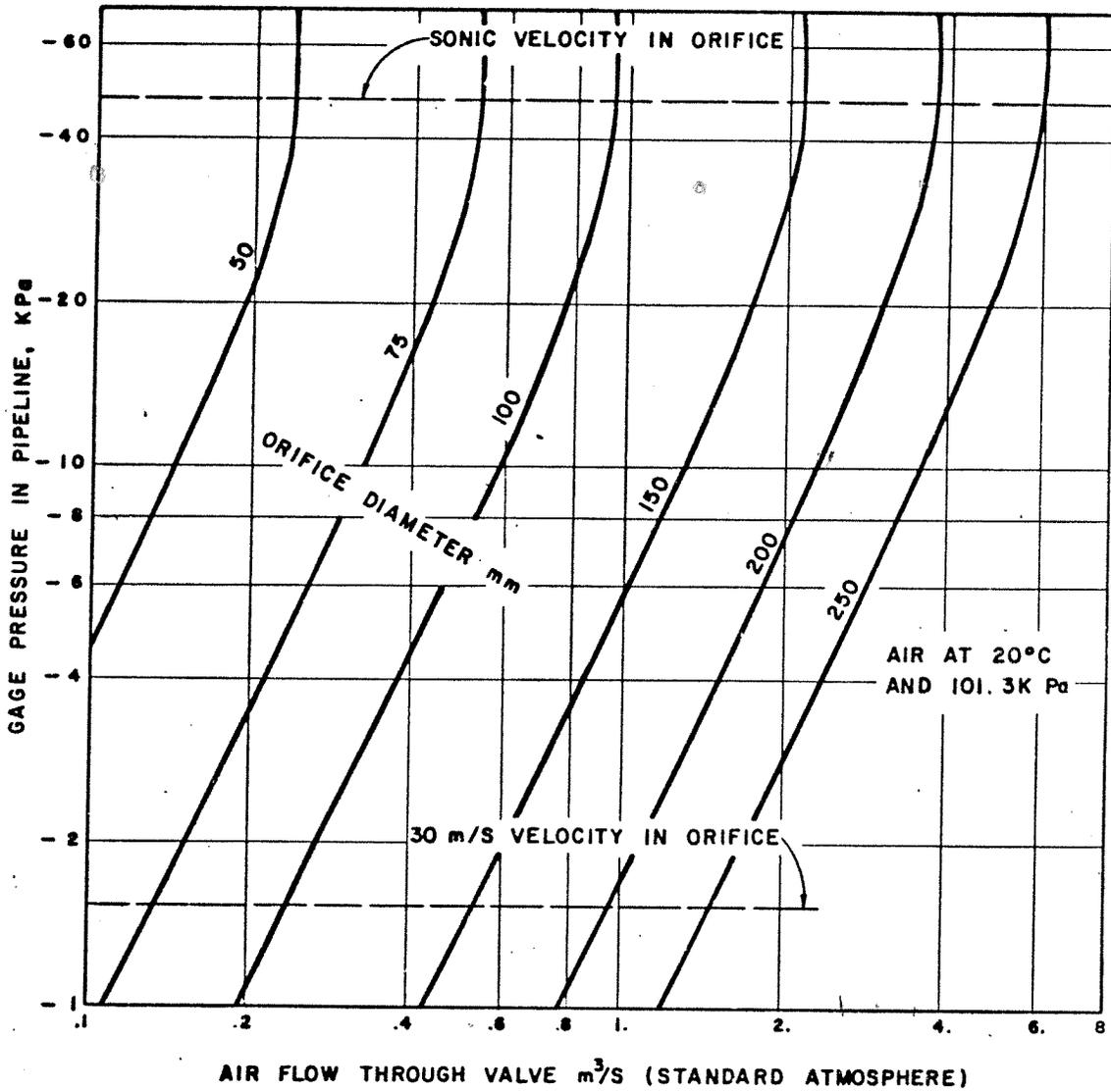


Figure 5. - Air valve characteristics

value requires a simultaneous solution of four equations using the air pressure in the downstream conduit as a parametric variable. These four equations are:

a. The guard gate equation:

$$Q_g = C_d A_g \sqrt{2g (Z_R - Z_g - \Sigma h_L + \Delta P/\gamma)} \quad (7)$$

where:

- Q_g = Water flow rate through guard gate
- C_d = Discharge coefficient for guard gate (fig. 6)
- g = Acceleration of gravity
- Z_R = Reservoir elevation
- Z_g = Centerline elevation at guard gate
- Σh_L = Summation of losses between reservoir and upstream face of guard gate
- $\Delta P/\gamma$ = Pressure drop across air valve

b. The control gate equation:

$$Q_c = C_d A_g \sqrt{2g (Z_a - Z_g - \Delta P/\gamma)} \quad (8)$$

where:

- Q_c = Water flow rate through control gate
- C_d = Discharge coefficient for control gate
- A_g = Total open area of control gate
- Z_a = Elevation of crown of conduit at air valve
- Z_g = Centerline elevation at control valve
- $\Delta P/\gamma$ = Pressure drop across air valve

c. Air flow rate through air valve:

$$Q_v = Q_p - Q_c \quad (9)$$

where:

- Q_v = Air flow rate through air valve

d. Air valve characteristic

$$\frac{\Delta P}{\gamma} = \frac{P_a - P_i}{\gamma} \quad (10)$$

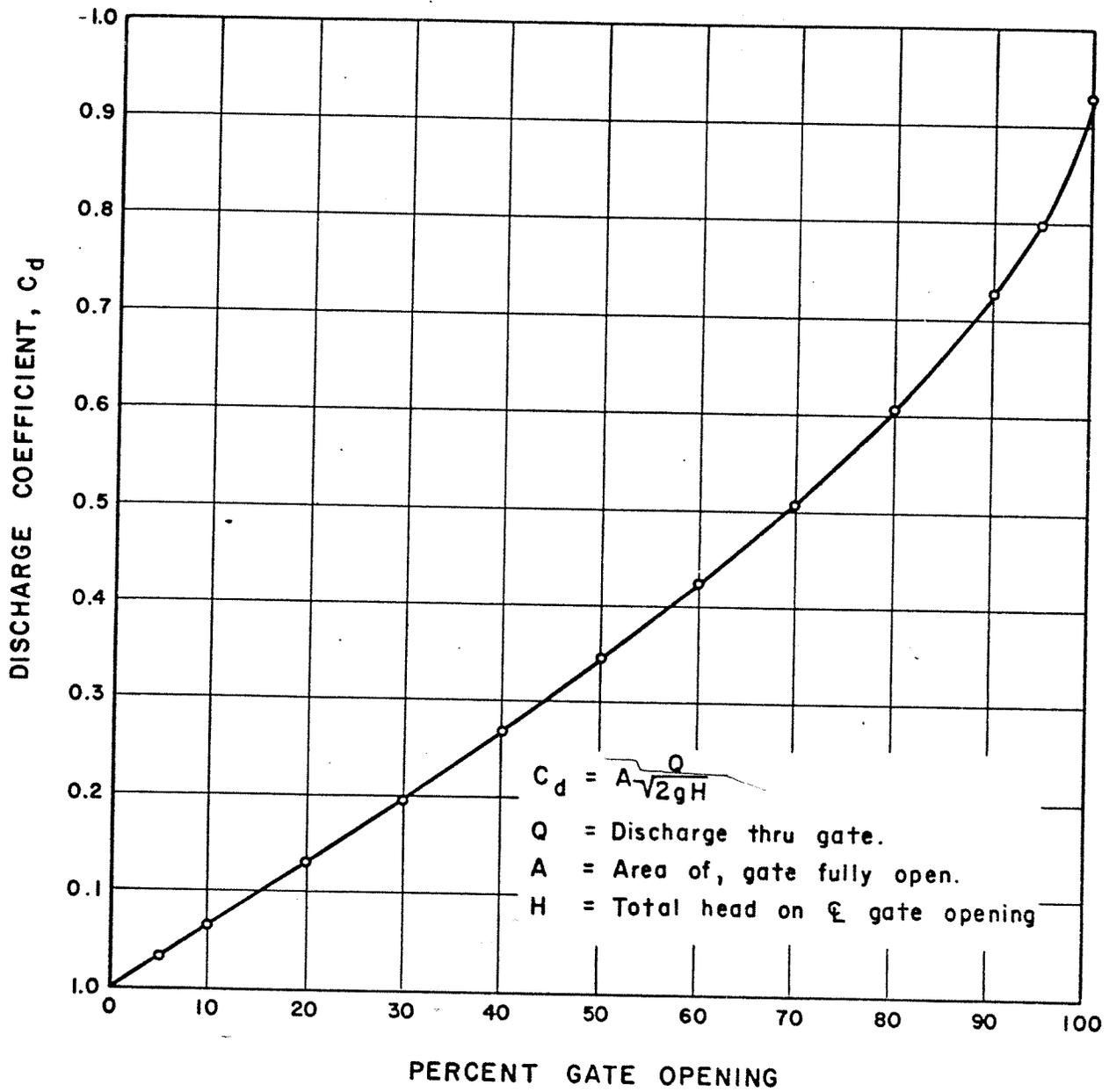


Figure 6. - Slide gate discharge characteristics

where:

P_i is determined from equation 5 or 6 for a specified air valve size by substituting P_i for P_d .

γ = Specific force of water

It should be noted that this step requires an air vent size to be specified. If, during the computations, the internal pressure P_i exceeds the allowable internal pressure P_d , the computations should be performed again with a larger air valve. The larger of the air valves determined from steps 3 and 4 is the valve which should be specified for the field installation.

BUREAU OF RECLAMATION
Engineering and Research Center
Denver, Colorado

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TR 80-02

TRAVEL REPORT

Code : D-1530 Date: January 29, 1980
To : Chief, Division of Research
From : Chief, Hydraulics Branch
Subject: Attendance at ASCE Committee Meeting

1. Travel period (dates): January 23 through 25, 1980.
2. Places or offices visited: Harza Engineering Company, Chicago, Illinois.
3. Purpose of trip (include reference to correspondence prompting travel):
To attend the annual meeting of the ASCE Hydraulics Division Session Programs Committee (letter from Dr. George Ashton dated December 28, 1979).

4. Synopsis of trip:

The committee meets in January each year to plan technical programs for Hydraulics Division Specialty Conferences and Division sponsored sessions for ASCE National Conventions. I am a committee member and will be chairman in 1981.

We reviewed details of the 1980 Specialty Conference in Chicago and the 1981 Specialty Conference in San Francisco and made initial plans for conferences in 1982 and 1983. I am a member of the Steering Committee for the San Francisco conference, which is a joint conference of the five water divisions of ASCE. I am also responsible for organizing sessions for ASCE National Conventions in October 1981 and April 1982, in St. Louis and Las Vegas, respectively.

Serving on this committee gives me a broad view of hydraulic research and design practices in the United States.

5. Conclusions: None. D. L. King
6. Recommendations: None.

Noted JAN 31 1980

Howard L. Cohan
Chief, Division of
Research

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D-1530

DLKing:mjs